THE PRINCIPLES
OF
IRON FOUNDING

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BY

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TO THE

FOUNDRYMEN OF AMERICA

WITH WHOM I HAVE WORKED, FROM WHOM I HAVE LEARNED,
TO WHOM THIS BOOK—THE RESULT OF A LIFE OF TOIL
AND MAYHAP SOME ACHIEVEMENT—IS DEDICATED,
IN GRATEFUL MEMORY OF UNVARIED KIND-
NESS CONSTANTLY RECEIVED.

PREFACE

The object of this work is the elucidation of the principles underlying all of the processes involved in the art of iron founding. The author has himself often felt the need of such a study, for while a number of books on the foundry exist—some very excellent in their way—these are either a collection of data often very poorly digested, or a series of descriptions of methods of operation without giving all the underlying reasons therefor.

The author, himself a foundryman, took up this work long after the completion of his University training, and subsequently occupying a chair of engineering at one of the American mining schools. He therefore knew how unsatisfactory any work performed must be to the thinking man if the reasons for so doing are not fully understood. Ever since 1890, therefore, he has worked in the laboratory and at cupola and furnace seeking the why and wherefore of the things that were done and not done. In the course of this scientific and practical experience, the author gained the cooperation and friendship of nearly all the world's great foundrymen—many of whom are still with us; and his connection with the foundrymen of America, as secretary of their National organization for a seventh of a century has put him rather closely in touch with the numerous and varied problems met within and without the foundry.

In all this active—almost frenzied rush of work, the author having made nearly quarter of a million tons of castings in his time—the great need of a thorough understanding of the principles involved in iron founding was ever present, and as so little was definitely known every new problem when fully worked out meant a definite advance. American foundrymen and metallurgists can properly claim the credit for the modern foundry development, and this because the disinterested workers gave the world the benefit of their investigations. The transactions of the foundrymen's associations and the great iron trade journals are still the repositories of this growing fund of information which nevertheless requires discriminating study to separate the kernel from the chaff.

The author, who has probably written as much as any foundryman on the operating details of his chosen field, nevertheless long hesitated to compile his observations and experiences into a book of reference. He knows that there is still so much to learn. The broader view, however, acquired during a long consulting experience after relinquishing active foundry connection, has resulted in the pages that follow. The author hopes that the foundryman who may be puzzled will find therein an explanation of his difficulty and the line of thought which will help him improve his practice.

The book is in no sense a "hand-book," but a study of the things upon which hand-books can be built. The book, therefore, does not contain a string of cupolas which have long become obsolete, or carbon diagrams which are interesting but useless to the foundryman; but goes into the elements of iron-making with its allied industries with the object of drawing conclusions therefrom of value to the foundryman in his daily work.

The author is at work on his second volume which will deal more particularly with general foundry practice.

RICHARD MOLDENKE.

WATCHUNG, N. J.,
August 1, 1917.

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THE PRINCIPLES OF IRON FOUNDING

CHAPTER I

HISTORICAL

The history of the development of the human race has been divided into certain epochs. These are characterized more particularly by the nature of the implements made for war and domesticity. From the rudely fashioned stone weapons of the eolithic age to the dawning of what is incorrectly termed the bronze era, at the close of the neolithic, man was fighting for existence against heavy odds. The great cave bear, the mammoth and other prehistoric animals were still in existence and had either to be exterminated or domesticated, agricultural implements adapted to the needs of a primitive, roving, hunting population, and cave life abandoned for villages on the plains or shallow lakes. The use of stone, horn, bone and wood was supplemented by iron and copper—the latter through impurities of arsenic, sulphur and tin, when melted and cast eventually becoming the bronze of the ancients.

That the "bronze" age is really a misnomer must be evident from the fact that the metallurgy of iron is much simpler than that of copper. Primeval man must have been aware of this situation and have used iron implements at least as early as bronze ones, if not before. The only records of these times are furnished by the content of burial places, and it would indeed be strange if on opening such mounds any iron had escaped the solvent action of the ground waters of passing ages. Hence remains of bronze alone have been discovered. Even in later times one can note the corrosive influences of moisture in the excavations of Pompeii, the Roman Colonies, etc., which show few remains of the well-known abundance of iron then existing. Indeed it is typical of the apparent predominance of bronze over iron for many centuries of the earliest civilization.

The first evidence of iron implements actually transmitted to us from ancient times comes from Egypt, the joint between two stones revealing a tool that had been lost. This was perhaps 5,000 years ago. But the earliest of recorded history has it that Tubal Cain (B.C. 3875) was known as a "master in every kind of bronze and iron work." Cast iron itself is quite a late achievement, evidently occasionally made in the "bloomeries" existing during the close of the dark ages. This process, conducted in an ancient form of hearth and blast furnace combined, is the prototype of our modern developments in these two directions.

The remains of some 400 of these prehistoric furnaces were discovered in the Bernese Juras and the type reconstructed by M. Quiquerez, a Swiss savant (1866). The enormous amount of charcoal used as fuel compelled the selection of locations rich in wood—charcoal being made on the spot. Ores of iron came from near by, and the mining operations conducted by these primitive men, on rediscovery by the German miners of the middle ages—who found stone implements in the tunnels—gave rise to the legends of dwarfs and gnomes implicitly believed then, and current in those regions to the present day.

A careful study of the furnace ruins—these having been found by tracing the paths of slag backward into the mountains—indicates that a hearth of fire-clay, about 6 to 8 in. thick was laid on the ground selected. Material of the same kind and thickness formed the furnace lining, which was reinforced by a heavy stone backing, the total thickness varying from 18 to 27 in. About 2½ to 3 in. above the bottom of the hearth a door was provided for—a substantially arched entrance having the full width of the shaft of the furnace and carried outward through the earth covering of the furnace proper. This shaft, or chimney, was 8 to 12 ft. high, and had on top of it a ring of stones to prevent damage while charging. The general shape of the furnace was that of a truncated cone leaning forward somewhat, so that in throwing in charcoal and iron ore on top, the door below would be kept free from accumulations.

After drying out such a furnace it was charged with alternate layers of charcoal and ore, lighted and left to the action of the natural draft. The temperatures obtained were such that the front of the furnace lining became only red hot, while the rear was glazed. The fire-cracks thus produced necessitated repairs, which are readily traced. One man remained with such a furnace constantly, and as slag would appear on the hearth, he would pull it out with a hook, slice up the fire and eventually draw out a red-hot cake of iron and immediately forge it into bars. As everything was done by hand, and only 30 to 60 lb. of iron were produced at a time, the metal was highly expensive, and hence even some of the hammers used and found in these excavations remained of stone. Furnaces of this kind were still in existence in the time of the early Romans.

The part that interests us particularly is the resemblance the furnaces have to the cupola—indeed as will be shown later, the very name cupola came from such a furnace—and the provision for a hearth slightly lower than the door in which later constructions enabled the gathering of molten cast iron.

While these simple furnacemen—who were held in high respect for their indespensible knowledge—were only aiming at the production of wrought iron, unquestionably they must have noticed occasional molten metal. Indeed this knowledge must have been old even though the use of cast iron in the arts is of very recent date. We have record of a bridge with cast-iron chains being built in Japan in the year 70 A.D. Pausanias speaks of cast-iron statuary introduced by the Samnian Theodorus a century later. Possibly the crucible figured considerably in these early developments, wrought-iron scraps and charcoal being melted together, but the first recorded example of pig-iron making harks back to 1311 A.D. in the Siegerland of Westphalia. About 50 years later we hear of cast iron in Sussex, England, which shows the spread of information even in those days of secretiveness.

In the very early days the production of molten iron in the furnaces then in use was considered a serious detriment, the operatives being heavily fined if this was the case. Only when it was found that this metal, which came from ores comparatively high in manganese and therefore white in fracture, could be successfully cast into cannon balls (1388, in Memmingen) did there appear the dawning of a new industry. The furnaces were then used alternately for the production of wrought iron and cast iron by proper draft regulation and an air blast, and as experience was gained, higher temperatures realized and low manganese ores brought into use, gray iron castings could be made—cannon and stove plates being the almost exclusive products.

This change from a puddling process direct from the ore to the actual making of pig iron took place in the fourteenth century. In England, the molten metal was run into open-sand molds, in the floor, shaped like sows with litters of sucking pigs—hence the name pig iron. The famous Armory of Berlin contains a copy of a rare early book on smelting, dated 1454, in which there is described the making of molten iron in the hearth furnace, the metal being run into well-baked and highly heated loam molds. Arsenic, antimony and tin were used in small quantities as alloying additions to render the metal more fluid. This book describes another furnace the hearth of which was used for stacking up alternate layers of wrought iron and charcoal, which gave a molten iron—thus corresponding to the previously mentioned crucible-made recarburized iron. The interesting portion of the description is that this furnace had above the hearth a chimney terminating in a "Kuppel" or cupola, this chimney, or "kiln," being intended for better charging purposes. Here we have the origin of the word "cupola," and also an interesting comparison of the furnaces of 1454 with the prehistoric furnace just described, as well as with our present-day cupola. Verily, "there is no new thing under the sun."

Charcoal was the only fuel used until some time in the first half of the seventeenth century, when coke was made from "pit-coal" in England, and used spasmodically only, for the first practical application to meet with commercial success was that of Abraham Darby, about 1730. The art of casting iron came to England before 1500, for shortly thereafter (1516) we have a record of a 5-ton gun called the "Basilicus" cast in London. The Berlin Armory has cast guns dating from this time also, and the Tower of London contains two guns brought from Ireland before 1540. Ralph Hogge had also cast cannon in Sussex in 1543. The German records, however, show that cannon were cast of white iron as early as 1414.

Since the casting of gray iron guns has ceased to be commercial—the longer range steel gun having effectually replaced them—a few words may be said on the termination of this historic industry. The cast-iron cannon attained its greatest development during and shortly after the American Civil War, when guns were cast requiring over 100 tons of molten metal for the mold, and finishing up considerably over 50 tons in weight. The difficulties attending the production of perfect castings of this size were such that governments requiring them looked about for a more reliable form of iron, and as steel was by that time possible of production in heavy tonnages, this naturally replaced cast iron.

The cast-iron gun as a molding problem will be discussed later on, but reference to the literature of this subject discloses an interesting publication[1] which may be found on the shelves of the Boston Public Library (published in Washington, D. C., 1878) entitled "Memorials on behalf of the South Boston Iron Co. and the West Point Foundry—manufacturing heavy ordinance." The text recites the general petition to Congress asking for continued appropriations for coast defense guns as made by these establishments—the principal ones at the time taking government contracts for guns and mortars. Attention is called to the reports (1877, 1878) of General Benet, chief of Ordinance in the army urging these necessary appropriations, and mentioning the fact that the 40-ton rifle of 12¼-in. caliber made by the South Boston Iron Co. had proved to be more powerful than guns of equal caliber made by the Krupp and Armstrong works of Europe. In the additional memorial by Wm. P. Hunt, then president of this company, some further interesting data are given. The plant was established in 1827 by Cyrus Alger (originally known as the Alger Iron Works), who had been working on the production of cast-iron ordinance since 1809. He died, while president of the South Boston Iron Co., in 1855. He made the first rifled cannon in 1834, the first "Malleable Iron" gun in 1836, the 12-in. "Columbiad" in 1842, and subsequently the original experiments resulting in the famous "Dahlgren" shell guns. It is also of interest to note that between the years of 1862 and 1877 alone, no less than 272 Rodman guns, of which 103 were of 15-in. caliber and weighed about 50,000 lb. apiece, were produced at this establishment.

Among the many other foundries which grew prosperous by making cast-iron guns at the time were the Builders' Iron Foundry, of Providence, R. I., and the Ft. Pitt Foundry, of Pittsburgh, Pa. The author possesses a 9-in. Rodman gun, made in the last-named foundry, which was used before Richmond, by General Grant, and is now mounted on the walls of his Castle.

Reverting again to early English foundry history, a Thomas

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[1] By courtesy of W. B. Leach, president of the Hunt-Spiller Mfg. Cor., of Boston, Mass. (The old South Boston Iron Works.)

Johnson[1] is mentioned as having cast forty-two 3-ton "great pieces of ordnance" for the Earl of Cumberland, in 1595. The Kings of England owned two blast furnaces (erected in 1550) situated in the Forest of Dean. At the time of Queen Elizabeth England actually exported guns to the Continent. By the time of James the First the forests of England had become so heavily encroached upon that laws forbidding the cutting of trees for charcoal-making for iron were enacted. The thriving industry, at that time producing 180,000 tons of iron annually, in consequence dwindled down to 17,000 tons in 1740. Essex, by the way, was exempted from that law. Eventually coke was used in place of charcoal, and the industry came to its own again.

Among the sporadic attempts at coke-making mentioned previously, the name of Dud Dudley stands out most prominently. In 1619 he received a patent for an improvement in iron-making which evidently referred to the use of soft coal—probably coking it in some manner. He made his pig iron in Pensnett, and refined most of it at Cradley Forges. He seems to have run up against an early trust of English ironmasters interested in charcoal, who, when they finally made themselves his selling agents, not only "detained his stock" but also "disparaged his iron." When Dud Dudley finally built a new furnace at Sedgley, with a specially interesting bellows to blow it, he manufactured 7 tons of iron per week with soft coal. The trust got after him again, for he was "thrown out of his works, and the Bellowes of his Furnace and new Invention, by riotous persons cut to pieces, to his no small prejudice and loss of his invention of making iron with Pit-cole, Sea-cole, etc."

Dudley was acquainted with three varieties of cast iron: the gray, the mottled, and the white which "is almost as white as Bell-mettle, but in the furnace is least fined and most Terrestrial" or impure. He sold many "tuns of piggs or cast iron" at two-thirds the cost of charcoal iron, and made good profit by it. It was, however, not until Abraham Darby took hold of the problem of "cooking his coal" for coke that melting iron with coke was successful on a truly commercial scale. He, and his assistant, John Thomas, first successfully cast cook-pots, and they—with their successors—kept this art a secret in England for over 100 years. In coking his coal Darby followed the method

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[1] Communicated to the author by Robert Buchanan, Past-President, British Foundrymen's Association (Birmingham, England).

of making coke in kilns, and to him is due the first successful use of this fuel in the blast furnace.

While loam molds were known to the ancients in connection with their bronze casting work, it remained for the Germans to develop the art of molding in flasks, though the first recorded evidence in the shape of a patent is given by the application of Darby in 1709.

Nothing is more instructive to the foundryman interested in the history of his art than the comprehensive collection of stove plate and oven parts gathered by the German Ironmasters' Association, and displayed at their club house in Düsseldorf, Germany. Those who have been shown about this wonderful exhibition, arranged in historic sequence, by the genial secretary, Dr. Schroeter, will long remember the treat.

The periodical clean sweep[1] of a country's scrap resources brought about by exceptional "boom" times, occurred in Germany, so far as historical art castings are concerned, in 1873, when enormous quantities of ancient oven plates went through the cupola. In spite of this iconoclasm many examples of early foundry work were preserved from destruction and are now kept in Luxemburg, the old Halberger furnace, and in the historical museums of Metz and Lübeck. Similarly French castings are to be found at Nancy, English ones in Brighton and Hastings, and many other smaller cities can show interesting collections made by public-spirited foundrymen.

In the Middle Ages—quantity production being unknown—when a bell was wanted, a monk would form up the mold in clay and make a bronze casting. The gunsmith would go about making a cannon the same way, and where ornamental pieces were desired, whether in cast iron or bronze, the "lost wax" (*cire perdu*) process was resorted to, patterns and cores not having been sufficiently developed as yet. A survival of this custom to the present day is found in the wonderful productions of the Russian *Moujiks*. These primitive artisans can be found in cellars in Moscow and other old Russian cities, fashioning in wax statuary of Cossacks in wild rides, treasure boxes, armor, and other artistic objects, with life-like fidelity. A clay mold is formed about the model, the wax melted out, and after pouring with high phosphorus metal a bit of perfection in cast iron results.

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[1] From articles by DR. OTTO JOHANNSEN and DIRECTOR J. LASIUS, in *Stahl und Eisen*, 1912, Nos. 9 and 13.

Unfortunately the appreciation of the general public for such cast-iron art work is not what it shall be in America, otherwise more would be seen of this delightful product so indicative of the artistic temperament of the untutored makers. Russia, the Hartz Mountains, Switzerland, and other lesser known regions, furnish these art castings as there is demand for them.

In the production of memorial tablets, stove fronts, etc., open sand work answered very well, and all that had to be done was to prepare a level bed, surround it with walls of molding sand, and cutting into these a channel to allow the surplus metal to flow away thus leaving the casting of the desired thickness. Such a level bed naturally tempted the molder to artistic efforts. He would imprint his pipe, hands, knife, or roll of tobacco in the sand, and the subsequently cast plate would give faithful reproductions. This tendency is noticed today in the German works, and indeed the author was not surprised to see a "hand" looking at him from one of the plates on a Virginia blast furnace. The application of a rope's end in this manner was a favorite decoration in the sea-coast towns, as one can still see in their building tiles and interior decorations. Indeed, the German family stove oftentimes reflected the artistic and vocational tastes of the region.

As time passed on, an ornament in relief by an artist was pressed directly into the sand, and thus became a pattern, as it could be repeated. The idea of such a pattern, when used as a die, was known to the old Romans, for one can see the repetition imprints of an ornamental die on some of their lead sarcophagi, unevenly spaced and overlapping. One of the finest examples of this repetition work in the sand bed prepared for an oven plate dates back to 1592, and was made at Neuhütte, near Strassebersback, in Germany. The plate represents the Resurrection, and every portion was made by impressing specially made dies into the sand. Even the frames were made with small sections of molding, the sand being compressed a little at a time. It was the day of the wood-cut and ornamental carving of interior decoration of churches and homes, and hence the foundryman had abundant material to work with in getting out the few castings required as ornamental in form as possible.

If the patterns thus worked out did not fit the required job so far as dimensions were concerned, the foundryman—or furnaceman in those days—would fill in with other ornaments from his stock, or use the pattern twice. Sometimes it is almost impossible to determine whether such loose patterns—or wooden dies, as it were—were used, the work being so accurate. Occasionally, however, this may be noted distinctly, as the die and sand-bed levels do not correspond.

Later on, one would affix a series of the above-mentioned dies upon the same plate used for pattern purposes and in this way get out very creditable castings. This is shown by an oven plate made in the eighteenth century, in which one ornament of the group indicates a shifting of the die about its point of fastening. The last stage came about when the pattern for a given casting was made in its entirety and no loose or separately attached parts which could get out of line were employed. Then the finish of the work became one of high art.

Plain, flat cast-iron plates—laid upon a brick hearth—were first used in 1468. The first iron stove is mentioned in 1474, though this is hardly the actual origin of the useful piece of domestic furniture in question, for numerous citations concerning it are to be found in the records of that period. As a matter of fact, however, the beginning of the iron foundry as a regular business can be fixed at about the year 1500. At first the stove—far different from our modern development—was to be found only in the castle of the ruling noble. Next, one potentate would present a stove to the other. Monastery and convent would purchase this foundry product, or more likely receive it as a votive offering. Next, rich cities would place a stove in their representative edifice—the city hall. The elite of the towns would have to possess a stove, and 50 years after the start was made we find even the farmer installing these heavy castings and enjoying life better than ever before.

When this period of quantity production had arrived we find the artistic quality lowered considerably, as patterns had to last as long as possible. This meant patching up the mold, much as it does today. The requirements of ornamentation, however, were unique. For instance, in the Alms Houses a stove would regularly show the "Cruse of the Widow," while in the vineyard regions of the Mosel the "Wedding of Cana" predominated—showing the interest taken even in those early days in turning water into wine.

In the first part of the nineteenth century patterns were gotten out in metal and were highly finished. Several of these are in the possession of the Society of German Engineers. Occasionally patterns are found on which an ornament was repeated, showing that a master-pattern was used. Nearly every blast-furnace establishment then existing turned out these stove plates. The Düsseldorf collection has them from the Hartz, Alsace, Nassau, Saarbrück and Wurtemburg, and has them still to get from Brunswick, Saxony, Silesia, Siegen, Eifel and Hunsrück to complete the list for Germany. A conspicuous industry of this kind (fire-backs) existed in Sussex, England, and the Norse countries of Europe furnished another set of examples.

Unquestionably the proficiency in the art of molding must have been in a high state of development in these later days. Collections of wooden ornamental patterns of the eighteenth century are still in existence. A splendid set of patterns of the "baroque" period of ornamentation was found in the garret of the old mining school near Saarbrück, and rescued from destruction. Some of these are of oak and in an excellent state of preservation.

In the molding-up process, an exactly level sand bed was first prepared and a planed rail of cast or wrought iron some 6 in. in height located on each side and firmly attached to a suitable foundation. Charcoal or coke cinders were placed on the bed and molding sand riddled on them to a depth of about ¾ in. This loose sand was spread out evenly with a lath and then compressed by means of wooden rolls of various diameters, the trunnions of these rolls running over the side rails. The patterns were now pressed into the sand bed, the use of the spirit level keeping things exact. Sand was next rammed between the pattern and the rails—the latter being perforated to allow venting of the sand bed. After drawing the pattern, the mold was dusted with charcoal or coke dust, and after arranging the overflow level the mold was poured. In order that the corners might be filled properly a stick with a cross piece attached to the end and previously dampened was used to push the metal into them. The gases were ignited to prevent explosions. As soon as the metal had set, the molders would put on weights to prevent warping.

In the case of patterns with detachable ornamental parts, these were unscrewed from the board and "returned" again, pressing the coke dust well into the sand, thus bringing out sharper outlines on the casting. All shot was carefully removed from the molding sand, this being considered responsible for casting losses. After a sufficient number of stove plates had been cast, these were put together in similarly cast frames, or on wrought-iron angles, and in this way a stove constructed oftentimes reaching a height of 37 ft.; as, for instance, the fine ornamental heating stove of the "Artushof" in Dantzig. The oldest example of a complete cast-iron stove in perfect preservation is to be found in the fortress Coburg, and goes back to the year 1500.

A very interesting series of analyses was made of the oven plates in the Halbergerhütte collection—these dating from 1508 to 1811.

Silicon	0.65 to 1.68
Phosphorus	0.26 to 1.53
Manganese	0.26 to 1.50
Sulphur	0.05 to 0.12
Graphite	2.45 to 3.60
Combined carbon	0.12 to 1.22
Total carbon	3.44 to 4.00

"Direct Metal" was used for all stove and commercial work in quantity production until the nineteenth century. Those cities which had foundries attended principally to jobbing work or art castings of bronze and brass. In the very early days the casting of bronze candelabra, baptismal fonts, and other ornamental articles of church and house furniture, was in the hands of a special Guild, called the "Apengeter," who thrived in the Hanseatic and other cities, more particularly in the early years of the fifteenth century. A Hans Apengeter, of Sassenland, was a founder in the early fourteenth century. The name "Apengeter" evidently comes from the curious figures of animals the early founders ornamented their work with. "Apen" is a corruption of "Affen," or monkeys. "Geter" is a corruption probably of "giesser" or founder of metals. Hence a "monkey-founder" was the forbear of a then as now highly respected family.

Turning to England, we have a very fine plate cast by Ironmaster Richard Lennard, at Brede Fournes (Sussex), and dating back to 1636. The plate exhibits the founder himself while holding his sledge. A weighted mold and a ladle are at his feet. At the left is a heavily ringed blast furnace with a modern-looking hoist. Above is seen his coat-of-arms, the hammer, tongs, rammer and weight. At the lower right-hand corner is represented a finished oven plate with the monogram R. L., above which is a female animal of wonderful shape—perhaps a "pig" emblematical of the art of founding. Finally, in the upper right-hand corner on a shelf, a bowl, pitcher, and large wine-glass of the period, showing that the dust and heat of the foundry engendered thirst even in those days.

In studying the artistic side of the productions so far mentioned, the question naturally arises as to who made the original drawings and designs which have been translated into iron by the deft hand of the skilled furnaceman-molder. In the sixteenth century and somewhat later, the length and breadth of Germany and contiguous countries was filled with hard-working creative artists properly called the "Lesser Masters." These men, whether in painting, sculpture, or exquisite carving of wood and ivory, copper-plate etching, or in gold- and silver-smithing, managed to turn out designs without number, which served to stimulate the foundryman in contributing his share to the general advancement of the times. A pertinent example is found in the cast-iron memorial tablet marking the grave of Margaretha von Elts, in the church at Boppard. The relief shown on the plate—exemplifying the Trinity—made by Loy Hering in 1519, is easily recognized in a wood-cut by Albrecht Dürer.

Equally as romantic[1] as the establishment of the first blast furnace in America at Lynn, Mass., in 1645 (Saugus Centre), was the development of the iron industry of Pennsylvania. This began in 1720, and within 30 years thereafter a number of blast furnaces were scattered within the Counties of Bucks, Chester, Lancaster, Lebanon, Cumberland, York and Schuylkill. Here, in the farm houses and residences of olden times, we find discarded stove plates brought from Germany by the Colonial settlers. They came from the Palatine, South Germany, Silesia, and even Switzerland, bringing their old German stove plates and complete stoves. They fled their countries to escape religious persecution, and the old castings, with their Bible verses and Bible pictures proved a real comfort to them while in the primeval forests of the Pennsylvania wilderness. The Lutherans and Moravians became the best of American citizens; the Menonites, Amish and Tunkers still remain apart to this day, having

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[1] Courtesy of Henry C. Mercer, of Doylestown, Pa., author of "The Bible in Iron," etc., etc.

forgotten Germany and not become Americans. To them, however, is due the American stove for as their plates would break they took them to the nearest blast furnace for recasting, and thus the English ironmasters, who cared nothing for the Biblical pictures or German inscriptions, were forced to go into the making of stoves, and found it a profitable business.

From the recasting of these stove plates—in which the clearness of ornamentation naturally suffered very much—there came distinctively American plates for similar uses. The first one is the "Fortune Plate" of 1726, showing the allegorical picture of Dame Fortune dancing on a flaming wheel, with flaunting scarf and Liberty cap, and a suitable rhymed German inscription. The casting dates of these plates are to be found in the more or less complete account books of the various furnaces, from which there is also taken the date of the first complete American stove—1756.

As already stated, all this work of casting iron is in connection with the production of pig iron for subsequent refining purposes, the cupola not being introduced into Pennsylvania until 1820[1]

Beginning with 1753, the adornment of stove plates with Biblical pictures were generally abandoned—the primitive religious fervor of the early settlers being modified in their children, through contact with the outside world. The ironmasters also began to advertise themselves and their furnaces on the plates. The designs became floral and were rather of a conventional type. One furnace tried to outdo the other in the profusion of this style of decoration. These stoves were not of the modern type, with stove-pipe draft connections, but discharged the gases into the room. They were used only as individual heat centers, and never for cooking purposes—this important domestic function being carried out on the open-fire hearth which every house possessed. Their end came suddenly, in 1768 or thereabout, when the furnaces began to make stove pipes and the early types of the ventilated stoves originated in Holland, spread over Germany, Norway, Sweden and Denmark, and finally reached perfection in Pennsylvania. Other types came into existence, such as the English cast-iron grate for burning soft coal (then imported from England, 1750), and Benjamin Franklin's down-draft fire place (1743). But the

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[1] Authority of B. F. Fackenthal, Jr., President of the Thomas Iron Co., Easton, Pa.

radical change from cooking on the open-fire hearth to the use of the cook stove came with the introduction of anthracite coal generally. 1840 may be given as the beginning of the modern stove.

Another form of early cast-iron art should not be forgotten, namely the fire-back. This is also an open-sand casting, 2 ft. or more square when in that form, but more usually shaped like the headstone of a grave, with rounded, scrolled or vaulted tops. The dates run back to 1488, but while not unknown in Germany, they were rather indigenous to the Netherlands and France. Coming to England from Flanders, they naturally drifted to America with the colonists and hence may be found in the mansions of all the thirteen original Colonies. Necessarily the decorations were entirely different from those on the German stove plates. Hence we see coats-of-arms of the English kings and high nobility, dates, inscriptions of various kinds. Also hunting scenes, representations of highlanders, horsemen, etc.

Besides the Pennsylvania and earlier New England developments in iron-making, there should be recorded that New Jersey began building blast furnaces in 1682, Maryland in 1723, Delaware in 1725, Virginia in 1727, New York in 1750, and the South began exporting pig iron in 1728.

In England the achievements of the Carron Brothers in their iron works at Carron have left an indelible impress on military history, for the first "Carronades" were cast in 1779. Before that time, in France, the foundry industry had flourished sufficiently to enable the laying of a famous line of cast-iron pipe in Versailles (1664–1686). When some of this was taken up a short time ago, the metal was found in an excellent state of preservation and 5 miles of it are still in use. Some of the 1-meter lengths of this pipe may be seen in the offices of the German Pig Iron and Pipe Syndicates in Cologne, and certainly show up an excellent grade of material.

Thus for centuries the art of founding went hand in hand with the actual production of the iron itself in the blast furnace. The uses for castings other than guns, shot, stoves, etc., were confined to kettles and smaller household implements. Hence we hear of itinerant founders in England, going from village to village—in more recent times—collecting scrap iron and casting kettles from little cupolas mounted on conveyances. The foundry as an industry, however, was forced to an issue by the development of our later-day civilization. Its establishment in America may be traced back to the sturdy New England people. The Saugus Iron Works were undoubtedly the first of the kind in the new world. It was really a Lynn institution, for the briefest of Massachusetts' legislative decrees says that "Saugust shall be called Linn." After the bog-iron deposits in the upper Saugus meadows were discovered by Thomas Dexter in 1643, a Capt. Robert Bridges became interested and raised the necessary capital in London to develop them. A bloomery and a forge were established and workmen imported from Hammersmith, England. Joseph Jenks was in charge as master mechanic, and evidently also built a small blast furnace, for the Essex East India Hall and the Essex Institute, both of Salem, as also the Lynn Historical Society claim to have castings made by him. Jenks must have been a mechanical genius, for in 1652 he made the dies for the first silver coined in New England, and in 1654 the parts of the first fire-engine in America—for Boston.

Tradition has it that the first castings made were a pair of hand-cuffs, and when one reads the romantic accounts of the early New England industrial centers, in which there usually figure diverse entries concerning 'lowance rum, this may not be wondered at. Whether the hand-cuffs or, as held by others, a "small kettle" began the foundry industry in America would seem a mooted question. Prejudice against the Saugus establishment on account of the rapid destruction of the forests for charcoal-making caused much litigation and by 1688 the works had ceased to exist, the property being cut up and passing to individual owners.

Taunton claims the honor of having the first operating foundry within its confines (built in 1653 and still operated in 1860). The town of Carver, Mass.,[1] has found an able historian to delve in the records of by-gone times and bring before us a picture of the little furnaces, with their topmen, guttermen and molders; the store accounts of molasses, West India rum, codfish and pork, given in trade for castings of kettles, etc., for little real money passed in those days. The ore was taken from the swamps and lakes of the South Precinct of Plympton, the charcoal from the hills abounding in good timber. Sea shells gave the necessary lime. Water power was imperative, and the buildings were of

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[1] Courtesy of Henry S. Griffith, author of the "History of the Town of Carver, Mass."

stone and conveniently grouped. The general superintendent was called the "skipper," the power from the water-wheel was transmitted to a huge beam weighted with rocks and extending out into the road. The wheel carried the end of the beam down and opened the wind chest connected with the bellows. After being freed from the wheel the weight on the beam ejected the wind by closing the bellows. The numerous "coalpit bottoms" still seen about the woods is evidence of the charcoal industry existing, and the incidental ruin of the soil for farming purposes. The saw mills made lumber for the flasks. The time was 1735, the names of those interested may be read today in the lists of directors of foundry enterprises of New England. Particularly that of Shaw (Jonathan Shaw ceded the land for the enterprise in question in 1735) is striking, for with that of Pratt (1819), these may be traced through a variety of vicissitudes and successes down to the present Walker & Pratt Foundry at Watertown Mass.

Pots, kettles, cauldrons, flat-irons, bake-pans, fire-dogs and andirons were the staple articles of manufacture. After operating 100 years, a cupola replacing the blast furnace in later days, the establishment closed down in 1836. The narrative of the trying times before the Revolution, during this period, and the prosperity during the War of 1812, read like a romance, and while this is but an isolated example of other enterprises, it shows up the homely character of the sturdy pioneers of New England, from whence so much of the strength of the United States has been derived.

Mention has been made of the development of the cupola from the charging shaft of the old hearth furnace. The latter was producing cast iron direct from the ore. Tradition has it that pig iron was first remelted in China several centuries ago, so the use of the cupola must have been understood fairly early, even if confined to very isolated cases. The real development came with the general introduction of coke, though anthracite was used where available. Under the term cupola there should be understood an apparatus for melting pig or cast iron, under forced draft or its equivalent, with metal fuel and fluxes superimposed. The molten metal to collect in the bottom and be capable of being tapped off as required.

The first recorded evidence of cupola melting in Europe seems to point to Réaumur (of malleable-castings fame), and dates back somewhat previous to 1750. He had a little portable cupola 16 to 24 in. high and 6 to 9 in. in diameter, operated by a hand bellows. It was made in two sections, the lower for collecting the molten metal and the upper serving as a chimney. Eventually Réaumur built his cupolas of a skeletonwork of iron, filled it out with fire-clay, and so placed it that when operating it would stand vertical, but could be tilted slightly as the metal collected on the bottom so that molds could be poured out of an opening slightly above. Cupolas were used in Russia and Sweden which were over 7 ft. high and between 2 and 3 ft. in diameter, showing the development as a demand arose. The placing of wheels on such cupolas made them easily portable, and no doubt accounted for the tinker-molder of England with his portable foundry.

The idea of the cupola soon gained ground and its development was rapid. A patent was granted to John Wilkinson, in England, in 1794, which comes pretty close to the modern cupola, and it was used very extensively subsequently in the industry.

And so in all parts of the civilized world the foundry was slowly developed as part of the blast furnace more particularly, until steam became an industrial factor of prime importance, and the uncertainty of "direct metal" as put into engines and general machinery compelled the remelting of pig iron as a regular business for itself. From that time we can speak of the foundry as an industry slowly establishing itself as an adjunct to machine shops formerly receiving direct metal castings, or else eking out a precarious existence as "jobbing" shops.

Necessarily the separation of the foundry from the blast furnace was a slow one, and for years they worked side by side producing castings for the trade. Even today most blast furnaces make their own castings without remelting pig iron, and several large foundry enterprises have reversed the process and purchased blast furnaces to obtain their molten metal at lowest figures. These concerns either run the furnace casts, as tapped into ladles, into "mixers" previous to pouring into molds, for the sake of uniformity and convenience, or else pour direct. In Europe the practice of using direct metal is more common, and particularly in Germany there is a constant clash of interests between founders and furnacemen regarding the prices charged consumers.

Mention has been made that the cupola was not introduced into

Pennsylvania until 1820. It came to New York City just a little later, for the well-known J. L. Mott Iron Works[1] began operations in 1828, at Mott Haven on the Harlem River, and there being no blast furnace about, used the cupola for making castings, importing patterns and some pig iron from England. On tearing down part of the old Astor House in 1913, some of the pipe and fittings made by this company in 1834 were found imbedded in the original stone walls. A few of these may be seen at the office of the Central Foundry Co., and are in a perfect state of preservation, in spite of the fact that the metal in some of the soil pipe was but 1/8 in. thick when made. The material in question served originally to care for the rain water from the roofs, but latterly the lines had been put to use for soil and waste purposes.

Another landmark of New York City recently taken down was the famous cast-iron water reservoir (made in sections) of the old Aaron Burr Water Co. (1798) the metal being as good today as it was a hundred years ago. Unquestionably the old Astor House was connected to this line until the Croton supply became available in 1845.

Founding iron was hard work. Simple men took hold of such propositions. Capital was too scarce to risk in elaborate ventures, and hence the foundry as the older men of today remember it, was an establishment archaic in character. The magic touch of modern development found its most obstinate and long-lived opponent in the foundry. Years of effort at enlightenment by unselfish men in the trade were required to overcome this inertia, and even today but a small percentage of our foundries may be said to be strictly up to date. However, even if not well-equipped, the modern foundry has in its proprietors men who know what should be provided. Since this condition of affairs is the result of comparatively recent mission work, it will be not amiss to consider the movement which brought it about.

MODERN FOUNDRY ADVANCE

"Modern foundry advance" is the most fitting designation for the achievements of those foundrymen—preëminent in their art—who brought about a revolution in the industry. Practically all of this work fell within the last 20 years of the nineteenth century. Moreover, this advance took place simultaneously and

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[1] Courtesy of H. Y. Carson, of the Central Foundry Co., New York City.

almost independently in the United States, Germany and Great Britain. The records may be found in the transactions of the numerous national and local foundrymen's associations. In fact this work of earnest and unselfish foundrymen so stimulated interest and compelled attention that the associations in question came into being, and have ever since done splendid service in the cause of industrial education.

What we may call the particular achievements of this modern industrial movement may be summed up in the following items:

1. The change in the valuation of pig iron from the unreliable method of judging it by its fracture to the definite one of its actual elemental content.

2. The introduction of machinery and processes to promote efficiency in operation and reduce shop costs—in specializing foundries enormously so. The molding machine is the most prominent example of this advance.

3. The study and rational use of the foundry raw materials, such as molding sand, fuels, smaller supplies, etc.

4. The machine-casting of pig iron.

5. The standardization of methods of sampling and analysis of pig and cast iron.

The preparation of standard drillings of cast iron for laboratory checking for universal application was first worked out by the foundry interests and is now a governmental activity.

6. The classification of finished castings by their analysis ranges, so that the best composition can be selected as suited to the requirements of the case, and ready duplication is possible.

7. The operation of both gray iron and malleable foundries with scientific laboratory aid.

8. The introduction of standard specifications for pig iron, cast iron, and for coke.

9. The broadening of shop practice to include oil and gas fuels, improvement of product by steel and alloy additions, the electric furnace, etc.

10. The study of the physical and chemical characteristics of cast iron, the results of which have taken it from the list of unreliable materials.

11. Development along lines of foundry betterment, such as lighting, heating, sanitation, safety, efficiency, and foundry education.

The first man to see the need of rational methods of operation in every department of the foundry was the late Thomas D. West, of Cleveland, Ohio. His first published article on foundry practice appeared in 1881 and gave the iron industry a momentary look into its most neglected constituent. For years West labored to advance the industry, making tests which opened up new lines of endeavor, writing numerous books on foundry practice—the first in 1882—and incidentally developing the system of standard samples of cast-iron borings for interchange and checking of chemical determinations, now taken over by the U. S. Bureau of Standards. He may be truly called the father of the modern foundry advance and will be always remembered by his many friends and those whom he helped out of difficult foundry troubles.

Meanwhile, Prof. A. Ledebur, a famous German metallurgist, had brought out his book on the foundry in 1881, following the standard work on foundry practice by Prof. Dürre, which appeared as early as 1865. Independently, Prof. Thomas Turner, of Birmingham, England, had issued his famous account of the action of silicon in cast iron, and this gave the real start to the science of foundry metallurgy. To show how little the knowledge of such investigations and advances got about in those days when scientific aid in works was held in contempt by the self-made practical man, and how independently investigators had to work, it may be of interest to state that the author, in 1891, not knowing anything of Ledebur's or Turner's work, also discovered the importance of silicon in connection with the production of malleable castings, and brought this interesting branch of the foundry within scientific regulation.

While West was studying the practical side of the foundry as it was affected by the physical and chemical phenomena exhibited by the various classes of cast iron, other investigators were specializing in their particular fields. Thus W. J. Keep, of Detroit, Mich., made very extensive researches into the physical strength of cast iron—from the standpoint of the mechanical engineer—developing therefrom a contraction (erroneously called "shrinkage") system of testing known by his name. This, however, through its unreliability in general foundry practice—a ½-in. square test bar being used—is practically obsolete at the present time. Keep, however, has been indefatigable in his labor and has piled results upon results. The trained metallurgist, who delves after light on some puzzling problem, will find valuable data at hand in these studies if he is careful to remember that they were made with little regard for the demands of iron metallurgy, and hence are weak in that respect.

In Germany, Privy-Councillor C. Jüngst and Oscar Leyde made extensive investigations on the physical properties of cast iron, as did Prof. W. C. Unwin in England. On the metallography of this material Prof. F. Osmond in France, Prof. H. M. Howe and Prof. A. Sauveur in the United States, and particularly J. E. Stead, of Middlesbrough, England, should be recorded, as also the late Privy Councillor A. Martens, Prof. E. Heyn and Prof. F. Wüst, in Germany.

On the general considerations of the subject the following may be said: John Percy (1864) gives many points in his classical book on the metallurgy of iron and steel. In more modern time W. H. Hatfield and Percy Longmiur have written valuable treatises. For the highways and byways of cast iron no man is better known than A. E. Outerbridge, Jr., of Philadelphia, while W. G. Scott and H. E. Field have done much to clarify the metallurgical side of the problem. Mention could still be made of many other able chemists and foundrymen who have advanced the art by their unselfish work, and in the pages to follow they shall be duly referred to.

Many of the names given above are of men still living when this book was written. The author counts nearly all as his cherished friends. They are known to the industry throughout the world —for they have given unselfishly what they have discovered, so that their fellow-men might benefit thereby. What the future will have in store for the foundry industry, who can say? With the advance of scientific knowledge new worlds will be conquered, and without doubt the foundry will hold its own in the never-ending race to perfection.

CHAPTER II

RELATION OF THE FOUNDRY TO MANUFACTURING ENTERPRISE

Agriculture, mining and manufacturing are the three principal activities of man. Of the last-named, the foundry forms but one item of a very long list. Necessarily the foundry is closely allied to many other industries, either deriving supplies of raw materials from them, or serving them with castings. It is, therefore, highly important for the foundryman to inform himself sufficiently concerning the lines affecting his interests so that he may be in position to buy economically and timely, be able to detect inferiority in supplies bought from personal knowledge of the processes involved in their manufacture, know the problems confronting his customers, and thus be able to serve them intelligently.

The foundryman should make it a point to visit the blast furnaces from which he draws his pig iron. It will be a revelation to him to see the differences in practice involved. He will see furnaces kept in tip-top shape all the time, until relining becomes necessary, and operated with a view to "quality" rather than big tonnages. Gradations in practice will be found, depending upon the financial soundness of the owners and the degree of alertness and ability of the operating end. The foundryman will even meet cases of furnaces just holding together, slovenly operatives, careless charging, the poorest of raw materials, etc. Where normally rich ores are bought, plenty of coke of proper ash and sulphur content is used; where the stack is shut down before it becomes necessary to play water all over the shell to prevent breaking through; where the superintendent makes good use of the laboratory provided, it is certain that good pig iron is made, and the foundryman is reasonably safe in stocking the metal. He may get good pig iron where the opposite conditions prevail, but the chances of doing so continuously are very slim.

Similarly with fuel purchases. A trip through the regions supplying a foundry coke or high-grade bituminous coal will give a fair idea of the conditions under which these supplies are produced, and usually leaves the foundryman more receptive to explanations in time of strikes and booms. He, moreover, may become impressed with the thought that possibly the best dealers to tie to are those who handle coke made systematically carefully; where coal, if necessary, is washed to remove slate, and the coke is not drowned in quenching. Again, in by-product practice, with the ability to mix coals to produce the highest grade of metallurgical coke, and shatter tests to cull out the material fit only for domestic use, the foundryman can ask for first-class fuel for his cupola.

What endless disappointment and trouble has not been caused by the irresponsible seller of foundry machinery. The road to cupolas is paved with molding machines. Conveying systems, sand machinery, etc., will be found in many a scrap pile—often through ignorance of the purchaser, but more usually as the result of an imperfect understanding by the maker of the requirements of a foundry. There is little wonder, therefore, that the foundry is classed as one of the most backward branches of the manufacturing business. If, however, the maker of foundry equipment will only study better the service his material must give day in and day out, and if he will help to hasten the very noticeable change in the type of men selected to operate his devices, and if possible even of the foremen in charge, there will be mutual benefit all around, and a rapid advance in foundry efficiency. More effective missionary work is needed and fewer visionary promises.

The manufacturers of supplies of smaller value or more limited application should be remembered here. What with the purveyor of "fluxes" for the cupola, or the seller of "knowledge," the path of the foundryman is not a bed of roses. When well-posted, so that he need not let these people do his thinking for him, his waste-basket attends to the mail end of this leakage of money, and the office boy the leakage of time. It is but natural that the seller of facings, graphite, core binders, etc., wishes to keep the ingredients and their value secret from the purchasing foundryman, but in these days of investigation all supplies that cannot stand the test of quality, combined with but a reasonable profit to the maker, should be discountenanced. Herein, particularly, it is necessary for the foundryman to inform himself thoroughly.

On the other hand, the well-posted foundryman is always more reasonable in his dealings with the allied industries. He will not reject car loads of pig iron or coke simply on their outward appearance and without fair trial. While exacting full value and reasonable service, he aims to cultivate agreeable relations with his fellow-businessmen and even with his competitors. He is, therefore, usually classed by those who supply him with the great majority of desirable customers, to be protected in quality and delivery at all times, the minority of "kickers" invariably getting the "leavings" in the end.

Much could be written on the matter of efficient service to customers. The more the foundryman takes pains to know the wants of his trade, the more he keeps in touch with the progress made in the lines for which he furnishes castings, the better will he build. This forms the item of "good will" which is intangible but nevertheless an asset of great value. There is no place like the foundry for "casting bread upon the waters" to eventually have perhaps one chance in a thousand come back as a "specialty" and making the business.

The relation of the foundry to manufacturing enterprise is indeed a manifold one, and a proper conception of the situation based upon sound knowledge differentiates the "big" foundryman from the general mediocrity.

RELATION OF THE FOUNDRY TO COMMERCE AND FINANCE

About 10,000,000 tons of gray, malleable and steel castings were made in 1916 in the United States and Canada. This would mean that perhaps 12,500,000 tons of metal passed through cupola and furnace in foundries, and indicates the important position of the industry in the world of commerce and finance. From the standpoint of the buyer of castings, it is a great wonder why the foundry product has not been safeguarded by proper specifications more effectively than is the case today. This situation is very patent to the competent observer who can make comparisons with the carefully watched steel industry, and brings on a train of thought not very complimentary to the foundry.

It should be remembered, however, that steel is a very uniform and high-grade material, whereas cast iron is neither the one nor the other. There is not that prevalence, therefore, of high-grade talent in the foundry which is met with in the management and construction departments of steel enterprises. Furthermore, the production of castings involves a very distinct "art"—that of the molder—and as this is a highly laborious one, the rank and file is better known for brawn than for brain.

The important bearing the foundry industry has upon the financial condition of a country is best understood when there is considered that every one of the many thousand foundries of all descriptions has to buy metals—principally pig iron, fuels, sand and usually considerable scrap. There results a great freight movement covering probably every railroad and waterway, raw materials coming in and castings going out. The production and distribution of pig iron has, therefore, become the criterion of the financial situation—the barometer of the times—and so sensitive is this measure of industry that its lessons are read by every banker and acted upon by him as well as by governmental heads in framing budgets and directing the golden river necessary to keep the channels of trade unclogged.

If such highly capitalized industries as iron and coke making require additional banking facilities to carry on their operations successfully, it is quite patent that the individual foundry, rarely provided with ample working capital, is even more dependent upon this class of help. In view of the intimate relations of the foundry with commercial and financial problems it is manifest that foundrymen should take a lively part in local and national boards of trade, industrial commissions, governmental activities, and the like. They have too much at stake to keep aloof.

Foundrymen who are geographically so situated should cultivate export trade relations with foreign countries. The more of finished product that can be sent to other countries, the better for home labor, more money is put into circulation, and the prestige of the country raised abroad. Undertakings of this kind are, however, carried on safest with the aid of internationally recognized standards for quality, thus discountenancing underhand trade methods and making merit the governing factor. Hence foundrymen should not only encourage the preparation of National Standard Specifications, but through the various organizations interested, government bureaus, etc., extend this service to International Standard Specifications for export, wherever the nature of the castings allows of it. This is possible of performance as it does not involve interference with home customs which it would be hopeless to attempt to change for internal-trade purposes.

INTERFOUNDRY RELATIONS

As a prerequisite to successful foundry expansion nationally as well as internationally, it is patent that attention must be given to interfoundry relations. The very need for such mutual service and its resulting benefits is best shown by the number of foundrymen's associations existing at the present day. Whether these organizations be instituted for mutual protection in times of labor agitation, or to promote efficiency in shop and office, they all have an additional social value. They serve to get foundrymen acquainted and bring out latent good qualities which tend to ameliorate asperities brought about by sharp competitive conditions.

The most valuable of this associated effort is undoubtedly that for technical progress and efficiency, as this reacts directly on the general good of a country, if not in even wider measure. America claims the distinction of having brought about the first national association of this kind, the American Foundrymen's Association—organized in 1896. Since that time similar bodies have been called into being in Great Britain, Germany, Sweden, France, and possibly one or two further countries. In Germany, as in North America, there are two national bodies, one for technical progress, and another for the promotion of certain business interests. While the former development is entirely free from governmental supervision, the latter is naturally closely concerned in statutary enactment as a definite stand is taken in connection with economic movements of the day. The author, from an intimate connection with association movements for many years feels free to hold that societies for technical improvement have the best chances for survival, for in addition to spreading knowledge broadcast for the good of the industry, irrespective of membership, they serve as a nucleus for special movements which are temporary in character and in which interest would die out after a crisis has passed.

In connection with the monthly or annual meetings of foundrymen's associations, at which technical papers are read and discussed, problems ventilated and solutions offered, of late years there has sprung up the making of exhibits of foundry machinery in full working order. The educational value of such exhibits is patent, and if carefully arranged and the mercenary side kept back as far as possible, such exhibits should be encouraged as an excellent medium of exchange of operative foundry knowledge.

Another associated foundry effort is to be found in bodies combining for mutual protection against labor exactions, unjust laws, and to promote a better state of working conditions in the trade. Under wise counsel such organizations are capable of doing much good, steadying trade conditions and employment, and conserving property.

Finally there are the foundry organizations to promote trade, with which foundrymen are urged to keep in touch, but the work of which falls without the province of this book.

FOUNDRY LABOR PROBLEMS

The relation of the foundryman to his employees is naturally a delicate subject, but upon which much can be written. In general, however, the ability to put oneself into the other man's place helps to overcome much of the friction certain to be present where men congregate. In spite of the inherent selfishness which is part of the human make-up, in any establishment every one is usually satisfied when a plain natural justice, tempered with an understanding of unessential shortcomings, is dealt out by the powers that be. Men, in the last analysis, always admire an exhibition of backbone, even if it does not fit with their demands, but they want justice and an opportunity to be heard. Hence the caution necessary in the selection of superintendents and foremen—over whose heads no employer cares to hear the complaints of subordinates as a general thing.

One of the most satisfactory methods of dealing with shop labor is the following general scheme of advancement from yard to superintendency. It was used by the author with signal success in several instances. All common labor of an establishment not subject to regular departments and their foremen is placed under the Yard Department, where pig iron is unloaded and stored, the mixtures made up, etc. The foreman of this department hires all unskilled help, and should preferably be very capable of judging men. An ex-police sergeant fills the bill best. Men are sent into the shop for odd jobs as required. When a foreman wants a man for permanent addition, the yard foreman sends in the one he thinks best suited for the work required. As this ordinarily means harder and more responsible work, a slight advance in pay should make this transfer a promotion. It makes the yard men anxious to get inside even if the work there is hotter or more exhausting. Unless special reasons exist a man thus transferred who does not like the change may not go back again, but leaves the plant. Similarly, if unfit for the new work and indicating that he would do no better in another department. In other words, a set of men is wanted in the yard who have the stuff in them that warrants promotion. The men thus taken into the departments inside are given ample opportunity to become proficient, advanced in pay as they deserve it, and have every chance for the foremanship. Men who work up in this way usually leave for an assistant superintendency elsewhere, as few plants have a sufficient number of openings, and they eventually make their mark in life.

The author has further used this method of disposing of the numerous young men coming with letters of introduction. If they looked the part, they were offered a chance to begin at the bottom, in the yard, and at laborers' wages, but also promised that an eye would be kept on them. Where they stuck, and shirked no duty required of them, they were moved inside fast, and many worked up into supervisory places with credit to the establishment and themselves.

With a general policy of this kind in force there will never be a lack of good material for skilled and common labor, as well as apprentices from among the sons of employees in ordinary times.

MACHINERY VERSUS HAND LABOR

It is a common dictum in the steel mills that it pays to invest several thousand dollars for machinery to replace one laborer. On the face of it, this looks like sound business. Unfortunately, however, it should be remembered that a machine will not run continuously and well without brains in charge of it. Many are the foundries in which machinery of one kind or another was installed originally, only to be torn out after constant breakdowns, simply because it was forgotten that a dollar-and-a-half a day man is not capable of caring for a complicated mechanism effectively—he would otherwise not be getting only a dollar and a half a day. Since the tendency is any establishment in charge of a superintendent without special mechanical training is usually to hold down the pay-roll at any cost, regardless of the demands of the situation, another plan must be used. The design and branching out of the plant must be so conducted that there is the least possible occasion for mechanical equipment. Things must be placed handy, short distances rule, supplies be centralized in places with railroad trackage so laid out that this can be easily accomplished. With a good labor market this is the preferable situation as in dull times there is no heavy investment to eat up interest.

Nevertheless, every item of foundry procedure should be studied carefully lest a costly mistake be made in turning down labor-saving equipment. The jarring molding machine is an example of this, for remarkable cuts in molding cost have been made by this simple transfer from hand to power ramming.

Hence, when it comes to deciding upon the question of replacing hand labor by power machinery, the foundryman, after assuring himself that the change figures out a handsome return on the money to be invested, should consider whether he can stand the sinking of this capital, and whether the temptation to cut running cost may not land him into future difficulties. In other words, whether the machine is reasonably "fool-proof."

SPECIALIZING IN THE FOUNDRY

The goal every foundryman aims at is the acquirement of a line of product which can be made as near a profitable monopoly as possible. Whether this is brought about by exploiting a basic patent, because of a thorough mechanical excellence in some general line, or the undercutting of every competitor through some special circumstance—for secrets in manufacture have no place in the foundry any longer—the fact remains that with a specialty that either pays well or keeps the shop busy making stock piles in dull times, a foundryman need not worry about the future as much as where this is not the case.

Foundrymen should, therefore, go out of their way a little to encourage new lines of work requiring castings, charging this to profit and loss if it becomes necessary. Further, they should be constantly on the lookout for connections that may mean stocking castings. The railroads and other large corporations constantly adding to their equipment are cases in point. For a consideration in the way of reasonable or flat rates in payment on work sent in by blue print—meaning the making of patterns and chancing the tonnage—a foundry may be guaranteed the acceptance of large additional supplies of designated castings. The arrangement of a warehouse to hold the material made in surplus, and filling up time between jobs in the foundry makes this method an exceedingly valuable one, and comes close to specializing.

The above refers specifically to the ordinary jobbing foundry, history showing that most of the present specialty foundries were once of that class. Once a specialty has been developed, an enormous expansion becomes possible in this country, as may be seen in the manufacture of stoves, car wheels, pipe and fittings, agricultural work, rolls, hardware, etc.

THE CONTINUOUS FOUNDRY AND THE PERMANENT MOLD

As forming a part of internal foundry conditions, the departures from common foundry practice indicated by continuous operation, and as an adjunct, the use of the permanent mold, there is this much to be said:

Where the nature of the work allows the molding up to be fairly rapid, so that were molten iron at hand and could the sand be retempered quickly, pouring off might be resorted to off and on during the day, it pays to consider the question of melting all day long. Foundries making cast-iron pipe, fittings, air-brake specialties, malleables, etc., have found this to be the case and saved themselves immense investments otherwise necessary for plant enlargement. After all, it becomes a question of the floor space taken up by molds ready to be poured off.

The introduction of the jarring machine, with the possibility of closing up the molds shortly after starting up, instead of days after as was formerly the case, should tend to this desirable end. Be it remembered that the curse of the country's manufacturing situation has always been overequipment—the capacity for turning out work far exceeding normal requirements. With more foundries running continuously in their melting, or at least partially so, there is not the temptation to add to plant capacity until it becomes absolutely necessary. A very considerable production above normal can be cared for by this method.

The author, at a time when he made some 50 tons of gray iron castings daily, found it convenient to start the cupola during the morning hours, run a while, shut down again, and then run the last hours of the day. This allowed the pouring off of many molds which would otherwise have been held, and the men kept on molding nearly all day. A study of the chapter on cupola practice will show how readily this can be accomplished, once the basic principles of melting are understood.

As to the permanent mold, of which one hears so much in the foundry, but which seems so elusive as yet, the day will unquestionably come when much of the repetition work which lends itself to this line of endeavor will be made in at least "long-life" molds, if not the so-called permanent (iron) ones. Most of the work done so far has been with cast-iron molds protected with more or less valuable coatings. Usually too much has been attempted, one system involving such enormous weights that it became prohibitive. Another system had such light molds that a hundred applications wore them out. Again, another experiment required iron practically free from manganese, another excessively high silicon, and so on.

The very use of a non-refractory material such as cast iron, would seem diametrically opposed to the requirements of the case, unless indeed the conductivity of the mold can be counteracted. This is attempted somewhat by the graphite coating applied.

Probably the ultimate solution will be found in getting hold of a refractory material able to withstand the high temperatures involved indefinitely, to resist the penetrating action of the metal, slag, etc., the wear and tear of service, and thus allow the construction of a mold of sufficiently long life to give an effective substitute for hand-molding. With a constant proportional diminution of the visible supply of molders facing the industry, it is to be hoped that the so-called permanent mold may eventuate, and much of the repetition work of the foundry be taken from the skilled men, so that their services can be used to better advantage elsewhere on the floor.

CHAPTER III

ORGANIZATION OF A FOUNDRY ENTERPRISE

In tracing the development of the foundry industry, it is well to consider how new enterprises of this kind have come to be established, in order to estimate the probable future expansion. Again, by observing the several stages of enlargement in instances of striking success, valuable lessons in organization may be learned. When all has been told, conditions being favorable as to location, that establishment runs full time longest when things grow dull, which has the best organization.

In providing the many visiting foundrymen of foreign countries with introductions to the prominent establishments of the United States and Canada, the author has always impressed upon them that the keynote of the successful operation of the plants they would see was to be found in the exceptionably able organizations, and unless the visitors could become acquainted with the business methods and operative policies, the full advantages of the inspection would not be gained.

Many foundries have been established as new departments of existing manufacturing plants. In former times the blast furnaces furnished all the castings of the iron mills. These establishments eventually, however, found it desirable to remelt their metal going into castings in the interest of soundness and strength. In more modern times we find the fluctuations of business activity, with the accompanying poor deliveries and excessive prices when times are brisk, bringing a manufacturing plant to such straits that in self-defense a foundry is added.

Again, a manufacturing plant may be so located that the purchase of castings becomes exceedingly inconvenient. The market drawn from may be a hot-bed of labor troubles. It often happens, moreover, that the castings required are so difficult to make that no conveniently located foundry cares to rig up for the work at the prices offered. Finally, when the tonnage is sufficiently large it certainly pays a manufacturing concern to make its own castings. Hence, the constant increase in the number of gray iron, malleable, steel and non-ferrous metals foundries from year to year, the sum total in the United States and Canada in 1916 being close to 6,300.

Then come the foundries established as independent ventures. Frequently these are the result of a patriotic spirit on the part of the local Chamber of Commerce, inducements in the way of land or exemption from taxes for a time being given. A newly conceived project is oftentimes made possible of existence in this way, or an old established concern starving in another location may be brought over and rejuvenated. As a general rule, proven by the successful exceptions, a concern that finds it necessary to depend upon such aid ultimately pays very heavily for it.

We also have the individual severing his connection with an existing foundry and branching out for himself. He may be the foundry superintendent or foreman, the foreman patternmaker, or an office man; or, better still, a foundry foreman and patternmaker sometimes combine, and this will be found to have been the origin of many a successful foundry of the present day. If in line with the development of possibilities in the region selected, enterprising men with ideas will create a good business.

It is necessary to consider one serious phase in such an industrial development, and that is the effect produced by the organizer of a new foundry enterprise who has no practical knowledge of the business. He induces others to join with him—often by means of a prospectus containing glaring absurdities in the way of promised returns. The start is made. Prices are slashed to get business, and not only will failure be the inevitable result, but the trade of the region affected is demoralized for a long time to come.

Whoever wishes to embark in the foundry business should first of all know what there is to it. Next, he must be assured of a reasonable market to take up a minimum daily production. Finally, he must have capital, and be able to get more. The first cost is not great, $10,000 oftentimes covering the ground, wooden buildings, second-hand equipment and working capital until the turn is made. Pipe, stove, car-wheel, agricultural and other foundries of comparatively large tonnage capacity, are invariably begun by an association of individuals knowing all about the business. Big capital is necessary here, as well as an assurance of a market for at least half the contemplated output.

Existing manufacturing plants requiring both iron and brass castings usually equip for iron first, as the brass product which involves much more expensive materials is a problem approached more cautiously. When it comes to adding a malleable or steel-casting department, peculiar care should be taken. A tonnage of sufficient size is absolutely essential as otherwise outside work will have to be gotten, and this usually at actual cost. The result, again, is a demoralization of the outside trade. Of late the addition of a malleable and steel department to large establishments operating the open-hearth furnace has become very advantageous. The author, in his own establishment, continually alternated malleable and steel heats in the same furnaces. Thus a smaller tonnage of each material would justify the creation of the new department, where with separate installations this would not be the case.

ORGANIZATION OF THE BUSINESS

Among the cardinal principles that should be kept constantly in mind by the management of a new concern, and impressed upon the employees all the way down, are the following: First, the aim should be to produce only high-grade work. At every point in the several processes used there should be provided some means to check the quality of output. Whether in the sorting, test room, or other parts of the shop, the manager of an establishment should make it his business to appear unexpectedly to inform himself at first hand on what is doing. There is a natural tendency to take chances, and even the superintendent hates to pass up statements showing heavy avoidable discounts.

Second, the high-grade work produced should be sold at as near the top figure the market may bear. This means good salesmanship. To do this it is necessary to observe a third principle. Know your costs to the smallest necessary detail. This cannot be urged too strongly. The great source of the evils resulting from injudicious competition is an imperfect cost system. Who, in asking prices on various classes of work, has not been astonished at the great variation in the quotations? Apparently the bidders were all able men in their line, and could judge the actual labor and metal cost to the fraction of a cent per pound. On their "overhead" expense, however, very few realized the true situation. The lowest man would get the job, and the best would think "if so-and-so, whose shop and costs are practically identical with mine, can take this work at his figure, I should be able to do the same," and next time all would be lower and take chances on losing money. Shrewd customers constantly play upon this characteristic of foundrymen and thus get their work cheap. The so-called "sleeping" customers of foundries have to make up these losses by paying non-competitive prices.

On the other hand, it is not necessary to go into shop costs in unnecessary detail. Every clerk added to the office represents the interest on a respectable amount of investment. No cost system should do more than show in the simplest and quickest way just what is needed to get reliable results. Any extra detail, while interesting to the efficiency expert, ordinarily is money thrown away.

The fourth principle to be adhered to is the fixing of responsibility from top to bottom. To get the best results an employee should be held to the full responsibility of the position he occupies. It follows as a necessary consequence that he should not be interfered with in directing his subordinates. Results are wanted, and these with the slightest amount of friction. If an officer or foreman cannot manage his men properly, or treats them unfairly, he should be gotten rid of quickly. This emphasizes the importance of selecting proper men. Indeed it is one of the essentials of success.

A foundry is always run best when there are as few rules posted as possible. The human element must be considered and employees have their personal liberty interfered with as little as may be, consistent with efficiency and the proper care of the property. By letting the men feel that absolute justice shall prevail, good work be rewarded, and every bad job will be fastened on the one responsible, selective advancement becomes possible in an establishment, and gradually a splendid and efficient organization will be built up.

This brings up the question of "welfare work" in the foundry. As men are constituted, they do not care for recreation rooms other than at home. Nor do they enjoy night-school lectures as a general thing. From the lower depths of foundry labor, where the water pail and possibly a piece of soap is used for cleaning up just before going home, if indeed even this trouble is taken, we rise to the efficient mechanic who appreciates the shower and sanitary toilets. The experience of the author indicates that it is advisable to keep the welfare facilities just slightly ahead of the make-up of the men. Nothing is more disappointing to a concern than to equip a fine change room, only to find it either little used or damaged through carelessness and ignorance. As the class of men rises in intelligence—and every works to have a chance to live must aim at this—improvements in the sanitary facilities offered should be made, welfare work of other kinds instituted, shop suggestions received and rewarded, and encouragement given the individual to rise above his surroundings.

In modern systems of management the committee idea is becoming more and more firmly intrenched. A one-man power is always irritating and those who have had experience in both directions vastly prefer to discuss and settle upon lines of policy and action in the committee room, every department interested being represented. From our very largest corporations, where everything is done by committees, to concerns which encourage the meeting of the shop management with representatives of the men employed, the most efficient work with a minimum of friction is brought about by this method of operation.

In a small foundry the owner of the business may require only a good foreman, a patternmaker, and a clerk. In a very large organization the Board of Directors are supreme as representing the investment. There may be a chairman of this board who looks after the political and legal sides of the enterprise. The president of the company has the general supervision of its activities and his special duty is to bring in new connections. The vice-presidents divide the operating, sales, and ordinary finance among themselves. The secretary has the office and correspondence. The treasurer, if not a figurehead, looks after the accounting, otherwise an auditor does this. Each general officer usually has a confidential assistant clothed with more or less power. The works are preferably operated by general superintendents in conjunction with advisory boards who report to them. These boards are made up of superintendents, experts and foremen, and these may also meet with the general officers of the organization. In the case of corporations with many works widely separated, a manager of works may be appointed, or even district superintendents required. A live concern watches for specially efficient men who are by disposition fit to be entrusted with supervisory work. Far better to advance your own men than to go outside. Superintendents and foremen should be sent about the country and even abroad occasionally to keep in touch with the art and pick up information. Certainly always to foundrymen's conventions to rub up against fellow-craftsmen and supervisors, and thus gain knowledge.

If the sales and operating forces are combined there is usually a general manager at the head, though this office is generally found in neither very large nor very small establishments.

It will thus be seen that the exigiencies of American manufacturing enterprise has brought about an elaboration of the supervisory end of the organization detail. This is the result of the terrific competition existing. In properly organized and conducted establishments every general officer is a man of high standing in the community, adding strength to the enterprise. Each superintendent is a man picked for his special fitness and commanding a salary which keeps him alert for fear of losing it. The larger the business the more it pays to see that every one does his work, and as by wise direction expansion cannot but take place in a growing country, the cost of supervision per ton of output should fall steadily.

A group of men, therefore, who contemplate the organization of a new foundry enterprise, can do no better than give the principles enumerated above careful consideration. They will then start right, and not have to pull up short after every foundry tramp of the country has passed through the shop, foremen have been lost and changed, and the shop generally run down.

CHAPTER IV

OUTLINE OF IRON METALLURGY

IRON

While foundrymen were formerly little concerned with the development of iron products other than pig and cast iron, the rapidly increasing demand for steel castings and the use of steel scrap in iron-foundry mixtures at the present day require some fundamental knowledge of the subject on their part. Hence, an outline of the relation of the element iron, and its compounds to the various divisions of the industry, together with the general processes involved, is given herewith.

Approximately pure iron was formerly a laboratory curiosity. Today it is made out of the remarkably pure magnetite concentrates of Sweden and enters into the production of the finest grades of crucible steel. When thus made by a reduction of the ore, allowed to cool before coming into contact with air, consolidated under enormous hydraulic pressure to prevent reoxidation in the subsequent heating, this practically pure iron is soft enough to be indented by the finger nail.

Nature gives us our available commercial iron only in the form of its oxides. It is the work of man to tear the metal from the ever-active oxygen, and when thus freed to protect it with every available means from returning to the original state. Witness the care taken to prevent rusting, as well as the evil effects of badly carried out heat-treatment and melting processes. All this means a partial reoxidation of iron.

Pure iron melts at about 2,900°F., and through molecular changes at high temperatures has been found to assume several allotropic forms—much as do sulphur, phosphorus, etc. These molecular changes in iron have to do with the peculiar magnetic and hardening phenomena shown by iron-carbon compounds. For practical purposes, however, pure iron, except when made cheap enough for use in high grades of crucible steel, is of little interest to the iron-maker. The important compounds of iron with carbon, and in lesser measure with other elements, are the ones to claim our attention, for upon them rests the whole superstructure of the iron industry.

IRON AND CARBON

The solution of relatively small percentages of carbon in iron—forming a series of combinations which can be likened to alloys—has a powerful effect upon the resulting materials. When the carbon percentage runs below 2.00 we have a steel, when above, a cast iron. Hence, beginning with pure iron, with no carbon whatever, we can run up a whole series from very mild to tool steels, and then beyond from the low-carbon, high-grade cast irons to the very low-silicon varieties of pig iron with as high as 4.30 per cent. total carbon.

Pure iron, in becoming saturated, can take up about 4.60 carbon. Manganese and chromium increase this saturation point, whereas silicon reduces it. Foundrymen know that the total carbon of the high-silicon irons is always lower than that of the low-silicon white-fracture irons.

The carbon of any iron in the molten state is always in one form—that in simple solution. When the molten iron solidifies, the carbon present may come out either as a free carbon, being graphite, or it may remain in solid solution—known to foundrymen as "combined carbon" but scientifically as "austenite." As the solidified metal cools down to ordinary temperatures, more or less of this austenite will be changed to another form of combined carbon—a definite iron-carbon compound (iron carbide, Fe_3C) called "cementite." While the foundryman will not distinguish between these two forms of combined carbon in his analysis, yet there is a difference between the two. Austenite has the characteristics of "chilled" cast iron and hardened, suddenly cooled steel, whereas cementite has the characteristics of slowly cooled steel or cast iron.

The matter of graphite in cast iron requires further attention. While reported as such in analyses, there are nevertheless two forms to be reckoned with. One is the ordinary crystalline form found in pig iron and gray castings, and the other is an amorphous form called "temper-carbon" (Ledebur), or annealing carbon, and is best seen in the "black-heart" fractures of the malleable casting. Under ordinary conditions of heat-treatment (annealing) the crystalline graphite content of gray iron remains unchanged in form, whereas if a malleable casting is brought to red heat and quenched, part or all of the temper-carbon present may go into solid solution again.

FIG. 1.—Pen sketch of needle and irregular shaped cementite in relief, in white field of austenite.

The practical foundryman is not particularly interested in the microstructure of his castings. Since a casting in the gray iron foundry—once made—cannot be changed through subsequent treatment (an exception to this rule being the occasional annealing given a hard casting to make it machine more readily), the science of metallography cannot be of great assistance. In the steel foundry this is quite different, and great strides have been made. The microscope will probably find its application in the foundry laboratory solely for the purpose of investigation and study "after the fact," and not before. For that reason but little need be given on the microstructure of the iron-carbon compounds. Fig. 1 shows the two forms of combined carbon above referred to. The white field is austenite. This form of

FIG. 2.—Pen sketch of graphite in field of comparatively pure iron.

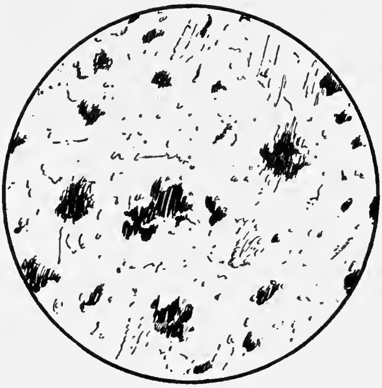

FIG. 3.—Pen sketch of "temper-carbon" blotches in clear field of comparatively pure iron (malleable casting).

combined carbon is difficult to obtain pure. Only heating at very high temperatures and quenching in ice-water will give reasonably good specimens. Decomposition of austenite to other forms is rapid. The portions standing out in relief consist of cementite, and are both in form of long needles and in irregularly shaped ridges. This cementite, though formed by the annealing of steel and the cooling of pig iron, is nevertheless an exceedingly hard substance, scratching glass. There are a number of other forms of combined carbon, such as martensite, troostite, etc., the two above given being the important ones, and as stated previously all reported in an analysis as "combined carbon."

Fig. 2 shows a field of comparatively pure iron in which may be seen the magnified streaks of graphite. As these crystals are mechanically mixed in the matrix of iron, they form planes of separation along which rupture under stress becomes easy. Hence, the comparatively low strength of cast iron when compared with steel. Fig. 3 shows the interior of a piece of "malleable." Here in the clear field of comparatively pure iron we see the blotches of "temper-carbon," which may be particles of very finely divided graphite, but certainly have not the flat crystalline structure which make them so weakening in gray cast iron.

IRON AND SILICON

Silicon is reduced principally from the ash of the coke in the blast furnace. This reduction takes place in the presence of carbon and under very high temperatures. The silicon goes into solid solution in the mass of iron (in the forms of Fe_2Si, $FeSi$, $FeSi_2$). When in iron up to 3 per cent., and in the absence of any carbon, no special effect is noticed. When, however, carbon is at hand a very material change takes place as the silicon is high or low, the carbon being either thrown out as graphite or kept retained as combined carbon.

Silicon reduces the solubility of carbon in iron, the low-silicon pig irons running higher in total carbon than those with a high silicon content. As this property is of some importance to the foundryman in connection with both chilled and sound castings, the following table—recalculated by the author from data published by Wüst and Peterson—will be of interest. In addition to the total carbon corresponding to a given silicon content—

no manganese supposed to be present—the setting (freezing) point of the several materials is given. It should be remembered that in cast iron and steel while in the molten state the carbon present is always in the same form, and whether as the metal sets this carbon remains as combined carbon or is precipitated as graphite, this has little influence on the degree of the temperature involved. The melting point of these irons is quite another matter, depending in the main upon the percentage of combined carbon present. Further, had some manganese been present in the tests above mentioned, the carbon would have been somewhat higher, as this element, particularly when in large percentages, promotes the retention of carbon otherwise removed by silicon.

Silicon, per cent.	Total carbon, per cent.	Freezing point, degrees F.
0.00	4.38	2,080
0.25	4.22	2,087
0.50	4.10	2,094
0.75	4.02	2,102
1.00	3.96	2,109
1.25	3.90	2,116
1.50	3.82	2,125
1.75	3.76	2,134
2.00	3.71	2,141
2.25	3.65	2,148
2.50	3.59	2,155
2.75	3.53	2,163
3.00	3.47	2,170
3.25	3.41	2,177
3.50	3.33	2,185
3.75	3.28	2,192
4.00	3.24	2,199
5.00	3.05	2,217
6.00	2.90	2,230
10.00	2.30	2,246
20.00	1.10	2,268
25.00	0.90	2,285

A comparison of the table above given with the analyses of various classes of well-made pig irons indicates a fairly close agreement. Occasionally the total carbon in the pig will be found higher, and apart from any richness in manganese this may be due to the incomplete removal of an excess of carbon taken up by the iron while in a highly overheated state within the blast furnace.

It is well known that at the extremely high temperatures existing in the electric furnace iron can take up much more carbon than is equivalent to the saturation point. Jüptner even claims that at 8,330°F. iron can take up 40 per cent. of its weight in carbon. Such supersaturated iron, on cooling to normal casting temperatures, throws out its excess carbon into the atmosphere in the form of graphite, and known about the blast furnace as "kish." Moissan took advantage of this property of carbon supersaturation in iron to prepare such a charge in the electric furnace, plunge the molten metal into quicksilver covered with water—thus chilling the metal particles outwardly and exerting enormous pressures within—and produced microscopic diamonds.

Very often, however, another situation is found with regard to the silicon-carbon relation in pig irons. The total carbon may be very much lower than given in the table in question. Here there is evidence of irregularity in the working of the blast furnace, and pig iron made under such circumstances is best kept out of the foundry. An occasional checking up of the total carbon of the pig-iron shipments is therefore advisable—not the graphite or combined carbon—if this is not done as a regular routine anyhow.

Necessarily the total carbon of the castings made, and consequently the cast-iron scrap these eventually become, cannot be judged thus, for the almost universal admixture of steel scrap in smaller or larger quantities is intended to reduce this element. The result is a reduction of the graphite crystals in size and quantity, thus forming smaller planes of separation in the sound metal, and hence increasing the strength of the material.

From the table it will be noticed that the freezing points of the several combinations increase regularly as the silicons rise and the total carbons go down. This, while interesting, is really academic, as within the ordinary foundry range—from 0.75 to 3.00 silicon —the variation is but 68°F.

Silicon is of interest to the foundryman solely for its powerful influence on the state of the carbon in castings. Low silicon means a white fracture, high silicon a gray one. Hence as in the iron-carbon series the range is from the softest iron to the tool steels and thence beyond to white cast iron, so with the foundry portion of the iron-silicon-carbon series, the beginning is made with hard white iron, then the mottled fractures, and finally the soft gray iron so highly thought of in the machine shop though rather low in strength.

IRON AND MANGANESE

Manganese alloys with iron in every proportion. In cast iron, however, it has a greater affinity for sulphur, carbon and oxygen than for the iron, so that it will be found present in practically two forms, namely as a manganese sulphide (MnS) and as an iron-manganese carbide $(FeMn)_3C$.

In studying the oftentimes contradictory statements made in regard to the effect of manganese in cast iron it is necessary to remember a few fundamental principles involved. Manganese has a greater affinity for carbon than has iron, and hence high-manganese pig irons, as well as the ferromanganese alloys, always contain a comparatively high total carbon. Again, with high-manganese mixtures going through the cupola—and proper melting practice observed—there is a chance of taking up more carbon. Similarly, there is a rise in the total carbon of a ladle of iron to which ferromanganese has been added. In passing, it may be mentioned that the tendency to increase the carbon when running high-manganese irons through the cupola is due not only to the affinity above mentioned, but to the fact that manganese protects the carbon by sacrificing itself to any oxygen that may be present. The result of this carbon addition is naturally to soften the metal. This effect is, however, somewhat counteracted by the property manganese has to allow carbon to remain in combination with iron—in other words, to increase the combined carbon content. This property is not marked until the manganese exceeds 1 per cent. The real difficulty brought about by high manganese where hardness is noted is the formation of the above-mentioned iron-manganese carbide, which is granular and hard, giving much trouble in machining. Indeed, powdered ferromanganese is sometimes applied to the face of a mold to practically "case-harden" the surfaces of the casting to be made therein.

The two properties of manganese which interest the foundryman particularly, however, are the effect this metal has on the sulphur in the mixture, and the deoxidation possible when manganese is added to molten metal from high-steel scrap percentage heats—the necessarily higher temperatures existing allowing this reaction to take place.

The combination of manganese and sulphur which takes place at very high temperatures can be used to some extent for the desulphurization of cast iron. Time must, however, be given this manganese sulphide to rise to the surface. Again, the element sulphur, in combination with iron, is not disseminated uniformly in the general mass of the metal, as may be readily observed with the microscope. Then, also, manganese is very prone to combine with some of the carbon present. Consequently, not all of the sulphur will be affected. Even under the most favorable circumstances in allowing the manganese and sulphur time and temperature to get together the residual sulphur will rarely fall below 0.035 per cent. Hence, time is necessary not only for the manganese sulphide to rise, but to actually form within the molten metal.

The statement is often made that manganese sulphide after rising to the top goes directly into the slag. This is true enough where a slag is full of lime and comparatively free from ferrous oxide. The latter opposes the proper reduction of iron sulphide, and this is always united with manganese sulphide. A separation is necessary before manganese sulphide will enter the slag. Blast-furnace slag is made with this situation in view and a good desulphurization is effected. The slag present on top of a ladle of molten iron, however, is something entirely different, and is not capable of dissolving manganese sulphide. This, in rising, will therefore form a layer between the molten iron and the slag cover.

A glance at the specific gravity of each of the materials involved will prove instructive. With white cast iron at 7.2 sp. gr., manganese sulphide at about 3.55 sp. gr., and slag (calcium silicate) at 2.91 sp. gr., the idea of layering looks plausible. Allowances should, however, be made, as molten iron may not be exactly 7.2 sp. gr., the manganese sulphide in question is the chemical, crystalline, product; and the slag is represented by a mineral calcium silicate.

That high temperatures—or rather a very fluid iron (with plenty of "life")—is a necessary requirement, is shown by the fact that when much manganese sulphide is present a goodly portion can be found remaining in the metal, and give subsequent trouble in machining through hard spots. Either this compound did not get out in time, or else in pouring over the lip of the ladle some of the manganese sulphide was washed into the running metal again. A bottom-pour ladle would overcome the latter trouble effectively. That there must be some uncertainty relative to the integrity of castings which contain much of this manganese sulphide or the iron sulphides themselves is shown by an examination of the microstructure. Such a metal may give very fair tensile and transverse strengths, and yet fail signally under repeated shock. Hence the introduction of low sulphur requirements in specifications in addition to the ordinary strength requirements. It is a fallacy in the manufacture of the malleable casting to assume that, because good physical tests are obtained, any comparatively high sulphur present has been neutralized by a suitable manganese addition in the charge. The real test such castings should be subjected to—that for resilience, or resistance to shock—has never been applied properly, the art of testing materials not having advanced sufficiently in this respect. This situation has been fully recognized in specifications for cast-iron pipe, which product is subject to the dangers of a "water-hammer" and hence must be kept comparatively low in sulphur.

To understand the situation more fully it must be remembered that manganese sulphide is present in a casting in the shape of a globule or string of a slag-like material. It is patent that if such globules are very small, or the strings run in the same direction as the strain applied when under test, the tensile strength will not be affected appreciably. Similarly, if a test piece is subjected to transverse pressure and the lower fiber is free from manganese sulphide, while the top may be full of it (tested cope side up), a good transverse test is obtained. Nevertheless, such separations of the sound metal by these slag-like inclusions, when subjected to repeated shock, mean the starting of a crack which eventually leads to rupture.

That this segregation of manganese sulphide in cast iron may be quite serious is indicated by some analyses given by Field, who found the sulphur and manganese content ½ in. from the top of a cylinder but 24 in. high to be 0.204 and 0.66 respectively, whereas 2 in. from the bottom these elements ran 0.148 and 0.54. Again, he quotes the results obtained from a cast-iron water pipe the top of which gave 0.306 sulphur and 1.14 manganese, while the bottom showed up only 0.076 sulphur and 0.58 manganese

Reverting again to the deoxidizing power of manganese. The rôle of oxygen in cast iron will be discussed later. At the moment mention need be made only of the well-recognized fact that in cupola melting the manganese present in a measure protects not only the carbon present from oxidation, but also the silicon, and to an appreciable degree the iron itself. Unless there is the best of cupola practice it is necessary to keep above the 0.50 point for manganese in the general run of gray iron castings to avoid shrinkage and gas troubles. Many a foundryman looking over his daily pile of defective castings and wondering at the vagaries of what he must think an unreliable material, would be saved worry and money if he could but melt right and interpret his analyses properly. Unless this is the case it is important to hold the manganese in the mixture sufficiently high to give about 0.70 on the average to the castings made. With good melting practice it is perfectly possible to fall considerably below 0.50, as witness the low manganese in cupola malleable practice.

This does not mean that any manganese lacking in the mixture should be made up by charging ferromanganese into the cupola, as this would be an expensive procedure and still leave that part of the mixture low in this element subject to oxidation while melting. Nor will it always do to add the ferromanganese in the ladle, as the damage has already been done in the melting, and unless the total carbon is fairly low with the temperature very high—as is the case with high-percentage steel scrap heats—deoxidation will not take place. Hence, special attention should be given to the purchase of pig irons having the right manganese percentage to insure safety in this direction.

IRON AND SULPHUR

Iron and sulphur combine readily up to 53.3 per cent. of the latter element. Iron sulphide (FeS) is a hard, brittle substance melting at a comparatively high temperature. In cast iron this iron sulphide is found in combination with 16 per cent. of iron as a distinct material which melts at a lower temperature (1,750°F.) than cast iron. When this is present in any quantity in the general mass of molten iron it solidifies last and separates out along the joints between the separate crystals of iron, greatly weakening the structure. Even when comparatively small quantities are present, distinct films are thus formed affecting the integrity of the metal.

Comparing this property with the effect of manganese sulphide, which separates out more particularly in globules, the iron sulphide is naturally the more dangerous of the two. In the analysis of cast iron, all the sulphur is reported as one item, without distinction as to its origin. Hence, the manganese should be watched to obtain an indication as to which form the sulphur present is likely to be in.

Sulphur is more prone to segregate than any other element in cast iron. Yet sulphide of iron does not segregate as badly as does manganese sulphide, the former being soluble in the molten metal and the latter not. This is further borne out by the fact that the specific gravity of iron sulphide is not far below that of the iron itself, whereas that of manganese sulphide is.

From these two factors the importance of good judgment in sampling pig iron for sulphur will be understood. Since the top of the pig not infrequently contains over twice the amount of sulphur as the bottom, it is wisest to bore clear through the cross-section for a proper sample, as will be gone into more fully later on.

The action of sulphur in cast iron is dependent mainly upon the percentage of the other elements in it. The relation of sulphur with manganese has already been gone into. The effect of sulphur upon the carbon is more complex, and is very powerfully affected by the silicon present. All theories to the contrary notwithstanding, the practical experience with high sulphur in cast iron is that it hardens the metal. A high sulphur content, however, is usually coexistent with poor melting practice in the cupola. Hence, it is a question of how much of the hardness in question is due to the sulphur taken up from the fuel, and again, how much from oxidation. Indeed the author is of the opinion that even the blow-holes in pig and cast-iron fractures, near the top, usually found associated with high sulphur analyses, are primarily due to oxidation and not to sulphur alone.

Porter has advanced the idea that we may be dealing with oxy-sulphides of iron rather than plain oxides or sulphides, in accounting for these hardening and gas effects. The fact remains, and has often been demonstrated by the author, that it is perfectly possible to get good soft castings with a normal silicon, even with 0.22 sulphur, provided unusual care is taken in the cupola charging and melting.

The hardening above mentioned, and supposed to be due to high sulphur, has always been counteracted by the addition of extra silicon in the mixture above ordinary requirements. Indeed, it is customary to allow about 0.10 additional silicon for every 0.01 sulphur expected over the usual percentages, which in the regular run of castings vary between 0.08 and 0.12 at the present day. The effect of this extra silicon is simply to throw out proportionally more graphite, were the sulphur not as it is, and hence the usual softness is obtained. The evil effects of sulphur are best seen in the edges of thin castings which require rapid machining, as for instance the armature cores for small magnetos, etc.

A number of invstigators have published data on the iron-sulphur question, and to show how marked the effect is when sulphur is at all prominent a micrograph (Fig. 4) by Stead, of an iron running about 4.2 per cent. in sulphur is given herewith. The black-looking, comparatively weak iron sulphide practically separates the entire crystalline structure of the iron and certainly tells the story.

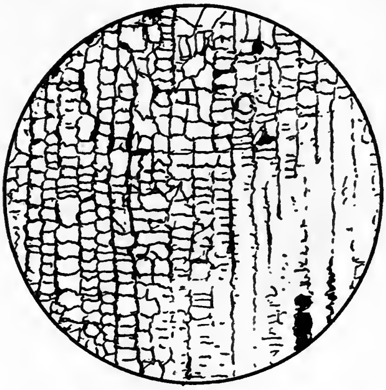

Fig. 4.—Pen sketch of iron crystallization with network of iron sulphide. Sulphur 4.2 per cent. (Stead.)

IRON AND PHOSPHORUS

Phosphorus has been made to unite with iron up to 24.5 per cent. by actual experiment by Saklatwalla, who extended the fundamental researches of Stead on this subject. The latter found that in the absence of other elements iron could contain phosphorus in solid solution up to 1.70 per cent. Above this the phosphorus would begin to form an iron phosphide (Fe_3P) until the 15.58 point was reached, when the entire mass would consist of this phosphide. Above this point other compounds of iron and phosphorus would form.

The action of phosphorus is to make iron hard and brittle, and in cast iron the only redeeming feature it has is to render the metal more fluid and hence useful for light and particularly delicate ornamental castings.

The characteristic effect of phosphorus on the structure of an iron is best seen in its micrographs, two of which are given herewith. Fig. 5 shows the distinct polygonal grains of iron, surrounded by a cellular envelop of iron phosphide. Fig. 6 indicates that when the phosphorus content goes up pretty high this iron phosphide becomes a definite constituent of the microstructure. A comparison of the sulphur and phosphorus micrographs shows how dangerous both elements may become to iron when present in too great a quantity—hence the desirability of starting with reasonably good pig irons in ordinary foundry routine rather than figuring on subsequent corrections.

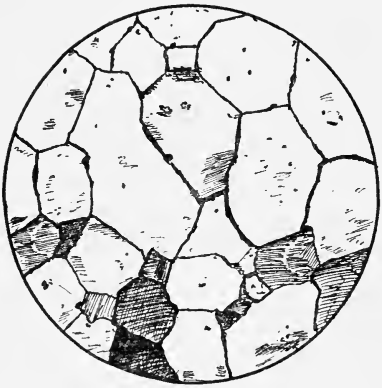

FIG. 5.—Pen sketch of iron with 1.8 per cent. phosphorous, showing polygonal crystalline grains of solid solution of iron phosphide in iron. Grains surrounded by cellular envelope of iron phosphide. (Stead.)

The introduction of carbon into the problem changes the situation somewhat. Mention has been made that 1.70 per cent. phosphorus can be retained by iron in solid solution (as an alloy practically). Carbon, similarly, exhibits this property up to 0.89 per cent. Free iron phosphide and free iron carbide, respectively, appear in the microstructure of the iron after these points have been passed. When carbon and phosphorus occur together in the iron, however, as is the case in cast iron, it is found that an increase in either the carbon or the phosphorus results in throwing out more phosphide or carbide, the particular element combining with iron from the alloy of the other one. Thus, with 3.50 per cent. carbon the original 1.70 per

FIG. 6.—Pen sketch of iron with 11.07 per cent. phosphorus, showing rhombic crystals of iron phosphide in ground mass of solid solution of iron phosphide in iron. (Stead.)

cent. phosphorus possible of retention as an iron-phosphorus alloy, has now been cut down to 0.31, the balance going into the iron phosphide network shown in Fig. 6. This property has its bearing upon the segregation of the phosphide into the small pellets of iron appearing on the surface of an open-sand casting, or within and attached to the walls enclosing a gas pocket. Ledebur investigated this phenomenon and found a pellet in one case to contain 1.98 per cent. phosphorus, while the surrounding metal carried only 0.44.

It is well at this point to consider the term "eutectic," so often found in modern treatises on metallurgy. The "eutectic" of cast iron is that portion of the molten mass which solidifies last. While the metal is setting in the mold, portions of the iron with its contained compounds and alloys freeze out, as it were, until the remaining metal reaches a certain composition, when the whole of the remaining mass solidifies. This remaining mass is the "eutectic" of cast iron. In German foundry practice of former days it was called the "mother-iron," conveying an impression to the mind of the foundryman similar to that of the "mother-liquor" on the chemist. The homliest simile would be the squeezing of a bag full of mercury. The pellets of iron above mentioned correspond to the drops of mercury coming through.

To revert again to the carbon-phosphorus question. While the influence of the former element is quite marked so far as the segregation of the latter is concerned, this is nevertheless observed only in cases rather out of the normal. The phosphorus in ordinary pig irons is not sufficiently high to cause special apprehension. The reduction in strength brought on by comparatively high phosphorus precludes the use of stove-plate scrap in making machinery castings, for instance, and where large surfaces of comparatively thin sections are joined to heavier ribs, as in condenser work, and these castings must be strong and free from strains, it is essential to hold the phosphorus content below 0.400. Ordinary castings may go up to 0.700, while stove-plate and art work exceed 1.000 per cent.

IRON AND OXYGEN

A simple glance at the analyses of a charge of iron before and after melting in the cupola, air furnace or open-hearth, will show that an oxidation of some of the ingredients has taken place. The products have passed into the slag and gases leaving the furnace. Thus, some of the silicon, manganese, carbon and iron have been oxidized and passed away. Sulphur will have been added from the fuel and phosphorus increased through concentration. It is a little recognized fact, however, that some of the oxidized iron may have remained dissolved in the molten metal obtained.[1]

Just as there is a residual sulphur percentage in cast iron impossible of removal through ordinary de-sulphurization processes, so there will remain a minute percentage of oxygen—probably in form of a dissolved iron oxide (ferrous oxide)—which cannot be removed by de-oxidizers under the temperatures prevailing. It is this phase of the situation which puzzles the steel metallurgist. He cannot conceive an iron with 4 per cent. of carbon and any trace of oxygen coexisting, though he has but to observe a boiling bath of cast iron in the air furnace. The early tests of Ledebur, the researches of the author, and latterly the series of analyses published by Johnson, have conclusively proven the presence of oxygen in cast iron, whatever difference of opinion may exist on the ultimate effect of this little understood but powerful element in cast iron. Furthermore, every one knows what "burnt" steel is, and the deleterious effects of oxygen on steel are generally admitted.

This problem can undoubtedly be traced back into the blast furnace. It is known in steel production that one axle, for instance, may be of a very high-grade material while another one, from a different heat though of apparently the same chemical composition and subjected to identical heat-treatment, may be worthless. This difference is due to an imperfect removal of oxygen from the molten bath of the last steel in question. Similarly, it is perfectly possible that the difference between a pig of iron which shows superior strength on being broken for subse-

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[1] Tests made by Wesley Austin (*Journal Iron & Steel Inst.*, 1915), in which he placed ferric oxide, magnesia and lime in the hearth of a small Girod electric furnace, using rods of pure iron for the electrode, resulted in a molten metal which when cast contained up to 0.288 oxygen. The ingots were rolled down into bars and subjected to a number of tests. It was found that the density decreased and hardness increased with the oxygen content. Microscopic investigation indicated that the iron oxide is soluble in molten iron, but on setting it separates, or rather segregates out of the main mass, in the form of scattered inclusions.

quent melting, and another pig of the same composition and manner of casting which breaks readily, lies simply in the percentage of oxygen retained in passing through the reduction from ore to metal, or more likely in a slight re-oxidation of the melted iron sponge as it passes by the tuyère zone of the blast furnace.

When it is remembered that with apparently identical compositions, there are definite qualities inherent in various brands of cold-blast and warm-blast charcoal irons, as also in hot-blast coke irons, which manifest themselves in greater or less strength, machinability and fineness in structure, there must be a reason for this situation other than a mysterious agency or heredity of ore qualities transmitted to pig irons—the view still held by many old-time foundry and furnacemen. This reason the author has for many years claimed to be the extremely small percentages of dissolved iron oxides contained in the several classes of pig iron in question.

The situation at the tuyères in blast furnace and cupola are certainly similar, and actual tests have shown the penetration of free oxygen from the blast to extend inward for some distance in each case. This is perfectly natural as the speed with which the blast passes through the fuel is terrific. In the case of the cupola free oxygen is still found 2 ft. above the tuyères, and in the blast furnace we have to reckon with blast pressures fifteen times as high as in the cupola; eight times the quantity of fuel per ton of iron involved, and from three to four times the volume of air. Adding to this the very delicate reaction in the final stages of the ore reduction going on within the furnace, it is easy to see that a poorly working furnace will by no means deliver iron entirely free from oxygen. Indeed careful steelmakers will never use molten metal from a furnace which is working badly for steel under severe specifications.

Hence, not only is there a chance of imperfectly reduced ore getting down into the zone of fusion in the blast furnace and affecting the good metal, but depending upon the nature of the fuel used and its avidity for uniting with oxygen from the blast more or less quickly, will there be a slight re-oxidation of the iron dropping down through the fuel into the crucible below. Iron has the power of taking up some iron oxide in solution, whether from unreduced ore or from a skin of oxide formed about the little pellets trickling downward.

From the nature of the case, a charcoal fuel under cold and under hot blast, or a coke or anthracite fuel under very hot blast—all of these will have different rates of uniting with oxygen passing by them. Hence, there is a variation in the degree of freedom from oxygen at given points from the tuyères—cold blast for charcoal fuel unquestionably giving the best results as the reaction is more intense with the oxygen in this more concentrated form. Moreover, the cellular structure of charcoal might be considered at a maximum while that of anthracite is nil, with corresponding great and small surface areas exposed to the passing oxygen.

The evil effects of oxygen in cast iron were first studied by the author, in 1897, in connection with a series of very bad "malleable" heats made in the open-hearth furnace. These heats, of apparently normal chemical analysis, were intensely hot but in spite of this the metal froze in the gates as molds were poured off. The hand-ladles skulled up rapidly, finally becoming almost solid, and the heats had to be pigged. It seems that the very slight drop in temperature from white heat as the metal ran over the spout into the hand-ladles was sufficient to take away the so-called "life" of the metal. Chemical investigation revealed the presence of an oxide of iron (obtained finally as Fe_3O_4) in solid solution in this iron, the percentage of oxygen falling somewhat below that found by Johnson in his recent investigations of oxidized charcoal pig irons—explained by the fact that in 1897 the method for oxygen determination in iron in the ordinary works' laboratory was practically unknown.

The direct cause of the ruin of the heats in question (they had 0.75 silicon, and hence were very susceptible to oxidation) was the coming up of pieces of the "bottom" which had been saturated with burned-up iron from pools of metal remaining on the carelessly patched hearth after tapping off the heat. This material, amounting to a highly silicious iron ore added to a bath of white-hot metal about ready to tap, so charged it with oxygen from dissolved iron oxides that the freezing point was raised materially and the metal when broken up was filled with blowholes and shrinkage spots.

For a long time after these rather striking occurrences, the author carefully examined the metal from every heat which had been prolonged beyond the regular melting time. He invariably found magnetic oxide of iron in the routine silicon determinations, noted an increase in the loss of castings through short-poured molds, spongy or cracked iron, and eventually took steps to add ferrosilicon for de-oxidation purposes. This procedure saved the heats, brought down the loss of castings to nearly normal, but left the iron considerably weaker than it should have been. Since these "long" heats were primarily caused by the efforts of a "steel-melter" to get good strengths by "refining" his metal —letting it soak, as it were—whereas in proper foundry melting it is necessary to melt as rapidly as possible with a minimum of refining action, this tendency, also observed in many other establishments in later years, has convinced the author that the further a "steel-melter" is kept away from air furnace and open-hearth melting for gray iron or malleable the better the results are likely to be. What is wanted is an able-bodied melter, unafraid of very hard work, who will so pile his metal that he can work pig after pig into the pool of molten scrap, rabble the heat to promote uniformity of composition as well as temperature, and thus save from ½ to 2 hr. time over indiscriminate charging methods used by steel-melters who have to wait for the charge to melt down and liquify in the bath while the top metal is boiling.

The bad effects of oxygen in the iron, as observed by the author, are as follows: First, the raising of the freezing point—or temperature at which the metal sets—with the consequent shortening of the "life" of the metal. Practical foundrymen are very keen on having their metal come from the cupola with plenty of life in it. That is to say, such molten metal should be safely held for possibly ½ hr. before it has to be poured, or otherwise be lost. Unless this is the case the foreman will have his hands full getting the floor of molds in shape for rapid work, and the iron will need accommodation instead of the last molds being closed up. The proper operation of the cupola means white-hot metal which can be allowed to stand a while. Poor melting practice means iron without life, that is, oxidized iron. Moreover, the desulphurization question from rising manganese sulphide fits in here.

The next bad effect of oxygen in cast iron follows from the above consideration. Since oxidized iron sets comparatively quicker, the feeding of the casting through the gates and risers is cut off prematurely. Interior shrinkages and voids, usually close to the gates, are the result. Such castings become unreliable, if not actually dangerous.

Another bad effect from the same cause is the tendency to increase the combined carbon content. This means harder castings with accompanying difficulties in the machine shop. While this actually makes the casting stronger, it is not a desirable advantage if hardness, shrinkages, gas holes, etc., go with it. The addition of steel scrap to the mixture, with extra silicon will give this greater strength together with normal softness better than an artificial oxidation of the metal.

The increase of combined carbon through oxidation means a greater contraction in the metal when compared with an unoxidized iron of the same composition. When the matter becomes serious it will mean cracked castings, particularly at sharp corners, in loose flat surfaces, and junctions of light and heavy sections.

Again, this increase in combined carbon evidences itself in the greater chilling qualities of oxidized pig irons. This fact is brought out in Johnson's investigations, though well known in practice long ago as concomitant with burnt heats. It has always been assumed that charcoal irons have peculiarly prominent chilling qualities, as compared with coke irons. This can hardly be called true as the means of comparison do not exist. Very low-silicon irons, made very readily in the charcoal furnace—and with low sulphur too—are not produced in the coke furnace except as "off" irons with high sulphur percentages. The author would never use a coke iron with silicon below 0.75 per cent., while he has used thousands of tons of charcoal pig iron with the silicon as low as 0.10. Here, again, we have to deal with the extreme cellular structure of charcoal as a fuel with few opportunities for a re-oxidation of the furnace iron. What chance would a 0.10 silicon iron have in the hot-blast coke furnace?

The last evil attributable to oxygen in cast iron is the matter of gas formation. It has been stated that, just as there is a residual sulphur which does not seem to be taken up by manganese because the minute particles scattered through the mass do not get to touch each other, so also there remain small percentages of oxygen, in iron oxide dissolved in the mass of iron, even when so great a percentage of carbon is present as in cast iron. The latest published oxygen percentages in cast iron do not run over 0.065 in the solid metal, and this is unquestionably all that remains from much larger percentages in the molten material while under cupola or furnace-gas influences, and having a chance to combine with the carbon at hand. Indeed this reaction of oxygen with carbon, forming a carbon monoxide gas, may be said to go on right in the actual mold while being poured; as the cutting away of the skin of castings on the cope side will readily show in the case of oxidized iron—a beautiful collection of pin holes, and gas pockets, with smooth walls being laid bare.

As a further proof of the above contention one has but to observe the origin of small gas bubbles in the surface metal of chilled rolls. This is not only highly interesting but very important in the making of the finest quality of finishing rolls, a blemish on the polished surface of which condemns them. Here the metal is sent into the "chiller" from the bottom swirling about rapidly to gather the dross in the center on top and thus out of the mold. The hot metal comes into direct contact with the cleaned surface of the iron cylinder forming the mold, and as frequently happens, to save money such chillers are used too often. Fire-cracks form on the inner surface. At such cracks there will be found gas bubbles in the chilled roll imprisoned while the metal was setting. The reason for this occurrence is the unavoidable formation of the magnetic oxide of iron within the fire-crack, which it is impossible to remove. The oxygen gets into contact with the passing metal just about to set, a reaction is accomplished with the carbon at hand, a bubble of carbon monoxide is formed, and this bubble is projected inward a little ways and deflected in the direction of the still moving metal. Fig. 7 shows the situation up plainly. *A* represents the heavy chiller into which the metal is run. *B* is the roll itself, the arrow indicating the flow of the metal while rotating spirally upward. The fire-crack in the chiller is observed filled with the black oxide of iron due to repeated heating of this metal. The bubble of gas which is formed practically instan-

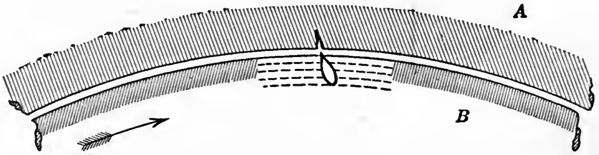


Fig. 7.—Showing the effect of iron oxide within a fire-crack of the "chiller" upon the surface of the roll. A gas bubble is formed by the reaction of oxygen with carbon in the molten iron.

taneously is squirted inward through the metal just crystallizing—also almost instantaneously, and deflected along the direction of the arrow as well. The circles drawn in the roll *B* represents the cuts taken by the tool. It will be observed that at first but a small pin hole is met with. The next cut shows this a little larger. Each successive cut opens the hole wider, and if cut down far enough the trouble will be overcome—provided too much of the chilled surface is not removed. Roll turners will, therefore, watch these specks closely as it may still be possible to save the casting.

Let us now look at what happens in the mold when poured with oxidized metal. Molten iron can undoubtedly hold some gases in solution, but if this gas were able to dissociate itself from the metal when setting, it should be found well distributed in form of microscopic bubbles throughout the general mass of the iron. This is not the case, however, as practically all the gas effects in a casting are met with just under the cope side of the mold as cast. To understand this one must have seen a mold just filled which through some accident has run out. On destroying the mold, a shell of iron, perhaps 1/8 in. thick will be found in contact with the sand surfaces. Hence, with badly oxidized iron, any reaction between the oxygen and carbon present forming gas (CO) means the rising upward of the latter until it hits this solid shell, to be imprisoned there by the metal setting inward. When this shell—the skin of the casting—is machined off subsequently, a collection of pin holes will manifest itself in most disagreeable fashion.

While there are many deoxidizers of iron—titanium being about the most active—the solution of this gas trouble lies not in deoxidation so much as it does in the prevention of this difficulty by proper melting methods and the selection of good stock. This much space has been devoted to a comparatively new subject by the author, part of whose life work it has practically been, because of its fundamental importance. He cannot but hold that the deliberate addition of oxygen to cast iron to increase strength and chill is simply an invitation to troubles which far outweigh the supposed benefits derived thereby.

IRON AND OTHER ELEMENTS

Iron and Copper.—As many pig irons contain copper to an appreciable extent, the effect of this element will be of some interest. Fortunately the percentage seldom runs over 0.02, and even in very exceptional cases not over 1 per cent. Hence, the resistance to corrosion noted in high-copper steels would have little bearing on the iron castings. Since, however, the presence of copper has a very marked influence on the accuracy of the volumetric determination of sulphur in cast iron, it is very necessary to check up the copper in new brands of iron, so that misleading results may not be reported by the foundry laboratory in which the more accurate gravimetric determination for sulphur is not used as much as it should be.

Iron and Nickel.—Since cast iron is practically a more or less high-carbon, impure steel, with mechanically mixed graphite interspersed within its structure, the foundryman has long desired to strengthen the steely portion of the mass by suitable alloying. The remarkable results obtained from nickel-steel naturally attracted attention to this metal, and as early as 1905 the author carried out a number of tests in this direction. As, however, he was not satisfied that the nickel additions had actually disseminated in the mass of molten cast iron with sufficient uniformity—as indicated by the analyses made—the results were never published. The very high melting point of the nickel added evidently brought about too great a cooling of the metal it was put into for proper dissemination before the material had to be poured.

Later, Webb conducted a set of tests, using "nickel thermit" in the bottom of his ladles, hoping in this way to obtain the dissemination desired. The molten iron used contained silicon, 2.12; sulphur, 0.086; manganese, 0.45; phosphorus, 0.620. The standard 1¼-in. diameter test bars, broken on supports 12 in. apart, gave 2,750 lb. for the metal without a nickel addition. With 0.67, 2.07, and 3.25 per cent. nickel added, the results were higher, but with additions of 1.18, and 6.65 per cent. nickel they came out lower. Evidently, therefore, the desired uniformity of nickel dissemination was not obtained in this manner either.

A better series of tests seems to have been obtained by Crowell, who melted charcoal pig iron in crucibles, with varying proportions of metallic nickel. The melts were cast into 1 in. square test bars, and these tested on supports 7 in. apart—a rather odd and short distance, accounting for the high figures obtained. The remelted straight pig iron ran 4,530 lb. transverse. With 0.75 per cent. nickel the record dropped to 4,400 lb. With 1 per cent. nickel even down to 4,175 lb. Then with 2 per cent. nickel the results went up to 4,800 lb. while with 3 per cent. nickel they rose to 5,200 lb. Since the addition of 3 per cent. of nickel only increased the strength 12 per cent., the expense of such a procedure would seem prohibitive as long as similar if not better results can be obtained in other ways, such as reduction in the total carbon, etc.

The subject, however, is attracting attention at the present time, on account of the recent introduction of Cuban iron ores rich in nickel and chromium. More will be said on this point under the effect of chromium on iron.

Nickel favors the precipitation of graphite. Perhaps in this way it counteracts the strengthening effect that it should give iron when alloying with it. The results so far obtained show that both cast iron and steel are injured by the addition of less than 1 per cent. of this metal, whereas over 2 per cent. seems to result in a beneficial effect.

Iron and Chromium.—The effect of chromium on the carbon-iron alloys is fairly important. Such an addition enables the taking up of more carbon, 10 per cent. chromium in iron corresponding to 5 per cent. total carbon content, and when 60 per cent. chromium is present, the total carbon can be 9 per cent. It seems that a double carbide of chromium and iron is formed with a hardening effect on the cast iron in question, which tendency is also noticed particularly in the chilling proclivities of the metal.

The presence of nickel and chromium combined in pig iron made from Cuban ores has been indicated above. This pig iron introduced into the market under the name of "Mayari" is of great interest as the effect of these new candidates for foundry favor can be studied at first hand. The pig iron in question contains from 2.50 to 3.00 per cent. chromium, and always half that quantity of nickel, or 1.25 to 1.50 per cent. In running the metal through the cupola some of the chromium is lost by oxidation, but the nickel remains untouched. It is further interesting to note that the iron also contains titanium and vanadium in small percentages, a typical complete analysis being as follows:

Total carbon	4.670
Silicon	0.800

Manganese	0.900
Sulphur	0.011
Phosphorus	0.047
Nickel and cobalt	1.300
Chromium	2.660
Vanadium	0.050
Titanium	0.180
Copper	0.035

The silicon of this iron is comparatively low, in fact the average is well below 1.00. The fracture of the metal is crystalline, and it is very hard. Hence, the metal is used only in admixture with other, softer, irons in foundry work. Nevertheless, there is evidently a partial balancing of the chilling effect of the chromium by the opposite tendency of the nickel, as will be seen in the tests below given. These are intended to show the strengthening effect of the two metals in question when present in the mixture as it is melted in the cupola and therefore uniformly mixed—in contradistinction to additions of chromium and nickel alloys in the ladle.

As will be seen from the analysis, No. 1 is an ordinary machinery iron. No. 2 would be useful more for light castings. No. 3 is machinery iron to which 10 per cent. of this Mayari pig iron has been added.

	No. 1	No. 2	No. 3
Total carbon	3.310	3.180	3.200
Graphite	2.570	2.550	2.540
Combined carbon	0.740	0.650	0.660
Silicon	2.010	2.420	1.380
Manganese	0.490	0.410	0.520
Phosphorus	0.595	0.755	0.469
Sulphur	0.086	0.108	0.107
Chromium	....	....	0.420
Nickel	....	....	0.290
Tensile strength, per sq. in. (average of 30 tests)	21,050 lb.	20,750 lb.	29,940 lb.
*Transverse strength (average of 30 tests)	3,220 lb.	3,112 lb.	3,620 lb.

* The standard arbitration bar of the American Society for Testing Materials.

A study of these figures shows that in spite of the great variation in the silicon, the total carbon being practically the same, the percentages of graphite and combined carbon have come out very close, and as the other elements are also similarly situated, the effect of the chromium and nickel can be seen very plainly. The considerable increase in strength would therefore seem to make the use of these metals in the foundry worth extended trial, particularly as good wearing qualities are claimed for the castings made—as is also the case with vanadium.

Iron and Vanadium.—The first comprehensive tests with vanadium in cast iron were made by the author and published in 1907. The results indicated that this metal is primarily a de-oxidizer, but this reaction once accomplished, any remaining vanadium alloys itself with the iron. An improvement of the material is noticeable more particularly in the dead-white irons, but not specially so in good soft gray iron castings.

A summary of the tests made with vanadium percentages, as shown below, added to gray and to white iron—the metal being cast into standard 1¼-in. test bars, and broken transversely on supports 12 in. apart—gives the following figures:

	0.00 V, pounds	0.05 V, pounds	0.10 V, pounds	0.15 V, pounds
Badly oxidized gray iron	1,310	2,220		
Badly oxidized white iron	1,440	1,910		
Good gray iron	1,980	1,980	2,373	2,360
Good white iron	1,470	3,020	2,800	2,950

Determinations of vanadium were made in the test bars which brought out the fact that this element was absent in the burnt-iron tests, having been oxidized and removed. Some, however, remained in the other tests, showing the effect of alloying. The point standing out very prominently is the remarkable strengthening effect of vanadium on white iron, a percentage as small as 0.05 added actually doubling the strength of the bars. Even for gray iron there was a considerable improvement, but it took more vanadium to do it.

Hatfield conducted later researches in this field, and found that the tendency of vanadium toward keeping the carbon in the combined form is due to its combination with the carbide of iron itself.

Much has been claimed for vanadium as increasing the wearing qualities of cast iron, and results both pro and con have been published. In view of Hatfield's researches, however, which fully substantiate the author's investigations as to the peculiar value of vanadium for white irons, without doubt the added stability given to the combined carbon in castings such as locomotive cylinders, etc., has a great effect on the ultimate wearing quality—for the harder and finely granular the structure of the metal the less the wear. Whether the same results cannot be obtained more cheaply by suitable silicon changes is an open question.

Iron and Titanium.—The first investigations on titanium in cast iron were also made by the author, originally in 1901, and more extensively in 1908. This element is found in pig iron very frequently, though in very small percentages, for the difficulty in smelting titaniferous ores of iron in the blast furnace has kept many a rich deposit out of the market. The electric furnace, however, is opening up this field and will eventually see titanium an important factor in pig-iron production.

The principal characteristics of titanium, so far as cast iron is concerned, is its remarkable de-oxidizing power. Indeed, the investigations of the author have shown that once sufficient titanium for this purpose has been added, further amounts have practically little effect. A summary of a series of tests in connection with the investigations mentioned, made on standard test bars tested transversely, is given herewith:

	Gray, pounds	White, pounds
Original metal	2,020	2,050
Original metal plus 0.05 Ti	3,025	2,410
Original metal plus 0.10 Ti	2,995	2,460
Original metal plus 0.15 Ti	3,190	

The grand average of the entire series shows an increase in strength of 52 per cent. for gray iron, and 18 per cent. for white iron.

As a further proof of the de-oxidizing power of this element, there was noticed in these tests a distinct diminution of the chilling effect, particularly when gray iron was run into iron molds for this purpose. Tests made in connection with the production of car wheels also showed this characteristic, a 1½ in. chill being reduced to 1 in. by the addition of titanium in the ladle. This would indicate that the freezing point of the metal had been lowered through the restoration of the iron to its original good condition—meaning thereby slower setting and good life. Hence, the contention of the author that while titanium added to originally poor stock or badly melted metal is a very beneficial in that it de-oxidizes it, the better policy in the foundry is to use good iron in the first place and to melt it properly. Then no de-oxidizing methods will be necessary.

When titanium is added to iron in rather higher percentages, say 1.00 per cent. and upward, there is a remarkable toughening effect noticeable. Indeed the 10 per cent. titanium-iron alloy made in the electric furnace has to be sledged apart, the crystalline structure being so tenaceous. More than likely the purifying action of titanium, so far as oxygen and nitrogen is concerned, is such that no gas layering or films of iron oxide may remain between the crystals and thus break the continuity of the mass in addition to the weakness due to graphite crystals. Since, however, the high melting point of titanium-iron alloys precludes the use of amounts calculated to give more than say 0.20 Ti to molten iron in the ladle, this toughening effect referred to above is unfortunately out of question in the foundry. Moreover, the straight melting of high titanium-iron alloys in the cupola is barred by the expense of the material. Hence, the previous statement that beyond an excellent de-oxidizing nothing more need be expected from titanium.

A final observation of interest to the metallurgist was made by the author during his early experiments with this element. After pouring the molds with metal to which titanium had been added the sprues were observed to cool down normally to dull red heat, but instead of going to blackness in the usual manner they were noticed to suddenly brighten up to full red heat and remain so a short time, then gradually going down to blackness. This phenomenon was observed for a dozen or more molds and commented on freely by the molders present, who had never seen this before. Very evidently the purification of the metal by titanium enabled the delicate heat changes embraced in the term "recalescence" to manifest themselves slowly and distinctly enough for observation in the rather dark foundry, for this is not ordinarily noticed in daily foundry work.

Iron and Aluminum.—In 1888, Keep studied the effect of aluminum on cast iron and came to the following conclusions:

That it improved the grain of the iron, removed blow-holes, precipitated graphite, increased strength and elasticity, and increased the fluidity of the iron. This, translated to modern views, would mean a de-oxidation of the metal with consequent beneficial effects.

The author, in 1891, also went into the matter, but more particularly in regard to the effect of aluminum when added to white cast iron. Instead of using the little "Keep" test bars, he made heavy open-sand castings 6 by 12 in. and 1½ to 2 in. thick. Regularly increasing aluminum additions in the ladle from 0.1 to 1.0 per cent. were made and the metal held until it had to be poured, to insure good mixing. As the amounts tapped into the hand-ladles used (from a 10-ton heat in the open-hearth furnace) varied somewhat, accounting for the varying thickness of the castings made, the aluminum added was recalculated and is given in the table below. The metal was in each case analyzed for any remaining aluminum, and particularly for the graphite and combined carbon to note the effect of the addition upon the total carbon present. The iron used was a malleable heat of charcoal irons, with the following composition:

Silicon	0.350
Sulphur	0.030
Manganese	0.180
Phosphorus	0.061
Combined carbon	2.730
Graphite	0.090

It was dead-white iron, and so hard that the first two tests in the series were metal that could not be touched with the drill.

No.	Al added	Al found	Graphite	Combined carbon
1	.....	.....	0.09	2.73
2	0.11	.....	0.08	2.74
3	0.18	.....	0.73	2.09
4	0.33	.....	1.49	1.32
5	0.37	0.09	1.53	1.28
6	0.54	0.07	1.80	1.01
7	0.58	.....	1.83	0.97
8	0.71	0.43	1.83	0.97
9	0.82	0.47	1.96	0.84
10	0.94	0.55	1.95	0.84
11	1.04	0.08	2.01	0.78

The steady decrease in the combined carbon, with corresponding increase in graphite tells the story. The fractures of this set, when broken and placed side by side, exhibited a regular progression of white iron to gray. Indeed it has been the custom of the author to make occasional gray castings from his very low-silicon malleable heats—when pressed for time—by adding from 2 to 3 per cent. of aluminum to the metal in the ladle. These castings, while comparatively weak, could be machined readily—though only 0.45 in silicon.

Iron and Magnesium.—While attending the Buda-Pesth congress of the International Association for Testing Materials, in 1901, the author discussed the de-oxidation of cast iron with the famous iron chemist Baron Jüptner von Jonstorff, who suggested the use of magnesium as best calculated to accomplish the desired object. This was duly tried out by the author and indicated that magnesium will alloy perfectly with iron. The resulting explosions, and more particularly the comparatively high price of magnesium, caused the abandonment of practical foundry trials before definite data had been secured. It was noticed, however, that the magnesium-iron alloy was extremely fluid, in fact acted like red-hot quicksilver. Cast into iron molds, the crystallization of the white fractured alloy was highly characteristic, and it was evident that to use magnesium successfully in the foundry, a rich magnesium alloy had to be made first, and this added to the molten iron, and not the magnesium direct, as is the case with aluminum.

When the time comes for a substantial reduction in the price of this metal, its remarkable affinity for oxygen may make it valuable in steel and cast-iron practice.

Iron and Occluded Gases.—Apart from those gases which may be contained in regular pockets, blow-holes, etc., and which may be considered present in an accidental sense only and differ but little in composition from the gases of occlusion, the latter may be divided into two general classes. Those obtained by simply boring into the metal, and others obtained by heating the borings to redness in a vacuum. While infinitessimal in percentage by weight, these gases occupy substantial volumes, and instances are known when the gases emanating from pig irons thus drilled amounted to 75 per cent. in volume of the metal removed. When special very flat drills were used, thus crushing the metal very thoroughly in removing it, this volume in one case rose to 600 per cent. of the metal removed.

In composition, these gases run about as follows:

Silicon of iron	CO	H	N	CO_2
0.20 pig iron..........	39.6	46.8	10.0	3.6
1.68 pig iron..........	37.3	58.3	0.5	3.9
2.50 pig iron..........	2.3	62.2	35.5	....
2.00 cupola iron.......	2.5	83.3	14.2	....

The effect of the blast can be readily observed from the above figures, for the nitrogen shows the entanglement of air, and the hydrogen the decomposition of water vapor, oxygen evidently going to the fuel and hydrogen being absorbed mechanically. An analysis made of the gases obtained by heating borings in a vacuum gave 16.8 per cent. CO, 73.6 H, 6.0 N, and 3.6 CO_2. The indications are that hydrogen is the most prominent component in all of these gases, and coming from the original water vapor in the blast used, its absence accounts for the fact that with the use of dry blast (Gayley's system) in the blast furnace much greater regularity in operation and results are obtainable. The less water to be decomposed the smaller the disturbances created in the ore reduction, melting, and final residual hydrogen in the metal. It might be well if foundries running continuously tried out a drying of the air used for melting and noted whether or not any beneficial results obtained in their castings.

CHAPTER V

OUTLINE OF IRON-MAKING PROCESSES

The title of this chapter refers to iron-making in its broadest sense—that is, to include the production of steel and cast iron. The term "iron" in its restricted sense is used more specifically to designate what we know as "wrought iron" only.

Since the reactions taking place in every process of the entire iron-making field, as well as the actual manipulations, are of more or less value to the foundryman in leading to a better understanding of the intricacies of his own work, the subject will be gone into briefly.

Iron is won from its ores by their reduction—that is, by the removal of the oxygen. The principal ores of iron are magnetite (Fe_3O_4), with 72.4 per cent. iron when pure; hematite (Fe_2O_3), with 70 per cent. iron; limonite, goethite, and turgite (Fe_2O_3 and varying combinations of water), with 59.92, 62.93, and 66.29 per cent. iron respectively; also a carbonate of iron, siderite ($FeCO_3$), with 48.3 per cent. iron. All of these ores have their iron content reduced more or less by the intermixed gangue—that is, the silica, clay, or lime rock. The iron sulphide minerals after roasting become available ores, as also iron-manganese ores, which form the basis of spiegeleisen and ferromanganese.

The reduction of the iron ores above referred to is brought about by a reaction with carbon from the fuel used to smelt them, at the high temperatures made to prevail in the container of the material—the furnace. As explained in the chapter on the history of cast iron, the winning of iron was accomplished in the old furnaces which yielded "blooms" of wrought iron, and later on with more advanced facilities, pig iron. So that the primary division of iron-making processes would be into two groups: first, direct wrought iron by the Catalan forge or bloomery; second, pig iron by the blast furnace.

DIRECT WROUGHT-IRON PROCESSES

The direct wrought-iron processes, while now obsolete, are nevertheless of sufficient interest for brief mention. The Catalan forge (Percy) named from Catalonia, Spain, is shown in Fig. 8. It is a low hearth provided with one tuyère which is inclined downward at an angle of 30° to 40°. This ends 9 to 15 in. from the bottom. The hearth itself is nearly 40 in. square and 16 to 27 in. deep, lined with iron plates and receives charges of ore from 300 to 900 lb. in weight. The hearth, red hot from the previous operation, is filled with charcoal up to the tuyère. Nut-sized ore and charcoal are charged side by side in two vertical columns, as shown. Moistened charcoal fines cover the top and compel the CO gas formed to pass through the ore and thus reduce it. Blast being turned on, the reaction begins. Charcoal is added as it is burned away, layers of fine ore being added.

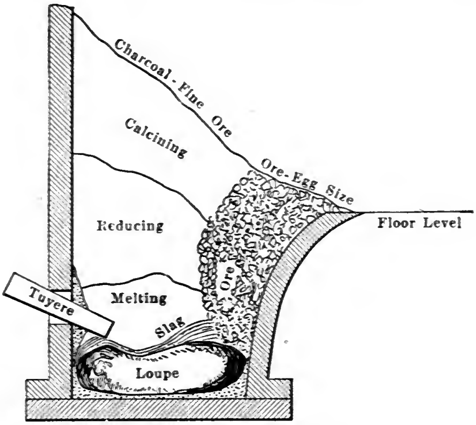


FIG. 8.—Catalan forge.

A basic slag rich in phosphorus collects on the bottom and is tapped off. The ore is slowly pushed into the tuyère region where the reduction is completed and finally a ball of iron forms (loup). The operation is stopped, the loup removed and hammered into a bloom. About three and a half times the weight of the iron will have been consumed in charcoal in the making.

The American bloomery process is somewhat similar, differing only in having the blast preheated by carrying the pipe through the upper part of the furnace interior. Then, the ore, and charcoal are mixed, with slag added—charging being attended to at intervals. The ball, when formed, is raised to the tuyère level and heated to welding temperature there before being taken out and hammered to the bloom. The author remembers seeing the remains of a number of these furnaces in the Adirondack region, the blooms from which furnished some of the cables for the famous Brooklyn Bridge.

A number of developments of the direct ore to wrought-iron process followed, but the high fuel expense and small tonnage produced rendered competition with the indirect methods beginning with pig iron impossible, and eventually they were abandoned. The point of interest to the foundryman, however, lies in the manifest difficulty of freeing iron from oxygen in furnaces which can be likened to cupolas on a very small scale, unless enormous fuel ratios and very high temperatures are used. This being out of question in daily practice, it is important not to get the metal oxidized in the first place to avoid consequent castings troubles.

THE BLAST FURNACE

This process is the basis of modern methods of reducing iron ores to metallic iron, and hence the starting point of the subsequent conversion and melting processes giving us our finished iron and steel products. The advantages of the blast furnace over the direct iron-making processes lie in the cheapness of the method, the recovery of practically all the iron from the ore, the delivery of both iron and slag in liquid form, and the desulphurization of the metal itself; further, for foundry purposes, the introduction of carbon and silicon in substantial percentages.

It is beyond the scope of this treatise to enter into the details of the subject further than to state that by the use of the waste gases for power purposes, the efficient water-cooling of the lining, the granulation of the slag to serve as building sand, and the installation of mechanical devices practically eliminating all hand labor, the blast furnace has not only become a stupendous metallurgical proposition—the first cost running up into high figures—but it requires the highest degree of skill to operate economically and successfully.

Fig. 9 shows an outline section of a blast furnace in its simplest construction. It is a huge round shaft furnace of fire-brick built upon very solid foundations. Alternate charges of ore, fuel and limestone go into the top. Blast is introduced near the bottom through water-cooled tuyères, and the gases drawn from the top. The metal is tapped from the lowest point in the hearth or crucible, and the slag slightly above, from the cinder-notch.

The furnace proper consists of three parts: the "shaft," or upper portion the diameter of which is reduced as it rises to the very top; the middle portion, or the "bosh," an inverted truncated cone which rests upon the walls of the third part of the furnace, the "hearth," or crucible. There are special reasons for the peculiar lines of the blast furnace. The bosh is made to flare out upward to check the velocity of the ascending gases and thus give them time enough to reduce the ore properly. On the other hand, the shaft from the boshes upward is contracted to reduce the friction of the stock as it descends. The hearth section of the furnace is the smallest, as at this point the ore has been reduced, the fuel burnt, and the molten iron and slag formed, all of which means a very much smaller volume than that required by the original material.

The gases are taken off from the top and go to the heating stoves, to preheat the blast to a high temperature, the surplus going to the boilers or in the best installations to gas engines for power purposes.

High and narrow furnaces make the descent of the material, as well as the ascent of the gases more difficult. Low and wide furnaces mean uneven working. Hence a medium course is pursued in blast-furnace construction. Modern furnaces are about 80 ft. high and have a cubic content of about 20,000 cu. ft., producing up to 650 tons in 24 hr., depending upon the grade of pig iron they are burdened for. The bosh line has an angle with the horizontal of 75°. The largest interior diameter of a furnace at the top of the bosh line may be 21 ft. From here the diameter decreases until at the top of the furnace it may be 14 ft., with the hearth slightly smaller than this. The lining of the

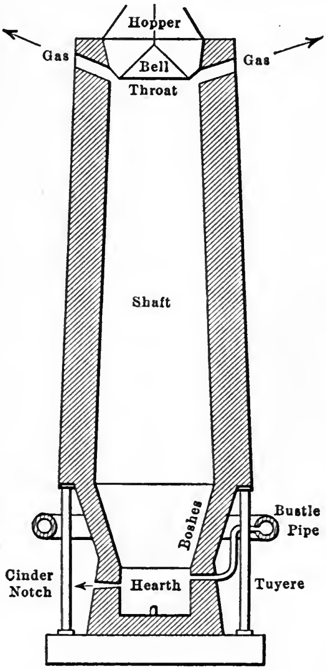


FIG. 9.—Blast furnace.

furnace, about 27 in. thick consists of a fine-grained, hard refractory brick for the shaft proper. The boshes are made of a coarse-grained, softer material, and should have higher refractory qualities than the brick used above, where abrasion is rather more to be guarded against.

It will be noticed that the interior lines of the blast furnace differ widely from those of the cupola, and it is well to make comparisons, as one often sees attempts to line cupolas to conform at least partially to blast-furnace construction.

The cupola, in its modern development, is a straight shaft furnace with the same interior diameter from the charging door to the tap-hole. Above the charging door the stack may be contracted if desired, to save first cost as well as offer a smaller surface for the entrance of rain and snow. Comparing the three divisions of the blast-furnace shaft with the corresponding parts of the cupola, the top, or furnace lining above the boshes, enlarges gradually as it is viewed from the very top downward, this being to facilitate the descent of the stock, as already stated. The mobile nature of the ore, fuel and limestone charges is such that a certain spreading tendency must be allowed for, otherwise bridging will occur, or scaffolding, with consequent slips and serious danger and damage. These conditions do not obtain in the cupola to such an extent. The alternate grids of pig iron and scrap, placed upon the coke charges, bind the mass together, and the whole column descends with very little spreading. There is no necessity for an expensive construction, as involved in a conical lining, and indeed there are numerous examples of straight stack cupolas—of diameters as small as 36 in.—which show no trouble whatever from bridging even when the height is up to 50 ft. from bottom plate to charging door.

The second portion of the blast furnace, the boshes, which represent a contraction from the largest diameter of the furnace downward to the smallest, at the hearth, receive this shape for reasons previously given. That is, because of the enormous shrinkage of the stock volume from ore reduction, gasification of the fuel, melting of gangue and limestone to slag, and final melting away of the iron sponge. Incidentally the requirement of a diminution in velocity on the part of the rising gases, to effect a proper reducing action upon the ore. At the hearth itself—the top of which is the tuyère line—a high gas velocity is desirable, as penetration of the fuel bed by the blast is essential.

In comparison, the cupola has but two things to do: the gasification of the fuel, and melting of the iron charged. There is no reduction of ores to effect, but one-eighth of the corresponding fuel to gasify, not much slag to care for, and hence this is accomplished far better under conditions allowing a dropping of molten iron and slag through incandescent fuel, to the bottom of a straight shaft cupola, than to receive this material upon the comparatively cold surface of sloping boshes, if the cupola is patterned after the blast furnace.

Finally, the hearth, or crucible, of the blast furnace as compared with the crucible of the cupola. In both cases this space is simply the gathering point of molten metal and slag, and therefore one of the required volume only. Cupolas are in operation today in which the crucible below the tuyères is greatly contracted, the idea being to save coke. A simple calculation will show the fallacy of this supposition, for the mere dropping of the tuyères will give the same results with the full diameter. No more coke is required, the same amount of iron can be held, and an additional height of stock column to the charging door is gained.

Hence, the necessity of keeping in mind that blast furnace and cupola are intended for entirely different operations, and the lines of the one should not be followed necessarily in the construction of the other. In fact the straight-shaft cupola, of the same diameter inside the lining from top to bottom is the ideal situation. More detailed references will be made to this subject in the chapter devoted to cupola melting practice.

The question of proper ore reduction—or the removal of oxygen from the iron oxides forming the ores—is one that interests the foundryman very closely, as it directly affects the quality of the pig iron he receives. Even with the best of intentions the blast furnace cannot deliver a prime quality of iron if deluged with "physic" in the shape of silicious slags made in heating furnaces at the rolling mill. Or, similarly, if coke be used containing 25 per cent. of slaty ash. A "hanging" furnace will suddenly let down a pile of improperly prepared stock, and pig iron results which is decidedly weak for its composition. Indeed this is well recognized in steel practice in looking for a big percentage of "seconds" in the rail mill when "slips" in the furnace are the order of the day. Simply oxide of iron passing into the molten metal as taken from the furnace, and remaining in part all through the conversion processes.

Pig iron under poor furnace conditions, or with a burdening of stock that presents exceptional difficulties in reduction, will be "off" both in composition and in fracture appearance, and this metal should not be sold to foundrymen without calling attention thereto. Since, however, the line of demarcation between the "honest" iron and the "off" variety is fairly wide and allows some latitude of thought, depending upon who does the thinking, the foundryman should pile his iron carefully, so that his charges may embrace a number of furnace casts and not be confined to only one. Moreover, in ordinary practice it will pay him to mix several brands of metal for his castings. Thus, with two or three brands of iron, and each brand piled to represent a number of casts, a founder will avoid the irregularities in product brought about by initial furnaces troubles. The testing of pig iron for quality will be discussed further on.

An exception to the above situation would be the manufacturing corporation of sufficient magnitude to operate a blast furnace of its own. There is no reason why this should not carry out successfully—in fact has been recommended by the author in several instances. Attention must be given to the storage of metal of the same analysis, to that as many casts as may be convenient can be drawn upon in shipment to the several plants of the concern. This will thoroughly mix the product so far as furnace peculiarities are concerned, and the result leaves nothing to be desired. The author for many months at a stretch melted nearly 100 tons of iron a day, from one furnace, but by proper piling of the metal as it came into the establishment from the cars, so that the analyses were grouped into four classes, very uniform material was made available, and oftentimes one analysis served for thousands of tons of metal. The physical tests of the castings made left nothing to be desired, and no difficulties from using one brand of metal was experienced. It does not follow, however, that the small founder who buys his pig iron by the car load can do this, for he has no chance to mix furnace casts of the same analysis before using the metal. The method is recommended only where very large interests are concerned, and the acquisition of a blast furnace would be a financial advantage. The best method of piling pig iron will be discussed later.

INDIRECT WROUGHT-IRON PROCESSES

These, with the conversion and finishing processes to follow, are embraced in the "Subsequent Treatment of Pig Iron." They all begin with this form of iron, either as cast in machine or sand, or with the liquid metal taken directly from the "mixer" attached to the blast furnace.

Instead of dealing with a de-oxidation of the ore to produce metallic iron, or carrying the operation further by adding carbon, etc., when melting is to be done, we have here just the reverse—namely, an oxidation of the carbon, etc., converting the metal to either wrought iron or to steel, depending upon how far this decarbonization is carried out.

The Charcoal Hearth Processes.—These are either single-, double- or triple-melting processes. The first—the *slag-bottom* process—provides for the melting down of small slabs of white iron drop for drop from the ends, on a small charcoal hearth with a tightly rammed rich slag bottom. The iron is pushed toward the tuyères as it melts off and the drops trickling down are decarbonized and collect at the bottom as a pasty ball. This is afterward hammered out in the usual manner. Imperfectly treated material goes through the same process. It is an Austrian process, used in Styria.

The double-remelting process—the *Swedish Walloon*—follows out the above procedure in rather more elaborate furnaces, which allow the tapping out of the slag when necessary. The pasty lump of iron, when made, is raised up through the charcoal and melted again with the addition of hammer scale and rich slag, this finishing the refining process. The famous Danemora iron is made in this way. Sweden, however, uses another process for all the rest of her high-grade wrought iron, the Lancashire hearth process. In this special provision is made for heating up the pigs red hot while the previous charge is worked up. When a ball has been made and removed, the hearth is filled up with fresh charcoal and the red-hot pigs pulled on it and covered. Blast is turned on and care taken to keep the pigs slightly above the tuyères. The drops, coming off slowly, have to pass by the tuyères and are decarbonized, collecting into a pasty ball below. This ball is raised up again and melted down with decarbonizing slags to bring about complete refining.

The triple melting, the *German process*, repeats the raising of the ball for another melt, thus making three meltings in all. The only advantage would seem to lie in making more certain the complete decarbonization of the original high-carbon pig iron.

The processes just outlined are of importance to the foundryman as having a direct bearing upon the cupola melting process. It will be observed that all of them correspond to a cupola run in which the fuel bed has been held exceedingly low. Instead, therefore, of holding the bed at a point corresponding to the minimum free oxygen present, together with a maximum temperature, the pig iron is placed so little above the tuyères that an abundance of free oxygen is present and just enough temperature to melt slowly from the ends of the pigs nearest the tuyères. The white-fracture charcoal irons used in these processes consist practically of only iron and carbon, for there is very little silicon, sulphur, manganese and phosphorus present. Hence, the operation is a real de-carbonization in the cupola. Naturally much of the iron must be oxidized also and pass off into the slag, for "rich" slags are mentioned continually—rich in iron.

If this oxidation of carbon and iron is possible when so good a fuel is used as charcoal, it is evident that with the less easily burned coke the chances for oxidation would be greater, as also lower temperatures found close to the tuyères. In making such high-grade metal coke is of course out of question, but applying the idea to the cupola, it will account for the making of very poor metal when the bed gets too low, if not the freezing-up of the entire operation, requiring the dropping of the bottom. Further, it accounts for the hardness of the last iron melted, particularly when the bad practice of omitting the last intermediate coke charge is resorted to. Mention must also be made of those cupola melting "improvements" in which a blast of air is introduced above the molten iron collected in the bottom. Here the iron trickling down has a further chance to oxidize the silicon, manganese, carbon and iron itself, with all the evils resulting, as described in a previous chapter.

The foundryman should remember that melting is what he is after and not refining. Hence, the fuel bed of the cupola should be high enough to melt under conditions of maximum temperature and minimum oxygen from the beginning to the very end of the heat. The iron trickling down through the coke below will then be so overheated and fluid that it has little time to become seriously oxidized before it arrives at the bottom.

The Puddling Processes.—The earliest of this group was called the *dry-puddling* process. It consisted in simply melting white iron on a sand-bottom hearth in a reverberatory furnace. While melting, the operator took pains to continually expose fresh surfaces of pig iron to the oxidizing influences of the passing gases. As the metal did not have to be very fluid comparatively little slag was produced and hence the process was considered a "dry" one. The loss of iron by oxidation was very great and hence this process, originated by Henry Cort, in 1784, eventually gave way to the modern *wet-puddling,* or pig-boiling process, perfected by Joseph Hall in 1830.

Attention must be called herewith to the analogy of the dry-puddling operation with that of air-furnace melting. Melting pig iron occurs in both cases. Instead, however, of working the bath to expose as much of the melting surfaces to the passing flame, the air-furnace melter tries to submerge the exposed pigs in the bath of molten metal as rapidly as may be. He thus prevents much oxidizing action. That some of this takes place in spite of the precautions observed both in working and in flame regulation, is shown by the loss of 0.30 to 0.35 silicon, etc., in ordinary air-furnace heats. On the other hand, carelessness in air-furnace melting, or unavoidable interruptions during the heat, accentuate this loss through oxidation, and oftentimes more than double it. It can readily be seen that by carrying the matter to an extreme the dry-puddling process eventuates. Hence, the constant attention of the foundryman must be directed toward running short heats in the air furnace, and these under conditions bringing about the smallest degree of oxidation possible.

In the modern wrought-iron process—the *wet-puddling*—another situation is met with. The single-hearth reverberatory furnace is provided with a bottom of cast-iron plates. These are coated with clay and then covered with mill cinder and scrap iron. Heat is now applied and when the scrap has melted some hammer scale is worked in and the hearth formed to the shape of a basin with one point low and a tap-pole arranged to take off slag. The sides of the basin are now lined with lumps of magnetite or hematite ore and the interstices between these rammed up with a puddle of finely ground ore and water.

Fig. 10 gives a sketch plan of the essentials of such a puddling furnace.

Gray forge and mottled pig iron are usually taken for puddling purposes, the object being the removal of silicon, manganese, carbon, phosphorus and some sulphur. Naturally, the smaller the percentages of these elements in the mixture, the quicker the process. The ordinary range of time required is between 1 and 2 hr. The slower the puddling is done the greater the removal of sulphur. Similarly, the more basic the slag the more of the phosphorus passes into it.

The puddling process consists of the "melting down" of a charge of somewhat over 500 lb. pig iron. To this charge about 200 lb. of rich cinder or roll scale has been added. This melting down takes about ½ hr. when a good man is in charge. The bath is rabbled for 10 min. to oxidize out much of the silicon. This operation is termed the "clearing stage." The flame is now allowed to become smoky, with consequent reduction in temperature, and rabbling continued to promote a reaction of the ore lining with the bath of metal. This means active "boiling" and burning of the CO gas formed to CO_2. In about 15 min. the boiling ceases and small points of white iron may be observed to stick out of the bath. The iron has now "come to nature." The heat is maintained and the particles of iron worked into a "ball," which is sliced up into pieces of about 80 lb. These are then taken to the "squeezer" and thence to the "muck-bar" rolls. The slag is in the meantime tapped from the furnace hearth.

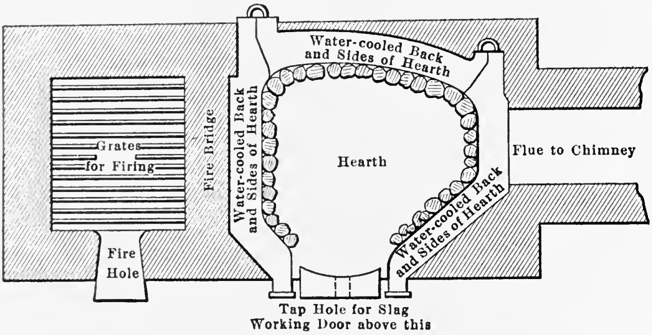


Fig. 10.—Sketch plan of puddling furnace.

The reactions taking place during the five stages of the puddling process may be indicated as follows: The simple "melting down" means the oxidation of silicon and manganese to some extent, not of carbon, and but very little of sulphur and phosphorus. In the "clearing" stage silicon is oxidized principally. In "boiling," manganese and carbon are cut down heavily. The reactions continue while "coming to nature" and in "balling." The finished "muck bar" weighs slightly more than the original charge of pig iron, in spite of a loss of about 12 per cent. in the conversion. The increment comes from the reduction of the ore lining the sides of the bath.

Mechanical Puddling.—This has been operated quite successfully, the furnaces being equipped with revolving hearths caring for about 1½ tons at a time and giving the "ball" in about 15 min. These furnaces are known as the "Danks" and the "Roe."

The point of special interest to the foundryman in these wet-puddling processes is the "washing" action of the ore lining the bath, as also of the oxides in the bottom. Instead of oxygen gas this element is put into reaction in solid form, with the elements contained in the molten pig. This reaction is very violent, the gases generated causing a lively boiling. The silicon, manganese and eventually the carbon is removed and wrought iron results. Since so-called "washed" metal is constantly presented to foundrymen for purchase it is well that they should know how it is produced and what are its characteristics. The simplest method of washing iron is to fill a suitable shaft with ore in lumps, get these red hot, and then allow the blast furnace metal to sink down through them. The more general way is to use the reverberatory furnace charged with ore or other oxides of iron and a basic slag, then to introduce the molten metal and allow it to remain long enough to accomplish the removal of perhaps 90 per cent. of the silicon and phosphorus but not to seriously affect the carbon. Since the washed metal of commerce is supposed to have the phosphorus content down to less than 0.025 and the sulphur less than 0.03, it is easy to see that "off" heats in this regard would seem desirable metals for the foundry—particularly for making malleable castings, where low silicon is the rule. The facts of the case are, however, that while oxygen may be easily introduced into a bath of iron, it cannot be taken out quite so readily at the temperatures existing in heats of cast iron. Hence the metal is much weaker than blast-furnace iron of corresponding composition which has not been so treated. This has been proven repeatedly by the author in his daily practice, and hence he cannot advise that washed metal be used in the foundry. In steel-making quite another condition supervenes. Here, after the carbon has been removed in the ordinary way, the temperatures are such that the final manganese addition does de-oxidize the metal completely, and good steel results. The low phosphorus and sulphur of washed metals are therefore quite desirable, if not too expensive.

This much space has been given the matter at issue for the reason that ore is sometimes used in the foundry air-furnace process to cut down the silicon rapidly, together with a little carbon. Since it is possible to get the proper silicon by judicious mixing with possible final additions of pig iron, and the carbon is better cut down by additions of steel scrap, this introduction of oxygen is not to be recommended. Castings are lost in larger percentage, and the service results are not as good as would have been the case with better attention in mixture making and rapid melting in the ordinary manner.

CONVERSION PROCESSES

The Cementation Process.—While it is possible to make steel by the processes for wrought iron just described—stopping the reaction just before the carbon has been completely removed—the results are uncertain and the product inferior. Hence, an early recognition of the desirability of adding the necessary carbon to a previously made wrought iron to obtain the desired grade of steel. Even Agricola makes mention of the conversion of bars of wrought iron into steel on continued immersion in molten cast iron (1561).

The process of cementation ordinarily used for the last two centuries consists of imbedding wrought iron in charcoal, and bringing this material—packed in suitable containers—up to yellow heat. Carbon enters the wrought iron and a "blister steel" results. If this steel is cut into pieces, made up into proper piles, heated and then rolled, the product is called "shear steel." Repeating the cutting up and rolling gives a "double shear steel." If, on the other hand, this blister steel is cut up and melted in the crucible, the result is a "crucible steel."

This process, used particularly in England, is of great interest as illustrating the migratory tendency of carbon. The passing of this element from a high-carbon plate to another one low in carbon when the two are put together under high temperature is well known. Also, the absorption of carbon by a low-carbon iron from suitable surrounding media in the "case-hardening" process. Even "Harveyizing" is nothing more than introducing carbon into armor-plate surfaces from the acetylene content of illuminating gas passed over it while under high temperatures. The part that the foundryman is interested in specially, however, is the reversal of this cementation process; namely, the diffusion outward of carbon from high-carbon irons. It is one of the underlying principles of the production of good malleable castings. In the making of "black-heart" malleable the integrity of the casting depends upon the conversion of the combined carbon to "temper-carbon," and in addition to the removal of much carbon from the surface metal, without the penetration of any oxygen. Where, through errors in operation, this has been the case, a white, crystalline, "burnt" structure is very much in evidence, and the castings will be quite weak. It should be stated, however, that with higher annealing temperatures and longer annealing periods, thin castings will have their structure opened up so seriously that oxygen does penetrate and practically all the carbon is removed. Here, in spite of the presence of oxygen, the castings will be serviceable, and are what go by the name of "white-heart" malleable.

The Crucible Process.—A variety of methods prevail under this general title. The "Huntsman" method is probably the oldest—1770—and consists of simply melting the blister steel in crucibles to clear the material from entrained slag. An improvement upon this method is the "Heath," which adds manganese oxide and charcoal to the charge. Some of the manganese is reduced by the charcoal, and this in turn de-oxidizes the steel. In America the development has been in the direction of using wrought-iron scrap or bars instead of blister steel, and adding the proper amount of charcoal or washed metal. Further, the addition of some ferromanganese for de-oxidation purposes, some potassium ferrocyanide to aid in the carburization, and salt to thin the slag. A final 0.10 of aluminum added while pouring the ingot takes away the last oxygen and quiets the metal. Alloy steels receive the necessary ferro-alloys in the mixture.

It will be observed that the crucible process is a de-oxidizing, carburizing and cleansing process. Melting is done under temperature conditions which prevent too violent a boiling and the reactions go on until completed. The last 45 min. of the 3 to 4 hr. required are given over to the "killing" of the steel, or letting it become quiet. In this period there is an absorption of silicon reduced from the walls of the crucible, which in turn means a decrease in the ability to dissolve gases on the part of the steel.

Referring back to the historical portion of the volume, it will be remembered that cast iron was made from scrap wrought iron and charcoal in crucibles in very early times. This material must doubtless have been very low in carbon as the absorption of this element in large quantities is not easy under the temperatures existing. Indeed it is necessary to add about 40 per cent. of carbon to the crucible in excess of that actually absorbed to make the steel. The development of the blast furnace naturally put an end to the making of wrought iron to be converted to cast iron by the crucible process, and so far as cast iron was concerned the subsequent use of crucible melting was simply the liquefying of small quantities of pig iron at a time for jobbing work away from the furnace.

The exigencies and competition of the business has eliminated crucible melting in the gray iron foundry. It is still found in some European malleable castings plants, and has so far held its own in the steel industry. In spite of the fact that the excessive operating cost has caused the foundryman to turn away from this process of melting, he still finds it of great interest because of its admirable features from the metallurgical standpoint. The comparatively small change in composition during the melt, the ability of the metal to clear itself of foreign admixtures, the freedom from contact with oxygen and sulphur, and the thorough mixing of the charge, all combined mean the production of high-grade cast iron. Hence, in the testing of pig irons for their general quality, for purposes of comparison rather than actual foundry runs, there is no better way than to melt a quantity in the crucible, cast the standard "arbitration" bars, obtain analysis, transverse strength and deflection, and then tabulate the results. A study of strengths for similar compositions gives a good idea of the relative excellence of the furnace product for the class of casting to be made in the foundry interested.

Finally, there might be mentioned the fact that many a brass foundry finds it a convenience to melt iron in crucibles for occasional castings wanted in a hurry. Similarly, the author many a time used crucibles for making steel castings in the malleable foundry by melting steel scrap with a very little low-silicon charcoal iron and ferromanganese, and found the results quite satisfactory for the purpose.

The Bessemer Process.—The effect of oxygen (in air) passing over exposed surfaces of melting iron, and oxygen in solid form in ore in direct contact with molten pig iron, has been noted. Now comes another method of introducing oxygen, and that is blowing it into highly superheated molten iron from blast furnace or cupola. This is the basis of the process invented by Sir Henry Bessemer in 1855, and known by his name.

In brief outline the process consists of introducing a quantity of molten metal of proper composition and temperature into a pear-shaped vessel through the bottom of which air is forced upward into the iron. The oxygen thus sent through the metal in a finely divided state at once sets up a violent reaction and oxidizes the silicon, manganese, carbon and some iron. A very low-carbon steel—corresponding to wrought iron in composition—is the result. Spiegeleisen or ferromanganese is now added to de-oxidize the metal and give the required carbon to make steel.

It is necessary to actually observe a "blow" to realize the violence of the reactions going on. As the action is brief—between 9 and 15 min.—the blows are but about 20 min. apart. Again, the tonnage handled being high (10 to 20 tons to a blow), the most careful kind of planning is necessary to realize efficient plant operation.

Fig. 11 shows an outline section of the Bessemer converter. It consists of a steel shell lined with either ganister or calcined dolomite, depending upon whether the process is to be "acid" or "basic." Ganister is a refractory sandstone or mica schist which is applied as a lining much as it is used in cupola lining repairs. In the bottom lining there are imbedded a series of tuyères each of which has a number of holes 3/8 to 1/2 in. in diameter, through which the air at 25 lb. per sq. in. is blown into the molten metal. The sketch indicates how the air is introduced. For the basic lining the calcined dolomite is mixed with 10 per cent. of tar and the material well rammed in.

The converter itself may be fixed or movable. The orifice may be concentric with the body or eccentric. Bottom-blow or side-blow may be used. Acid and basic operations require different classes of metal and yield different kinds of slag, though the steel products are practically identical. American iron ores are peculiarly adapted to the acid process, and hence the basic is not found there. In England both processes are used, while the high-phosphorus ores of Germany make that country peculiarly the home of the basic Bessemer process, called the *Thomas*. Practice differs considerably in regard to the composition of the metal charges in the acid process, so far as the silicon is concerned. In England it is high, from 2 to 3 per cent. Continental Europe desires a medium range, from 1.3 to 2.0 per cent. Sweden and America blow with 0.6 to 1.3 silicon. Neither sulphur nor phosphorus are removed in this process and hence these elements must be sufficiently low in the irons used before melting. Thus, the phosphorus must not exceed 0.100 (known as the "Bessemer limit"), nor the sulphur 0.05. The silicon may run between 1 and 2 per cent. Manganese ordinarily is not specified. For basic Bessemer pig iron the following requirements govern: silicon, up to 1.00; phosphorus, up to 3.00; sulphur, below 0.10; manganese between 1.50 and 2.50.

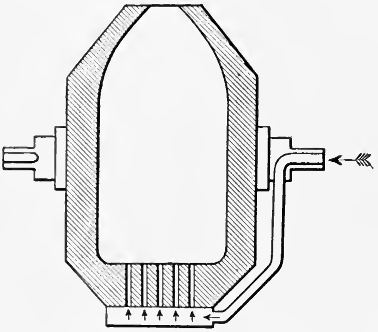


FIG. 11.—Outline section of Bessemer converter.

In operating the converter this is first turned horizontally and the molten metal from the furnace mixer or cupola introduced. Blast is now put on and the converter turned upright. The air pressure is sufficient to prevent any molten iron running into the tuyère openings. The silicon begins to burn and in so doing greatly increases the temperature. It takes but a few minutes to use up the silicon and then the carbon begins to go, as shown by the brightening up of the flame issuing from the mouth of the converter. Sparks of burning iron and particles of slag are also expelled, and considerable rumbling takes place. When the carbon has gotten down to 0.04, the flame suddenly drops and then begins to look brown from burning iron. The blow is over, the converter is tilted and ferrosilicon shoveled into it, or molten spiegeleisen added—as the case may be—the slag removed, and the steel teemed into ingots or into ladles for subsequent pouring into castings. Of the manganese added about 70 per cent. goes into the steel, the rest being used to de-oxidize it. Of the carbon thus added (in the ferromanganese or spiegeleisen) about 80 per cent. enters the steel.

The loss of 30 per cent. of the manganese added to the steel before it can be poured is illuminating. It shows how badly the metal must have been oxidized during the operation. Indeed, had the steel been teemed just as blown the resulting ingot would have been exceedingly porous, or of little value in these days of strict requirements.

Foundrymen are occasionally offered processes which amount to a side-blow converter action upon the molten metal held in the cupola. It is claimed that this additional air blast strengthens the metal. Unquestionably this is the case to some extent, for the silicon is lowered by this introduction of oxygen. Unfortunately, however, either too little or too much blowing is done and in any case the metal will be somewhat oxidized. This means defective castings, as explained in the chapter containing the discussion on iron and oxygen. The temperature is not gotten high enough for subsequent de-oxidation with manganese in the ladle unless nearly all the silicon is sacrificed, and the uncertainties of these processes are such that they are invariably thrown out after more or less extended trial.

Improper cupola practice oftentimes gives rise to conditions approaching a Bessemerizing action. Many a foundryman has experienced this trouble. When the fuel bed in the cupola is allowed to sink down too low during a heat, the metal is forced to melt too close to the tuyères with the resulting oxidation of not only the silicon, manganese and carbon, but also of much iron. This iron oxide attacks the lining and with the ash and sand present from coke and pig-iron charges gives a copious "foaming" slag. The blast takes this upward and sends it out of the charging door. If the blast is shut off this slag drops again and floods the wind box through the tuyères, making a nasty mess of it. Hence the supreme importance of melting in the proper position of the cupola above the tuyères. It is the basis of successful cupola practice.

For purposes of making steel castings, where the converter is to be used, the side-blow method with very small units is now used almost universally. Air is blown upon the surface of the metal instead of through it. The direction of the blast is about 5° to 9° downward from the horizontal, and causes a rotation of the metal within the converter and brings fresh surfaces to the top constantly. This adaptation of the Bessemer idea was brought out by Tropenas and goes by his name.

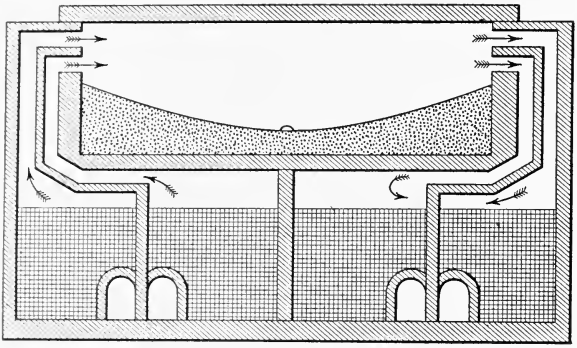
One of the important problems connected with the operation of a Bessemer steel plant is the supply of large tonnage of molten metal of fairly uniform composition and temperature. When connected with a blast-furnace installation this is solved by the introduction of a "mixer"—practically a tilting open-hearth furnace fired with furnace gases. This mixer is usually of very large capacity and receives the molten metal directly from the furnaces as they are tapped. Hence a fair chance for uniformity not only of the metal from the furnace ladle, but a succession of such ladles. So valuable has this auxiliary apparatus proven that it has been adapted to foundry requirements where large bodies of metal are required to be of uniform composition, such as in making cast-iron pipe, etc. Indeed, the mixer has been successfully used for ordinary light machinery castings in one case where enormous quantities were required, and what is more, with direct metal from a blast furnace thus mixed and held for hours under oil firing to afford a chance for partial de-sulphurization (action of manganese present on the sulphur). Whether in connection with "direct metal" or the cupola product, the mixer is bound to become a foundry factor some day as tonnages increase still further.

Where cupolas are used for melting pig iron for Bessemerizing purposes, it is necessary to have sufficient reserve capacity available at all times. Continuous melting is in order for the converters are run night and day. In steel-castings plants, however, this is not the case, for the exigencies of molding operations mean blowing steel in the afternoon only as a rule. The lining of the cupolas is usually made very much thicker than for ordinary melting, and at the melting zone is usually of the same composition as the converter lining. This allows it a chance to cut out considerably before repair are necessary—some of these cupolas being run a week before shutting down. The tuyères are placed rather high, perhaps 3 ft. above the bottom, to afford ample room for storing metal for the next blow.

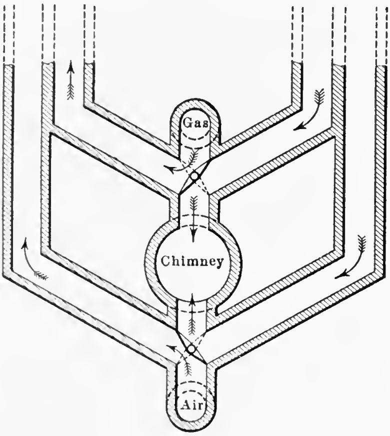
With all the advantages the Bessemer process in small units has for steel-casting work, chief of which are the high temperatures attained and small tonnages at a time at short intervals—allowing green sand molds for light work and conforming with foundry pouring practice—there is nevertheless a very heavy melting loss to consider. Ordinary figures for the Tropenas method, from cupola charge to finished steel in the ladle, average a loss of 20 per cent. of metal. Coupled with this is the manifest inferiority of Bessemer metal when compared with open-hearth or electric-furnace material. Hence, the future for this process is not a bright one, and in reality it only awaits the development of the electric furnace to the proper degree of economy to be seriously menaced. The lesson to be learned by the foundryman from the metallurgical points brought out is that his entire procedure must be directed toward keeping strictly away from any chance of Bessemerizing action taking place in his melting practice.

The Open-hearth Processes.—The open-hearth furnace is primarily an improved form of air furnace, which in itself is the development of the ancient hearth furnace. The essential feature of the open-hearth is the regeneration of air and gas used in its operation. The oxygen, therefore, enters under temperature conditions which make for an exceedingly high heat over the bath of metal. It is not possible to produce steel commercially in the air furnace because of the insufficiency of temperature, whereas in the open-hearth the situation is ideal. A comparison of efficiency tells the story, so far as simple melting of iron is concerned. Under the best of conditions in the air furnace 1 lb. of coal will melt 4 lb. of iron. Similarly, in the open-hearth it will melt 6. Again, an air-furnace heat will be made in say 4 hr., whereas the same charge in the open-hearth is ready for tapping in 2½ hr. This shows what the preheating of fuel and air will do when the furnace is built with this end in view.

Fig. 12 illustrates the open-hearth furnace in outline section. Gas and oil are the only fuels that can be used in this furnace, hence solid fuel must first be converted into gas form. As the gas and air enter through the ports on one side of the furnace, combustion takes place with a long flame sweeping over the hearth. The furnace lining is thus brought up to incandescence and the radiation of heat from the walls melts the metal on the hearth. The products of combustion now pass through the opposite ports downward into the two checker-chambers provided, where they give up part of their heat to the bricks that fill them, thence passing out up the stack. This goes on until the bricks in question cannot take up much more heat from the waste gases without undue loss of time, and hence the valves are reversed. The gas and air now go the opposite way, first through the red-hot checker-chambers just serving the waste gases. Here they acquire the heat previously taken up. They enter the combustion chamber through the ports opposite the ones first mentioned, combustion takes place, the waste gases pass through the opposite ports downward on the side of the



FURNACE SECTION



PLAN OF FLUES

Fig. 12.—Open-hearth furnace.

furnace opposite to that first mentioned, leave their heat in the second set of checker-chambers, and pass up the stack.

About 20 min. elapse, ordinarily, between the reversals in this operation. This allows sufficient time for giving up heat by the waste gases, as also for acquiring heat on the part of the freshly entering air and gas, and the result is a fairly uniform and intensely hot situation within the furnace over the hearth. If oil is used, this is introduced into the gas ports through the end walls of the furnace. In that case the two checker-chambers on each side of the furnace are operated as one, and for the air only.

The open-hearth process dates back to 1865, when Martin Bros., of Sireuil, France, succeeded in melting down wrought iron and pig iron mixed, thus obtaining a medium-carbon steel, by the addition of Siemens' regenerators to their hearth furnaces. The additional temperature thus obtained, as mentioned in connection with air-furnace melting, marked a new epoch in steel-making. The process is therefore known as the "Siemens-Martin" in Continental Europe, while in England and America it goes under the name of the "open-hearth."

There are two types of the process, depending upon the nature of the hearth, namely the "acid" and the "basic," just as in the case of the Bessemer converter. The acid process has a sand-bottom hearth, whereas in the basic this is of magnesite. Both have silica (acid) brick walls and roofs, the basic furnace having a separation between hearth and walls of neutral brick made of "chromite."

There are several methods of operation in steel-making. First, the pig and scrap method, in which the high carbon of the pig iron charged is diluted with wrought iron or low-carbon steel. Next, the pig, scrap and ore method, in which the final oxidation of the carbon is accomplished by an ore addition—this being the process most generally used in America. Finally, the pig and ore method, in which no scrap is used.

While the ordinary open-hearth furnace is stationary, and with checker-chambers beneath the hearth, there are many variations existing. In some cases the checker-chambers are to one side, thus insuring better foundations for the hearth and port construction. Again, the furnace body itself may be movable, as in the best example, the *Wellman tilting furnace*. In this type of furnace it is possible to remove excessive slag, as well as take off metal as desired.

Another important improvement is the *Wellman charging machine*, by means of which time and labor can be saved in steel-making, though for simple melting there is not the same command of the hearth surface for piling metal as is had when the ordinary "peel" is used by the competent melter.

Natural gas, where available, is a much desired fuel as it is highly calorific and does not require regeneration in the open-hearth furnace—similarly with oil—but if it is desired to send natural gas through the checker-chambers, it is necessary to allow a little steam to enter also, and thus avoid the deposition of "soot" from the gas through decomposition under the excessive heat present.

Producer gas is the standard fuel of the open-hearth furnace, bituminous coal being gasified in many different types and constructions of gas producers. Care should be taken to hold the free oxygen in this gas below 1 per cent., the carbonic acid below 5 per cent., and to have the hydrogen content not too high, with the carbonic oxide as high as can be gotten.

In carrying out the acid open-hearth process the pig and steel scrap percentages are so chosen that when melting is complete the carbon runs about 0.75. The silicon and manganese by that time are practically gone. This usually means two-thirds pig and one-third steel scrap in the charge. Since no sulphur and phosphorus are removed it is necessary to use the so-called "fancy" irons, which run very low in these elements and hence are rather expensive.

After melting down and holding the bath quite hot, ore is added in small quantities at a time and the remaining carbon oxidized out. Next, spiegeleisen (when high-carbon steels are wanted) or ferromanganese (for low-carbon steels) is put in to de-oxidize the metal, and if for steel castings some ferrosilicon also to give a silicon sufficiently high to prevent blow-holes. The steel is then teemed. Of the manganese added but 60 per cent. gets into the steel; of the silicon, but 50 per cent. The balance of each is used for de-oxidation and goes into the slag.

In the case of the basic process a lower silicon content is better, and while as much phosphorus can be present as desired, care should be taken that the sulphur in the mixture does not exceed 0.10, as only part of this is removed. What is removed goes as a calcium sulphide, and the phosphorus as a calcium phosphate. When the metal is charged, it goes upon the hearth which already has a portion of the calcined limestone put on it. More lime goes with the charge of metal, and the balance after melting as required to keep the slag basic enough for the phosphorus removal. The quality of the steel, for removal of carbon and phosphorus, is tested periodically by pouring small test ingots. When the "phosphorus cross" is gone, and the heat is finished, the necessary ground coke for carburization purposes is added and absorbed by the molten steel (a lump coke from the petroleum distillation process is one of the best materials for this purpose). If necessary, manganese is added for de-oxidation, though usually enough manganese remains in the charge to require but little additional, and the metal is teemed.

There are a number of modifications of the open-hearth process, such as the Bertrand Thiel, the Talbot, etc. In these several furnaces are used, a part of the metallurgical reactions taking place on one, and the rest in a second furnace. In this way time is gained for a given tonnage requirement, the reactions can be carried out better, the slag problem is eased up, etc.

The quality of the steel made in the open-hearth processes is second only to that made in either the electric furnace or the crucible processes. The metal is uniform in character, comparatively free from slag enclosures, and may readily be made to meet required specifications. It is the ideal commercial steel-making process of today. Moreover, for simple melting of iron it stands at the head of all melting processes for quality. Hence, it is comparatively strange that the open-hearth furnace has not long ago replaced the air furnace in the gray iron foundry. It has made heavy inroads in the malleable casting industry already. While the first cost is high, and it is necessary to run daily to get good economy, yet probably all those establishments melting with the air furnace today are in position to work with the open-hearth if they had the enterprise to tackle the problem.

Since, however, the conservatism of foundrymen is great, and their hesitation to spend money on lines new to them is proverbial, little immediate progress is likely in this direction. Furthermore, in the few instances where the open-hearth has been installed in malleable foundries and failed, this has been due to poor design, construction and operation. The happy-go-lucky way of running the cupola or air furnace cannot be applied to the open-hearth furnace, where everything must be kept and operated in strictly first-class order. Hence, the introduction of this important improvement in foundry melting practice will have to be left to a coming generation of men of broader metallurgical training, and in a time when quality work will be demanded irrespective of higher costs and selling prices.

Electric-furnace Process.—This comparatively recent method of steel-making has for its object the attainment of extremely high temperatures within very confined spaces, and the ability to bring about any of the desired reactions readily and efficiently. The result is that steel made by this process is uniform and of high quality—like crucible steel. It will have but slight traces of oxidation and the segregating of elements contained, the elimination of sulphur can be made almost complete, the other elements are under perfect control, injurious atmospheric influences are avoided, and the steel can be poured at any temperature desired. Naturally this process has a great future before it.

There are two types of furnaces: the *arc*, and the *induction*. In the first-named furnace a current of proper intensity and strength is made to pass between the metal charge as one pole and a huge rod of carbon as the other. The intense heat thus generated does the melting and allows the desired refining to take place under exceptionally favorable conditions. The other type of furnace makes use of the heat generated within the metal charge as the secondary element, by passing the proper current through a primary one surrounding the crucible holding the charge. In the latter case the temperatures can be regulated to a nicety. In the former the lower temperature ranges are not kept so readily. Both methods make good steel if the furnaces are run properly, and are also capable of making very bad steel if not run right.

Steel can be made either direct from the ore, or by refining that already made by other processes. Since there is no process cheaper than the blast furnace to make pig iron—the ordinary starting point for steel—the electric furnace is applied most advantageously as the final refining element in the chain of operations. Steel from the converter or open-hearth is therefore taken and given the final touch in the electric furnace to produce the highest quality of metal demanded. For steel-castings purposes, however, the electric furnace is made to supplant the open-hearth only, and both for melting and refining, as the units are usually too small to warrant the installation of the electric furnace together with either open-hearth or converter.

It is a question whether the iron foundry will derive much benefit from the introduction of the electric furnace. The comparatively cheaper air furnace and the open-hearth give a quality of metal amply good for any purpose to which gray iron may be put. If something better is wanted, the steel casting is demanded and may be made by any of the processes outlined. Nevertheless, it is well to keep the electric furnace constantly in mind as the modern tendency in the gray iron foundry is toward the addition of steel-castings departments—to hold trade which would otherwise slip away. With an electric furnace at hand there is no reason why an occasional heat may not be made for gray castings of special-quality requirements.

As it is not the purpose of this treatise to go into the steel-making processes exhaustively, but to give merely a sufficiently comprehensive outline of the metallurgy involved therein, so that the foundryman may know what to avoid in his own work, mention need be made only, in conclusion, of the straight melting processes in which the foundryman is directly interested.

MELTING PROCESSES

A study of the iron-making processes just described, as affecting the combination of iron with the several elements as discussed in Chapter IV, will readily show that the iron foundry needs but simple melting of the metal wanted for castings, with as little exposure to oxidizing (refining), carburizing, or other effects, as possible. It will be noted further that to obtain changes of composition in cast iron through these influences means the introduction of elements of uncertainty if not of actual danger not possible of proper control. Finally, that the application of correctional means in case of trouble, under the comparatively low melting temperatures for cast iron existing, gives unreliable results. Hence, in view of the fact that it is perfectly possible to make up any composition desired in the mixture, simple melting is all that is necessary.

The foundryman should, therefore, give his melting processes the fullest attention, so that he loses as little silicon, manganese and carbon as possible in the operation. In other words, that he gets out of his cupola or furnace as nearly the same metal as he puts in.

The processes available for straight melting are the crucible, cupola, air and open-hearth furnaces, and the electric. Of these the cupola, or *shaft* furnace, the air and the open-hearth, or *hearth* furnaces, are the only commercial ones. These will be discussed at length in succeeding chapters.

CHAPTER VI

PROPERTIES OF CAST IRON

FUSIBILITY

When cast iron is melted, held for pouring, and finally put into castings, a number of phenomena may be observed each of which has its bearing upon the success or failure of the operation. The melting point of the metal is not the only property to be considered in arranging for the melting and pouring practice. There is the question of fluidity when melted, the "life" of the metal, its freezing point, the point of "set," and a number of minor occurrences connected with the actual melting, holding and pouring which are of great interest as well as of practical importance.

As a freshly broken piece of pig or cast iron is heated up, its fracture surface acquires the series of successively appearing colors seen in tempering steel—though not with the same degree of brilliancy. Next, the piece becomes dull red, then bright red, melts and is then "superheated." If, while the colors are playing, the application of heat should be suddenly discontinued and the piece be quenched, the colors remain permanently. White iron shows these colors more distinctly than gray, while spiegeleisen exhibits them most brilliantly. These colors are the result of the formation of exceedingly thin layers of iron oxides which have the power of refracting light, and are dependent upon the degree of heat applied. They begin with light yellow (about 450°F.), then successively dark yellow, yellowish-brown, brownish-red, purple, violet-blue, light blue, and finally gray (about 625°F.).

These colors are of interest to the foundryman in the following way: When he breaks off the gates and sprues of his castings in "shaking out," and they happen to be still hot enough to fall within the temperatures indicated above, the corresponding colors will appear upon the freshly broken fractures, Oftentimes, where the continued annealing of a piece of gray iron at very high temperatures has produced a banded structure (crystallization layers with varying percentages of graphite), and the piece is broken while just hot enough to let the colors run up slowly—the iron cooling below color temperatures the while—the bands in question will acquire different colors and the entire fracture present the appearance of the so-called "calico" iron in malleable practice. In heavy pieces of metal varying temperatures as the result of unequal rates of cooling in the sand will, when broken at the right moment, show a play of various colors which, however, merge into each other and are not distinctly banded as in the gray iron above mentioned.

When cast iron is heated up to redness, and particularly so when this heating is very long-continued, or bringing to red heat and cooling alternated repeatedly, changes in the physical structure are bound to occur. This may be readily observed in the behavior of grate bars, furnace sections, retorts, melting pots, in fact wherever gray iron is subjected to the influences of extreme heat. The surface metal of the castings will have been converted to layers of iron oxide, oftentimes containing slaggy or partially melted portions. The sound core has become coarsely crystalline and of a structure more open in appearance than that of companion castings made at the same time but not yet used. In the case of "dead gray" iron more than the white varieties the volume of the metal will have been increased visibly. The castings have "grown" in length and cross-section. Continued subjection to such drastic heat-treatment finally breaks down the structure, cracks form—particularly at reëntrant angles, pieces of metal come away, and if not put out of commission by breaking the castings are buckled up, weak, and no longer serviceable.

The causes are both chemical and physical. Every foundryman has observed the effects—for that matter probably every layman. The most extended investigations, however, were made by Outerbridge who followed up the subject in the most systematic manner and made his iron specimens grow to an astonishing extent. He found that the most marked effects were obtained with cast irons high in silicon and consequently graphite, and that it required repeated heating to temperatures between 1,400° and 1,600°F. This resulted in a coarse and open-grained structure allowing what Outerbridge calls the "mobility of the molecules of cast iron" to come into play. Rugan and Carpenter, who took up this subject long after Outerbridge's investigations had received world-wide publicity, think that this peculiar phenomenon is due to the oxidation of iron silicide by air coming in by way of minute cracks along the faces of the graphite crystals. Also by pressure exerted by occluded gases. Porter thinks it a volume change coincident with *alpha* iron going to *gamma* iron when heated above 1,300°F., and a mechanical influence of the graphite crystals on cooling, resulting in a permanent extension. While undoubtedly all the reasons above given have their bearing upon this peculiar phenomenon, those who have had much to do with the effect of oxygen on iron at high temperatures will conclude that the crystalline structure of the metal opens up under such circumstances, allowing oxygen from the surrounding air to permeate and pass through the metal—as is well known in the case of furnace gases passing through red-hot stove plate. The individual crystals touching the graphite planes either become badly coated with an oxide skin or the whole crystal becomes slightly oxidized as in the case of "burnt" steel. This must produce a permanent swelling for the oxides of iron take up more room for the same iron content than iron *per se.*

The castings thus treated therefore increase in volume—an increase up to 46 per cent. in volume being noted by Outerbridge, as also in length of 17 per cent. The iron, however, becomes weaker and weaker as it grows, and the most pointed change is noted in the specific gravity, this dropping from 7.13 down to 5.49.

From the above outline of the behavior of cast iron under temperatures short of actual melting, the foundryman will see that a coarse, open-grained, high-silicon and graphite iron is about the last thing to use for the heat-resisting castings he may have to make. Where white iron may not do on account of its brittleness, the next best thing is to select a mixture which will give a close-grained metal just beyond a "mottled" fracture and on the way to grayness. The tendency of gray cast iron to "grow" should exclude it from use for annealing boxes and pots, as well, as "chills" where it is certain that these may become red hot every time they are used.

In the selection of pig iron for this class of work it is simply necessary to remember that the smaller the percentage of foreign elements contained the better the metal for heat-resisting purposes. Thus, the presence of a given amount of carbon being unavoidable, it is desirable to select the lowest silicon ranges possible consistent with the necessary fracture requirements; further, low sulphur, phosphorus, and only enough manganese to hinder a change of combined carbon to the "temper-carbon" variety. These requirements are best filled by the selection of the "Bessemer pig iron" varieties, and hence these are recommended for the ordinary requirements of service.

A word in passing on the effect of extreme cold on cast iron. But little is known on this subject beyond the experiments of Dewar and Hadfield, who found that under the extremely low temperatures produced by the application of liquid air cast iron became stronger but also more brittle. Since cast iron, however, is never used under shock in regions of extreme cold—as is the case with steel rails in the North countries—the question has so far remained an academic one.

Continuing the subject of heating cast iron. As the temperature rises up to the melting point of the particular piece affected, its behavior while melting will be of interest. It has long been held that the hard cast irons melt more quickly than the softer varieties. As, however, this contention never had any basis of actual proof and was constantly assailed by those who thought they had observed otherwise, the author, in 1898, conducted an elaborate series of melting-point determinations which effectually settled the matter for the time being.

In connection with these tests the author also made some observations on the behavior of hard and soft cast irons while actually melting and noted the following peculiar phenomena: The open-hearth furnace was selected for the tests as it would be impossible to see the iron actually melt while in the cupola. Hence, after the furnace had been regularly charged, refractory tiles 18 in. square and 3 in. thick were placed upon the charge in the center of the hearth and facing the middle door. Thus the whole process could be easily observed, as well as providing the means to insert heavy steel rods to exert pressure upon the test pieces. On these tile there were placed the test pieces selected—sections of white and gray pigs of iron as well as similarly fractured castings. The most interesting pieces, however, were those made by West in his twin-shaft cupola and described in his "Metallurgy of Cast Iron." Here charges of the same metal were melted side by side, under identical conditions, the molten iron from one side of the cupola being poured into sand molds and that from the other going into chills. The comparatively low silicon used meant that one set of castings was gray, the other white. The analyses of the series was made by the author at the time and some of the product subjected to the test being described.

From their position in the open-hearth furnace, all the test pieces melted more rapidly than the heavy metal charge below, and allowed the prompt removal of the tiles and non-interference with the conduct of the heat. While the pieces were melting rods were occasionally inserted through the peep-hole in the door and pressed upon them to note the resistance met with. The results of these rather rough but practical tests indicated that white irons begin to melt before gray irons of similar section every time. In the case of the white irons the surface was seen to wrinkle slightly, gathering into drops which ran off the side and on the tile—like water—and leaving the remaining iron solid as before. Pressing a rod upon the metal indicated a firm resistance to the force applied. The piece gradually became smaller but retained its firmness to the end.

The gray fracture test pieces, on the other hand, acted quite differently. The formation of drops on the sides was hardly observable, but the pieces seemed to soften throughout the whole mass and flatten perceptibly. Indeed, applying the rod resulted in spreading out the semi-molten mass much as is seen in the behavior of the plumber's "wiping metal." When thoroughly softened, the whole mass would become liquid and run from the tile. It would seem a pity that the temperature range of this softening of gray cast iron lies so high in the scale and is comparatively limited, otherwise there would be a means of making castings by an "extrusion" method—like type metal and "die castings" in bronze and composition metal. Unfortunately there are no materials from which to make the necessary machinery which will stand the temperatures involved.

The practical application of the characteristics of cast iron above described are of importance in cupola melting practice. While in the tests themselves the sharpest contrasts were shown by the "dead-white" as against the "dead-gray" fractured metals, a sufficient difference in behavior was noticeable in the range between these extremes to make the matter worth considering in cupola charging operations in order to promote uniformity of metal as coming from the cupola spout. It will be readily seen that if hard irons are charged below the softer ones of equa section, and the metal is caught at the spout and poured direct, there is a chance of hard metal coming first and the softer castings later on. If the charging process had been reversed uniform metal would have resulted as the harder metal trickling down over the softening gray metal below would have washed it along and both would have been melted up practically simultaneous.

Again, a thick piece takes more time to melt than a thin one. Similarly, steel requires a much higher melting temperature than cast iron. Hence, in charging, it is advisable to take these things into consideration, and to place the steel on the fuel, the pig irons on the steel and the sprues on the pig iron. Also to keep in mind that the harder pig irons go over the soft ones of equal section, and that very heavy scrap corresponds to pig iron so far as melting is concerned. Such a charge will melt at practically the same time and give very uniform metal. If the charges are made small enough and the melting practice is carried out on proper principles, the molten metal will be uniform in composition and uniform in temperature, and when run into the usual bull-ladle holding one and a half charges, will give about as perfect results as it is possible to obtain from the cupola.

The results of the author's investigations on the melting point of cast iron indicate that this is dependent in greatest measure on the percentage of combined carbon present, and not as previously held, on the phosphorus content. Thus, of the 48 pig irons and 15 cast-iron specimens tested, the white irons melted between 1,990° and 2,070°F., and the gray irons between 2,260° and 2,280°F. These figures are for the "dead-white" and "dead-gray" varieties. All others fell between these extremes. Hence, there is an actual difference of nearly 300°F. in the melting points of cast irons. Since the steels tried out ran around 2,450°F. the philosophy of the charging methods according to fusibility and section alluded to above will be apparent.

It took the author several years to collect, analyze and test the pig irons, cast irons, and ferro-alloys in question. Then, in conjunction with his friend S. H. Stupakoff, one of the foremost authorities on practical pyrometry, an adaptation of the Le Chatelier pyrometer was devised which allowed the thermocouple to be inserted into a hole bored into the center of the pig section—about 1/8 in. of highly refractory clay protection being given the platinum: platinum-rhodium wires, and the iron actually melted off the instrument. As the metal rose in temperature, the instrument readings went up slowly but steadily. Just as the last iron dropped off the clay tip of the pyrometer, the readings jumped up suddenly, and thus the actual point of melting was caught with a fair degree of accuracy. The melting was accomplished in a specially built cupola, operated with compressed air, and provided with an opening in the side at the point of maximum temperature within the coke bed.

A few only of the results are given in the following table. They are sufficient to show that the combined carbon content of cast iron governs its melting point—as a general proposition.

TABLE OF MELTING POINTS OF CAST IRON

Combined carbon	Graphite	Silicon	Manganese	Phosphorus	Sulphur	Melting point, degrees F.
			Pig Irons			
3.98	.....	0.14	0.10	0.220	0.037	2,030
3.74	0.14	0.38	0.16	0.172	0.032	2,040
3.52	0.54	0.47	0.20	0.200	0.036	2,100
3.22	0.68	0.71	0.09	0.142	0.038	2,055
2.28	1.14	0.42	0.13	0.185	0.026	2,110
1.96	1.90	0.75	0.63	0.097	0.028	2,170
1.72	2.17	1.88	0.54	0.446	0.028	2,190
1.48	2.30	1.41	1.39	0.168	0.033	2,210
1.24	2.68	0.65	0.26	0.201	0.020	2,230
0.87	3.10	1.34	0.42	0.158	0.030	2,230
0.80	3.22	1.30	0.59	0.172	0.042	2,230
0.38	3.43	2.44	0.57	0.422	0.048	2,250
0.24	3.48	2.54	0.30	0.060	0.020	2,260
0.13	3.43	2.40	0.90	0.082	0.032	2,280
			Cast Irons			
4.20	0.20	0.63	0.33	0.254	0.040	1,990
3.90	0.16	0.75	0.66	0.240	0.030	2,000
3.40	.....	0.42	0.07	0.196	0.029	2,040
1.63	2.27	1.46	0.50	0.092	0.032	2,170
1.22	2.66	1.69	0.47	0.274	0.037	2,240
0.17	3.57	2.09	0.43	0.272	0.042	2,260

An interesting point noted was that with the same combined carbon, a piece of steel melted at 2,450° and the gray iron at 2,260°F. This difference in temperature is evidently due to the fact that as the gray iron softens the graphite is dissolved to some extent forming combined carbon—and to that extent lowering the melting point.

The percentage of phosphorus in commercial irons falling below 2.00 ordinarily, this element has little effect on the melting point. It is only when the phosphorus present rises considerably that the melting point of the iron in question will be lowered appreciably. It should be remembered in this connection, however, that while phosphorus does not affect the melting point of an iron seriously, it does increase the "fluidity" to a remarkable extent. This matter will be discussed further on.

From the determinations made on some of the common ferro-alloys it was found that apart from the combined carbon and phosphorus content, the silicon, manganese and sulphur present had little to do with the melting points in question. Vanadium and titanium alloys were not available at the time these tests were made, and very likely the latter element has a very marked influence in raising the point of melting.

FREEZING POINT

In molten iron all the carbon present is in the combined state. The presence of any carbon over normal percentages, held in a state of "supersaturation" at the extremely high temperatures of the blast furnace, results in throwing this off as the metal cools to ordinary ranges, in the shape of a finely crystalline graphite, called "kish" about the blast furnaces. Mention has been made of this in a previous chapter.

The freezing point of a molten cast iron, or its "point of set" will be practically the melting point of another cast iron with the same percentage of combined carbon. That is to say, the melting point and freezing point of a white cast iron may coincide, whereas the freezing point of a gray iron will be much lower than its melting point. If, therefore, a gray iron containing say 3.50 per cent. of total carbon is melted (about 2,260°) the metal can be allowed to cool down to the point at which a white iron with 3.50 per cent. combined carbon melts (2,100°), before this molten iron will "set." This property accounts for the well-known fact that molten gray iron can be held much longer in the ladle than white iron before it must be poured.

Another point must be considered in this connection. There is more required than a simple melting of the iron. It must be "superheated" considerably to insure good fluid metal. This superheating is readily effected in the cupola by arranging for melting in the hottest portion of the "zone of melting." The air furnace presents greater difficulties in this respect, and unless the greatest efficiency in firing is attained, the metal may be badly oxidized by the time it has reached the proper degree of heat.

Since the hottest point in the cupola may reach almost 4,000°F. there is no reason why metal melting at that place may not acquire 200° to 300°F. additional above the melting point. Adding to this the ability of the metal to lose another 150°F. before it sets, a fair leeway should be available for pouring operations. The loss of heat, however, is quite rapid at these high temperatures. The mere running of iron down the cupola spout into the ladle means a reduction of about 25°F. on the part of the metal. One has but to observe the color of the molten iron returned from the pouring of distant molds to note how rapidly heat is dissipated when iron is carried about in very small units. On the other hand, in large bodies, as for instance in the transportation for miles of direct metal from the blast furnace to the steel converter, no difficulty has been experienced from cold metal even where an accident held up the delivery for 8 hours.

FLUIDITY

The fluidity of molten cast iron—briefly touched upon above—is the property the metal has of flowing easily, thus filling the finer parts of the molds completely and giving perfect reproductions of the pattern. The principal factors which affect the fluidity of the molten cast iron are the following: The degree of superheating above the melting point as the metal leaves the cupola. The available temperature above the freezing point of the metal as affected by its composition. The percentage of phosphorus present. The degree of oxidation of the metal, and the percentage of silicon.

Molten cast iron with a high phosphorus content will be extremely fluid if melted hot and free from dissolved iron oxide. Castings of wonderful delicacy have been made with such metal, as for instance specimens of lacework, every thread of which was reproduced. Indeed it would be useless to attempt the making of art castings with low-phosphorus irons, unless a molding sand be secured which is extremely fine-grained and at the same time highly refractory. The temperature required to give the necessary fluidity to low-phosphorus irons is such that the ordinary sands used for this class of work would cut badly and hence give poor surfaces. This difficulty is noticeable in the production of stoves at establishments also making cast-iron boilers. The latter castings require a lower phosphorus for strength, and unless the two classes are divided by running separate heats for each, the artistic results are certain to suffer.

Silicon, when present in sufficient quantity to give gray fracture iron, assists in holding it fluid while in the mold. This has been best described by Field who gave special attention to the subject. As a gray cast iron is melted—this consisting in effect of an impure steel with a high percentage of graphite by volume, mechanically mixed—the solution of the graphite renders a considerable quantity of heat latent. Conversely, as the metal cools and the silicon compels the bulk of the carbon present to separate out as graphite, heat is given up and the fluidity of the metal thus slightly prolonged. The bearing of this phenomenon may be readily observed in the malleable foundry where low silicons are the rule. The fractures of the castings in ordinary green-sand molds being required white, there is no possibility of a graphite separation and high temperature prolongation, and hence for very light castings it is actually necessary to "throw" the metal into the molds by a twist of the wrist controlling the pouring. Otherwise, the gates may freeze up before the mold is entirely filled.

In this connection it may be stated that the higher the total carbon the longer the period of fluidity in the case of the high-silicon irons. This is a common observation in the foundry, by contrast, now that so much steel is charged in the regular cupola mixtures and the consequent reduction of the total carbon compels particular attention to rapid pouring facilities.

The presence of dissolved iron oxide in the molten metal is probably the most serious drawback in the production of sound and smooth castings. The prevalence of "cold-shuts" (deep lines in the surfaces of castings indicating an imperfect junction of separate flows of metal coming together), shot, imperfect filling, interior shrinkage, cracks, gas pockets, pin holes, etc., are all traceable to this cause as has been previously described. In spite of the proper phosphorus content and sufficiently high temperature, the fluidity of the metal has been impaired and the freezing point raised.

One further trouble requires mention in this connection, and that is the entraining of slag into the metal poured. Foundrymen will often have observed, when the heats are not what they should be, that, after cleaning off the slag cover on a ladle full of molten metal drawn from the cupola, fresh slag will appear, sometimes in considerable quantity. The metal seems to clear itself of this admixture very slowly and the question arises as to why this should be. Metal of this kind, poured into castings, will sometimes show aggregations of slag located in the shrinkage spots, unquestionably having come through the cupola, ladle, and into the casting.

Here is a case of lack of fluidity. As the metal melts drop by drop in the cupola, and is accompanied by slag similarly melted, the loss of fluidity brought about by oxidation tends to hold the slag in suspension in the metal. In the bottom of the cupola there is little chance of a proper separation under the circumstances, as the molten materials simply fill interstices between red-hot (not always white-hot) lumps of coke, and slag may stick to the bottom surfaces of these lumps if not thinly fluid. The result is the carrying along of some of this slag over the spout and into the ladle. From thence, with iron of poor fluidity, it may enter the castings if not allowed a full chance to separate out on top of the metal. Properly melted iron, of good fluidity, seems to clear itself of slag without much difficulty in the cupola bottom, the drops of iron running down so much faster than slag that they run down comparatively clean.

The pouring of "fluidity strips" is a common method of testing out the fluidity of molten iron. These are rather long wedges, usually 1 in. wide, ½ in. thick at the base and tapering off to nothing at the other end. They are ordinarily cast under a flat cope of sand, or in the case of the high-silicon irons under plates of cast iron to chill the metal. The measure of fluidity is the distance the metal has run up the mold to the thin end. Probably the only use of such fluidity strips is in the making of comparative tests. In ordinary foundry procedure it is impracticable to test the fluidity of the metal in a ladle before pouring the castings. In making special tests, however, or in getting a line on the daily run of metal made for shop information, these fluidity strips prove very useful.

The color of molten cast iron is of some interest, particularly as this, in connection with the play of the oxide films on the surface, gives an intimation of the character of the metal in the ladle. Caution must, however, be exercised in judging by color, as from the author's observations a ladle full of snow-white low-silicon iron may actually be lower in temperature than one of dull-red high-silicon, or gray-fractured cast iron. In general it may be said that the color of the molten white irons run from red to pure white, whereas that of the gray irons carries an orange to yellow shade. Furthermore, the brilliance of the color is different, the flat smooth surface of molten white iron giving less light reflection and refraction than the rougher surfaces of molten gray iron.

In the days before the advent of chemistry in the foundry every phenomenon likely to give even a crude idea of the character of the molten iron was carefully observed, since the making of mixtures based upon pig-iron fractures was uncertain at best. One is not surprised, therefore, to see considerable space devoted to the discussion of the oxide films formed on the surfaces of molten cast iron. Even the jumping of sparks from the stream of iron running over the cupola spout come in for its full share of attention. In modern practice these things occasion little comment for the phenomena are observed "after the fact"—the composition and consequent melting results being known. With lower ranges of silicon, therefore, bright sparks thrown from the metal are expected, where formerly their appearance when dead soft castings were wanted occasioned alarm. There is, however, a distinct value to the foundryman in these observations. If the cupola charges were all identical and marked differences in color, sparking and film appearances of the surface metal are noted during the heat, these are indications that the cupola practice requires immediate attention.

The "film play" above mentioned is noticeable particularly as extremely hot metal begins to cool slightly. The rising of impurities together with contact with the oxygen of the air result in the formation of a skin or film on the surface of the molten metal, which is cracked up into patches continually by the ebullition going on. These film surfaces, being rougher than the clean metal surfaces showing through the cracks, look much lighter, and there is a continual shifting about of points and patches which enables a melter to get a fair idea of what his castings will be like when poured if he cares to study this phenomenon. The air furnace, with medium-silicon and low-carbon mixtures gives a better film play than cupola metal, while the blast-furnace runs show up best of all.

A very important foundry operation is made possible in connection with the plastic state of gray iron just before melting—the point at which graphite begins to go into solid solution in the iron. This operation is the "burning on" of metal to repair defective or broken castings.

If highly superheated iron is made to flow over a surface of gray cast iron the temperature of the metal in immediate contact with the stream is quickly raised and eventually the metal attains the plastic state, the outer portion actually melting. The result is a union of the surface with the new metal poured on, and if properly confined within sand walls, allows the making of a perfect joint.

This process is constantly adopted in making welds between cast iron and steel; also with wrought iron to a fair degree. The most recent development, however, is the actual melting of the surface by means of the oxygen-acetylene flame and the simultaneous melting of rods of soft cast iron to supply the metal required. For heavy work, however, the old "burning on" method is most reliable, the application of heat not being quite so local and the resulting strains not so liable to cause subsequent rupture.

It was the published description of the repair of a broken roll, under the caption "Burning Heavy Castings" by West, in the *American Machinist*, Jan. 15, 1881, that proved the beginning of the era of the modern foundry advance. The method, while appearing very simple on the face of it, must nevertheless be conducted with precautions, otherwise unsatisfactory results will eventuate. First of all, the surface to be "burned" or welded, must be clean, that is free from rust, sand, and particularly a casting skin. Unless this is taken into account a refractory material will remain between the two metals and prevent their perfect union.

Next, the portion of the metal to be "burned," or the two surfaces to be united, must—after cleaning—be heated red hot, to reduce the quantity of molten metal required for the joint to a minimum, and to extend the heating effect far enough backward to prevent the setting up of internal strains certain otherwise to result in subsequent cracks. Carelessness in this particular is the reason for most defective welds. One has but to recall personal experience with patched automobile cylinders to understand why some concerns in that line of work are known by reputation to have competent operatives and others not.

Good soft and highly overheated metal must be used for the weld, a sufficient quantity being made to flow over the surface in question to insure actual melting. Ordinarily but unimportant surfaces or corners of castings are thus repaired, though the method is capable of application to heavy, most complicated and important work. Careful "bedding in" of the defective casting, so arranging the inlet for the molten metal that fresh iron is continually coming into contact with the surface to be repaired, and proper preheating of the exposed metal will result in good welds. The quantity of superheated metal to be poured over the surface in question naturally depends upon its area, degree of preheating, and the available heat in the molten metal. In ordinary cases but a few hundred pounds are thus employed, otherwise there would be but little economy in the procedure. The foundry foreman will have to judge whether the molding cost of the defective casting, the additional scrap involved, the chances of failure, the importance of the casting, the urgency of the case and the general effect on the molding efficiency of the shop will warrant much of this kind of work being taken in hand. Usually a high figure already spent on the casting or the necessity for prompt shipment decides the case.

THERMO-PHYSICS

A study of the heating and melting phenomena of cast iron would be incomplete unless supplemented by a short discussion of the thermal relations involved. The question of utilizing the sensible heat of blast-furnace metal for direct casting purposes comes up too often to be ignored. While the remelting of pig iron on a large scale involves an expenditure of 75 cts. a ton upward only, there are comparatively few foundries of sufficient size to consider the building of their own blast furnaces. The half a dozen or so that are so situated, however, have before them not only the saving of the remelting costs, but also the original profit on the pig iron, not to speak of freedom from many economic difficulties.

Again, the electric furnace has come to stay and gives the foundryman a ready means of handling problems in quality castings—controlling composition and melting troubles being particularly in line of ordinary operation in this furnace. On account of its high first and operating cost, however, the introduction of the electric furnace into the gray iron foundry will be slow unless advantage is taken of the thermo-physical properties of cast iron as indicated further on.

The melting points of various classes of cast iron have already been discussed; similarly, in a general way, the point of freezing. It is now necessary to consider the capacity of cast iron to take up heat during the heating and melting operations. This may be divided into three distinct phases: the absorption of heat up to the point of melting; the rendering latent of heat during the melting operation (heat absorption without rise in temperature); finally, the heat absorbed in superheating the molten metal. A number of calorimeter tests were made by Vathaire, Gruner, Deny and others, from which the following are selected. The measure of this heat absorption is the British thermal unit—the heat necessary to raise 1 lb. of water 1°F. at 39.1°F. In case it is desired to work with the French unit, the "calorie," which is the heat necessary to raise 1 kg. (2.2 lb.) of water (at the point of maximum density, 39.1°F.) 1°C., British thermal units (B.t.u.) may be converted to calories by multiplying by 3.968, and calories to B.t.u. by multiplying by 0.252.

The following gives a summary of the results obtained:

Material	B.t.u. per lb.
Gray iron, under slag within blast furnace	1,310
White iron, under slag within blast furnace	1,110
Gray iron, cupola remelt, as tapped	1,152
Gray iron, cupola remelt, just beginning to set	1,012
Gray iron, cupola remelt, completely set	893
White iron, cupola remelt, as tapped	1,032
White iron, cupola remelt, just beginning to set	972
White iron, cupola remelt, completely set	853

The above figures are typical only, as it is most difficult to obtain reliable data at such high temperatures, particularly when the observer has to deal with masses which do not change from liquid to solid conditions uniformly, and *vice versa.*

A set of average figures obtained by Gruner gives some information on the relative amount of heat required to bring a pound of cast iron up to melting, and that for actual melting.

Cast iron	B.t.u. up to melting	B.t.u. of melting
Gray	880	90.5
White	777	135.0

This bears out the contention that it requires a greater quantity of heat to bring gray iron to the point of melting than it does in the case of white iron. The results given indicate that it takes more heat to actually melt white iron than gray, once the metal had been brought to the melting point. This may be so or not, as other investigators find a closer agreement in results, the B.t.u. of melting being about 120 in each case. Adding the amounts above given, however, shows that gray iron melts under the application of 970.5 B.t.u., and white iron with only 910, which bears out the practical observation that white iron melts faster than gray.

There is another question, however, and that is the degree of superheating obtained in ordinary cupola melting. Adding the B.t.u. up to melting with those of actual melting, to obtain the total quantity required to get the metal liquid (in the above table) and comparing with results obtained as previously given, the following is shown:

1 lb. cast iron	B.t.u. as tapped	B.t.u. as just melted	B.t.u. of superheating
Gray	1,152	970.5	181.5
White	1,032	912.0	120.0

which again is in line with practice, white iron not permitting the same degree of superheating as gray, with safety from undue oxidation.

So far as the use of blast-furnace iron is concerned, when compared with cupola metal, the following B.t.u. values would appear from what has been given:

1 lb. cast iron	B.t.u., blast-furnace tap	B.t.u., cupola tap
Gray	1,310	1,152
White	1,110	1,032

These figures indicate that the blast furnace yields metal with a considerable higher quantity of heat (also higher temperature) than the cupola for both kinds of cast iron. And since it would be necessary in considering the use of "direct metal" for special lines of foundry work—to care for gates and sprues, these could be heated up to nearly melting with the waste furnace gases in suitable soaking pits, and added to the furnace tap.

From the tables given it will be noted that there is a margin of 158 and 78 B.t.u. per lb. of iron available between furnace and cupola iron as tapped. Since the gates and sprues of a foundry able to use direct metal (as for ingot molds, water pipe, etc.) would hardly amount to 20 per cent. of the melt, and the difference between these when up to melting and the temperature required of cupola metal amounts to 272 and 255 B.t.u. respectively; one-fifth of these amounts, or 54.4 and 51.0 would seem to be well covered by the margin of heat referred to, thus:

lb. cast iron	B.t.u. of cupola tap	B.t.u. up to melting	B.t.u. required	⅕ B.t.u. required	B.t.u. available
Gray iron	1,152	880	272	54.4	158
White iron	1,032	777	255	51.0	78

The author has therefore repeatedly recommended that blast-furnace metal be treated by the addition of white-hot steel scrap and foundry sprues in an oil-fired open-hearth "mixer" of large capacity, so that the total carbon might be reduced sufficiently to overcome the formation of "kish," open-structure iron and the coarseness of grain incident to direct-metal castings made at blast furnaces.

Further, by installing electric furnaces for final treatment of small units of metal taken from the "mixer" continuously, there should be no reason why the greatest degree of flexibility and economy cannot be attained in those large foundries where the blast furnace would appear the *ultima ratio.* It should be remembered that taking a charge of molten metal from a mixer and treating it in the electric furnace is an altogether different proposition from melting cold metal in that expensive furnace in the first place.

GRAIN STRUCTURE

When molten iron is poured into sand molds cooling takes place and the metal "sets." The interval of time required for this action depends upon the rapidity with which the heat units in the metal above the setting point are dissipated. As the molten metal touches the cold and damp mold surfaces heat is conducted away and a thin shell of solid iron soon formed. This rapidly grows thicker and finally the whole mass becomes solid.

Referring to the tables of heat units in every pound of molten metal as given above, it will be observed that 181.5 B.t.u. of every 1,152 present are necessary to carry gray iron from the stage of just melting to full cupola heat. On setting, however, as a gray iron remains liquid until the melting point of a white iron has been reached, 1,152 minus 912 (white iron just melting), or

240 B.t.u. per lb.—which amounts to 21 per cent. of the total heat present—must be dissipated in pouring and through the mold walls before the gray iron casting will be fully set. This corresponds to a drop in temperature of about 300°F. In the case of white iron the heat to be dissipated before setting can take place is 120 B.t.u. per lb., or 11.6 per cent., and the drop in temperature is about half as much. Hence the comparatively rapid setting of white castings.

That the setting of gray iron is retarded somewhat by the liberation of the latent heat of melting plus that given out when graphite is thrown out, is shown by the behavior of the metal in molds which are accidentally broken some time after pouring. They may "run out," and on shaking out a shell of metal, perhaps 1/8 in. thick, will be all the iron that has as yet set. In the case of large molds which have to be "pumped" for some time to facilitate the feeding of the casting the process of setting on the part of the iron can be observed by the sense of touch, the end of the iron rod meeting solidifying metal nearer and nearer the riser until the setting is complete. The foundryman will find the controlling of this action a most fruitful field for study. It has a very definite relation to the production of sound castings.

Molding sand is essentially silica and clay—both highly refractory materials. It acquires an intense surface heat rapidly, particularly if dried, and does not dissipate the heat of molten iron readily. There is enough moisture in green-sand mold surfaces, however, to reduce the temperature of the metal touching them fairly quick, if that metal can remain stationary long enough—from 5 to 10 per cent. of water being used in "tempering" green-sand. Further, it will be clear to the foundryman that if his metal has to enter the mold at one point, the sand surfaces close to this spot will be very much hotter than those covered by comparatively colder metal, as for instance right under the cope. Now since the iron, in setting, contracts sufficiently to require considerable feeding of liquid iron into the mold during the operation, it is patent that this fresh metal must enter either at the gate, or point of original entry, or else draw down from the heavy risers usually provided for through the cope. The situation in the mold is supposed to be the following: The iron is poured through the gate into the mold and begins at once to give up heat to the sand it comes into contact with. It flows along the bottom and rises upward until it fills the mold, coming out through the risers and overflowing the pouring basin. The further it goes the colder will the initial iron become. On the other hand, the sand over which fresh iron is constantly flowing will acquire more heat from it than the sand next to the first metal poured. So the setting of the metal should begin at the point of coldest iron and coldest sand. Setting should thus begin at the far end of the mold and continue backward to the gate. The fact that the iron and the sand is hottest at the gate should so retard the setting of the iron that in spite of the very narrow passageway allowed liquid metal should be able to enter the mold up to the last moment—until the last of the iron within the mold has set. Unless the metal has sufficient "life" it frequently happens that the metal in the gate sets before the interior has become completely solidified and the consequence is a very distinct "draw" or shrink-spot in the casting just below the surface of the metal at the gate. The setting process within the mold was just a little too slow for the metal, whether this was too cold in the first place, or had lost its "life" or fluidity as the result of oxidation during melting.

On mentally following the course of molten iron in a complicated mold, it will be understood how easily the iron may remain stationary in some parts and may keep on moving until the mold is full in others. This can result only in unequal times of setting, and it must therefore be impossible for some points to get a supply of fresh metal. These parts will be unsound, or at least coarser grained than those which have been duly fed. The example of a large flywheel is perhaps a pertinent illustration. The molten iron may be fed at several points and the mold fill up quickly and pass out of the risers. The chances are, however, that the arms will set first, then those portions of the heavy rim furthest away from the gates, where the iron was coldest when pouring was complete. The comparatively long time required for complete setting of the rim means that the gates will have frozen up long before, and hence the almost certain prevalence of large shrinks and cavities in the flywheel rim. The safest way to secure soundness in heavy castings—and for that matter in lighter classes of castings also—is, wherever possible, to let the iron enter directly from the top through a large series of small round vertical pencil-like gates, called "top gates." The metal drops straight to the bottom, keeps the surface agitated, but allows the metal directly below to remain quiet and set—feeding itself from the hot metal above as it does so. If the entrance of the iron into the mold in this way is slow enough it is possible to have the bulk practically set when the pouring it complete. This method, instead of having cold iron on top, has it hottest there. It keeps dirt from being held in the metal and substitutes a number of small feeding points for one or more heavy risers with their chances of unsound metal beneath the base. Flywheels of very heavy proportions are obtained with this method of gating, without the use of any risers, and the metal will be reasonably sound throughout. It is simply taking into account the conditions under which the metal has to set, and heading off feed ing troubles by removing the necessity for feeding at all.

As sufficient heat is dissipated from the metal remaining in contact with the sand surfaces of the mold to make it set, a crystallization of the iron is induced, at right angles to the surfaces in question. Furthermore, the more rapid the heat reduction the smaller will these crystals be, and in the case of gray iron, also the plates of graphite precipitated between them from the iron-carbon solution. Gray cast iron, which consists of crystals of impure steel more or less separated from each other by mechanically mixed plates of graphite, will when broken separate along a series of these graphite plates and present a ragged fracture. The otherwise bright crystals are masked by a covering of graphite, and the fracture appears nearly black. Taking a freshly fractured pig and scratching vigorously with a steel brush, removes this graphite, and the fracture becomes steely white.

It has been shown that the precipitation of graphite from an iron-carbon solution depends upon the silicon present, the rate of cooling, and the initial heat of the metal. With the lower ranges of silicon the last two factors are very important and may result in either gray- or in white-fractured castings, as follows: If the cooling is very rapid, as for instance when pouring into iron molds, there may be no graphite precipitation at all and the casting is chilled to a white fracture. On the other hand, if the mold is hot and kept heated the reduction of temperature may be so slow that nearly all the carbon will come out as graphite. So far as the pouring temperature is concerned it is noticed that a very hot iron chills deeper than the same metal poured cold, which appears contradictory, but this has to do with other phenomena. Between the two extremes in the temperature reduction of the iron there will be found an adjustment of the crystallization and graphite precipitation which gives the normal gray iron castings. That is to say, close to the sand the crystallization will be very fine, for the withdrawal of heat is rapid, whereas further inward the crystallization of iron and graphite is coarser, the granular structure more open, and the percentage of graphite precipitation higher—the total carbon content of the casting being practically constant throughout.

The statement just made—that the percentage of graphite precipitation within a casting is higher than at the surface—requires more elaboration, as this situation is the basis of an important property of cast iron, namely, its "machinability." With a given percentage of total carbon present, the more graphite is precipitated, the smaller the residual combined carbon and hence the softer the casting will be. In machining, as the tool is pressed against a crystal of iron it has either to cut through it, or tear it bodily from its neighbors. The extremely weak plates of graphite seaming the metal in every direction aid the tool in doing these things as well as lubricating it as it passes along. Now if the iron crystals contain much combined carbon they will be hard and cannot be easily cut or removed. The tool point will be damaged badly, the tool and casting surface will heat up, for there are fewer graphite planes met with and lubrication is imperfect. It is therefore necessary to avoid the retention of carbon in its combined form as much as possible consistent with the requirements of the case, and any unncessary chilling of the surfaces resulting in hard corners and skin will be paid for heavily in the machine shop. The constant cry here is for "soft" castings. Hence the mold surfaces must not be too damp nor sand edges swabbed too heavily, the silicon content must be sufficient, and "lifeless" oxidized iron avoided by all means.

Since, however, it is becoming more and more necessary to turn out castings both soft and strong, the situation aimed for is to keep low not only the combined carbon, but also the graphite. Hence results a low total carbon, nearly all of this being in the form of finely divided graphite. This is accomplished by the addition of low-carbon steel scrap to the mixture and melting very carefully. The silicon content is held high enough to give a low combined carbon and while machining is not as easy it is satisfactory.

Attention must be directed to the so-called "skin" of iron castings. A number of things may happen while the iron is setting in the mold. The sand surfaces being damp more or less steam is generated, some of which is decomposed and gives its oxygen to the iron. This forms a hard skin of iron oxide. Next, the comparatively sudden cooling of the extreme layer of metal means high combined carbon, and hence a hard skin. Then a possibility of carbon absorption from the facings used, the retention of entrained slag and grains of manganese sulphide at the surface, etc. The resultant of these possibilities is a covering layer which is very hard on the tool. Hence, in machining, it is desirable to begin cutting under the skin and not sliding over it. Once the tool point enters the softer metal directly under this hard skin, and pushes forward, the hard metal is broken away and lifted off automatically with little damage and difficulty.

By means of special devices to regulate the removal of heat through the sand it is possible to obtain effects on the grain structure of castings of great value. For instance in the making of castings subject to heavy wear it is very desirable to produce a fine-grained structure where most required, which means the holding of sufficient carbon in combination by the proper rate of heat removal. Thus, the guide frames for presses and planer carriages, tin-plate rolls, engine cross-head slides, etc., have their life wonderfully prolonged by employing suitable molding methods. Casting the molten metal into "chills" would harden them too much for subsequent machining, hence the introduction of heavy masses of cast iron into the sand mold close to the surfaces required of finer-grain structure, to withdraw the heat through the comparatively thin layer of sand or loam between the mass and the molten metal. Similarly the introduction of coils of water pipe at the locations to be cooled more rapidly, the circulation of cold water doing perhaps more effectively what imbedded masses of iron would, though not quite so evenly. The making of heavy cast-iron guns successfully depended greatly upon the water-cooling of the core forming the bore. The metal thus cooled artificially, and yet not chilled, became very fine-grained and gave a far higher resistance to the sudden demand for strength when the shot was fired than if the metal structure had been more open as the result of ordinary cooling methods. The foundry industry is indebted to Bole for the very thorough development of water-cooling sand molds. Indeed if the makers of great engine castings for steam and gas would take the time to study the methods he has outlined, and note the saving in defective work accomplished, they would be much benefited.

The grain structure of a casting necessarily refers to the appearance of a fractured surface to the eye. This surface is rough and in the case of strong, tenacious iron is badly torn up. In fact one of the old tests made by the foundryman to judge the quality of his iron was to pass a freshly fractured surface over the back of his hand. If the hair was caught and torn out, he knew he had a tough metal and was correspondingly pleased. It is very easy to distinguish a fine-grained structure from a coarse one, also to note the transition of one to the other. Indeed, in times gone by, when chemistry was unknown to the foundryman, the fractured surface of pig and cast iron was the only guide available to judge of the probable physical qualities. Hence also the very slow and stubbornly contested conversion of the blast-furnace operator and foundryman from fracture grading of pig iron to that by analysis.

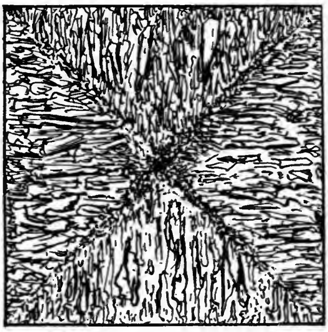


Fig. 13.—Pen sketch of white cast-iron fracture, showing crystallization at right angles to chilled surfaces.

While it is easy to distinguish the grain structure of a casting by the eye—really the grouping of crystals torn from each other and covered with graphite—it is very difficult to see any crystalline structure in gray iron. Only preparation for the microscope will show the structure outline sufficiently well to prove a crystallization at right angles to the mold surfaces for a short distance inward. In the case of white iron, however, the eye can follow this condition nicely, for the crystallization is very brilliant and in some cases so plain that in square sections of metal cast into chills the Cross of St. Andrew is most strikingly represented, as in Fig. 13. This represents remelted car-wheel iron cast into chill cups, the silicon being 0.60, and the sulphur 0.11.

POROSITY

Referring again to the setting of iron in a comparatively thin gate before a casting has been fully fed up with liquid metal, not only will there be a bad shrink-spot present, but much of the adjacent metal will be very porous and of open structure. As such iron—in ordinary cases—was probably oxidized in melting, it not only contained considerable occluded gases, but had them formed within by the reaction of oxygen with carbon during the pouring. The early cutting off of the gate and formation of a void below results in the removal of the ferrostatic pressure at that point, and the iron just below will relieve itself of surplus gas held in solution under pressure. The situation can be likened to a bottle of soda-water on the removal of the cork. The upper portion immediately sends off its surplus gas in numerous bubbles whereas the lower portion retains it. The bubbles in the iron may be too small to see, but it means porous iron just the same.

Much of this trouble is also found with very good iron, and is due to improper gating and in the design of the casting itself. The flywheel has been quoted as an example, the arms setting long before the rim has solidified completely. Shrink-holes, with the very best of iron, are unavoidable unless the gating method previously mentioned is adopted. Castings such as cylinders for air and ammonia are particularly liable to trouble from unsound metal simply because of differences in the time of setting—some portions being prematurely cut off from proper feeding. In spite of the fact that such castings, on being broken up, show perfectly sound metal fractures, when testing the work under air pressure and coating the outside with soapwater, the junction of flanges and cylinder wall only too frequently indicate porous iron by the appearance of bubbles.

That even crystalline white iron of high specific gravity and appearing dense as glass may be porous was noted by the author in the subjection of white iron castings to an oil-quenching process On breaking the castings subsequently they were found not only unimproved but certain spots of considerable size and of apparent soundness were found saturated with oil which had seeped in from the surface, indicating porosity.

The opening of the grain structure under high temperature is well recognized. The passing of gases through red-hot stove fire-pots, the percolation of iron sulphides through the crystalline structure of steels (discovered by E. D. Campbell), and the movement of the molecules and permanent growth of cast iron, with corresponding porosity of the metal, brought out by Outerbridge are ample proof of this condition. The more serious manifestations of the situation, however, will be discussed later on under the heading "Shrinkage."

SPECIFIC GRAVITY

While on the subject of pouring molten iron and the structure of the resulting castings, the density of the metal naturally is of special interest, and has been touched upon somewhat in discussing its porosity. It must be patent that an iron full of crystals or plates of rather light graphite will weigh less per cubic inch than one in which this is not the case. The specific gravity of cast iron—or the relative weight compared with an equal volume of water—is therefore a variable quantity, and depends upon a variety of factors. In general, the higher the temperature of the blast furnace, thus increasing the silicon and consequent graphite precipitation, the lower the specific gravity. Charcoal irons, therefore, run heavier than coke, and cold-blast iron is denser than hot-blast metal. The presence of much phosphorus in the gray irons also seems to increase the density, doubtless by reducing the graphite content. The very soft high-graphite irons would, therefore, be at the lower end of the range and the glassy chilled white irons at the upper. The range is given by a number of investigators to be as follows:

Lowest point, sp. gr. 6.64, corresponding to liquid metal, and weighing 415 lb. per cu. ft.

Highest point, sp. gr. 7.88, corresponding to nearly pure white cast iron, and weighing 490 lb. per cu. ft.

The weight per cubic foot is readily obtained from the specific gravity by multiplying by 62.425, the weight of a cubic foot of water, the specific gravity of which is taken at 1.

The following list gives the range of specific gravities in more detail:

Metal	Specific gravity	Pounds per cubic foot
Coarse-grained gray pig iron	6.80	425
Coarse-grained gray cast iron	7.00	437
Fine-grained gray cast iron	7.20	449
Mottled pig iron	7.64	477
White pig iron	7.69	480
White, charcoal, high-phosphorus cast iron	7.80	487

For purposes of calculation in making estimates of weight the following averages may be taken:

Average gray iron, 7.10 sp. gr., or 443 lb. per cu. ft.
Average white iron, 7.50 sp. gr., or 468 lb. per cu. ft.

or 0.256 and 0.271 respectively for those who wish to use the weight per cubic inch.

To calculate the ladle capacity for molten iron—white and gray iron when melted having approximately the same specific gravity —6.65 may be used as the specific gravity of the molten metal, or 415 lb. per cu. ft.

The *ferrostatic head,* or height of the column of molten iron, makes a slight difference in the specific gravity, as has been found by Mallet, who cast a number of cylinders 13.78 ft. high. The specific gravity of the metal at the top of three of these was 6.96, 7.05 and 7.03, whereas the metal at the bottom ran 7.10, 7.14 and 7.12 respectively.

The following might be included under miscellaneous figures:

	Specific gravity
Very open gray coke pig iron	6.79
Remelted in the air furnace	7.50
Cold-blast coke pig iron	7.07
Remelted in the air furnace	7.68
Gray charcoal pig iron for malleable	7.06
Remelted in the air furnace	7.52
Gray charcoal pig iron, cast in sand	7.15
Same metal, cast into chills	7.53
Gray interior of chilled roll	7.06
Chilled portion near surface	7.52

These will be sufficient to show the increase in density coming from the reduction of graphite in the sample, either through a silicon reduction or hastening the rate of cooling by chilling the metal.

A very interesting development in this connection is to be found in the production of cast-iron borings compressed into "briquettes." This new industry has attained considerable dimensions particularly in Europe, more than 25 plants being located in Germany, Austro-Hungary, Switzerland, Italy, France and England. The borings, after cleaning in a current of air, are run into chutes feeding large hydraulic presses with revolving tables. Pressure is applied in several stages, the last up to 35,000 lb. per sq. in. This consolidates the borings into what appears almost a solid mass, and without the aid of any binder. Indeed, in the case of copper chips the line of separation between the individual particles is practically wiped out, showing the "flow" of this metal under the enormous pressure.

While the pressure is so great that the work done causes the briquettes to heat up considerably, the specific gravity of the finished product runs between 5.4 and 5.8 only, showing that considerable porosity must still exist, as ordinary pig iron has 7.0 sp. gr. Two factors should be considered in this connection, however, and they are the loss of graphite incident to the crumbling of the structure of cast iron under the tool—tending to increase the density of what remains. As against this comes the dirt and other foreign matter swept up with the borings about the machines, which regularly drops the iron content of even the best of borings below 85 per cent.

Extended researches made with the briquetting process have shown that if the pressure is raised up to 65,000 lb. per sq. in., it is possible to get the specific gravity of the material up to 6.5 —particularly if the borings are ground up fine. The great cost of operation under such enormous pressures, however, militates against the economy of briquettes so heavily that it is out of question to run above 35,000 lb. per sq. in. Even then, time must be given the material while under pressure, to allow the entrained air to escape, for it has been found that the storage of briquettes for 24 hr. after making renders them better fit for transportation without breakage—the weakness due to entrained compressed air being removed.

CHILL

The property of some irons to "chill" when poured under conditions insuring very rapid abstraction of heat is a very important one, and is taken advantage of where surfaces of great hardness and polish are required. The metallurgical features of this property of cast iron have been dwelt upon previously, the absence of much silicon, the pouring into iron molds, etc., allowing enough of the carbon present to remain in combination with the iron when setting to give it a white fracture.

Since the heat of the interior of a casting being poured into iron molds cannot be abstracted as fast as that from the surface it is perfectly possible to have a gray fracture interior with only a rim of white iron. The thickness of this rim, and the change from white to gray, will depend upon the percentage of silicon present in greatest measure, and the sulphur, phosphorus, etc., only if very pronounced. It is assumed that the iron mold is of sufficient thickness to absorb the heat of the molten metal readily and without danger of surface destruction. The possibility of making castings with a strong and yet machinable interior and a hard face of sufficient depth to give good wear in service has meant the development of a number of lines of foundry product of great importance. Among these there may be mentioned the car wheel, chilled roll, rock crusher, grinding mill, etc. Even in military science the "bomb-proof" covers for guns and ammunition stores in fortifications, when thick enough and with well-chilled surface, are capable of successful resistance to ordinary attack.

The inherited knowledge that white or mottled charcoal pig irons when used for castings requiring chilled surfaces gave highly satisfactory results accounts for the belief even today that only these irons may be used successfully. As a matter of fact, however, the same depth of chill is obtained with coke and anthracite irons for the same silicon content. There is this to say, however, coke irons are never blown as cold as charcoal. This means that very low-silicon coke irons are not made ordinarily, at least for foundry consumption. If, therefore, a low-silicon coke iron—one which would give the proper chill in the castings—is offered the foundrymen by the furnace the chances are that this is an "off" iron, made as the result of a furnace irregularity, and has either an abnormally high sulphur content or more than likely is badly oxidized. The resulting casting will surely be inferior to one made with good charcoal iron of the same composition apart from sulphur and oxygen. The experience of the author has been that any coke iron with silicon below 0.75 had better be kept out of the foundry.

Science has given us the means of forecasting the chill in castings for given mixtures fairly accurate on their silicon content. Since, however, the exigencies of melting may upset the best of calculations in cupola and air furnace it is necessary to supplement the work of the laboratory by certain fairly delicate shop tests to insure the proper composition of the metal actually in the ladle. This is best done by pouring so-called "chill tests," which are small blocks of metal of iron poured into an open-sand mold, one face of which was formed by a heavy plate of cast iron. These blocks are removed from the sand as soon as set, cooled quickly by dipping into water, and when sufficiently cold to prevent a change in fracture appearance on being broken, are cracked in two to observe the chill. If the depth of chill as shown by the test differs from that wanted in the casting the proper correctives are applied to the metal before pouring.

Before going into these corrections it should be stated that even with these chill blocks a certain allowance must be made in judging the chill, for the abstraction of heat in a comparatively small test piece is a different matter from the behavior of a heavy casting. Furthermore, the metal taken from the cupola spout or dipped from the bath of metal in the air furnace is always hotter than that actually poured into a casting, and hence the "chill" in the test piece will be usually found deeper than that in the casting. While in cupola iron but little allowance need be made, in the air furnace a loss in depth of nearly ¼ in. must be provided for—that is the test piece should show a chill just so much deeper than is required in the roll or other casting. These test pieces should be made fairly large so as to be in some relation to the thickness of the castings. For instance in roll-making, a block 3 in. square by 6 in. long, one side cast against a chill-plate, gives a very good test, for when broken through the middle gives a section 3 in. square showing the depth of chill in the fracture very plainly. For car wheels the block can be smaller as it is not necessary to measure chills up to 3 in. deep. The actual allowance for proper judgment is naturally a matter of practice, each establishment having its own experience.

There is a further advantage to such a chill test. It can be used in the case of the fine-grained gray irons, where no chill is required or wanted: for instance, in the case of castings for heavy wear, tin-plate rolls, and such castings which must be dense and yet machinable. Here the silicon will be low enough to give a very light chill when poured into iron molds and yet give gray fractures when poured into sand. Making a chill test in such cases becomes a valuable check on the metal to be poured.

To correct the metal in the ladle or furnace in case the chill test has indicated either too much or too little chill—meaning in effect that the silicon is too low or too high—except in one instance is not difficult. If the furnace heat has not yet been tapped, the addition of a suitable amount of ferrosilicon or of very low-silicon pig iron, as the case may be, and after thorough rabbling to incorporate the metal added, will either correct the difficulty or show how much more has to be added on the making of another test. In the case of cupola metal in the ladle any deficiency of silicon can be readily overcome by adding powdered ferrosilicon (ordinarily the 50 per cent. variety, in special cases the 75 per cent. alloy is to be preferred). When the chill is a little too light in the case of cupola metal—which cannot be tested before tapping—advice is difficult, as in this instance corrections are unsatisfactory. The addition of low-silicon metal or steel scrap usually cools the iron too much, though this would be the best way of handling the situation. The chill can be increased by dosing heavily with ferromanganese and getting the so-called "manganese chill" a very undesirable procedure, for the chill is not strong and strange to say (comparing with manganese-steel conditions) not hard.

In this connection mention should be made of the action of very small percentages of manganese in the ladle. Where the chill test shows that too little silicon is present and hence the chill is a little too deep, instead of adding ferrosilicon to increase this element suitably, small quantities of manganese give identical results so far as chilling is concerned—as discovered by Outerbridge. The explanation is evidently that manganese de-oxidizes the metal sufficiently to restore to it its "life." This enables the metal to retain its fluidity long enough to throw out more graphite and hence show a lighter chill. The efficacy of this manganese addition in improving the metal by purification and thus strengthening it in spite of the softening effect was demonstrated in the early days of the modern foundry advance, and while the use of manganese in car-wheel practice was known as early as 1880, to Outerbridge is due to knowledge of its beneficial qualities when used in very small quantities. Incidentally the chilled car wheel is an American invention, Asa Whitney, of Philadelphia, taking out a patent on annealing these wheels as early as 1847.

Since the best classes of chilled castings are made in the air furnace, it will be of interest to give the approximate silicon necessary in the mixture to give the required chill depth in the casting. Allowing 0.30 as the silicon oxidized out in the melting (poor melting has it 0.35), the corresponding silicon content of the casting itself is also given.

These figures are taken from actual practice and represent the best grade of work, that is the use of very heavy "chillers,"

Si in mixture......	1.20	1.10	1.00	0.90	0.85	0.80	0.75	0.65	0.60	0.50	0.40
Si in casting.......	0.90	0.80	0.70	0.60	0.55	0.50	0.45	0.35	0.30	0.20	0.10
Depth of chill, inches..........	½	⅝	¾	1	1¼	1⅜	1½	1¾	2	2½	3

quick-melting and holding up to the proper pouring heat, testing, tapping into ladles, and pouring as quickly as possible thereafter. The figures would, therefore, give the best depths of chill, the sulphur, phosphorus, manganese and total carbon being within ordinary ranges. Had the chills been light, or the metal held quite a while before pouring, the chances would be for chills of less depth, and this will also account for the great discrepancies to be noted in the published results of car-wheel chills, etc. Again, with badly oxidized metal the chill is deeper, as it sets so fast when the temperature is lowered slightly that time is not given the carbon to separate out as graphite. The character of the chill, however, is not good, the structure being irregular and in practice is termed "mushy." Sulphur also deepens the chill when present in unusual quantity, and has on occasion been used for this very purpose when the chill test indicated too light a chill for metal already in the ladle. The practice is naturally not to be recommended.

Attention might be called at this point to some interesting investigations by Thrasher, who studied the chilling effect on cast iron when both silicon and total carbon varied. He found that high-total-carbon, low-silicon metal, and low-total-carbon, high-silicon iron, would show similar degrees of chill. Temperature conditions, however, had to be identical to have the comparison hold, as with the class of metals tested (in malleable-castings practice) it is perfectly possible to obtain gray, mottled and white fractures from the same ladle of iron by varying the pouring temperature.

The character of the fracture of a piece of chilled iron should indicate a transition of the gray to the white metal, mottling intervening. Where the separation of gray and white is along a sharp line, the metal is not so good, and attention should be given the chemical composition. While strongly disputed, this condition is supposed to be due to high phosphorus, and is known as the "phosphorus chill." Whatever may be the cause, it is well to limit the sulphur, phosphorus and manganese closely, so that the silicon-carbon effect may not be interfered with to any serious extent.

Occasionally one sees broken castings with this sharply defined line, which on investigation prove to have been poured with two kinds of iron, the chilling metal to cover the bottom of the mold, on the chiller, and a soft iron poured upon it for backing. The Huth process of centrifugal casting is used considerably in Europe, one metal being poured into a revolving mold and being thrown outward to the rim, followed by pouring the balance of the mold with another iron. Even steel and iron are thus put into the same casting successfully.

A curious and very annoying "internal-chill" phenomenon is noticed occasionally in the production of thin gray castings as one extreme of section, and pig iron as the other, with no published records for sections between the two. This is the formation of white iron enclosures in gray iron bodies. In pig iron a white iron center is observed in the gray fracture, where the reverse is to be expected as the chilling action of the damp sand bed. Since all pig iron is remelted the only difficulty resulting from this occurrence is that of selling the iron to foundrymen. In the case of remelted iron, however, the matter is more serious, particularly where machining is to be done, as the striking of such a white spot means the ruin of the tool besides the rejection of the casting itself. Ordinarily this phenomenon is observed in the stove and fitting shop, light sections of soft iron being the rule. Fig. 14 shows such sections, and one can readily understand what would happen if a thread is to be cut into the flange of the elbow shown.

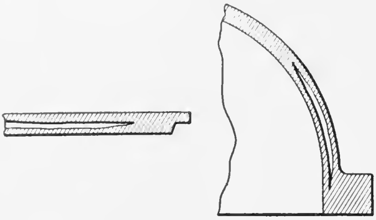


FIG. 14.—Sections of thin gray castings showing internal chill.

An explanation of this occurrence has always been carefully avoided by authorities as the theories advanced would not fit the case. Observation points to the fact that these castings either come from the first part of cupola heat or run through it successively, probably a quantity of castings from each charge. The trouble comes and goes in foundries, without warning or knowledge of how the matter was overcome. It would, therefore, seem to be connected particularly with the melting practice which is the basis of nearly all the foundry troubles which come and go. Translated into basic facts, we have here the strong probability of melting done at the critical point of the fuel bed —either as the result of the drastic lowering by melting a double charge of metal as the first charge, or the successive dropping of the bed at the end of melting each metal charge before restoration by the intermediate coke charge. Chemically speaking, there was free oxygen present at the melting of the last of each charge of iron, with a consequent oxidation.

To speculate upon how this situation may result in the phenomenon in question the following facts must be borne in mind: When the mold is filled with molten iron a shell is formed promptly, leaving some liquid iron within for a time. As the gate freezes and thus cuts off feeding there is the natural tendency to produce a shrink-spot below it if the iron has either been slightly oxidized, or with good iron if the gating arrangements are poor. In the case of very badly oxidized metal, however, another set of conditions intervenes as the occluded gases, and dissolved iron oxide tending to make them, may be sufficient to not only prevent any shrinkage tendency on the part of the iron, but to actually cause it to try to expand. (This is entirely apart from the regular "contraction" of iron on cooling from "set" metal to ordinary temperatures, erroneously called "shrinkage," all of which will be explained later.) A practical demonstration of this contention may be seen in foundries having trouble with their iron, on looking over the tops of the sprues of the freshly poured molds. If a slight funnel-shaped depression is observed, the chances are that the iron was fine. If flat, showing that no feeding has taken place, there is possible trouble—the situation is just on the edge. Puffed-up sprues show badly oxidized iron, of an open structure, porous metal full of gas and pin holes under the cope.

With the above in mind, it is quite possible to understand why any such badly oxidized iron, coming from the end of those of the cupola charges which have melted too low in the bed, may on filling the mold form a shell of gray iron, and after the gate freezes imprison the remaining liquid iron within. This, on trying to puff out, or expand comes under sufficient pressure to prevent graphite formation, which means white iron.

Only a knowledge of what oxidized molten cast iron is and will do can explain the situation adequately, and only a return to correct melting practice will overcome it.

A final point in connection with the chilling of cast iron, and which still requires a convincing explanation, is the fact that an iron poured hot chills deeper than the same iron poured cold, whereas the reverse would be expected since there is more heat to be abstracted from the hotter metal. Since this phenomenon is one of the factors influencing the behavior of cast iron, a thorough understanding of the situation would be welcome. That it is a serious problem will be recognized from the fact that one of the extremely annoying manifestation in the malleable industry is the making of white and gray fracture castings from the same shank of iron. The first is the correct result, the last is radically wrong. Pouring a heavy section casting from a ladle of hot metal of the critical composition into a mold close to the furnace may give white iron, and carrying the remainder of the iron across the foundry to a similar mold may mean just enough cooling to give that casting a gray fracture. The point is respectfully commended for study by our metallographists.

HARDNESS

The effect of chill in cast iron and its hardness are closely related, for an increase in the rate of heat removal from molten iron results in more carbon remaining in combination on setting. The degree of hardness depends primarily upon the quantity of combined carbon present and its condition, in lesser degree upon the other elements in the iron, and finally upon the state of the iron itself. The last assertion has to do with the generally accepted theory that iron hardens when heated above 1,680°F. in assuming an allotropic state called *gamma* iron. This state of the iron can be retained at ordinary temperatures if the metal is cooled very quickly, otherwise on cooling as ordinarily a reversion to the regular soft variety of *alpha* iron takes place.

In the presence of carbon the retention of iron in the *gamma* form is greatly facilitated, a brake action taking place thus retarding the change and enabling the hardening effect to appear at lower temperatures. Hence the chilling of cast iron from its liquid state is certain to leave the steel matrix harder than would have been the case in a thoroughly annealed piece with the same combined carbon content. Many light castings, with no abnormal sulphur or combined carbon percentages at the edges, are difficult to machine simply because of this allotropic form of iron, caused by too rapid cooling and cured by subsequent annealing.

The hardening effect of sulphur, manganese and phosphorus in combination with carbon has been discussed in Chapter IV. Mention was made of "case-hardening" soft cast iron by applying powdered ferromanganese to the mold surfaces. A similar effect can be obtained by using powdered carborundum (silicon carbide), but the iron must be extremely hot to get the best results. It is rather a rare situation to want hard surfaces on soft castings, in fact the problem is rather to get a "soft" surface on soft castings, particularly where these are very light. Nevertheless, the foundryman confronted with the case-hardening situation thus has two methods to get his results. "Case-hardening" is here intended to convey the idea of a surface hardening only, and not a carbon addition to the skin of a low-carbon iron as in the true process of that name.

There remains but to consider the principal hardening agent in cast iron—the combined carbon. The quantity of this present in a casting is, as has been stated, dependent upon the silicon content and the rate of cooling, for similar pouring temperatures. Hence, if there are carefully kept away influences likely to upset the normal sequence of developments, such as wet sand, oxidation in melting, etc., there is no particular difficulty in regulating the combined carbon by suitable mixture-making.

In general, if the combined carbon in a casting runs below 0.75, it may be classed as readily machinable. If 1 per cent., machining becomes difficult, and at 1.50 it becomes impossible, as ordinarily understood. It should be remembered further that the combined carbon of the interior of a casting is likely to be lower than at the surface owing to the more rapid withdrawal of heat at the latter place. This, however, should not militate strongly against the machining qualities unless some exceptional circumstance intervenes.

As was mentioned in Chapter IV, combined carbon may be present in cast iron in two forms: as austenite, or the hard variety found in chilled white iron; and as cementite, or the softer iron carbide compound. Under ordinary conditions in gray iron the latter is the prevailing form met with, for if the hard combined carbon were to approach 0.8, the casting could not be touched with a file. Hence the necessity of avoiding any chance for a surface chill in gray iron castings. Annealing will change the hard to the softer form of combined carbon, but prevention is better than cure in foundry practice just as elsewhere.

In large establishments it is becoming more and more customary to check the castings coming from the foundry department for machinability—or in other words, their hardness. It gives a line on the mixtures and melting practice from day to day and promptly records a deviation from adopted standards. Perhaps the oldest method in use is the application of a file to an edge of the casting to see if it will "bite" properly. Another method is to use the chisel to chip off a little metal, thus exposing the fracture, and judging from this whether the castings run soft enough for proper machining.

Where a comparable record is wanted the simplest machine is the drill press provided with twist drills of standard size and temper. The idea was first brought out by Prof. Thos. Egleston, in 1878, and the machine built by Brown & Sharpe. Reference to Vol. V., of the *Transactions* of the American Society of Mechanical Engineers (1884), page 140, will show that the testing machine in question was used in connection with the study of "fatigue" in metals and alloys. C. A. Bauer, a well-known manufacturer of his day, adapted the drill press for this line of work in simpler form, and it has since been amplified again by Keep, Kessner, and others, so that by means of the autographic attachments a curve of the drilling operation is given showing the hardness by inference. The drill is under standard pressure and number of revolutions, and the depth obtained within a given time is the measure of the hardness of the casting.

Martens and Turner have devised extremely accurate tests for hardness by weighting a diamond and drawing it over the metal surface. The width of the scratch is measured and by comparison with hardened-steel standards gives the degree of hardness of the piece tested. In spite of its value, however, this method is not handy enough for the shop and hence is used only in laboratories.

Henning, of Krupp's, devised an ingenious apparatus along this line, which consists of a round-faced hammer pivoted at the end of the handle on a suitable stand, so that the head can swing in a circle upward and be made to drop upon the surface to be tested as if wielded by hand. A suitable scale is provided to measure the rebound, the hammer being lifted to a vertical position and allowed to drop. A spring retards this rebound and holds the hammer so that convenient measurements can be made. The instrument can be placed wherever desired so long as the surface is horizontal.

A more refined instrument on practically the same principle is the Shore Scleroscope, which measures the rebound of a ball of hardened steel after it strikes the surface to be examined. It consists of a graduated glass tube in which the steel ball of standard size and hardness can move about freely. The instrument is placed vertically on the surface, the ball sent up into position by air pressure, and allowed to drop, the rebound being read off the scale. Inasmuch as this instrument is found in many foundries, and its values are being specified by purchasers of castings desiring special softness, a few remarks on its applicability will not be amiss. Care must be taken to never let the ball drop on the same spot twice as the pening action of the blow is sufficient to change the hardness at that point. Serviceable results are obtained with soft cast irons to medium, but for the harder varieties the figures are generally unreliable—the austenite and cementite values evidently fluctuating in so unhomogeneous a material as cast iron sufficiently to vitiate any attempt at obtaining the relative hardness. Even in the case of very soft castings, dropping the ball upon different points of a finely finished section surface gives divergent results between edge and interior. Nevertheless, in the case of specifications for soft castings giving outside limits for hardness between which they must run, if sufficiently wide to allow for the well-known lack of homogeneity of cast iron, the test becomes a reasonably fair one. It is to be hoped, however, that it may not find too wide an application, for the tendency toward ease in machining can be overdone. Quality suffers, and it were better that the European method of making casting to suit service requirements and irrespective of machining qualities be followed.

The best test for hardness for shop laboratory use is undoubtedly the Brinell ball test, a standard sphere of hardened steel being pressed into the surface of the casting under a standard load, and the area of indentation measured under the microscope. The diameter of the balls is usually 10 mm., and the pressure corresponds to a weight of 3,000 kg. Comparison is made with standard numerals obtained with the machine on materials of known constitution.

The Brinell test is unquestionably so much superior to the other methods for testing the hardness of cast iron that it should be used in specifications where needed. Service requirements have become so severe in the case of locomotive, gas engine and automobile cylinders, etc., that it is becoming necessary to provide for the wear on the piston rings not haphazardly, but by actual test of hardness. Sooner or later, therefore, the hardness limits under the Brinell test will be applied in specifications for cylinders and the piston rings to go with them. Foundrymen should therefore prepare to familiarize themselves with this interesting and useful instrument. Several modifications of the standard instrument have been devised for quick shop tests and give excellent service. It must always be remembered, however, that the surface of the casting requires careful preparation, and that the same place cannot be tested a second time as the structure is radically changed by the first impression.

The practical application of any of the above methods of testing hardness may best be made on the standard test bar run in connection with the daily work. After breaking this bar transversely, the freshly fractured face is turned off in a lathe and the chips thus made taken for analysis. It is a comparatively simple matter to smooth up the face and cut off a section for the hardness test in question. Ordinarily, however, it becomes more important to know whether certain special castings are soft enough, and here it is necessary to make a representative selection from the day's work, and test each one of these separately.

SHRINKAGE

This is the term used to cover a volume reduction in the fluid mass of iron as it sets, which gives rise to empty spaces within its structure. This may result in only a slight porosity on the part of a casting, but in thick sections may actually exhibit itself in the shape of large voids. These manifestations of shrinkage are invariably produced by an insufficient feeding of liquid metal where required as the iron in the mold sets—as has been explained in previous pages. It is one of the serious problems in the art of founding and puts the ingenuity and skill of the founder to the fullest test, insofar as gating and pouring are involved, while demanding eternal vigilance in the melting practice.

As will be understood better from the text to follow, there is no such thing as an *entirely sound* casting. The foundryman gets as close an approximation to the ideal as his art teaches him. Unless, however, the setting of the metal can be made infinitely slow, and the feeding of fresh molten metal absolutely perfect, to provide for the volumnar contraction taking place from liquid to solid state, a sound casting in the ideal sense is an impossibility.

Attention should be called at this point to a constant confusion of terms. When the shrinkage *of* a casting is spoken of there is meant the difference in the size of a casting and the pattern. The shrinkage *in* a casting refers to the true shrinkage manifestations under discussion.

This difference between size of casting and pattern is the "contraction" and is given in fractions of an inch per foot, though in reality it exists in all three dimensions and should be called "volumnar contraction," carefully studied and described by Schuman.

The study of shrinkage in cast iron from the standpoint of the investigator is a very unsatisfactory one. Much has been written on the subject by Keep, West, Turner, Wüst, etc., and many have been the speculations. After all, the best of theories are rendered doubtful because we not only deal with a very unhomogeneous material, but that this material does not set all at once, but little by little from the outer shell inward. The result is that the physical effects noted on instruments intended to measure changes in length in the test pieces used will record only what has happened to the outer portions of the metal, and give no indication whatever of the situation within the casting. Even in this, the line traced by the recording point gives but the resultant of those forces acting simultaneously, strongest at the skin and weakest near the liquid metal, and possibly opposing each other. We have, therefore, to take what little information we can get as there is no other present way out of the dilemma.

It will be readily seen from the above that any change in the fluidity of the metal, as also the shape of the test piece used, will seriously affect the cooling curve obtained. Drawing specific conclusions from such records is therefore unsafe, though general tendencies indicated may be readily accepted. Perhaps the most satisfactory way to look at the question is to study the cooling curves given by Turner. These are shown in Fig. 15.[1] The method adopted was to make these test pieces in "T" form—cast flat in open-sand molds. A steel pin was inserted in the mold at the cross of the T, thus holding that end of the casting firmly, whereas the leg of the T was free to move in the mold. The lower extremity of the T was suitably connected with a pointer which indicated as well as highly magnified the expansions and contractions of the casting. While the bars were but ½ in. square and thus suffered from undue cooling of the sand—the figures therefore not being applicable to large castings—yet much of the irregularity from differences between skin and interior were thus eliminated and better curves obtained. The bars were 12 in. long. A pyrometer couple was placed in actual contact with the casting at about its middle point to obtain temperature readings.

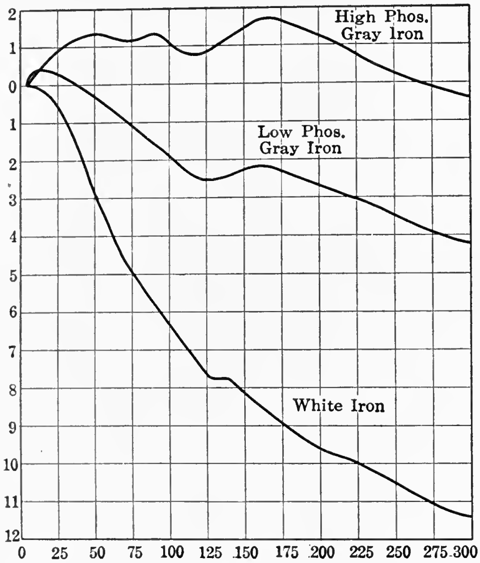


FIG. 15.—Typical cooling curves of cast iron. Illustrating the "shrinkage" of gray and white irons.

The records taken, in connection with the time element, were plotted as curves shown in the illustration. The vertical dis-

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[1] *Journal Iron and Steel Inst.*, No. I, 1906, p. 48.

tances correspond to hundredths of an inch of expansion above the zero point, and contraction below it. The horizontal distances give the time, each division being 25 sec. The curves given show the three types of cooling characteristic of cast iron. The first, of white iron, has but one arrest, or retardation, which may or may not lead to an expansion. The second type indicates two of these arrests, while the third actually shows three of them.

The analyses of the three irons, before careful remelting in crucibles and pouring, were as follows:

Iron	Sil.	Sul.	Phos.	Man.	Combined carbon	Graphite
White pig iron (washed metal)..................	0.01	......	T.aces	......	2.73	
Low-phos. gray pig iron.....	3.47	0.03	0.04	0.55	0.86	2.53
High-phos. gray pig iron....	3.98	0.03	1.25	0.50	0.15	2.60

Examining the curve for white iron, but one retardation will be noticed. The temperature reading at this point shows this to occur at 1,230°F. There is no actual expansion at any point, simply the checking of the process for a few seconds. The low-phosphorus pig iron, remelted, shows two actual expansions during the cooling process. These are accompanied by rises in temperature at about 2,075° and 1,250°F. The high-phosphorus iron, finally, which indicated three distinct expansions, though without accompanying rises in temperature, had them occur at about 1,950°, 1,650° and 1,350°F.

It is quite evident that this first expansion in the case of the gray irons is due to the separating out of graphite, there being none in the white iron to show in the curve. The second expansion is due to the solidification of the iron-phosphorus eutectic compound (see Chapter IV, "Iron and Phosphorus") and a second separating out of some graphite. This expansion is prominent only in the high-phosphorus gray irons. The third expansion—doubtless in consonance with the retardation point in white iron—is held by Porter to be due to a change in the iron itself, namely from the hard *gamma* to the softer *alpha* iron. It is from this place in the cooling curves of all three irons that the real contraction of the castings commence, for the physical structure is now permanent. Since, however, the high-phosphorus iron only shows a greater volume than the pattern, whereas the other irons are less, the total contraction in the latter case will contain some of the shrinkage previous to the position in question.

Glancing at the illustration it will be noted that the actual expansion and shrinkage registered in the gray-iron curves before the point is reached at which the real contraction commences amounts to about 0.02 in. for the 12-in. test pieces. Since the so-called "shrinkage" of gray iron (the "contraction" would be the proper term) is taken at 1/8 in. per ft. ordinarily, or six times the above amount, it will be seen that the importance of the subject is more academic than real. It explains, however, why the chances for sharp reproductions of patterns are facilitated in the case of iron which expand in the early setting stages—apart from the fluidity question.

There is a further property of cast iron, both gray and white, which must not be overlooked in this discussion, and that is the so-called "stretch" of this metal while setting. The familiar case of the flywheel, with its arms setting and contracting long before the heavy rim is sound, may be quoted. Even with strains remaining within the structure of the arms there must have been some stretch, as otherwise rupture would have taken place. Indeed, with oxidized metal this is very often the case. In the case of white iron it is a matter of almost daily observation—the contraction being double that of gray iron, in addition—for the only way to save such castings as hand-brake wheels (for malleable work) from cracking is to take them from the sand while red hot and anneal them over night in specially fired ovens. If the metal were not able to stretch, broken arms and rims would be the rule instead of the exception. A further interesting case is the chilled roll. The cylindrical surface is necessarily solidified quickly by the chilling action of the iron mold while the interior is still liquid. This quickly setting metal would contract heavily and pull away from the "chiller" were it not for the pressure of the liquid metal behind it. Hence it must stretch or tear. When set solid thick enough to resist this pressure, the reduction in volume takes place and oftentimes one can see some liquid metal forced from the top of the mold. On the other hand, the reduction in volume of the chilled metal may take place upon an interior that is just setting and has the periods of expansion previously discussed. This means such a strain upon the chilled surface iron that unless of the highest quality the roll will crack longitudinally, and usually at some place of defect in the "chiller." To prevent this situation from occurring it is important to cast a roll as hot as the iron mold will bear it without cutting. On the other hand, for metallurgical reasons in air-furnace practice, the heat should not be kept in the furnace any longer than is just necessary to do this, for heating beyond this temperature and allowing to stand to cool off means the exposure of the metal to just so much more oxidizing influences with consequent damage. A very queer and apparently contradictory phenomenon, in this connection, is seen in the fact that many a successful roll has been cast with the metal so cold that it went over the lip of the ladle in lumps. The metal was, of course, poured into the riser head and not through the regular whirl gate. Evidently another case of pouring heavy flywheels with small top gates, so that the metal sets almost as fast as poured. In such rolls both white and gray iron would set so fast that any interior expansion of the gray metal would find the exterior white iron soft enough to stretch and both would then undergo their normal contraction. Foundrymen will, however, hardly take such chances unless they must.

The application of stretching phenomenon to the consideration of cooling curves lies in the fact that "freedom" in the mold of the test pieces thus measured up is a matter of opinion. Unquestionably some of the curve is not caught at all, for the iron is too weak to respond to any interior forces until set sufficiently. Just how long this condition operates and allows the sand surface of the mold to grip the test piece is a question. About the only researches made in this direction are by West, who cast open-sand "I" pieces so molded that the central arm had either to stretch or tear. He also proved that it is quite possible for a casting to come out longer than the pattern and that this was not due to excessive "rapping" of the latter in drawing it. This stretching was noticed particularly in the case of light work with many internal cores which resisted the tendency of the metal to contract. West also cast open-sand "T" pieces, held firmly at the top and with the free end provided with a projection so that heavy weights could be attached. A suitable pointer registered the expansion points and when the period was reached at which shrinkage stopped and contraction commenced the weights were attached and the action noted. Side by side with these weighted "T" pieces others were cast which were left free.

The readings of the companion pieces always indicated a much greater contraction for the unweighted piece.

West also quotes the making of a balance wheel 18 in. in diameter, and with a rim of about 2 in. in thickness. The spokes in this were but 1/4 in. thick. The maintaining of the temperature of the spokes equal to that of the rim unquestionably helped. but had the metal not actually stretched it would have snapped very quickly. The author made cast-iron journal boxes by the hundreds daily, and for a time had to keep on correcting the patterns until certain parts of them had no allowance for contraction in the iron whatever, such was the stretching of the metal caused by the green sand core used.

Nevertheless, for every-day practice it is necessary to have some measure of the total contraction of cast iron for purposes of pattern-making. If this measure of the contraction be taken at 1 per cent , the pattern will have to be 101 units for every 100 of the casting required.

While many methods of measuring the total contraction of metals have been devised, that of Keep is simple and convenient, giving good results when inch square bars are made use of. An iron follow-board carries the patterns made of brass and provided with a skim-gate. Iron chill blocks, previously moistened with kerosene, are placed at the end of the patterns, the test bars carefully molded up and poured with iron of average temperature. The castings are placed on the follow-board just as the patterns would lie, the chills placed in their exact positions and the contraction measured by inserting a taper scale between chill and casting. The reading will give the contraction per foot.

The following table gives a summary of the contractions of various classes of castings, compiled from many sources. It is arranged from the heaviest to the lightest total contraction in sixty-fourths of an inch per foot.

Castings	Sixty-fourths inch per foot.
White iron	16 to 12
Mottled iron	9
Light gray iron	9 to 6
Medium gray iron	8
Columns	7
Cylinders and engine frames (large)	6
Heavy gray iron	6 to 5

From which it will be seen that the ordinary rule of 1/8 in. to the foot allowance is fairly reliable for the general run of work. The subject of shrinkage (apart from the eventual contraction) in cast iron is so important that the phenomenon deserves a closer study. The principles underlying it have been so well stated by Heyn (Martens-Heyn: "Materialienkunde für den Maschinenbau," II a, page 438) that the essentials given in what follows will be of particular interest to the foundryman:

Let us assume that we wish to make a fairly large cube of cast iron. The mold is to be filled full, but no feeding whatever provided for. For purposes of demonstration, let us assume that the metal shrinks as much as 25 per cent., and that the setting takes place in three distinct stages. In the first stage, after pouring, a solid crust of metal of uniform thickness will have formed at bottom, top and sides of the mold. The liquid metal thus taken from the whole amount being enclosed in the space between the dotted lines *B* and the mold surfaces (see Fig. 16,*a*). But this liquid metal shrinking 25 per cent. in volume in setting will take the position *A*—the illustration giving a vertical section

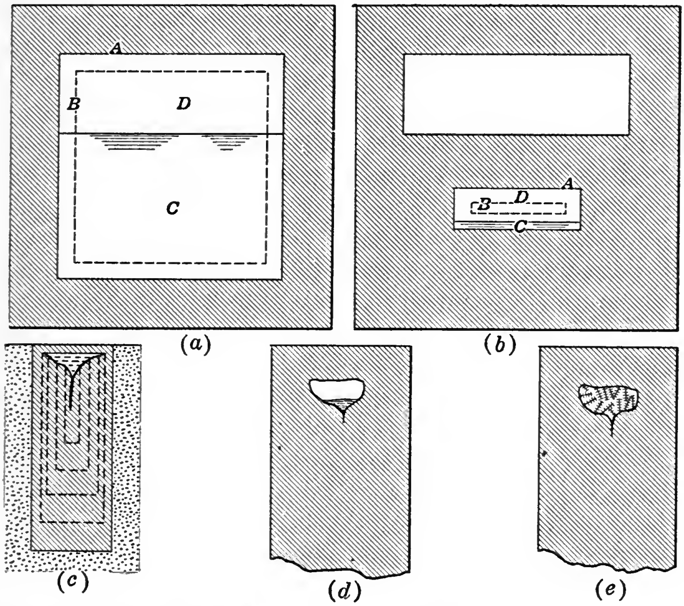

FIG. 16.—(*a*, *b*) Illustrating process of shrinking in cast iron. (*c*) Shrinkage of cast iron in open sand mold. (*d*, *e*) Illustrating formation of pine-tree crystal sponge in cast-iron shrink-spot.

through the cube—and the remaining liquid iron occupies the space *C*. Thus there will be left the void *D* within the casting and not connected with the surface in any way.

The second stage in setting now takes place. The metal sets all around the surfaces touched by the liquid metal and on top, everything solidifying except that which would have remained within the dotted lines *B* (Fig. 16,*b*). This metal, however, shrinks from the space *B* to the space *A*, and hence the remaining liquid metal takes the position *C*, leaving a second void *D*, within the casting.

The third stage is now at hand, and the remaining liquid sets completely, in the same way as above, but so small in scale that it cannot well be illustrated. Now, as a matter of fact, the shrinkage of cast iron is not 25 per cent. but about 1 per cent. The setting does not take place in three stages, but in a series of them making the process practically continuous until completed. There are questions of expansion, heat absorption through the casting and the voids, etc. But the example shows that there will be a successive series of voids in an unfed casting, diminishing in size until all the metal has set.

Fig. 16,*c*, illustrates the shrinkage of an open-sand casting, successive stages of setting being indicated in sufficient number to show the formation of the shrink curve and pipe downward; also a crust formed on top. In the case of a feeding head, riser or pouring basin, the metal from the bottoms of which will flow into the casting for some time after pouring, the shrinkage will be even more pronounced—a fact which can be easily verified particularly in the case of white iron castings.

In the case of smaller voids these may be found filled with a very porous structure of iron crystals. To explain this let us suppose the existence of a void with some liquid metal still within it, as in *d*, Fig. 16. As the void is formed and the metal shrinks away a series of "pine-tree" crystals shoot out into this space from the walls. The remaining metal sets in this way and the space becomes a sponge, for all purposes, with the metal evenly distributed throughout it, as in *e*, Fig. 16. The shrink spot then forms a collection of voids grouped together. In the case of white iron, where such a shrink-spot is near the surface, and has an outlet to it, the crystallization is usually wonderfully colored through surface oxidation. With no access to oxygen from the air in the mold, the crystals will remain silvery white.

From the above consideration of the shrinkage question it will be seen how necessary it is to provide proper feeding facilities for castings through adequate gating of the molds, provision for risers, pumping, etc., or preferably for a gating and pouring practice which will practically let the metal set as it is poured. Still more, however, will there be a necessity for the best of melting practice to insure unoxidized metal, which is fluid and full of "life," so that the casting when fully set may be free from shrinkage.

It may not be amiss at this point to call attention to keep the iron last poured fluid for proper feeding purposes. Filling up the pouring basins or risers with freshly tapped metal is common practice. "Pumping" the risers is also resorted to, as this churning action breaks up the setting of the metal somewhat along the mold faces and the riser bottom, allowing the casting to be fed a while longer. Gradually the metal congeals from the bottom upward, and the casting is completed.

Instead of pouring in some extra metal in this way into heavy risers for big castings it would be well to first insert highly refractory hollow tiles, heated red hot, into them and pour the fresh metal through these. This would force the colder metal out over the basin and give fresh superheated iron just where wanted. Special provision would have to be made to hold the tiles down, and they could be withdrawn after use.

Another method tried, but which has never seemed to give satisfactory results, is the application of a "thermit" can in the riser, to rejuvenate the molten iron. The temperature of the metal is certainly increased, but unfortunately the freezing point also, as this material is a very low-carbon steel and takes but a small drop in temperature to make it set. If such a "thermit" mixture could be made to contain a carbon content equivalent to that of cast iron other results might be recorded, and it would pay to have a few cans on the shelf for emergencies.

Occasionally heavy rolls have been saved when the metal in the head could not be kept fluid long enough to feed up completely, by throwing in a handful of sulphur. The iron sulphide formed immediately lowered the freezing point of the metal, the heavy shrinkage in the neck was avoided, even it it had some mighty poor metal in the center. This procedure is naturally not recommended for every-day practice.

The real solution of the problem of sound castings lies in a close study of the conditions affecting the setting of the metal and so arranging the gating and pouring that the iron farthest from the source of heat sets first and the iron practically feeds itself as it sets. Proper designing and the best of melting practice are naturally essential.

The growths of pine-tree crystals, while very beautiful when viewed under the microscope, are observed by foundrymen with considerable concern, for they mean trouble and indicate that one or more points of practice are faulty. Furthermore, the application of "chills" to the castings at such places, while removing the evidences of shrinkage, usually send the difficulty to other points. Even when the shrinkage of the metal coincident with crystallization effects amounts to but a more or less pronounced porosity, as is shown very plainly in Fig. 13, the result is a decided weakness which must be reckoned with in designing work.

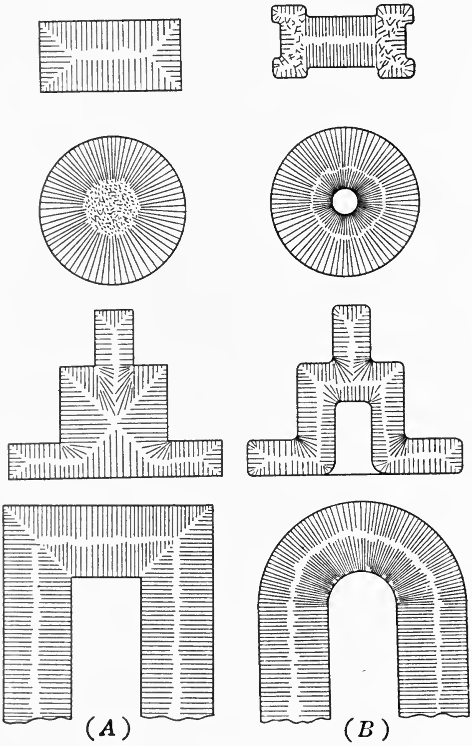

Fig. 17.—Crystallization of cast iron in sections of various shapes.

Means should also be adopted to break up as much as possible any distinct line of separation between the grouping of crystals. This is indicated in Fig. 17, which shows the crystalization of several sections under "*A*" and the correction under "*B*." The careful designer will so proportion his metal that when at all possible corners are rounded off and re-entrant angles supplied with "fillets."

In the illustration the crystallization of a flat piece is shown. The rounding off of the corners and depression of the middle parts of the flat surfaces are often noted in the case of agricultural malleables. The original white iron castings of this section are thus greatly improved in their crystalline make-up. Similarly the heavy round section. Arranging this on the principle of the hollow shaft makes for strength as the otherwise spongy interior is replaced by a crystallization of sound metal. In the next section the application of fillets in the re-entrant angles and the rounding of the corners makes a useful casting out one otherwise liable to many planes of weakness. Finally, a section of an hydraulic cylinder, bottom up. This is the old example quoted in every text-book so far written, illustrating how to prevent the bottom being blown off by making it spherical. The crystallization speaks for itself.

To the above examples another important one can be added, namely, the ordinary test bar, whether round or square. This is in effect a very long casting for its section, and is prone to shrinkage troubles if not carefully made. Little difficulty is experienced with gray iron, as the standard bars are cast vertical and with top pour. The metal dropping in this way promotes effective feeding and the result is a sound bar. In the case of white iron, however, for malleable work, the bars are cast flat as a rule. Since this metal sets very quickly and the shrinkage is double that of gray iron, there is every likelihood of an imperfect core of metal in the central part of the bar. This may even be aggravated by a series of cracks, or rather tears, in the metal at intervals and perpendicular to the central axis. The setting of the metal inward and at right angles to the long surfaces is so rapid that liquid metal from the gates at the pouring basin and the riser may not feed in fast enough to care for the shrinkage, and the result is shown in Fig. 18, in by no means exaggerated fashion.

When such a test bar is put into the machine for a tensile strain it will naturally break at the largest shrinkage plane, as shown in the section. Should the break be near one end, a second pull will result in a fracture at the next weakest point, and consequently give a higher result. The author has oftentimes been able to make three tests on the same bar in this manner, and the results rose rapidly. With a comparatively ductile metal such as steel this increase in strength is attributable to an entirely different cause. In the case of cast iron, however, particularly in the white irons, the cause is as above stated, there being no stretching whatever. With the malleable casting the elongation is highly local and the bar is but little affected at any points other than close to the break, hence the cause above given holds also.

Where foundries are turning out castings, which are not to be machined, it is desirable to know whether the iron has any undue tendency to shrink heavily or not. While this is really beginning at the wrong end, for attention should be given all points in daily practice to prevent shrinkage of a serious nature in the metal put into castings, yet it is one of the checks on his practice that the foundryman can use to advantage. In this case the best test piece would be the "K" casting, as shown in Fig. 19. When this is broken across the middle—where the metal will have remained liquid last—any undue tendency to shrink, through imperfect melting practice or oxidized stock resulting in molten iron without sufficient life to feed up well will quickly show itself in either sponginess or actual voids.

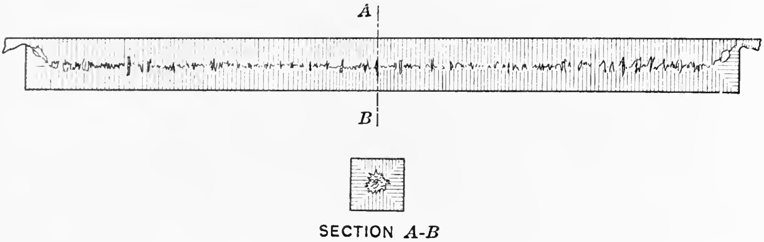

Fig. 18.—Crystallization and interior shrinkage of white iron test bar.

To revert again to the subject of "shrinkage" and "contraction" of cast iron. The emphasis that has been laid upon proper feeding will be found justified by the following data: Molten iron, whether of a composition to give white- or gray-fracture castings has a specific gravity of about 6.65—all carbon is in combination. An average gray cast iron, however, has a specific gravity of 7.00, and a white cast iron runs 7.70 on the average.

Hence there has been a rise of 0.35, or 5.2 per cent. in the case of gray iron, and 1.05, or 15.8 per cent. for white iron. More correctly, for the purpose intended, an equal weight of molten iron in setting gray in fracture will have lost 5.2 per cent. of its volume, and similarly 15.8 per cent. in the case of setting white in fracture.

This seems rather startling, but foundrymen all know what quantities of molten metal can sometimes be fed into a mold during the setting operation. Again, in the case of white iron, if the gates and sprues required to get sound castings are carefully examined, the funnel-like cavity and heavy "shrinkages" in the pouring basins and sprues, as well as in any risers that may have been used, quickly tell the story. This shows how important it is to feed a casting sufficiently, and conversely, what poor chances for sound iron when feeding is neglected. Naturally the question of proper gating must be solved first, for without this and iron with plenty of life, sound castings are out of question.

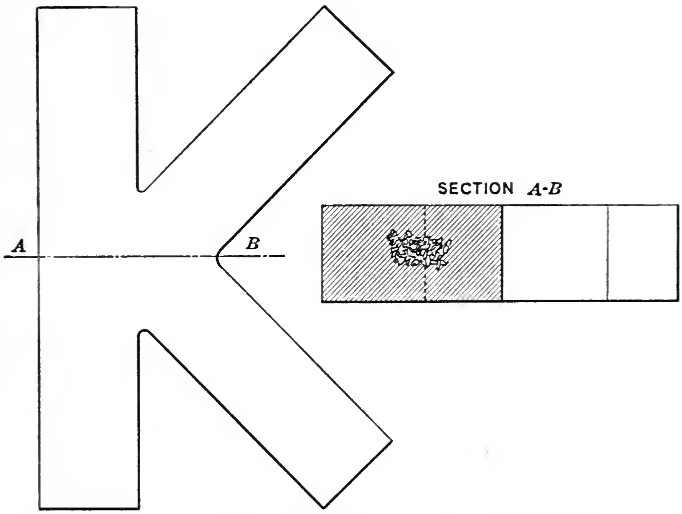

FIG. 19.—"K" casting. A shop test for interior shrinkage.

Comparison of these percentages in volume reduction with the figures incident to the final "contraction" of a casting is illuminating. Since the linear contraction is $\frac{1}{8}$ in. to the foot for gray and $\frac{1}{4}$ in. ot the foot for white cast iron (about), and these for every dimension, the reduction in volume would correspond to cubes with edges of 1/8-in. and 1/4-in., respectively, in a corner of another cube with 1-ft edge.

If the greatest of care is taken to allow for this infinitesimal volume contraction in the pattern, how much more attention should be paid to the real shrinkage in volume of the molten iron as it sets and makes the castings themselves.

SEGREGATION

The fundamental conception of cast iron as being a steel of given (combined) carbon content filled with a quantity of mechanically mixed graphite at once brands it as a comparatively weak material. An investigation of the steel proper shows it to be high in silicon and sulphur compounds of iron, and enormously so in the iron phosphides—showing how very poor a steel it is at that. There is little wonder, therefore, that cast iron exhibits the evil effects of "segregation" to a very marked degree. This collecting together of the compounds in question into spots, as well as the variability of the state in which carbon is found—due to unequal cooling conditions—has given cast iron the reputation of being a very unhomogeneous material.

As the iron phosphides, sulphides and silicides, as well as manganese sulphide have different freezing points, the slower the setting of the metal the greater the chances for segregation, and *vice versa.* This situation is well recognized in the sampling of pig iron, particularly for its sulphur content, the upper portion of a pig, as cast, containing a higher percentage than the average. It is necessary, therefore, to drill clear through the pig and mix the borings very carefully in order to get the correct sulphur content. As the stream of molten metal from the blast furnace fills up the pig bed, making open-sand castings, the metal in contact with the sand surfaces of each pig will set first. This metal will have a uniform sulphur content. As the setting extends inward —the top slower than the rest—the liquid sulphides are pushed inward and rise at the same time. Hence the middle of the upper half of a pig—as it was cast in the sand—will have a higher sulphur percentage, and the middle of the under half a lower content of sulphur than the average for the whole pig.

Another very interesting segregation effect is that from the iron phosphides present. In the case of very heavy sections of gray iron in which high phosphorus metals have been used, some of this very liquid material escapes entrainment in the setting metal and arrives at the center of the casting It is usually part of a spongy core of iron of a lighter color. This phenomenon is naturally not observed often as no one with any pretense of metallurgical knowledge will use high-phosphorus irons for heavy sectioned castings. Occasionally the passage of this liquid phosphide is obstructed and a crack in the surface crystallization enables it to exude from the surface—particularly in the case of open-sand work. These little globules of iron have been examined chemically by Ledebur and others, and the following analyses show the composition of such a globule as compared with the mother-iron.

	Mass of iron	Globule
Phosphorus	0.440	1.984
Silicon	2.044	1.635
Sulphur	0.086	0.052
Manganese	0.430	0.420

The big drop in silicon, the lower sulphur, and practically the same manganese, apart from the phosphorus change, show how radically different the composition of the original metal has been constituted in the globule through the effects of segregation. Many examples of this kind will be found quoted in papers on the subject, and two lines of investigation are or special interest: First, the exuded globules above mentioned (on the surface of open-sand castings) and to be found in interior cavities; second, the crust formed on ladles from the rising of slag and union of this with the products of oxidation formed by the continually changing skin on the molten metal as it stands in the ladle.

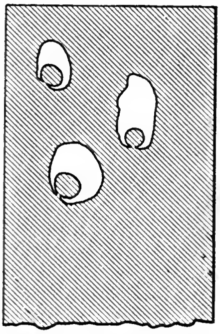

FIG. 20.—Segregation globules in gas pockets in cast iron.

Many a foundryman judges the little globules found in interior cavities of castings to be "shot" carried there by metal splashing into the mold. This is not the case, for such shot is always found on the surface of the casting or swept into some corner. When the globules found within the cavities in question—the walls of which are bright—are examined closely, they will be found attached at one spot, having been exuded from the setting metal as the point of least resistance after the cavity had been formed by gas. Fig. 20 shows the section of a casting having such cavities and globules in them. The following analyses (by C. Platz) give the phosphorus of five pig irons and of globules found in gas cavities in them.

No.	Original P	P in globules
1	0.290	2.368
		2.026
		3.303
2	0.289	1.819
		2.385
3	0.295	1.440
		0.664
4	0.398	1.653
5	2.046	4.062
		6.075

They show a remarkable increase in the phosphorus content, particularly in No. 5, which is a high-phosphorus Luxemburg pig iron.

Ledebur investigated the material collecting on the surface of a ladle of standing iron, as previously mentioned, this being metallic in character. His analyses are as follows:

	Iron in ladle	Metallic crust
Total carbon	3.463	3.818
Silicon	2.196	1.869
Phosphorus	*	0.475
Sulphur	0.056	0.223
Manganese	2.620	5.188

In most instances the crust in question is rather of a non-metallic nature, the oxidation of the surface metal of the molten iron being very rapid. The composition of this crust is, however, of great interest in showing what kind of metal comes up to the top while the ladle is standing. Analyses by B. Platz, shown in table on p. 149, indicate this.

The author has recalculated the second part of the above table for the silicon, phosphorus and manganese contained in the respective oxides, so that an easy comparison might be made with these elements in the original iron in the ladle.

Incidentally Platz managed to secure some of the skin coating formed on the molten iron in its earliest stages. The phos-

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* Phosphorus not determined, but was much lower than that found in the metallic crust. These analyses are chiefly of interest because of the de-sulphurization by manganese.

Iron in ladle					Crust			
Si	P	Mn	SiO_2	(Si)	P_2O_5	(P)	MnO	(Mn)
0.13	0.408	1.71	4.12	1.92	5.91	2.58	8.97	6.94
0.21	0.752	1.86	4.92	2.30	9.75	4.26	12.80	9.91
0.50	0.768	2.29	11.16	5.21	7.55	3.30	14.54	11.26
0.85	0.398	1.92	22.30	10.41	2.57	1.12	15.52	12.02
0.98	0.289	0.72	23.28	10.86	2.02	0.88	9.61	7.44
1.16	0.290	0.78	29.42	13.73	1.36	0.59	11.23	8.70
1.47	0.397	2.33	29.36	13.70	1.65	0.72	23.43	18.15
1.67	0.283	0.96	32.43	15.14	0.39	0.17	13.01	10.08
2.25	2.130	0.53	24.26	11.32	2.65	1.16	4.43	3.43

phorus ran low in this and the silicon very high. From the results of a number of such tests it was indicated that the silicon and manganese go, rapidly at first, until the crust forms, and the phosphorus is oxidized in increasing measure. The comparatively heavy loss in manganese, which accumulates in the crust, shows the de-sulphurizing action very plainly and points out the advantage of melting extremely hot in the cupola, allowing the metal to stand in the ladle as long as is wise, removing the crust—which takes with it the manganese sulphide—and then pouring, preferably from the bottom. Unfortunately the tests above given did not extend over the sulphur also, but the inference is plain enough in view of other investigations.

While it may seem unnecessary to dwell specially upon the "crust" formation in iron-foundry practice, yet this subject is of considerable importance as it is concomitant with open-sand casting work. The skin of the ordinary sand-molded casting is bad enough, consisting of a collection of iron and other oxides, slag, sand, facing, etc., besides being chilled by contact with the damp sand surfaces; but the open-sand casting fares much worse. Here the element of time comes into play, contact of the surface of molten metal with the air allowing a very considerable oxidizing effect, just as is the case with the holding of a ladle of iron. The crust formed, or rather a heavy skin in this case if the metal was reasonably clean, is practically a magnetic oxide of iron, with accompanying silicates, phosphides, manganese sulphide, etc.

The disagreeable part of the situation, however, is the reaction taking place between this oxide of iron with the carbon in the molten metal just below it. Gas is formed and, the crust preventing proper egress to the atmosphere, this gas puffs downward into the metal, giving a section of it the appearance shown in Fig. 21. Hence the poor appearance of open-sand surfaces and difficulty of doing satisfactory machine work on them.

There remains but to point out another phenomenon in this connection. There are probably few pig irons which do not carry some entrained slag. Observing a fractured surface under a microscope of low power, will show the white hair-like strands readily. In melting such irons, particularly under poor cupola practice, this slag may be carried over the spout into the ladles, and perhaps take with it more slag from the cupola itself. At any rate, there is such a thing as "dirty" iron, which if possible to hold in the ladle for some time, will clear itself of much foreign matter.

If dirty iron is poured into castings, the tendency to segregate will exert itself, and as the metal sets inward the slag and sand, facing, etc., from cupola and mold are pushed inward, usually accumulating at shrink-spots, or where the iron was liquid last. This situation emphasizes the necessity of melting hot and skimming carefully, as also proper care of the molds.

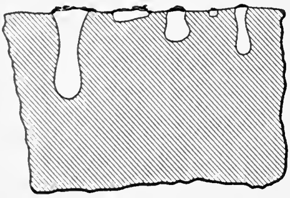

Fig. 21.—Gas pockets caused by iron oxide crust in surface of open-sand casting.

In addition to the above situation there is every chance of trouble from irregular mixing of the molten material as it melts and is drawn from the cupola. One would suppose that the individual pigs and pieces of scrap in melting drop by drop would tend to a thorough mixing in the crucible of the cupola. Further, as the metal is tapped, the stream of iron flowing from the interior reservoir should aid this tendency. As a matter of fact, however, the crucible of the cupola is not like a pool of molten metal as in the air furnace or open-hearth, where a perfect diffusion is possible—if handled properly. The space provided for the liquid material dropping from above is filled with lumps of coke, compelling the metal to occupy the voids between them. There is but little chance for a movement other than flowing to the tap-hole when this is opened, and the result is that a considerable irregularity in the composition of the metal as it is tapped out becomes possible when widely different irons are melted together.

This situation is even accentuated in the following manner.

Where very rich alloys, such as ferrosilicon or ferromanganese, are added to the cupola charges to make up deficiencies in the elemental percentages, it is quite possible for small lumps to melt, pass through the cupola and ladle right into the castings without diffusion into the rest of the metal. The author has repeatedly run across this fact with both cupola and furnace metal, for on breaking up gray castings and finding white globules in different portions as integral parts but nevertheless clearly outlined, the inference was naturally made that some of the alloy had passed through unmixed. This actually proved to be the case, by analysis, and indicated that in charging the cupola some of the smaller lumps rolled into the bed where the temperature was lower and where much free oxygen was present. While the lumps melted or at least became pasty, a skin of iron oxide or silicate forming protected them from diffusing in the surrounding molten iron, and the globule of the ferro-alloy passed through unchanged and unmixed.

This situation is more important to the foundryman than he perhaps imagines, for not only does it show that it is inadvisable to charge high-grade alloys into the cupola, rather making such additions in the ladle, but that it is very dangerous to charge "shot" iron even if of proper composition. This, in melting, will lose silicon and become oxidized if it drops into the bed—as it certainly does. If the little shot is kept from diffusion in the general mass, there is every chance of a hard spot in the casting to the detriment of any tool passing over it. Hence not only are the spots of manganese sulphide to be feared in castings requiring machining, but also melted fine lumps of metal that are added to the mixture for purposes of economy. As a corollary it may be stated that a cupola mixture should be made of irons with as nearly a uniform composition as circumstances admit. It is not good to mix very high- and very low-silicon metals, but to select as nearly as possible that which is wanted from the cupola plus the unavoidable melting loss. Any reasonable correction can be made in the ladle, provided so little high-grade alloy is used that the temperature does not suffer. This situation will be gone into more thoroughly in a subsequent chapter.

STRENGTH

The resistance of cast iron to failure when subjected to various kinds of stress depends primarily upon its composition, and of this the carbon situation is most important. As most of this has been given in the previous chapters it is necessary only to review the salient features.

Total Carbon.—Apart from its division into graphite and combined carbon, in general it may be said that the lower the total carbon the stronger the casting, within limits. Hence the addition of steel scrap to the mixtures to cut this element down to the lower safe percentage ranges, and thereby getting very strong metal. Very high-total-carbon iron, when practically all in the graphitic state in a rather weak material, though excellent for castings requiring much machining and where strength is not essential.

Graphite.—This is the great weakening constituent of cast iron, as it is not only weak in itself, being uncombined with iron chemically or as an alloy, but through its long, thin, plate-like crystalline shape, fills the casting with innumerable planes of separation and thus renders it particularly vulnerable to shock and stress. The smaller the crystals of graphite and the fewer their number—as brought about by the reduction in total carbon and with proper silicon percentages—the stronger the metal.

The question of the size of the graphite crystal obtrudes itself very prominently at this point, for the very fact of its presence in the casting is a direct invitation to breaking down when strain is applied. Given the starting point of a crack, and fracture soon follows. Every flake of graphite represents a crack in a casting. All tests of cast iron are liable to be affected by these minute cracks. Even in the case of using coarse sands for molding test bars there is a likelihood of an uneven surface and possible fine hair cracks in the skin. Hence somewhat lower results in testing than the metal was capable of yielding. Many investigators have therefore formerly machined their test bars before breaking them. The objection to this, however, is that the great majority of castings these bars are to represent are not machined and hence the bars should be tested as cast.

Cook and Hailstone,[1] of England, have investigated the effect of large and small crystals of graphite in irons of practically the same composition. They made 60-day test runs of two sets of pig irons each, getting practically the same general analysis in the case of all of the heats. The strength of one set, however, was very much higher than that of the other, so far as the tensile

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[1] *Transactions* of the British Foundrymen's Association, 1908–1909, p. 99.

results gave this information. The analysis of the low bar of set "*A*," and that of the high bar of set "*B*" are given herewith:

	A 20,380 lb. per sq. in.	*B* 40,990 lb. per sq. in.
Silicon	1.328	1.314
Sulphur	0.095	0.101
Phosphorus	0.923	0.909
Manganese	0.290	0.335
Total carbon	3.250	3.192
Graphite	2.397	2.289
Combined carbon	0.853	0.903

The tensile tests were made on 1¼-in. square coupons attached to castings (and hence open to grave doubt). They were machined down to 1 in. square, and the averages of all the tests were 23,970 and 35,390 lb. per sq. in., respectively. The transverse test bars were 1¼ in. square also, but cast separately, machined down to 1 in. square, and broken on supports 12 in. apart, giving 2,310 and 2,910 lb. averages respectively. These figures show up the real strength of the two metals, and as the relation of the transverse strength to the tensile under the conditions of bar and test approximate 1 to 10 pretty closely, the averages of the tensile bars, if cast separate, would more likely have broken at 23,000 and 29,000 lb. per sq. in. This is not so serious a difference as the two bars *A* and *B* above given would indicate. The microscopic examination of numerous samples of these irons show the graphite to be smaller in the stronger set of irons. The phosphorus eutectic also shows up more regular in structure. Unquestionably the graphite situation is the real cause of the difference in strength, and while the investigators hold that the cause is traceable to the ores used in the blast furnaces, the author thinks it far more probable that the operation of the blast furnaces themselves is to be charged with the effects in question. Pig iron which has been injured in the making by oxidizing agencies retains much of this trouble in successive remelts (see Chapter V, on testing pig iron). Were this not so, foundrymen would not be so careful in the selection of their brands of pig iron.

The uncertainty that results from this situation, however, means that it is practically impossible to predict the strength of a cast iron from a given composition. All that can be given is an approximation, and in fact the best results are obtained when a foundryman builds up his own table of strengths, as his daily practice furnishes him the data to do it with.

TENSILE STRENGTH

In order that some idea may be had of the *tensile strength* of cast irons of given compositions—no claim for accuracy being made, as few of them were tested under standard conditions—the following table is given. The analyses and corresponding strengths were gathered from the publications of the investigators mentioned, and embrace all kinds of test bars, rough, machined, grooved, diameter drawn in at middle; both round and square. Also, charcoal and coke pig irons, various scrap and pig percentage mixtures, and cupola as well as air-furnace melting. The list is arranged according to the silicon content. The total carbon and the tensile strength per square inch follow, in order that the three important items may be readily compared. Then come the carbon divisions, the rest of the elements, and finally the authority.

The hopelessness of predicting the strength of a cast iron from its composition will be apparent from these results, though also the possibility of a better lining up of the figures if the standard "Arbitration Bar" had been used, as well as a definite melting practice carried through.

Silicon	Total carbon	Tensile strength, lb. per sq. in.	Graphite	Combined carbon	Sulphur	Phosphorus	Manganese	Authority
0.71	3.00	30,100	1.62	1.38	0.580	0.540	0.39	West
0.92	3.55	34,460	2.61	0.94	0.070	0.260	1.04	Meyer
0.94	3.07	31,350	2.44	0.63	0.050	0.440	0.31	West
0.97	4.17	20,980	3.43	0.74	0.060	0.301	0.40	Moldenke
1.00	2.50	33,000	1.40	1.10	0.050	0.300	0.60	West
1.02	2.65	34,450	2.28	0.37	0.118	0.496	0.35	Howard
1.06	3.46	32,170	2.60	0.86	0.080	0.275	0.93	Meyer
1.06	3.31	41,420	2.40	0.91	0.080	0.290	1.05	Meyer
1.06	3.31	32,010	2.83	0.48	0.070	0.238	0.36	Howard
1.08	3.36	27,990	2.40	0.96	0.134	0.505	0.34	Howard
1.09	2.82	31,110	2.39	0.43	0.140	0.497	0.45	Howard
1.14	3.34	27,700	2.44	0.90	0.113	0.572	0.34	Howard
1.15	2.77	31,020	2.58	0.19	0.115	0.762	0.36	Howard
1.18	3.17	31,990	2.48	0.69	0.120	0.673	0.45	Howard
1.19	3.18	37,100	2.05	1.13	0.055	0.410	0.42	West
1.21	3.46	35,000	2.64	0.82	0.080	0.140	1.01	Meyer
1.21	3.56	45,500	2.61	0.96	0.130	0.770	0.96	Meyer
1.21	4.17	32,400	3.56	0.61	0.125	0.665	0.45	Howard
1.22	3.17	28,520	2.54	0.63	0.090	0.766	0.36	Howard
1.23	3.23	32,980	2.49	0.74	0.125	0.816	0.45	Howard
1.27	3.23	22,610	2.42	0.81	0.071	0.114	1.17	Meyer

Silicon	Total carbon	Tensile strength, lb. per sq. in.	Graphite	Combined carbon	Sulphur	Phosphorus	Manganese	Authority
1.30	2.99	30,750	2.26	0.73	0.114	0.491	0.35	Howard
1.31	3.09	41,200	2.31	0.78	0.080	0.290	1.51	Turner
1.31	3.19	40,990	2.29	0.90	0.101	0.909	0.33	Cook
1.32	3.52	26,480	2.54	0.98	0.130	0.642	0.35	Howard
1.34	3.22	37,360	2.90	0.32	0.140	1.090	1.38	Turner
1.36	3.03	31,810	2.73	0.30	0.125	0.477	0.46	Howard
1.41	3.33	31,240	2.62	0.71	0.066	0.128	1.12	Meyer
1.42	2.78	31,140	2.12	0.64	0.125	0.678	0.45	Howard
1.46	3.43	34,130	2.89	0.54	0.160	0.930	0.75	Jüngst
1.51	3.23	31,980	2.49	0.74	0.118	0.521	0.46	Howard
1.53	3.52	30,000	3.10	0.42	0.050	0.290	0.45	West
1.54	3.40	30,290	2.65	0.95	0.180	0.730	0.49	Meyer
1.55	3.11	30,280	2.47	0.64	0.110	0.700	0.79	Jüngst
1.55	3.36	27,440	2.69	0.67	0.081	0.660	0.62	Meyer
1.56	2.84	29,100	2.06	0.78	0.115	0.619	0.46	Howard
1.57	3.41	28,130	2.72	0.69	0.080	0.700	0.64	Meyer
1.63	2.90	34,040	2.60	0.30	0.120	1.100	1.29	Turner
1.65	3.35	27,320	2.89	0.46	0.105	0.487	0.46	Howard
1.67	3.87	13,930	3.44	0.33	0.032	0.095	0.29	Moldenke
1.83	2.95	36,860	2.44	0.51	0.100	0.650	0.55	Diller
1.91	3.11	29,120	2.75	0.36	0.095	0.420	0.44	Howard
1.93	3.31	31,850	2.81	0.50	0.071	0.760	0.60	Meyer
1.95	3.82	14,980	3.23	0.59	0.042	0.405	0.39	Moldenke
1.96	2.18	31,400	1.62	0.56	0.030	0.380	0.60	Turner
1.96	3.29	21,760	2.84	0.45	0.068	0.750	0.64	Meyer
1.96	3.32	14,700	2.99	0.33	0.081	0.522	0.48	Moldenke
2.04	3.84	16,020	3.52	0.32	0.014	0.587	0.39	Moldenke
2.32	3.12	24,880	2.62	0.50	0.044	0.676	0.43	Moldenke
2.36	3.23	31,560	2.15	1.08	0.064	0.330	0.24	Diller
2.44	3.05	28,010	2.77	0.26	0.110	0.587	0.47	Howard
2.49	3.39	17,450	2.99	0.40	0.084	1.160	0.38	Moldenke
2.99	3.38	41,000	2.46	0.92	0.041	0.777	0.95	Colby
3.00	3.46	15,000	3.21	0.25	0.041	0.770	0.95	Colby
3.19	3.41	15,340	3.08	0.33	0.084	1.160	0.38	Moldenke
4.19	3.88	14,850	3.03	0.85	0.080	1.126	0.67	Moldenke

An analysis of the figures given in the table above would develop the following:

No. of items	Range of tensile strength, lb. per sq. in.	Average tensile strength, lb. per sq. in.	Total carbon	Graphite	Combined carbon
8	Up to 20,000	15,280	3.63	3.31	0.32
2	20,000 to 22,500	21,370	3.73	3.13	0.60
2	22,500 to 25,000	23,740	3.18	2.52	0.66
3	25,000 to 27,500	27,080	3.41	2.71	0.70
6	27,500 to 30,000	28,240	3.24	2.60	0.64
18	30,000 to 32,500	31,350	3.16	2.55	0.61
6	32,500 to 35,000	33,840	3.04	2.04	1.00
4	35,000 to 37,500	36,080	3.20	2.51	0.69
4	Above 37,500	41,150	3.24	2.37	0.87

No attempt was made to average the silicon, as any chilling action would vitiate the conclusions derived therefrom, the carbon condition in some of the tests showing up this situation plainly. Nor were the other elements taken into consideration, as with few exceptions the unduly high impurities were coincident with low strengths. In general, the total carbon averages seem almost immaterial, as they vary so much. With the graphite, however, there is a distinct dropping of the percentages—possibly accompanied with a reduction in size of crystal—as the strengths go up. The combined carbon content tends upward with the strengths, as might be expected, the range, however, not going beyond the possibility of machining. On going over the details of the tests here enumerated, as described more or less completely by the several investigators, one cannot help but feel that a much closer concordance in the results would have been obtained had they all been cast under standard conditions. Since the cry is all for very strong castings which can be machined readily, the foundryman must aim at low-total-carbon ranges with sufficient silicon to keep the combined carbon below 0.75.

Combined Carbon.—This is the great hardener of cast iron. Coming back to the primary conception of cast iron—as a steel of given carbon (combined) content, with graphite in mechanical admixture—we will find that the ranges from soft to hard, weak to strong, black to white fracture, depend chiefly upon the combined carbon content. Hence, the business of the foundryman, as above stated, is to so regulate his mixtures and melting practice that the combined carbon may be kept low enough for safe machining, and the total carbon low enough also to hold the graphite percentage down, with consequent reduction in the planes of separation within the metal.

On the other hand, where great hardness is wanted, and strength is not essential, a very high total carbon, all of it combined, is desirable and is best obtained with the high-carbon, low-silicon, charcoal irons. Should strength, however, be required together with hardness, the total carbon must be lowered somewhat, by steel additions, though with this some of the hardness is sacrificed.

Silicon is important for its action upon the carbon present in the iron. The lower the silicon, the higher the combined carbon—everything else being equal—and the stronger the metal up to a certain point when more combined carbon begins to run the strength down.

Sulphur, Manganese and Phosphorus.—An increase in the percentages of these elements above the ordinary ranges carries with it an increase in the combined carbon. The injurious effect, however, of these higher percentages of sulphur, etc., counteract any additional strength the carbon change might carry with it.

The effect of oxygen, as well as other elements not ordinarily connected with cast iron, has been discussed previously. The strength of the castings made is naturally seriously affected, though small in comparison with the fundamental carbon relation.

The range of the tensile strength of cast iron may be placed from 11,000 up to 45,000 lb. per sq. in. The reasons why it is undesirable to judge cast iron by its tensile strength rather than the transverse will be gone into under a special chapter on the testing of the metal. Since, however, steel is judged by its tensile strength and accompanying phenomena practically altogether, it is but natural that the designer of machinery and structures asks for similar data for cast iron. So while the above very wide range is given for cast iron, ordinarily good foundry product will run from 18,000 to 24,000 lb. per sq. in. In fact, the first figure is specified for light castings, the last for heavy castings, and 21,000 lb. per sq. in. for medium-thickness work. Incidentally everything below ½ in. thickness may be classed as light- and above 2 in. thickness as heavy-sectioned work, with the medium grade between the two figures given.

As, on account of its great brittleness, there is no well-defined "elastic limit" in cast iron, and the "permanent set" at such a point—if properly determined—would be exceedingly small, the consideration of these matters in designing work is out of question, and the ultimate strength only is taken—but coupled with a good factor of safety. Unwin recommends the following figures for cast iron:

A dead load	4
A live or varying load of one kind	6
Equal alternate stresses of different kinds	10
Varying loads and shocks	15

Tests made on the elastic limit of cast iron, by Bach, gave the following results: Two test bars with an ultimate strength of about 16,000 lb. per sq. in., gave a "permanent set" of 0.29 and 0.03 per cent. respectively, while three others running about

11,500 lb. per sq. in. ran 0.085, 0.015 and 0.002 per cent. Contrasted with elongations of 25 to 40 per cent. as in steel, the question for cast iron would seem negligible.

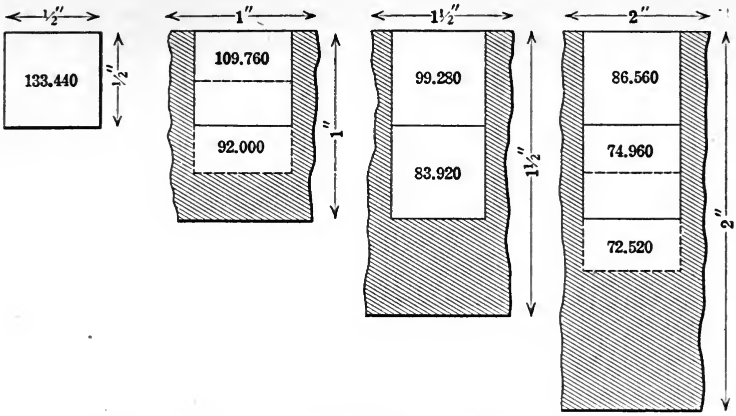
The **Compressive Strength** of cast iron—its most valuable property—varies from 60,000 to 200,000 lb. per sq. in. There is no metal better suited to carry a quiescent load, in compression, than cast iron, hence its use for base-plates in structures, bridges, etc. Also in the case of moving parts when not subjected to shock, as in engine frames, electrical machinery, heavy bearings, etc. Ease in machining, comparative cheapness—allowing massive construction—and ability to resist compression, mean the holding of this field for cast iron against the invasion of steel.

While the cheapness of cast iron allows a very large factor of safety to be used, and the full ability of the metal to resist failure by compression is rarely called for, yet it is necessary to understand the fact that the compressive strength of metal at the surface of a casting is a different thing from that of its interior. The author has conducted many tests in this direction and quotes the one to follow as a type of them all. Iron of the following composition was used, the sample being taken from the 1-in. test bar.

Silicon	1.950
Sulphur	0.042
Phosphorus	0.405
Manganese	0.390
Total carbon	3.820
Graphite	3.230
Combined carbon	0.590

Test bars of eight sections were molded up in the same flask, in vertical position, the flask dried and poured from the top. Half-inch cubes were cut along the middle line at right angles to the bars, and the cubes tested to destruction in the position as cast. Fig. 22 illustrates the results. Additional cubes (shown by dotted lines) were also cut, where required, for comparison of the middle metal of the bars in the series.

From the figures given it will be seen that not only is there a wide variation in the strength of compression from edge to center of the bars in question, but that the surface and interior irons of the bars differ among themselves. The series illustrates the effect of different rates of cooling in cast iron very nicely, for all the bars were cast at the same moment with iron from one ladle.



½" Cubes Cut along Sections of Test Bars, through Middle
Crushing Strength in Lbs. per Sq. In.

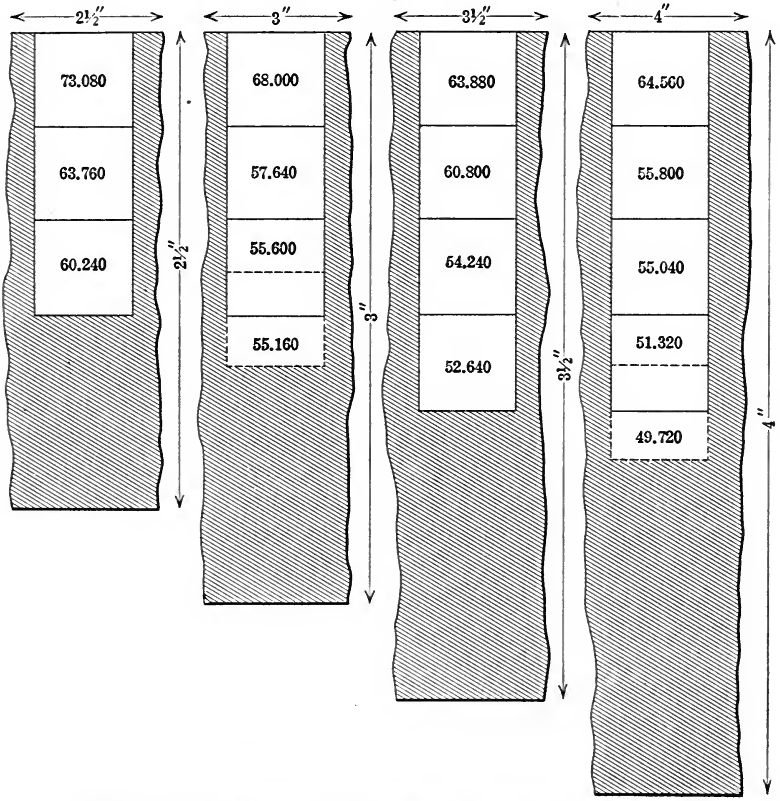


Fig. 22.—Comparative Compressive Strengths of Cast-Iron

This is a further illustration of how little value may be placed on determinations of graphite and combined carbon in cast iron unless the exact spot of taking the sample is indicated. The relation of the two for a given total carbon is dependent (apart from silicon) upon the rate of cooling, and this in turn affects the strength as shown.

The cross-breaking, or **TRANSVERSE STRENGTH** of cast iron is in reality the most practical and reliable information to obtain for this material. The test is easy to perform, the necessary machinery does not call for a prohibitive outlay, and the results are so good a check upon the daily practice that no foundry can afford to be without the means of carrying it out.

The same difficulties are met with in correlating composition and transverse strength in cast iron, as was the case with the tensile strength, and hence the very urgent necessity of adopting a standard method of determining this property soon made itself felt in the early days of the modern foundry advance. The author had much to do with this situation and national standards were soon adopted in America and Germany, being seriously thought of also in other countries. At the time this book was written active steps were being taken by Walter Wood and the author to obtain international agreement on a standard "Arbitration Bar" to serve all civilized countries for their export trade.

It has been very difficult to reconcile every branch of the American foundry industry to the use of the standard bar—which is 1¼ in. in diameter and is broken on supports 12 in. apart. In fact, the pipe industry still uses the 2 by 1-in. bar placed flat on supports 24 in. apart, and many car-wheel men likewise. Many shops still retain the old 1-in. square bar, broken on supports 12 in. apart, simply because long-accumulated data would have to be discarded otherwise. Most of them, however, are running the standard bar in connection with the older ones, in order to be prepared for specification work. One still sees antiquated inch square bars broken on supports 3 ft. apart, and hears of inspectors demanding that a similar bar, on supports 5 ft. apart, carry a 500 lb. weight without breaking. Such situations speak of "sleeping" customers whom foundrymen delight to count as clients. They are "easy."

As it would be of no permanent value to give the transverse strength of test bars other than the standard "Arbitration Bar," of the American Society for Testing Materials—the American standard—and as this bar, originally named by Walter Wood in 1903 and adopted in 1905, has not figured in many published records and most of these without detailed analyses, it is impossible to give a diversity of complete results as yet, though many of them must exist in every modern foundry. It may be stated in this connection that the American Standard Specifications call for the following transverse strengths in the "Arbitration Bar:"

Light castings	2,500 lb.
Medium castings	2,900 lb.
Heavy castings	3,300 lb.

The deflection to be in no case less than 0.10 in.

The table below is taken from records published by Matthews and also selected from the author's tests. While not very varied they show a fair agreement, and for the particular lines they

Silicon	Transverse strength in pounds	Deflection in inches	Total carbon	Graphite	Combined carbon	Sulphur	Phosphorus	Manganese	Authority
0.44	1,250	0.04	3.48	0.06	3.42	0.146	0.720	0.31	Moldenke
0.52	1,420	0.05	3.88	0.10	3.78	0.136	0.421	0.38	Moldenke
0.68	1,700	0.05	3.74	0.22	3.52	0.121	0.460	0.34	Moldenke
0.97	2,290	0.10	3.94	3.18	0.76	0.067	0.064	0.27	Moldenke
1.47	2,790	0.13	3.72	2.86	0.86	0.105	0.780	0.42	Matthews
1.51	2,920	0.14	3.74	2.86	0.88	0.110	0.820	0.44	Matthews
1.56	3,015	0.14	3.70	2.68	1.02	0.110	0.800	0.42	Matthews
1.59	3,280	0.13	3.75	2.71	1.04	0.110	0.760	0.45	Matthews
1.65	2,930	0.13	3.59	2.80	0.79	0.100	0.810	0.45	Matthews
1.87	2,700	0.14	3.58	2.88	0.70	0.065	0.820	0.44	Matthews
1.89	2,960	0.13	3.59	2.85	0.74	0.065	0.770	0.43	Matthews
1.94	2,670	0.12	3.75	3.05	0.70	0.072	0.790	0.50	Matthews
2.04	2,940	0.11	3.71	3.16	0.55	0.055	0.411	0.52	Moldenke
2.05	3,860	0.15	3.13	2.48	0.65	0.072	0.522	0.59	Moldenke
2.08	2,960	0.14	3.54	2.80	0.74	0.080	0.800	0.47	Matthews
2.12	3,285	0.15	3.54	2.84	0.70	0.075	0.800	0.49	Matthews
2.34	2,880	0.14	3.59	2.84	0.75	0.075	0.850	0.38	Matthews
2.35	2,920	0.15	3.75	3.30	0.45	0.037	0.571	0.63	Moldenke
2.36	3,310	0.18	2.59	2.06	0.53	0.036	0.039	0.12	Moldenke
2.37	2,825	0.13	3.52	2.78	0.74	0.080	0.880	0.36	Matthews
2.44	2,900	0.14	3.61	2.91	0.70	0.080	0.860	0.41	Matthews
2.50	3,010	0.15	3.43	2.96	0.47	0.032	0.554	0.80	Moldenke
2.52	2,650	0.18	3.60	3.10	0.50	0.024	0.571	0.85	Moldenke
2.65	2,695	0.14	3.77	3.02	0.75	0.080	0.700	0.65	Matthews
2.68	2,980	0.15	3.77	3.02	0.75	0.080	0.740	0.67	Matthews
2.72	2,360	0.11	3.85	3.27	0.58	0.650	0.688	0.55	Moldenke

represent (cast-iron pipe, ordinary machine castings and white cast iron) could be multiplied considerably from data available.

The cross-section of test bars for transverse strength affects the results obtained just as in the case of the tensile test, and hence the necessity of standard conditions. There are two further complications, however, to be reckoned with: First, with transverse bars of any cross-section, the modulus of rupture will vary considerably with the distance apart of the supports—a situation which will be discussed more particularly under the testing of cast iron. The second trouble is met with in horizontally cast bars, the strength when tested in the position as cast being better than when the cope-side is turned downward in placing the bars upon the supports. The reason for this is evident. As the molten iron runs into the mold from one end, it flows over the sand bottom, heats this and in turn is cooled. The iron rises to the upper sand surface, and hence cold iron is in contact with cold sand, whereas on the bottom it is hot iron on hot sand. Since the hotter the iron the deeper the chill—or more combined carbon and hence strength—the end of the bar near the gate will be stronger than that opposite, as also the bottom stronger than the top. To avoid confusion it has been customary to specify horizontally cast bars to be tested as cast, but as this may favor the results somewhat, the correct method is to use the vertical position in casting.

Shearing Strength.—It would almost seem idle to discuss the shearing and torsional strength of so brittle a material as cast iron. However, when thin, this metal is occasionally punched to save drilling expense. Since punching involves a shearing action, it is worth while investigating. The shearing strength of cast iron is found by dividing the pressure necessary to effect perforation by the area of the surface punched.

Published results are very scarce along this line, but the following may serve:

Investigator	Shearing strength in lb. per sq. in.
Rankine	27,700
Stoney	18,000 to 20,000
Merriman	20,000
Frémont	14,200 to 29,800

It is quite evident that the tests above given represent a very limited amount of effort—with the exception of Frémont's work, which, however was done upon very small bars. The general consensus of opinion seems to be that the shearing strength of cast iron runs with its tensile strength, and this is probably very nearly right.

From the practical standpoint it must be evident that the softer the cast iron, the more easily it can be punched without cracking. Returning again to the fundamental conception of cast iron as a steel with mechanically mixed graphite, there is no reason whatever why such a steel, if mild enough (low combined carbon), should not shear very nicely, the graphite helping to lubricate the action. On the other hand, with a high combined carbon, or tool-steel matrix with little graphite, the piece is bound to crack. Consequently, also, the results quoted evidently refer more particularly to the softer range of irons.

Mention should be made here of a unique proposal of Frémont to test cast iron by shearing it. He takes the casting to be tested and drills it with a core-drill of a little over 0.5 in. diameter at some unimportant point, the core taken out being 0.3 in. in diameter. This core is shaped to a rod 0.2 in. square. Shearing pressure is applied to this rod cutting off little pieces every eighth of an inch, and the average taken. The proposal is exquisite in its novelty and ingenuity. The practical aspects can be best judged from the claim of the discoverer in that "these shearing tests will give accurate information on the quality of the cast iron, with rapidity and economy." Further comment would seem unnecessary.

Finally, it will interest foundrymen generally to know that cast iron when heated red hot can be cut with the ordinary carpenter's saw. It seems that the blacksmiths of the region about Hildesheim, Germany, have a habit of adjusting the skeins on their axles, if received too long, by cutting them down in this way. Sven Rinman, the father of Swedish iron metallurgy, in his book published in the early years of the seventeenth century describes the cutting of cast iron, when red hot, by means of a wood rasp. The subject was subsequently discussed in French and German periodicals as early as 1812.

Torsional Strength.—Information on this subject would be of particular value to the roll-maker were it not for the enormous sections required to resist the bending strains involved in rolling ingots, etc. Otherwise, with these not considered, a tendency to twist off the necks of the rolls would manifest itself when the ingot is gripped and the power continues to act.

Experimental data indicate that the so-called *modulus of torsion* of cast iron agrees very closely with the shearing strength (Merriman).

Resilience.—The power of resisting deformation, the springiness in cast iron. This is a measure of its resistance to shock. It is obtained from the transverse test by multiplying the breaking weight by the deflection, and dividing by 2. Dividing this result by the volume of the metal between the supports gives the resistance to shock in inch-pounds per cubic inch of metal. For practical purposes, however, the bar is weighed and the resistance to shock computed per pound of metal between the supports.

Johnson recommends the following resilience values:

Common castings	20 to 30 in.-lb. per lb.
Good machine castings	40 to 50 in.-lb. per lb.
Impact machinery, stove castings	60 to 70 in.-lb. per lb.

(Breaking weight times deflection, divided by twice the weight of metal between supports.)

Evidently the more modern cast irons, in which large proportions of steel have entered into the charges, will run considerably higher. To show how relatively poor a metal cast iron is to resist shock, the author can state that as the result of some 20,000 resilience tests on malleable castings (test bars), the resilience of this form of (originally) cast iron ran all the way from 500 to 1,650.

Impact testing of cast iron has always been attractive to the consumer of castings. He has observed that they usually break under shock, and hence wishes to test them that way. If, as in the car wheel, a small percentage selected from a shipment is put under the drop weight and will not fail until very severe measures are applied, the material is considered satisfactory.

Because of the inherent defects of impact machinery and the form of castings or bars to be tested, the reliability of results obtained would seem open to question. The tests themselves are really of a transverse nature with pressures applied at extreme speed. It is a question, therefore, whether the simple transverse breaking test does not after all give more and better information on the character of the cast iron, if coupled with resilience calculations. The very action of the destructive forces would seem to bear this out. The mechanism of the impact test, whether a drop weight or a swinging pendulum is made use of, rarely causes fracture at the first blow. In fact this is not desired. As was mentioned in the case of the Sclerometer, which is an impact-hardness testing machine, the dropping of the little steel ball upon the flat surface of the casting changes the character of the metal sufficiently—pening it—causing a second drop on the same spot to show an entirely different result. So also with the striking of the weight in impact testing. It destroys the crystallization of the metal locally, the next blow extends this injury, and so on until failure. Instead of maintaining the same height of drop or angle of swing, these are usually increased as the test progresses, thus applying a continually increasing destructive force to a continually weakening material. Hence the results must be questionable.

As fitting in very logically at this point, the dynamiting of large castings may be mentioned Persons not expert in this line of work regularly make the serious mistake of increasing the charge for every successive shot when they find no apparent effect. The disastrous results of such practice is current gossip for years after the blasting of huge flywheels or other obstructions resulting from some local fire. As a matter of fact every charge of dynamite produces a given destructive effect on the material. The repetition of the shock, with the same-sized charge, extends this, and so on until final failure. Hence an initial charge should be powerful enough to be safe but effective enough to require but one or two further charges of the same or smaller power. Otherwise there will be a scattering of fragments with serious danger to life and property.

On examining the vast quantity of impact data, but little of real value for daily practice will be found. The test itself is a nuisance, and the machinery and installation—if made adquate to the requirements—costly. It has a general value, however, in determining the shock-resisting value of different ranges of irons. For instance, the low-phosphorus cast irons show up much better in this respect than those with higher percentages, everything else being equal, a fact not brought out quite as clearly by transverse testing and resiliency calculations, though sufficiently so for practical purposes.

Resistance to Alternate and Repeated Stresses. Endurance.—But little has been done in this direction, steel and the high-grade bronzes claiming the attention of investigators. As previousy stated, the factor of safety used for cast-iron structures under these service conditions is taken so large that any refinement in testing would appear quite unnecessary. Cast iron would indeed prove a weak material when tested under heavy bending pressures which alternate and are often repeated, for the crystals of graphite imbedded throughout the mass are a tremendous weakening factor, particularly at the surface where they would form the starting point of cracks.

Excellent work has been accomplished on the endurance of high-grade materials by Martens, Howard, Souther, and others, though but little bears upon this property of cast iron.

Before leaving this subject it is necessary to call attention to a series of tests made by Outerbridge on the effect of "rumbling" test bars to clean them properly. He noticed that when instead of simply brushing off the burnt sand from the bars they were put through the mills with the other castings, the test records ran up very considerably—some bars as much as 20 per cent. above the average. An extended investigation confirmed the matter beyond doubt, and the result has been that every set of specifications for cast-iron products contains the clause that "test bars should not be rumbled, but be simply brushed to clean them." Outerbridge attributes the increase in strength noticed to an easing up of the internal molecular arrangement of the metal, thus removing casting strains. Keep, on the other hand, thinks that the surface metal has been pened by the numerous blows during the rumbling process, thus closing up surface cracks, and the general strengthening of the outer fibers of the metal to be subsequently strained under test. While the latter view might have a slight bearing upon the subject, those who are familiar with the powerful influences acting upon the molecular structure of cast iron during the period of set, will incline to Outerbridge's thought and see an annealing effect in the rumbling process sufficient to at least partially remove many of the internal casting strains.

The data presented under "strength" of cast iron do not show the regularity found in steel and other rolled material. This is in a great measure due to the lack in homogeneity of cast iron, but also to internal casting strains incident to all products of the foundry. If a piece of cast iron, which should normally withstand a tensile stress of say 24,000 lb. per sq. in., when normally tested breaks at 17,000 lb. per sq. in. and an examination of the fracture shows perfectly sound metal, it is evident that some internal forces of 7,000 lb. per sq. in. intensity existed before the test was made. Hence the policy of cooling important castings in the sand before shaking-out to avoid or at least reduce to a minimum these dangerous conditions. Flywheel explosions, and similar unexpected ruptures in castings can be traced to the addition of a slight load to what appear sound cast-iron structures, but which in reality are dynamite waiting for the match, because of the internal casting strains.

Careful designing, avoidance of sharp corners and gross inequalities in section, etc., will help considerably; and fortunately the property of stretching during the period of "set" characteristic of gray iron saves many a big casting that would otherwise be lost from this difficulty. Nevertheless, it is always advisable to use a good big factor of safety in planning cast-iron work.

There is, however, another help for the trouble, and that is the easing up of strains brought about by time. The castings "season," and through the mobility of the molecules, their relative positions are adjusted and the material regains its normal strength value to a greater or less extent.

Where this property of cast iron is known, particularly by makers of staple machine tools, stock is ordered far ahead and piled up in the yard to season. Unfortunately, however, the purchasing public is not very well informed, and even where this is the case a constant fear of running into bad castings in the bottom of an old pile causes hesitation. It is certain, however, that future specifications for such castings as automobile cylinders, pistons, etc., will contain a seasoning clause, as only in this way will it be possible to attain that accuracy in finishing which is so essential for proper service.

The example of planing up the sides of a slab of cast iron alternately, to get a true surface, is well known. Similarly also the finishing up of pistons, which unless seasoned or annealed—preferably after taking off the first cut—cannot be gotten perfectly true. This characteristic of cast iron deserves extended study, to determine the time of quiescence best suited for various kinds of castings, and particularly to learn more of the strains arising from the casting operation.

ELECTRICAL PROPERTIES

Since cast iron is a very important material in electrical construction, it becomes of moment to know the characteristics of the metal giving the best results. The three properties to be considered ordinarily in this connection are the *conductivity*, *permeability* to magnetism, and *hysteresis*—or loss of energy through internal friction of the molecules and consequent manifestations of heat.

In electrical machinery those parts for which cast iron is used are of ample enough section to prove excellent conductors of electricity. Hence this property need not be considered. Similarly, the hysteresis problem falls away as cast iron is not used for those parts of dynamos, converters, etc., in which this phenomenon is likely to manifest itself. But the permeability of cast iron must be reckoned with. This property refers to the ability of passing magnetism through the metal, this magnetism being popularly likened to a field in which a more or less dense collection of lines of force traverse it in one direction. The more lines per square inch of this field, the more powerful the magnetism. Hence, the composition of the cast iron should be such that it may pass the maximum quantity of magnetism through a given cross-section without any disturbing effects.

On the other hand, the cast iron should be so magnetically "soft" that as little as possible of the magnetism sent through it is retained when the source of energy is cut off. This is diametrically opposite to the condition of a permanent magnet, which is magnetically "hard."

The two elements which require attention in cast iron, in this connection, are manganese and carbon. It is probable that manganese, through its power of retarding the change of *gamma* iron to the *alpha* variety, tends to hold a magnetized metal magnetically hard, though *gamma* iron itself is well known as non-magnetic. In fact a cast iron with 12 per cent. manganese cannot be magnetized at all for practical purposes. The investigations of Nathusius have shown that the higher the carbon —meaning most likely thereby the combined form—the magnetically harder the metal, the lower the permeability to magnetism, the higher the hysteresis or loss of energy through heat and, finally, the greater the residual magnetism. Conversely, by keeping the total carbon low through additions of soft-steel scrap in the mixtures, by using only the best of melting practice to prevent oxidation of the metal and thus require the use of manganese as a deoxidizer; and by, if necessary, annealing the castings to hold down the combined carbon, the best results are obtained.

Silicon has a beneficial effect, in holding down the combined carbon, though if present in too great a quantity interfering with proper conductivity. Phosphorus and sulphur seem to have comparatively little influence on the results in the percentages met with ordinarily.

OTHER PROPERTIES

Resistance to Corrosion.—The resistance of cast iron to continued and alternating high temperatures has been discussed previously. Its resistance to corrosion has been the subject of much investigation of more or less value. In general the influences to be considered are the action of *rust*, cold or hot *acids* and *alkalies*, and *electrolysis*.

The rusting of cast iron is influenced by the nature of the corrosive action it is subjected to. For instance, when completely submerged in clear fresh water, Mallet found the removal of metal in 100 years to be but 0.02 in. (based upon observations which indicate that cast iron goes half as fast as steel). In sea water, when clear, the loss would be about 0.10 in., and if foul, double as much per century. The same authority gives the loss of cast iron for the same period of time in bridges running over tidal estuaries—or in an alternating wet and dry atmosphere charged with salt—at 0.42 in. While these figures were published in 1843, or before the days of leaky electric transmission, they nevertheless emphasize the importance of proper protective coatings where cast-iron structures are exposed to atmospheric influences. When it comes to cast iron underground, such as soil pipe, water mains and the like, the question is a most serious one. In general, comparing cast iron with steel, with a rate of corrosion double in depth in the case of the latter and a thickness of metal of only half for equal original strength, the case of cast iron versus steel for water pipe is effectively settled, except where extreme pressures render the use of steel imperative.

The action of alkalies and acids on cast iron are such that the same precautions must be taken in regard to the composition of the metal as in the case of high-temperature service—very low percentages of the impurities, excepting silicon, and the less graphite the better. Alkali pots, for melting soda, etc., are now made entirely under guaranteed life, and a very close-grained, comparatively low-sulphur, phosphorus and manganese cast iron is essential.

The action of acids on cast iron is peculiar. Sulphuric acid can be concentrated (when already high-grade) in cast-iron retorts without any difficulty, and yet when dilute this acid eats up iron very fast. This can be readily seen in any pickling vat in those foundries where galvanizing is carried out. Here, again, white iron resists corrosive action much better than the gray. Those who are well informed on this subject prefer the use of hydrofluoric acid for cleaning castings to that of sulphuric. The former attacks the sand and the iron but little. The latter eats away the iron surface, loosening the sand which drops or is washed off. The author, in pickling some 25 tons of small white iron castings daily in hydrofluoric acid for months, took occasion to observe the rate of corrosion. Castings kept immersed in this dilute, hot acid, for long periods did not show the slightest signs of wasting. The difference in weight was inappreciable and the corners remained as sharp as when originally cast. With sulphuric acid this was quite different, the castings being badly wasted in a short time.

Of late very high-silicon castings are being used as acid-resisting media. They contain up to 20.00 per cent. silicon, and when of the ordinary total carbon content for this high silicon would be classed as cast iron. The severe casting strains involved—the final contraction being nearly that of steel castings—call for the most careful kind of molding, pouring and subsequent treatment. Otherwise the castings will be cracked and unserviceable. Once gotten, however, these castings do very well in chemical factories and wherever corrosive influences are to be resisted.

The strength of these high silicon castings is low, being about 10,000 lb. per sq. in. tensile, and 1,000 lb. transverse for the standard bar. These figures would correspond to the values obtained with a poor white iron. Hence, such castings are made comparatively heavy and, being very hard, require grinding to finish them easily. As a consequence of the problem of machining lower-silicon ranges are the rule, from 12.00 to 14.00 silicon being found in the castings ordinarily, even though 15.00 per cent. may be claimed. Again, in spite of the claims for low combined carbon, high graphite, etc., the carbon analyses quoted must be open to considerable doubt as few laboratories are accustomed to handle such determinations in the presence of very high silicon. The great variation in sulphur, manganese and occasionally phosphorus can be attributed to the great scrap percentages carried in the mixture, as the loss of work is very high. The repeated remelting of so much rejected material must necessarily result in actual analyses quite different from the percentages desired.

While nothing is given out regarding the process of manufacture of these high-silicon castings, it is well understood that the ordinary air-furnace melting process of the malleable foundry is used. The pig iron taken is one running about 16.00 per cent. in silicon, with the other elements somewhat as in foundry iron. The broken castings and sprues are charged with enough of this pig iron to make a heat of the desired tonnage. Melting is carried out in the usual way. The work is poured and the flasks shaken out enough to enable the loosening of the cores—as the softest core will not prevent cracking unless broken up promptly—the castings being immediately covered with the sand again. When cool enough to take away, the castings go to the cleaning room.

Experience has shown that little is to be gained by annealing the work by the ordinary methods. Further, it is impossible to "burn" the cracks, as they simply extend on application of the flame. The appearance of the castings which are grayish white in fracture and in some makes show the presence of graphite, is rather different than that of ordinary white iron. Some of the surfaces are smooth and glittering. They often show the appearance of being stretched while setting, and the fractures exhibit a center line of strong shrinkage manifestations as well as occasional pin holes from gases.

These castings come into the market under trade names with the idea that secrecy will give a greater reward than allowing the customer information which might result in mutual improvement and advantage. That such a procedure only lasts a short time is shown by the fact that the trade names mentioned below are already in competition with a fairer designation—"acid-proof" castings—given the product by one of the manufacturers. It may be suggested that if the class be simply designated as "acid-resisting" castings the whole truth is given at once and no secrecy is needed. The author is reluctant in giving any trade names in this book, but in justice to the founders who have spent much money in developing the art, and to connect the better-known names with analyses which will give the purchaser some idea of the content of the metal, the following may be said:

"Duriron" has an analysis—furnished the author by the makers—as follows:

Silicon	14.00 to 14.50
Manganese	0.25 to 0.35
Sulphur, under	0.05
Phosphorus	0.16 to 0.20
Carbon	0.20 to 0.60

The carbon is evidently meant to refer to the graphite content only, for the author has seen heats of this material run, knows that the pig used was the very high-silicon foundry article, and hence had the total carbon of this class of iron. The combined carbon is evidently missing in the above analysis.

This metal gives very good service in the chemical industry. Special precautions are taken to retard the cooling—as mentioned previously—so that the work may not crack. Like ordinary white iron castings, it is possible to drill this line of work if light cuts are taken and the proper kind of tools, running at low speeds, are used.

Another maker of the same metal calls it "Acid-proof Iron" which, as stated above, comes very near the proper designation for this interesting metal.

Another acid-resisting metal which also gives good results goes under the name of "Tantiron," and has an analysis as given the author by the makers as follows:

Silicon	14.00 to 15.00
Manganese	2.00 to 2.50
Sulphur	0.05 to 0.15
Phosphorus	0.05 to 0.10
Graphite	0.75 to 1.25

The manganese content is striking, the sulphur given very frankly. The higher graphite is aimed at purposely to allow better machining. The total carbon not being given, the percentage of combined carbon cannot be learned.

The Pacific Coast furnishes another candidate for industrial favors under the name of "Corrosiron," the range of composition of which as given the author runs as follows:

Here the graphite is pushed up, and if the manganese and

Silicon	13.00 to 14.00
Manganese	0.15 to 0.20
Sulphur generally under	0.03
Phosphorus	0.10 to 0.15
Graphite	1.20 to 1.30

sulphur determinations are not in error on the decimal point (this being supposed the same as "Tantiron") the general understanding is confirmed that the same pig iron is used for all these acid-resisting products—the "Tantiron" varieties being given extra manganese. Unfortunately all the makers are evidently poorly served on the laboratory end, and the continual remelt of the high percentage of sprues and broken castings must make the analysis desired one thing and that gotten quite another. It were much better that every heat consisted of a definite percentage of pig and scrap, and that all surplus scrap be cast into acid-resisting floor plates, etc., so as to eliminate this element of danger to all the work made. While the trade names above mentioned will eventually disappear, the fact remains that the silicon range quoted does constitute a division in castings which is peculiarly "acid-resisting."

While on the subject of abnormal castings, and the evident desire to group high-phosphorus steels with cast iron instead of where they belong, mention may be made of a material presented to foundrymen at the close of the last century. This was called "Ductile Cast Iron" and did not get far beyond the distribution of samples. The author's analysis gave the following composition:

Silicon	0.09
Manganese	0.46
Sulphur	0.02
Phosphorus	0.50
Total carbon	0.35

This is unquestionably a steel—in fact the material could be bent and twisted. Yet the phosphorus was unusually high—more than ten times the amount found in the best grades of steel. A reflection on the subject, however, will show that there is nothing so impossible about the situation—provided that such materials are not subjected to sudden shock. The basic conception of a gray cast iron is that it is a steel in structure (of the carbon content corresponding to the "combined carbon") with graphite mechanically mixed between the steel crystals. Now this "steel" in gray cast iron may contain over 2.00 in phosphorus and still be servicable. The cast irons of Europe made with Luxemburg and also some English irons, show this very markedly. There is no room for materials of this kind, however, in regular industrial service, as they have no properties of value to commend them which may not be found in better measure in the equally cheap basic steel casting.

Electrolysis, or the decomposition of a compound into its component parts by the electric current, is responsible for the corrosion of much of the cast iron placed in the ground; also in the case of hot-water heating and transmission systems. The author has seen cast-iron pipe in railroad yards corroded so badly that it resembled a tube of mixed iron ore and graphite. Similarly parts of feed-water heaters and boilers, originally of cast iron, which had failed when the remaining core of sound metal finally became too thin, could be whittled with a knife.

Soil pipe, when buried in damp ground, is also subject to corrosive influences. In addition to moisture within and without, decomposing organic matter and sewer gases also providing an interior hydrogen sulphide atmosphere, the situation is usually complicated by stray currents from buried transmission lines. Hence the necessity of proper preservative coatings to act as insulating layers, and periodic investigation. The subject is one of extreme importance, and is not understood well enough as yet to indicate proper correctives and methods by which cast iron or steel may be made to resist the effects of corrosion.

Resistance to Friction. Wear.—This problem is met with in cast iron subjected to sliding friction, with constant loads as in the cylinder, or extremely variable ones as in the brake shoe. A cylinder is supposed to remain as nearly constant in diameter as when first bored. Any wear should be taken up by the piston rings. Hence a close-grained cast iron—as hard as is possible with due regard to machining—is used for the cylinder, and a comparatively softer cast iron for the rings. Nevertheless the latter should have enough combined carbon to render them elastic. A new departure in this direction consists in using a set of two rings, one inside the other. The inner ring is highly elastic and comparatively hard, the outer being dead soft and without much elasticity. The inner ring pushes the soft outer one against the cylinder and makes it take the wear.

Cast iron to resist wear would then have its silicon as low as possible, the sulphur preferably high but commensurate with safety. The total carbon should be low for strength—which means steel additions to the mixture. Manganese fairly up to aid in keeping out oxygen, and phosphorus medium.

In the case of the brake shoe, the problem is to save the tread of the chilled cast iron or steel wheel from wearing too much and unevenly. Hence, the shoe must be softer than the surface it rubs against. The softer the shoe the higher its braking power for a given pressure application, and *vice versa.* Soft shoes wear away quicker than hard ones, while hard ones have a disagreeable property—also shared by soft low-total carbon shoes—of flowing in spots, forming small slivers on the surface of the shoe and thus reducing the area bearing upon the wheel very materially. Sometimes these flakes are pushed off to the end of the shoe and actually fuse together. The metal of the shoe, to give the best braking results, should be removed in the shape of grains, somewhat like the wearing down of an emery wheel. Hence, a granular structure is essential, and to strike the best medium between the soft, fine-braking but quickly worn-out soft shoe, and the hard, poor-braking but long-lasting shoe, this granular structure should be very fine, meaning the lower ranges of silicon and a medium suphur.

Theoretically a high sulphur would be ideal, as the iron sulphide would be disseminated about the individual grains of the metal. In action this iron sulphide would allow the grains (or iron crystals) to be torn out readily without any flowing action. In fact the finest coefficients of friction in brake-shoe tests are obtained with high sulphur. However, sulphur being a "red shortener," or breaking down under high heat, a high-sulphur brake shoe is dangerous in service, going to pieces more readily and thereby giving rise to serious accidents.

The recommendation of the author to those desiring to enter the brake-shoe business is "don't," for as simple as it looks, it is a life study and requires a vast experience to master the intricacies of the service requirements, particularly as these castings are now usually sold under a service guarantee.

In closing the chapter on the properties of cast iron, the author cannot help but feel that the ground has but been scratched. There is a vast *terra incognita* ahead of us yet, the exploring of which will add to the stability of cast-iron foundry practice.

To be as successful as may be with what we now know, the foundryman must keep the properties of cast iron constantly in mind, in selecting his metal, gating his molds, and pouring properly after melting under the best possible conditions. By the manner in which he takes cognizance of these multitudinous points will he make or mar his results.

CHAPTER VII

CLASSIFICATION OF CASTINGS

Having discussed the properties of cast iron in connection with the general subject of iron metallurgy and processes, the classification of cast-iron products according to their chemical composition would seem next in order, as their properties are dependent upon this in so great a measure.

From the vast mass of published analyses of more or less value, Porter has collected an admirable set of working percentages. In his original report to the American Foundrymen's Association he gives the ranges of the several elements and a suggested analysis for each class of castings. These data have been consulted in presenting what follows. Furthermore, as the rate of cooling plays so great a part in the carbon situation, and it is necessary to regulate the silicon accordingly, the author has wherever possible divided the field into thin, medium and thick sections. Such matters as the quality of metal used, etc., are indicated in the discussion of items as they follow in alphabetical order.

Acid-resisting Castings.—The analysis recommended is as follows:

	Thin	Medium	Thick
Silicon	2.00	1.50	1.00
Manganese	0.75	1.00	1.25
Sulphur		not over 0.05	
Phosphorus		not over 0.20	
Total carbon		not over 3.25	

Naturally, a considerable variation from the above is possible, as good results have been obtained with higher phosphorus, sulphur and carbon. But the above will be a good composition to aim for, and the pig iron that suggests itself is the so-called Bessemer malleable, or low-phosphorus iron used for malleable castings. Manganese can always be increased by the addition of ferromanganese in the ladle and the total carbon held down by adding soft-steel scrap to the mixture.

Where it is desired to make the high-silicon castings previously mentioned, for this particular class of work, the above composition will do very well, except that the silicon is held to come out at 12 to 15 per cent. The air furnace is the proper melting method to be used (or open-hearth), and the ferrosilicon added toward the end of the heat to avoid excessive oxidation losses. In the absence of this furnace, however, there is no alternative to the cupola melting process, and care must be taken to have a high fuel bed and to charge carefully. The loss of ferrosilicon, thus melted in the cupola, will not be prohibitive. It is not possible to add the required silicon to ordinary mixtures in the ladle without chilling the metal beyond redemption.

Agricultural Machinery.—As some of this is extremely thin, a special column is given in the range of composition, from which, as in practically all cases, a degree of variation is quite permissible. This class of castings requires some strength, and hence the total carbon should be held low in the heavier sections, by suitable steel additions to the mixture. In other respects, however, the agricultural casting is much like any other ordinary cast iron.

	Very thin	Thin	Medium	Heavy
Silicon	2.75	2.50	2.25	2.00
Manganese	0.60	0.60	0.70	0.80
Sulphur	0.05	0.06	0.08	0.10
Phosphorus	0.80	0.75	0.70	0.60
Total carbon	3.75	3.75	3.50	3.25

Air Cylinders.—Castings of this class in addition to wearing well must be very dense and impervious to the leakage of air. The best of melting practice is essential so that the metal may not exhibit sponginess, particularly at the flanges. After machining the castings they are usually tested under air pressure to maximum requirements plus 50 per cent. The surface is coated with soap water, any leakage through the metal showing itself in the formation of soap bubbles. As in all cylinder work, a medium to high sulphur is not objectionable as it brings out a finely granulated structure which polishes up highly. For strength it is well to add soft-steel scrap to the mixture. Special attention should be given to the gating so that the castings may feed properly, and this with iron having plenty of "life" should result in a small discount. The suggested analyses are as follows:

	Thin	Medium	Thick
Silicon	1.90	1.50	1.00
Manganese	0.70	0.80	0.90
Sulphur	0.08	0.09	0.10
Phosphorus	0.50	0.40	0.30
Total carbon	3.40	3.25	3.00

✓ **Ammonia Cylinders.**—This class of castings is even more particular than air-cylinder work, for the vapors of ammonia are dangerous and expensive. Moreover, very heavy pressures are used and the temperature runs up and down rapidly and radically. Particular attention should be given the irons used, charcoal pig irons for at least part of the mixture being preferable. Attention must again be called to the employment of rational melting methods, so that the molten iron may feed up sound and be free from gas holes when the metal has set. The medium and heavy sections of the table for air cylinders will serve for a suggested set of compositions for ammonia work. Air furnace iron is preferable to cupola metal if both methods are available.

✓ **Annealing Boxes.**—The composition recommended is suitable for pots, pans and boxes subject to the severest service requirements, as in annealing malleable castings. When used for annealing gray iron castings, the life of the boxes will naturally be longer as the exposure to high temperatures is shorter. In general, since every heat a set of annealing boxes is put through shortens their life correspondingly, so that but six to ten anneals may be counted on ordinarily, evidently the very best of material is only good enough. Hence, if not too expensive, charcoal irons, or scrap malleable castings made of charcoal irons (couplers, dating back to the earliest days) are to be preferred. Tests made by the author on the life of annealing boxes for malleable casting work indicated that with ordinary good practice the average life was nine anneals. With the very greatest of care in packing the castings, luting up the cracks between the several boxes used to make up the individual "saggers," and a cast-iron plate luted over the top—all this to stop a possible circulation of air currents within—and further, with a regulation of the gas supply and damper arrangements, the average life of the annealing boxes was raised to 15 heats.

Annealing boxes are usually made an inch in thickness and of whatever size that may be necessary. Hence but one composition is given. It is a white iron corresponding to "heavy malleable."

Silicon	0.65
Manganese, below	0.20
Sulphur, below	0.08
Phosphorus, below	0.20
Total carbon, below	3.50

Automobile Cylinders.—The requirements of this class of castings are most severe. The walls are made thin, to radiate out heat rapidly—into the cooling-water of the surrounding jacket. There must be absolutely no leak, for obvious reasons. The metal must be strong enough to withstand the severe shock due to constantly repeated explosions within the cylinder, and besides all this the cylinders must wear well.

Molding, gating and pouring automobile cylinders is an art in itself, and its acquisition is always paid for heavily in discounts before being fully attained. The melting practice must be perfect and the cupolas used preferably of small diameter to insure uniformity in operation. Charcoal irons are preferable—if obtainable at reasonable figures—and the addition of soft-steel scrap to the mixture helps the strength, though it increases the discounts. The suggested analysis, which can be varied considerably, is as follows:

	Light	Medium
Silicon	2.25	2.00
Manganese	0.65	0.75
Sulphur	not over 0.08	
Phosphorus	not over 0.40	
Total carbon	not over 3.25	

Balls and Shoes for Grinding and Polishing Mills.—The problem here is to produce the hardest kind of casting. Strength is not so essential in this case as in making crusher jaws, where hardness and strength should be combined. Many tests made by the author on the proper metal to use for the shoes placed on marble slabs to smooth and polish them while the machinery revolved, indicated that a very low-silicon, high-carbon material gave the best results. In fact nothing worked better than the hard malleable casting of the old charcoal-iron days before steel additions came into use. Even tool steel fell far behind for wear. As, however, it is quite possible to obtain very high-carbon coke pig irons, there is no reason why these should not be used successfully. It is recommended that the castings be chilled by pouring into iron molds, if possible.

	Medium	Heavy
Silicon	0.75	0.50
Manganese	above	0.50
Sulphur	below	0.15
Phosphorus	below	0.40
Total carbon	above	3.75

Bed Plates.—These castings may be classed as ordinary cast iron in which there is a wide permissible range of the constituents. Usually a heavy scrap percentage is arranged for—40 to 60 per cent.—and as the castings are massive in the larger sizes no special strength is required. It is well, however, to keep the phosphorus within limits, to prevent shrinkage and segregation troubles, as in pouring this class of molds the iron oftentimes has to run a long distance and therefore shows considerable differences in temperature. This in turn affects the setting and feeding situation, and high phosphorus would retard matters to the disadvantage of the casting. A suggested set of analyses would be as follows:

	Light	Medium	Heavy
Silicon	2.00	1.75	1.50
Manganese	0.70	0.75	0.80
Sulphur	0.08	0.10	0.12
Phosphorus	0.60	0.50	0.40
Total carbon	3.75	3.50	3.25

Boiler Castings.—While cast iron is gradually disappearing as an integral part of high-pressure steam boilers, it may still be found in use for mud drums, headers, etc. in certain types of construction. The analysis suggested is for these castings only. The usual cast-iron frames and doors for boilers of any type come more properly under the heading of "Heavy Stove Plate" or

"General Machinery Castings." Again, hot-water and low-pressure steam-heating boilers are discussed under "Furnace Castings."

From the analysis given below it will be seen that the Bessemer malleable variety of pig iron seems most acceptable, and an addition of a small percentage of soft-steel scrap is beneficial.

	Medium
Silicon	2.00
Manganese	0.80
Sulphur, under	0.06
Phosphorus, under	0.20
Total carbon, under	3.50

Brake Shoes.—The varied requirements of this class of castings makes it difficult to give a typical analysis. Moreover, the necessity of using very high scrap percentages for cheapness, much of this material containing steel parts, such as the steel back or insert scrap brake shoe, means that the mixture cannot be well regulated by analysis. Hence the use of the chill test for every ladle tapped from the cupola, with corrective measures by ferrosilicon additions.

Foundrymen are again cautioned not to take up this line as a new venture, for there is much more to it than is generally supposed to be the case.

	Soft	Hard
Silicon	2.00	1.50
Manganese	over	0.50
Sulphur	under	0.08
Phosphorus	under	1.00
Total carbon	under	3.75

Car Wheels.—For railway service the chilled cast-iron wheel is subject to a carefully developed standard set of specifications, the work of the American Master Car Builder's Association and the American Society for Testing Materials. These specifications are rigidly enforced by the foremost railway systems, and less so by the smaller roads. The chemical requirements of the chilled car wheel, for silicon, are such that a chill from ¾ to ⅞ in. may result in the tread of the wheel. In the case of street-railway wheels, which are much lighter, the chill is not so deep, and the metal is strengthened by scrap-steel additions to the mixture. The latter is necessitated by the usually poor condition of the roadbed and consequent pounding of the wheels.

A special requirement of chilled car wheels is their subjection to a "thermal" test—that of pouring molten metal around them. They must not crack under this. The test is intended to duplicate the action of a melting brake shoe through frictional heat in emergency braking.

Unchilled car wheels are discussed under "Mine Wheels."

The typical analysis of chilled car wheels is as follows:

Silicon	0.65
Manganese	0.50
Sulphur	0.08
Phosphorus	0.35
Total carbon	3.50

Chilled Castings.—A considerable variety of work would ordinarily come under this heading, but as chilled rolls, crusher jaws, shoes, etc. have special requirements of their own, these are discussed spearately. The general chilled casting is one having a hard face—to resist abrasion or penetration—and a soft back, enabling machine processes to be carried out. Occasionally such castings are made by using the two kinds of metal in the same mold, the hard iron to lie against the chills going in first and the other poured on just as the first has set. But usually the composition is selected to accomplish the purpose without this uncertain procedure.

Armor plate of chilled cast iron, so much used in "bombproofs," would come under this head.

Since silicon is the chief factor in determining the depth of chill, and the percentages of this element corresponding to depths up to 3 in. have already been given in Chapter VI, under "Chill," these may be referred to. The other elements would run about as follows:

Manganese	1.00
Sulphur, under	0.06
Phosphorus, under	0.20
Total carbon, under	3.50

Chills.—The requirements here are a metal which will be sufficiently heat resistant to keep from fusing to the casting itself—or a very soft (low combined carbon) gray iron. On the other hand, the chills should not alter their shape through repeated use, which would mean a white iron, as gray irons "grow." These are diametrically opposite requirements, hence a compromise is necessary. Again, ordinary chills intended for placing in molds to compel the molten metal to set faster in given spots are usually small and not machined, and hence the following analysis will serve:

Silicon	1.00
Manganese	0.50
Sulphur	0.05
Phosphorus	0.20
Total carbon	3.00

When, however, these chills become practically ingot molds which require machining, as for chilled rolls, the silicon in the analysis just given must be increased to about 1.50 per cent.

Crusher Jaws.—Contradictory requirements are found here also. Extreme hardness of the face, which requires white, high-total-carbon metal, should be combined with strength, which means low total carbon. The compromise to be necessarily made is apt to give uncertain results, and hence manganese steel has replaced the old chilled cast-iron crusher jaw to a large extent. It is therefore wise to use charcoal irons, or the newly introduced chrom-nickel pig irons, or both, in order to get a greater measure of strength from "quality" metal and still be able to keep the total carbon up for hardness.

The silicon will vary with the depth of chill required (see Chapter VI, "Chill"), but for ordinary requirements the following will serve:

	Medium	Heavy
Silicon	1.00	0.80
Manganese	1.00	1.25
Sulphur, under	0.04	0.06
Phosphorus	0.20	0.20
Total carbon	3.50	3.25

Dies, for Power Hammers.—The high measure of resistance to shock required in these ordinarily heavy castings means that they should have few planes of separation in their structure aiding the starting of cracks. Hence, low graphite. The combined carbon should, however, be low also as this makes for brittleness. Hence, a very low total carbon is aimed for, with enough silicon to keep the combined carbon down also. The graphite will then be in small crystals and these rather more scattered, so that the metal will be pretty sound and strong. Steel scrap up to 50 per cent. of the mixture can be used to advantage, and if scrap nickel-chromium steel projectiles are available, so much the better.

In the case of dies for power presses, in which the surfaces are exposed to heat applications of greater length, the combined carbon can be somewhat higher, meaning lower silicon, as it is necessary to avoid the "growing" tendencies of gray iron, which would eventuate into fire-cracks and a ruined die in a shorter time of service than should be the case.

For hammer dies the following will serve:

	Medium	Heavy
Silicon	1.50	1.25
Manganese	0.60	0.80
Sulphur	0.05	0.06
Phosphorus, under	0.20	0.20
Total carbon	3.00	2.75

For power-press dies, the analysis for heavyweight hammer dies above given will do for the smaller range of work. In the case of heavy dies, the silicon can be dropped to 1.00 per cent.

Dynamo Castings.—There are various kinds of castings embraced in this line of work, the most important being the pole pieces through which magnetism is made to pass. These, as described in Chapter VI, should contain as little combined carbon as possible to prevent residual magnetism, and also little graphite, to keep the permeability high. Hence a low total carbon combined with great softness. For base frames, spiders, etc. ordinary machinery iron would do, but the foundries making this line of work usually run two mixtures only, one for the heavier group including the magnetically important castings, and the other embracing the small castings for which a stoveplate mixture with rather lower phosphorus answers best.

The two lines of work would analyze about as follows:

	Light	Heavy
Silicon	2.50	2.15
Manganese	0.50	0.50
Sulphur	0.05	0.06
Phosphorus	0.75	0.50
Total carbon, under	3.75	3.25

Electrical Castings.—These would include magneto parts, armature cores, telephone and box-bell castings, in fact light variety work of sufficient softness to machine readily. Drilling, turning and planing must proceed without danger from hard corners or spots. Hence very high silicon and low sulphur, particularly in the lightest work. The heavier sections, in which magnetic permeability is an object, should have a low total carbon.

	Light	Medium
Silicon	3.00	2.75
Manganese	0.50	0.50
Sulphur	0.03	0.05
Phosphorus	0.60	0.50
Total carbon	3.75	3.50

Engine Frames.—A higher degree of machinability is required in these than is the case in bed plates—hence a somewhat higher silicon for the same section. Since the frames have to take up considerable vibration due to the reciprocating movement of masses of metal forming part of the mechanism a low total carbon is desirable in order that the castings may have the necessary strength in case of extraordinary shock through accidents.

	Medium	Heavy
Silicon	2.00	1.75
Manganese	0.60	1.00
Sulphur	0.08	0.10
Phosphorus	0.50	0.40
Total carbon	3.50	3.00

Fire-pots, Stove Grates, Etc.—These are primarily heat-resisting castings, and hence should really be of white iron, as gray iron castings "grow" under the service conditions in question. The usage these castings get, however, both in assembling stoves and furnaces, in shipping them, and in actual use is such that if of white iron they would quickly crack. Hence a gray iron must be used which, to be reasonably successful, should be low in total carbon and not too soft. The following analyses would cover the case:

	Light	Medium
Silicon	2.25	2.00
Manganese	0.60	0.80
Sulphur	0.05	0.06
Phosphorus	0.20	0.20
Total carbon	3.50	3.25

Flywheels.—This title embraces a variety of constructions, but the underlying principle is essentially the same, namely, a weight at a fixed distance from a point and revolving about it. There is a storage of energy which serves to equalize the effect of the impulses continually imparted to the weight, and the greater this is the more uniform the motion. Also, the more dangerous the situation, as illustrated in the havoc wrought by bursting flywheels.

As already discussed previously, the greater part of the success in making flywheels lies in the gating and pouring methods employed, every effort being bent upon insuring feeding and setting conditions tending to the nearest approach to soundness possible in such work. Also, the easing of the internal strains in the arms by proper adjustment of the setting periods of the metal poured into the molds.

Flywheels could be classified to embrace many subdivisions, such as for automobiles, small and large engines, compressors, power pumps, etc. After all, these all depend upon the strength of the impulses given, and the degree of uniformity in motion required, which resolves itself into the cross-section of the rim of the flywheel and its distance from the shaft, etc. Hence only a general analysis for three typical sections needs to be given, as follows:

	Light	Medium	Heavy
Silicon	2.00	1.50	1.25
Manganese	0.50	0.60	0.70
Sulphur	0.05	0.06	0.08
Phosphorus	0.50	0.40	0.30
Total carbon	3.50	3.25	3.25

Friction Clutches.—The metal required for this class of castings must have excellent braking power—or a high coefficient of friction—and since strength is not so essential a soft pulley iron is desirable. The discussion of the brake shoe in Chapter VI should be referred to in connection with the reasons for a higher sulphur content than ordinary light machinery iron. The analyses below given will cover this class of metal:

	Light	Medium
Silicon	2.40	2.00
Manganese	0.60	0.70
Sulphur	0.10	0.12
Phosphorus	0.70	0.50
Total carbon	3.75	3.50

Furnace Castings.—The constantly increasing use of hot-water and low-pressure steam boilers for domestic purposes demands special attention to the requirements of this line of work. It is not advisable to put the ordinary stove mixture, with its high phosphorus, into furnace sections, for these would crack too readily in service. On the other hand, unless there is sufficient phosphorus the percentage of misruns and losses from cold-shuts will run up too high. Hence a medium course is desirable, and the following analyses are suggested:

	Light	Medium
Silicon	2.40	2.15
Manganese	0.60	0.80
Sulphur	0.05	0.06
Phosphorus	0.60	0.50
Total carbon	3.75	3.50

One of the difficulties with this class of work comes from the scrap used. Large quantities of stove-plate scrap are usually taken to cheapen the mixtures for purposes of competition. A glance at any pile of stove-plate scrap in any foundry yard of the country will quickly reveal the presence of more or less in the way of burnt stove grates. It is this material which is responsible for so many troubles, as it contains badly oxidized iron, some of which is bound to pass into the molten metal, with the results explained in Chapter IV, under "Iron and Oxygen." Many of the failures of furnace sections by cracking in corners or other critical places can be traced to the weakness of the metal when resisting internal strains—in fact, the presence of the strains themselves are due in a great measure to the irregular setting of metal having little life as the result of dissolved iron oxide when run into large castings of comparatively thin sections.

Gas-engine Cylinders.—These are practically automobile cylinders on an enlarged scale. The requirements are comparatively thin cylinders to allow water-cooling, great strength to resist the shock of explosions, particularly those of the high-compression Diesel type of gas engine. Then there are the ordinary wearing requirements of engine cylinders. Hence low silicon, total carbon and phosphorous for strength, with sufficient hardness, and fairly high sulphur for that granular structure which gives a good finish and wear. In the Diesel engine, as in the large gas-engine units, there is the further item of high temperatures to be reckoned with, which not only give oiling troubles, but also affect the surface where it is not directly subject to water-cooling—notably the piston head and cylinder ports and head.

The analyses suggested for this class of work are as follows:

	Light	Medium	Heavy
Silicon	2.00	1.50	1.25
Manganese	0.70	0.80	0.90
Sulphur	0.08	0.09	0.10
Phosphorus	0.40	0.30	0.20
Total carbon	3.25	3.00	2.85

Gears.—Strength and good wearing qualities are the requirements here, but in general machinery iron serves the purpose.

	Light	Medium	Heavy
Silicon	2.25	2.00	1.50
Manganese	0.60	0.80	1.00
Sulphur	0.08	0.09	0.10
Phosphorus	0.70	0.60	0.50
Total carbon	3.75	3.50	3.25

Glass Molds, Pipe Balls.—The best results for this class of work are obtained by casting high-silicon irons into chills, the composition being so selected that a very dense, fine-grained gray iron is obtained which shows no actual chilling, and thus allows machining. It is necessary to have the grain structure of the casting present as few planes of separation by graphite as possible, to prevent corrosive action by the molten glass, or tearing away of the surface metal of the ball. On the other hand, the combined carbon must be low in order to have a high melting point.

The interior surface of glass molds must be highly finished, and in using them they should be kept at as uniform and low a temperature as can be, consistent with the service required. This will prevent undue surface oxidation, growing of the metal, and the formation of fire-cracks, all of which result in shortening the life of the mold.

In the case of pipe balls, resistance to abrasion as well as high temperature effects is necessary, with sufficient softness for the little machine work required. The lower the combined carbon and denser and fine-grained the structure, the more easily will the ball resist the stripping action of the red-hot skelp as it is formed into pipe by the rolls.

A general analysis would be as follows:

Silicon	2.50
Manganese	0.60
Sulphur	0.04
Phosphorus	0.20
Total carbon	3.25

The total carbon is kept low by additions of soft-steel scrap to the mixture, and the effect of the high silicon on the structure modified by the chilling action above mentioned, otherwise the grain would be very coarse and open.

Grate Bars.—While the ideal grate bar would be a white iron casting strengthened by tungsten or vanadium additions, the cost of this metal while economical in the end would require good salesmanship in placing the product. Hence gray iron will continue to hold the market in spite of the unsatisfactory service when in the hands of poor firemen. It may not be amiss to call attention to the care of grate bars at this point. With cold air passing through the grates under a fire continuously heat is taken from them rapidly and the surface of the bars only are subject to the action of the fire. If, however, clinkers are allowed to accumulate the passage of the air will be obstructed in places sufficiently long to allow the grates to become red hot and eventually warp, grow and burn out. The same situation exists if hot ashes are allowed to accumulate under the grates thus heating the air as it enters the ash pit. The grates then have no chance for radiation and fail very rapidly. Instances can be cited by the hundred along this line in connection with boiler plants that are either overloaded or else in charge of incompetent help. A well-kept power or heating installation should have grate repairs very seldom. In the author's extensive residential hot-water heating installation, where the ashes are removed from under the grates as shaken out, over 10 years' service has left the castings as good as new and gross carelessness would seem necessary before the first replacement of a bar becomes necessary.

An analysis of metal suitable for grate bars—indicating that Bessemer malleable pig iron is best adapted—is given herewith:

Silicon	2.00
Manganese	0.60
Sulphur	0.05
Phosphorus	0.20
Total carbon	3.50

Gun Iron.—This is essentially an air-furnace iron, and having been put into cast-iron cannon from the earliest times, has retained that appellation. At present this grade of metal is used for the most important classes of work, and being expensive to produce only the best of pig irons enter it as a rule. Without attempting to go into refinements in comparing air furnace with cupola castings, for practically identical sections and compositions, the foundryman has but to observe the interior fracture of two chilled rolls of large diameter, one of air-furnace iron and the other cast from cupola metal, side by side. The latter will show the gray portion varying from fine to coarsely open structure from chill to center, whereas the air-furnace metal appears practically uniform within the chilled rim.

Besides chilled and sand rolls, important gas- and steam-engine cylinders, liners, piston rings and the like are now made from the air furnace, and the more advanced foundries of important national industrial establishments are equipping in this direction.

While the analyses given are general in character, there is no difficulty in getting much lower sulphur results, and since the percentage of steel that can be added successfully runs up to 30 per cent. before trouble is met with, enormous strengths can be attained in thin sections. The greatest of care is, however, necessary in the melting practice for information on which another chapter should be consulted.

	Medium	Heavy
Silicon	1.50	1.00
Manganese	0.50	0.60
Sulphur, under	0.05	0.05
Phosphorus, under	0.30	0.30
Total carbon, under	3.25	3.00

Hardware.—This is practically ornamental work and does not ordinarily require any machining. When it does, the sulphur must be kept low, as the sections are usually thin. As the metal must be very fluid, the silicon and phosphorus should be high. A good analysis would run about as follows:

Silicon	2.50
Manganese	0.70
Sulphur	0.08
Phosphorus	0.80
Total carbon	3.75

Heat-resistant Iron.—The lighter classes of this metal are covered by the analyses given under "Fire-pots," etc. The heavier ranges are used for blast-furnace stove castings, molds, such as for the copper and pig-iron casting machines, valves for furnaces, etc. There is little machine work required, and were it not for the chances of cracking the castings in the early stages of their service, a white fracture iron would be best. As it is, the following analyses will cover the two classes used:

	Medium	Heavy
Silicon	2.00	1.50
Manganese	0.80	1.00
Sulphur	0.06	0.06
Phosphorus	0.20	0.20
Total carbon	3.25	3.00

Hydraulic Cylinders.—This line of work demands very dense and strong metal. While it should be machinable for purposes of assembling the presses the metal is not subject to wear, but only to the effect of enormous pressures applied again and again. Low silicon and total carbon are essential, and the phosphorus should not rise above medium, better to have it low, to prevent segregation in the usually very heavy sections. Heavy steel scrap percentages should be used in the mixtures where the foundryman understands the art of gating to get his metal reasonably sound.

	Medium	Heavy
Silicon	1.50	1.00
Manganese	0.80	1.00
Sulphur	0.05	0.08
Phosphorus	0.40	0.20
Total carbon	3.25	2.85

Ingot Molds.—The governing requirement is length of service. Formerly it was a sulphur and phosphorus percentage within the Bessemer limit. The basic steel process has, however, obviated the phosphorus end of this and the fact that the mixtures are of practically all pig iron—in the most advanced cases "direc metal" is used—leaves the sulphur question safe. Steel mill purchasing ingot molds want them to last as long as possible, and put the scrap molds directly into their open-hearth furnaces.

Silicon	1.25
Manganese	0.80
Sulphur, under	0.06
Phosphorus, under	0.20
Total carbon	3.75

Locomotive Cylinders.—For the latest type of compound engines operated with superheated steam at very high pressures, only the best of irons should be used and preferably melted in the air furnace. The metal must be strong and sound as otherwise leaks develop which cause loss of power to a serious extent. Moreover, the iron is under very high temperatures and unless low in graphite will give serious trouble from "growing." In other respects these engine cylinders are no different in their requirements than those for gas engines, and hence the analyses given for the latter will answer (see "Gas-engine Cylinders").

Machinery Castings.—This embraces practically the bulk of jobbing foundry work, and may have a wide range of analyses, provided only that the combined carbon is held under 0.60, so that machining may be reasonably easy. When specially fine and close-grained structure metal is required, as for some planer beds, the silicon may be run up a little and the sliding surfaces be chilled. Or else the analysis given used and the finishing done by grinding.

A general set of analyses is given herewith:

	Light	Medium	Heavy
Silicon	2.50	2.00	1.50
Manganese	0.60	0.80	1.00
Sulphur	0.08	0.09	0.10
Phosphorus	0.70	0.60	0.50
Total carbon	3.75	3.50	3.25

Mine Wheels.—This class of work would include parts of the rolling equipment of mine machinery, cranes, elevators, conveyors, etc. Great toughness, and hence low total carbon, is essential. The silicon can be held to suit the thickness of the work to be made. A general analysis would be the following:

Silicon	1.50
Manganese	1.00
Sulphur, under	0.10
Phosphorus	0.20
Total carbon	3.00

Ornamental Work.—This metal should be high in silicon and phosphorus for very light work. Where used for railings, or under the somewhat stronger requirements of architectural construction a lower phosphorus is better. The metal must be extremely fluid, particularly when reproductions of lace-work and very delicately worked out designs are to be made. The range of analyses is given below:

	Very Light	Light	Medium
Silicon	2.75	2.50	2.25
Manganese	0.50	0.60	0.70
Sulphur	0.04	0.06	0.08
Phosphorus	1.25	0.90	0.80
Total carbon	3.75	3.75	3.50

Piano Plates.—These must be strong and very stiff, but just soft enough to drill readily. Steel scrap will give the necessary toughness, and where, with good melting practice, the sections will crack, special attention should be paid to the design, as this is oftentimes very faulty.

Silicon	2.15
Manganese	0.80
Sulphur	0.05
Phosphorus	0.50
Total carbon	3.25

	Light	Medium	Heavy
Silicon	2.25	2.00	1.50
Manganese	0.60	0.80	1.00
Sulphur	0.06	0.08	0.10
Phosphorus	0.80	0.70	0.60
Total carbon	3.75	3.50	3.50

Pipe.—This refers to water pipe more particularly, and not soil pipe. Soundness, strength and ability to resist shock are required. Good melting practice is necessary and careful attention to every detail in the manufacture as the specifications under which water pipe are made are very strict.

A considerable variation from the analyses given may be made before the results obtained fail to yield satisfaction.

Pipe Fittings.—For ordinary cast-iron pipe fittings the analyses given for machinery castings will answer. In the case of superheated steam, a stronger metal is necessary and can be made with the same percentages of the elements except for total carbon, which should be 3.25, 3.00 and 2.85 per cent. respectively for the light, medium and heavy classes of work.

Piston Rings.—Springiness is necessary here. The rings should be just a little softer than the cylinders they run in, and hence the combined carbon must be held down somewhat, or a little more silicon used. This springiness can also be obtained by raising the phosphorus, but this is apt to run the brittleness up unduly. The following analyses will cover the situation:

	Light	Medium
Silicon	2.00	1.75
Manganese	0.70	0.80
Sulphur	0.05	0.06
Phosphorus	0.60	0.50
Total carbon	3.50	3.25

Plow Points.—These are chilled castings taking about the following analysis:

Silicon	1.00
Manganese	0.60
Sulphur, under	0.06
Phosphorus, under	0.30
Total carbon	3.50

Pulleys.—Close-grained, strong but soft iron is required for the rims, in order to resist centrifugal strains while running. The arms and hubs can be of coarser structure—the larger sections will of necessity make this so.

	Light	Medium	Heavy
Silicon	2.40	2.15	1.90
Manganese	0.50	0.60	0.70
Sulphur	0.05	0.07	0.09
Phosphorus	0.70	0.60	0.50
Total carbon	3.75	3.50	3.25

Radiators.—These are stove-plate, furnace and ornamental castings combined. The iron must be very fluid to avoid cold-shuts, and particularly well melted and with life enough to feed up well and give sound castings. As the sections are thin and in hot-water heating considerable pressure from the head, in high buildings, is likely, the castings must be fairly strong. The following analysis will serve:

Silicon	2.25
Manganese	0.70
Sulphur, under	0.06
Phosphorus, under	0.80
Total carbon, under	3.50

Rolls, Chilled.—A special study of its own. In fact, it may be said that the production of chilled rolls successfully, as representing heavy lines of castings, and automobile cylinders for the light, means the holding of the highest degree, *summa cum laude*, conferred by the foundry industry upon its ablest students.

The silicon necessary in roll castings to secure the required depth of chill should be looked up in Chapter VI under "Chill." The other elements run about as follows:

	Medium	Heavy
Manganese	0.80	1.00
Sulphur, under	0.06	0.08
Phosphorus, under	0.40	0.30
Total carbon, under	3.25	3.00

Rolls, Sand.—These are very heavy castings, as a rule, unchilled, and used for rolling sheets, tin plate, and similiar products, They must be very strong and wear long. The silicon naturally varies with the size of the diameter, but for ordinary purposes runs about 0.75. The other elements are as given for chilled rolls.

Sash Weights.—Anything called iron that can be put through the cupola, with the aid of a melting ratio as low as one to one occasionally, will give this class of castings. These may be white in fracture and as long as not seriously honeycombed—thus affecting their weight for a given pattern—are absorbed in the market. The author has often melted 25-ton heats of nothing but tin cans. Then again, bed springs, galvanized-iron clippings, steel borings and even steel wool. The melting loss is naturally very high and the fuel cost terrific. Unless the material is given a chance to take up carbon from a great excess of fuel present, the cupola will freeze up. Judicious mixing in of stove plate, brake-shoe scrap and other stuff unfit for general use will carry the poor or burnt material. Copious slag formation must be cared for and the lining of the very large-diameter cupolas used renewed very frequently. On the whole, however, the sash-weight foundry is a very useful institution as it is the scavenger of the industry.

Soft Castings.—Where softness and extreme machinability are the prime requisites the following will answer:

	Light	Medium
Silicon	2.60	2.40
Manganese	0.50	0.60
Sulphur	0.06	0.08
Phosphorus	0.60	0.50
Total carbon	3.75	3.50

Soil Pipe.—As this material is not subject to water-hammer, as in the case of water-pipe, the sulphur may run up a little higher safely.

	Light	Medium
Silicon	2.25	2.00
Manganese	0.60	0.80
Sulphur	0.08	0.10
Phosphorus, under	0.80	0.60
Total carbon	3.75	3.50

Steam Cylinders.—Ordinary steam-engine cylinders do not require quite the strength of locomotive cylinders, hence more attention is given the wearing qualities than the actual strength. The following analyses will cover the case:

	Light	Medium	Heavy
Silicon	2.00	1.60	1.25
Manganese	0.60	0.80	1.00
Sulphur	0.08	0.09	0.10
Phosphorus	0.50	0.40	0.30
Total carbon, under	3.50	3.50	3.50

Stove Plate.—The title describes the class of castings. Requirements are softness, great fluidity, and a little strength. (The salesman of the "Malleable Stove" has a habit of dropping it to the ground "accidentally" when delivery is made, for the advertisement.) Further, the stove is highly ornamental, which means high phosphorus metal, as well as carefully selected grade of molding sand.

	Light	Medium
Silicon	2.50	2.25
Manganese	0.50	0.60
Sulphur	0.06	0.08
Phosphorus	1.00	0.80
Total carbon	3.75	3.50

Valves.—These castings require considerable machining and hence must be reasonably soft. On the other hand, they are subjected to severe usage, which means tough metal. A low total carbon with fair silicon content is therefore essential.

	Light	Medium	Heavy
Silicon	2.25	1.75	1.25
Manganese	0.60	0.80	1.00
Sulphur	0.07	0.08	0.09
Phosphorus	0.50	0.40	0.30
Total carbon	3.25	3.00	2.85

White Iron Castings.—If it is simply a question of getting white iron castings, irrespective of special grinding and heat-resisting qualities, the range of impurities can be extended considerably over that given under "Balls and Shoes," further back. The following limits will cover the case:

Silicon, below	0.75
Manganese, above	0.20
Sulphur, below	0.25
Phosphorus, below	0.75
Total carbon, above	2.50

The tables of analyses given in the above classification of castings must, as was said at the outset, be considered only as typical. Very good castings can be made with considerable variations in the elements. This is because the unhomogeneous character of cast iron compels the use of large factors of safety, and hence the designer intuitively plans his castings much heavier in section than a strict regard for the tensile and transverse strength of the material would warrant, were it as reliable as steel. There is no objection to this, for the metal is cheap and chances must not be taken.

In the figures given it will be noticed that the total carbon is not divided into the combined and graphitic components. The reason is obvious if one remembers the action of silicon, rate of cooling, etc. Where such figures as 3.75 represent the total carbon, this means that the ordinary practice of up to 40 per cent. scrap with the rest pig iron will care for the carbon situation without any further trouble. Where the total carbon runs 3.50, this is either the result of a much higher scrap rate (say 60 per cent. scrap and 40 per cent. pig) or else the addition of small steel percentages (say 5 to 10 per cent.). For such low carbons as 2.85 there may be needed as much as 40 to 50 per cent. steel additions to the mixture.

Again, the sulphur and phosphorus percentages given—except where wanted high—can be anything below the figures. It will, however, be only in the regions tributary to the Lake Superior charcoal furnaces that very low sulphur and phosphorus results can be obtained; the rest of North America will have to be content with the higher ranges for castings which cannot stand fancy pig-iron prices.

Manganese has been given at 0.50 minimum throughout the list, for below this point—with the regular run of pig irons—it means poor cupola practice. There are, however, a few very well-made pig irons with the manganese below 0.50, and remelting these give perfectly good results with usual care in charging; so that it is quite possible to shade the manganese percentages successfully in such cases.

A further consideration requiring changes in the analyses for certain classes of castings is the fact that a foundry making several lines may not be able to run two or three mixtures in the cupola safely, and hence an analysis is selected which will just care for all the work. Usually the wide latitude allows this, but if not, then the foundry has to put up with heavy discounts for the line which is injured most. The European practice of installing a group of small cupolas, in place of one big one as in America, has an undoubted advantage in this connection.

Semi-steel (?).—Perhaps a paragraph should be devoted to this misnomer. Those who have followed the pages of this chapter and have compared the analyses suggested for the various classes of gray iron castings, will have noted the variations in total carbon not only for different classes of work but for different section thickness in the same class. To get such a heterogeneous collection of castings into one group, particularly as steel scrap may be used for making gray iron castings in proportions of from 1 to 100 per cent., is an impossibility to begin with. Further, to give such a theoretical group a name having no connection with the properties of the castings, so far as they resemble steel, points to the existence of an Ethiopian in the wood pile. Indeed in many cases the "wish is father to the thought" and the purchaser of castings is made to believe he is getting a costlier and better article. Mixtures having high steel-scrap percentages, even if melted to yield a lower total carbon in the castings than would have been the case without the steel addition, give an iron with considerably higher freezing points than the ordinary, and hence set very rapidly. Feeding is difficult, and shrinkage in the interior of heavy sections very marked. Even the grain structure shows wide variations in the same casting. Hence while the test bars may show up beautiful and strong iron, the castings may come no where near this quality.

To these troubles there should be added the heavy chances for burnt metal, particularly where thin steel scrap is used. Blowholes, cracks, big contraction and hard spots are likely to show up unless the greatest of care is exercised in mixing and melting. Nevertheless, good work can be produced with steel additions, the author himself having often made runs with 50 per cent. steel and gotten fine, machinable, strong castings. Indeed, he has repeatedly run cupola heats with all steel (using from two to four times as much coke as in ordinary practice). All the castings made, however, were just cast iron, with none of the properties of steel, for an unusually good strength for a given silicon content, with steel in the mixture, can be duplicated, when leaving out steel, by a silicon reduction or some other method of increasing the rate of setting.

The history of the appellation "semi-steel" is interesting and dates back to the era just preceding the modern foundry advance. Seaman, a famous Pittsburgh foundryman, brought out the use of steel up to 30 per cent. in air-furnace heats, and thereby obtained something so much better in cast iron than had been made previously that he gave the metal this name and reaped a well-deserved reward thereby. In those days nothing was known of foundry metallurgy, and this procedure was a real discovery. Today, however, we know that the function of the steel is simply to reduce the total carbon—to reduce the planes of weakness from graphite in the iron by having less of them there. This when the melting is done right. Also that with poor practice there often is no noticable reduction in the total carbon at all. Hence, why encourage a name that gets closer to deliberate misrepresentation the better posted the foundryman and his customer becomes?

Similarly with air-furnace practice, the addition of steel to the bath can be duplicated by holding the heat a longer time and the carbon lowered in this manner. The steel addition is the better way, but the result is cast iron just the same. It is to be hoped that when the constant agitation for "semi-steel" on the part of interests and parties profiting by the ignorance of the other fellow ceases, the name will be decently buried and forgotten.

CHAPTER VIII

FOUNDRY RAW MATERIALS

The basic supplies entering the foundry for routine production purposes may properly be designated as "raw materials," for they are consumed in the various operations incident to the manufacture of finished iron castings.

These foundry raw materials may be grouped broadly into metals, fuels, fluxes, refractories, sands, and smaller supplies.

METALS

Pig Irons.—The product of the blast furnace, or any other process for reducing iron ore to iron rich in carbon, cast into convenient "pigs." Ordinarily subsequent remelting is resorted to—with accompanying unavoidable refining action—before casting into finished product.

Pig irons may be classified in a number of ways, each one being of direct interest to the foundryman. The distinction made in the product of the blast furnace of the least metallurgical importance is that in the manner of casting—whether into sand molds in the casting-house floor, or into iron containers presented to the furnace ladle successively by suitable conveying machinery. Pig iron is therefore known as either "sand-cast" or "machine-cast."

While the physical structure of iron from the same ladle cast into sand and into metal molds will be quite different—due to slow and fast rates of cooling—when remelted and cast into ordinary sand molds the chemical composition and physical structures will be practically identical. The advantages and disadvantages of the two kinds of pig iron under this classfication, when contrasted with each other, are as follows: Sand-cast pig iron is covered with a layer of sand adhering to the metal more or less firmly. While the metal is melting in the cupola or furnace this layer forms a protective coating which prevents surface oxidation to some extent until the iron begins to run. On the other hand, this sand cover is expensive if paid for as iron, and while most of the sand is supposed to drop off during transit from furnace to foundry a glance at a shipment of poorly made pig iron which carries much entrained slag will be illuminating so far as the ability of sand and gravel to stick to the iron is concerned. Indeed, in the Pittsburgh and Valley districts an allowance of 28 lb. is made over the 2,240-lb. ton to cover the sand problem. Incidentally it may be stated that America and Great Britain sell pig iron on the 2,240-lb. basis per ton, while Continental Europe uses the metric ton of 1,000 kg. (2,200 lb.).

Further, in the case of sand-cast pig iron the slag problem is more serious, more fluxing being necessary particularly in long heats. A further serious disadvantage, where pig iron is still bought under the antiquated "fracture grading" method, comes from the ability of changing the fracture appearance of the metal at will. The retardation of the period of setting by having very heavy sectioned pigs, and covering the metal with sand as fast as the molds are filled, makes for a very open, coarse-grained and black fracture. What would therefore, if cast as ordinarily, have been a No. 3 pig—under the old grade number system, whatever even that meant to seller and buyer—might show up as a No. 1 iron and command a corresponding increase in price.

Machine-cast pig iron, by reason of its accelerated rate of cooling, has the fine-grained structure of chilled metal where the silicon is high, and is white in fracture where this is low. The retention of a higher percentage of the total carbon in the combined form is responsible for this, and the result is a lower melting point and consequently a slightly smaller fuel requirement in remelting. A comparative analysis of the same metal poured into sand and metal molds, with corresponding melting points, is given herewith, and shows the differences due to the two rates of cooling very plainly. The metal was cast by West, the analyses made by the author.

	Sand-cast	Machine-cast
Silicon	0.590	0.570
Manganese	0.250	0.220
Sulphur	0.048	0.044
Phosphorus	0.271	0.266
Graphite	3.160	0.030
* Combined carbon	1.600	4.670
Melting point (degrees F.)	2,210	2,000

The absence of sand on pig iron makes for a cleaner melt, so that in case of dull iron coming from the cupola less slag is likely to be entrained in the metal—a situation, however, which should not eventuate in a properly operated foundry. In the purchase of machine-cast pig iron payment is made for the metal only and not for additional foreign matter, even if this be present in but a small percentage. Finally, in spite of the claims made by furnacemen that they can grade machine-cast pig iron by fracture better than the sand-cast variety, it is absolutely necessary to use this material by analysis only, and hence the foundryman knows exactly what he puts into his mixture.

About the only objection to machine-cast pig iron, as made in America, is the section of the pig. This is very large and results in the melting lumps descending pretty far into the bed before final disappearance, which in turn means possibility of undue oxidation. Some furnaces have recognized this factor, and make their metal intended for foundry consumption of smaller thickness, by not filling the molds as completely as for metal going into the open-hearth furnace for steel-making. The German system is a better one, the machine-cast pigs being identical in size and section with the ordinary sand-cast product.

A final point in favor of the machine-cast iron is the fact that it has solved the labor problem at the blast furnace, and hence the

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* The abnormally high total carbons shown by the analyses can be explained only by the fact that the original high-carbon charcoal pig iron, used for a special series of tests, was remelted four times under conditions of excessive fuel, extremely high heat and a minimum of silicon oxidation. Hence, a remarkable absorption of carbon from the fuel, and retention of the excess above normal in the comparatively small section test bars which cooled rapidly even in a sand mold.

The reduction in silicon from 0.82 in the pig to 0.75, 0.66, 0.62 successively, and finally 0.59 and 0.57 in the test above given, indicate this situation, as also the rise of the total carbon from 3.94 in the pig successively to 4.08, 4.30, 4.44, and finally 4.76 and 4.70.

frequent interruptions in operation caused by strikes and alcoholic indisposition on the part of the very low class of labor available for this exhausting work, have ceased.

In general, considering the relative advantages and disadvantages of the two classes of pig iron, the machine-cast product is to be preferred at all times. Only progressive furnaces install such a casting plant, and only progressive furnaces can be counted upon to make uniformly good grades of pig iron. Machine-casting is a distinct aid in this forward movement.

The second classification of pig iron is based upon the method of manufacture. The bulk of the pig iron produced today is made with coke as the fuel and always with hot blast. This includes even those rare cases in Scotland where a strong bituminous non-caking splint coal is used, for this retains its strength and is practically coked as it descends.

A small percentage of pig iron is still made with anthracite coal, in eastern Pennsylvania—the home of this fuel. On account of the smaller output of the furnaces, however, it is customary to partially replace the anthracite by coke, the situation becoming one of costs. Coke, with its higher freight rates from western Pennsylvania, is more expensive, but is consumed more rapidly and consequently increases the furnace output. Hence the most economical mixture of the two fuels is arranged for.

The next variety of pig iron is that made with charcoal as the fuel. This is again divided into pig iron made with a cold blast and that with hot. As the blast temperature in the latter case, however, is not as high as when using coke it is usually spoken of as "warm-blast" charcoal iron.

Electrically made pig iron would complete this classification. The temperature conditions existing during the smelting operation are so high that the form of carbon employed matters very little.

Of the product of several processes of manufacture, cold-blast charcoal iron may be said to be the best in quality, some brands commanding a price per ton three times as high as that of the ordinary coke metal. Warm-blast charcoal iron would come next, and then the coke and anthracite irons according to the degree of care exercised in the making. Electrically made pig iron is still in its infancy and has not been used long enough to enable a comparison being made with the standard varieties above mentioned.

The foundryman naturally wants to know why there should be any differences in the quality of pig irons, particularly in the light of our present knowledge of its chemistry. The old tradition of ore qualities directly transmitted to the molten metal has long been discarded and every furnaceman thinks himself capable of making as good a metal as the best cold-blast charcoal variety. Apart from temporary furnace troubles, the general causes which underlie the differences in quality which distinguish charcoal irons from those made with coke, are, in the estimation of the author, to be found in the action of the blast upon the fuel used, the reduction of the ore to iron sponge, and finally in the melting of the latter to the finished material. The chain of reactions thus produced will be more or less complete, will take place at more or less favorable zones in the furnace, and consequently leave the finished product in a more or less perfect form—if we assume the perfect form to be iron plus carbon, manganese, silicon, and the unavoidable phosphorus and sulphur; but absolutely free from oxygen, nitrogen, and other elements that have no business there. That the blast furnace product is made in a "more or less" perfect form is known to every foundryman who has taken the trouble to break pig irons of various brands and yet of identical composition as shown by his analysis slips.

The blast-furnace process consists essentially in exposing iron ore to the reducing action of carbon monoxide gas. This reduction begins almost at the top of the furnace and is supposed to be nearly complete by the time the charges get near the melting zone. A second reduction is supposed to remove all the oxygen as the iron sponge made of the ore melts. The carbon monoxide gas in question comes from the burning of the coke by the air blast, in the presence of an excess of the fuel. Right here is found the first opportunity for differences in the furnace reactions. Comparing the accessibility of the fuel to the oxygen passing over it—or the relative "cell structure"—it will be noted that anthracite is the worst fuel in this direction. It offers little surface to the blast and hence burns slowly. Coke has a greater area to present to the blast owing to its cellular structure, and hence burns from two to two and a half times as fast as anthracite. Finally, charcoal, which has a still greater cell structure, burns at a rate three times as fast as anthracite, and is therefore the most desirable fuel of them all.

As the blast enters the furnace hearth through the tuyères—acting exactly as in the cupola—it attacks the fuel, burning the carbon to carbon dioxide (CO_2). Instead, however, of finding charges of metal at hand and thus giving up most of the heat to melt them, this carbon dioxide finds a heavy layer of incandescent fuel still ahead, takes up some of the carbon from it forming carbon monoxide (CO), exactly as would be the case in the cupola with the bed entirely too high. The similarity goes one step further. In spite of the lightning speed at which these reactions take place at the points of actual contact, it takes some time for every particle of oxygen to get at the necessary particle of carbon and in the meantime, the blast moves with a tremendous velocity. Hence, just as in the cupola, free oxygen will be found some distance inward, carbon dioxide will not have been completely converted to carbon monoxide—the final form in the blast furnace—for some distance upward, and the importance of all this will depend upon the fuel used. It is not difficult to see that with anthracite fuel unconsumed oxygen will travel inward much farther than is the case with charcoal, the latter offering the greatest possible surface for contact with the attacking oxygen. Similarly the final formation of carbon monoxide will be brought about more rapidly with charcoal than with anthracite.

In the case of hot blast the situation is more complicated. The very high temperatures at work from the start mean a much greater efficiency on the part of the fuel used, and in fact the relative quantity of this is actually cut in half. The attenuation of the hot oxygen coming in must mean a further penetration before being used up. and carbon dioxide itself under high temperatures is an oxidizing medium to a certain extent. Johnson very properly claims that the carbon dioxide first formed is not entirely changed to carbon monoxide until the blast has reached the top of the bosh—or more than 10 ft. above the point of entry in ordinary cases—and that there is a narrow zone of carbon dioxide of intense heat and a relatively oxidizing influence right above the tuyères. Above this the temperature drops quickly and thereafter more slowly as the gases ascend to the upper part of the furnace.

From the above it will be seen that even if the iron sponge made in the zone of reduction and subsequently melted in the zone of melting were perfectly free from oxygen, there is a chance of a slight re-oxidation of the metal in going through the region just above the tuyères, and this chance is more serious with the fuels allowing oxygen to pass inward farthest. Cold-blast charcoal iron would then seem least subject to such a deterioration, and this is exactly what the author has contended for many years; namely, that the differences in quality between pig irons of the same composition when made with charcoal as against coke fuel is due to the relatively smaller chances of containing dissolved iron oxide in the former case.

Another point in this connection is the chance of unreduced ore entering the melting zone. It is a well-known fact that while the hematities and limonites are almost entirely reduced in the blast furnace before reaching the zone of melting, this is not the case with the relatively denser magnetites. The latter seem so impervious to the reducing gases that some of them arrive unchanged at the point where melting takes place, and hence must pass into the slag, giving it a very scouring characteristic. The silicates of iron, from the puddling process, heating furnaces, etc., act in a similar manner, and hence are used as furnace purgatives in case of trouble, if not as a matter of economy. The result must mean trouble for the iron, as iron oxide is soluble to some extent in molten iron, and hence not all of the unreduced ores will pass into the slag.

To realize this situation better, attention is called to the refining action going on in the open-hearth furnace when making steel. Here the addition of ore, as also the mere passing of hot oxygen over the surface of the molten metal, means a more or less violent reaction between oxygen and carbon within the bath resulting in the removal of the latter at a more or less rapid rate. Similarly for silicon and manganese. The point of interest, however, is that oxide of iron is dissolved or formed in the liquid mass first, and this acts as a carrier of oxygen to the carbon, silicon, etc., and results in their oxidation and removal.

Hence, in addition to a possible re-oxidation of otherwise good metal as this passes through the blast-furnace melting zone, there is a good chance for the presence of a residual dissolved iron oxide in pig iron as it accumulates in the crucible previous to tapping out. The amount is naturally so small that it can coexist with the comparatively large carbon content, as otherwise a reaction would take place similar to that when ferromanganese is used in the final de-oxidation of steel, manganese being substituted for carbon in searching out the last traces of oxygen in the metal.

As the blast furnace is charged in layers the reactions taking place are intermittent and sometimes even counteract each other, the end result only being under actual observation. It can be readily seen that if a furnace is working badly, scaffolds are forming, slips occur, the blast loaded with moisture, etc., the chances for poorly made pig irons are greatly increased. Indeed, this gives the "off" irons so seductively placed before the purchasing agent of an establishment operating a foundry, at bargain prices. If it is difficult enough to produce "honest" pig irons in first-class blast furnaces under normal conditions day in and day out, and requires the highest degree of skill and eternal vigilance, what can be said of the quality of those pig irons sold to foundrymen, which are made in furnaces just holding together, in which mill cinder, dirty coke, impure ores, rule-of-thumb supervision, no laboratory, etc., are the rule? Fortunately, for the good name of the iron industry, the latter type of furnaces are few, for when "iron is pauper" instead of "prince" the process of elimination sets in. The moral for the foundryman, however, is to let the other man worry with the "off" pig irons.

Concerning the elements entering pig iron other than carbon the following may be said. Phosphorus, manganese and silicon are more difficult to reduce from their oxides than iron, but the process cannot be operated in such a manner that these elements are kept out of the metal produced. Practically all the phosphorus of the ores and fuel goes into the pig iron. Nearly two-thirds of the manganese is reduced with the iron in ordinary practice, while running the furnace colder cuts this down to less than half, as may be seen in charcoal-furnace practice.

The silicon content of pig irons comes from both the silica in the ores and that in the ash of the fuel. The hotter the furnace is operated, the greater the silicon reduction. In this way pig iron up to 13 per cent. can be gotten from the blast furnace. For higher percentages recourse must be had to the electric furnace.

In the case of sulphur the situation is more complicated. Some ores of iron run so high in this element that a preliminary roasting is essential. In the well-known case of the Cornwall mines near Lebanon, Pa., the sulphur often ran up to 3 per cent.

Roasting cut this down to about half the quantity. Again, much sulphur is brought in by the fuel. Coke should not carry more than 1.25, though it sometimes runs up to 2 per cent. On the other hand, charcoal seldom goes above 0.02 for this injurious element. Finally, the limestone used as the flux may bring in some sulphur. As it is necessary to remove as much of this element as possible, forcing it into the slag as a calcium sulphide (CaS), the furnace should be operated for a hot, fluid basic slag, and the more nearly this is obtained the lower in sulphur is the pig iron made.

Before taking up the third method of classifying pig iron, a word should be said about the value of brand names. Probably no assest in the blast-furnace industry making foundry irons is so valuable as a "brand" with a good reputation. Every foundryman, on harking back over a lifetime of melting, will instinctively have come before his mind's eye the names of a few brands of pig iron upon which he could place absolute reliance. Indeed, in the malleable-castings industry, when everything goes wrong with the heats, the old and tried correction is to clean out the whole shop of sprues and remelted stock, scrap, etc., and begin again with all pig heats of reliable metal. Well-made pig irons, of which the furnaceman is proud, where only the best of ores and fuels are used, and no tap cinder or rich iron slags are put through the stack, come to be known as "honest" irons.

The third method of classifying pig iron, that by analysis, at once divides and diverts this material into channels leading to recognized divisions of the iron industry. Thus, an analysis which runs 1.00 to 2.00 per cent. in silicon, and sulphur and phosphorus not over 0.035 each, at once fixes the material as "low-phosphorus pig" and particularly valuable for the production of acid open-hearth steel.

The range of analyses and markets to correspond, for the pig irons regularly made in blast-furnace practice, may be given as follows:

Bessemer Pig Iron.—For the acid Bessemer process and the making of ordinary grades of acid open-hearth steel, the silicon should run between 1.00 and 2.00 per cent. Phosphorus not over 0.100, and sulphur not over 0.05.

In England, the so-called hematite pig irons are used for the acid Bessemer process (West-coast and East-coast hematites differ slightly in their manganese content) and have the silicon about 2.50, phosphorus about 0.035, rarely as high as 0.06, and the sulphur about 0.035. On the Continent, where a higher range of phosphorus is found in the ores in some districts, the *Basic Bessemer,* or *Thomas* process rules, this process also caring for English high-phosphorus irons. The general requirements are: silicon below 1.00, sulphur preferably below 0.10, phosphorus up to 3.00, not below 1.00 as the lowest limit, and manganese 1.50 to 2.50.

The standard American Bessemer pig iron is oftentimes used in foundries to reduce the phosphorus content of a mixture, or for special fairly low phosphorus charges for some varieties of gray iron castings. This iron costs but little more than ordinary foundry brands and is far cheaper than the special "fancy" low-phosphorus irons.

Malleable Bessemer, or *coke malleable* pig iron is used particularly in the production of malleable castings. Originally the standard Bessemers running close to the 0.10 phosphorus limit, and perhaps over it a little, found their way in the malleable foundry—the author being probably the first to introduce this metal in replacement of the more expensive charcoal irons, and using about 10,000 tons in his mixtures, the first year. Later on, when a steady market for this material had been developed, the phosphorus limits were widened almost up to the charcoal requirements, and the specifications now call for silicon from 0.75 to 2.00, as selected by the purchaser, sulphur, not over 0.05, and phosphorus below 0.200.

Basic pig iron is used for the production of basic open-hearth steel. The essential characteristic of this metal is its high phosphorus content. It differs, however, from the high phosphorus stove-plate foundry pig iron in that the silicon content is held below 1.00 per cent. Hence, the specifications would call for silicon below 1.00, sulphur below 0.05, and the phosphorus anything below 0.500, but actually running from 0.30 to 1.00.

Low-phosphorus pig iron is the "fancy" iron used for making specially low-phosphorus steel. The price is accordingly. The best of ores are used in its production, and the supply is naturally limited. Silicon runs between 1.00 and 2.00 ordinarily, and the sulphur and phosphorus must each be below 0.035.

Washed Metal (See Chapter V).—This is made by treating molten pig iron, or direct metal, with iron ore (or manganese ore) at comparatively low temperatures and in the presence of a very basic slag. The result is the removal of most of the silicon and phosphorus before the carbon can be seriously affected. The result is an iron having sulphur from traces up to 0.03, and phosphorus from almost nothing up to 0.025. The price paid will vary according to the degree of freedom of the metal from sulphur and phosphorus.

While washed metal is excellent for low-phosphorus steel-making, it is not recommended for foundry use. From the very nature of the process of making it, there must be residual oxygen present, and this manifests itself in the shape of the troubles in castings previously discussed under "Iron and Oxygen." Extensive tests made by the author with this material indicate that even where the castings would pass inspection as to soundness, the metal itself was weaker than an iron of similar composition made in regular furnace procedure.

Foundry Pig Iron.—In spite of the attempts on the part of blast-furnace proprietors, through their organizations, to perpetuate the method of selling pig iron by grade numbers, special names, etc., specification by chemical analysis is now almost universally used. Progressive furnacemen would no longer like to see a return to the old and uncertain fracture grading method, as they know by sad experience that the foundryman's mistakes are invariably thrown upon the iron and the coke furnished.

Even the concession to modern demands of giving analysis ranges to correspond to given pig-iron numbers serves but to hold an advantage over the poorly posted foundryman, who may thus get a little safer iron for general purposes, but will not be as successful in specializing as he should be. Furthermore, the analysis ranges corresponding to the published grade numbers vary with the geographical divisions of the blast-furnace industry, and give rise to confusion in the mind of the purchaser. Thus, in the published furnace grade of No. 2 iron, the analysis range for southern points has the silicon running from 2.25 to 2.75 per cent. For eastern points it will run from 1.75 to 2.25 (and the 2X grade 2.25 to 2.75 silicon). The same No. 2 iron for the Central West and Lake points runs 1.75 to 2.25, and for Buffalo shipments the silicon is 2.00 to 2.50, with Chicago again at 2.25 to 2.75.

A foundryman, unaccustomed to mix his metal by analysis, is therefore liable to get 1.75 to 2.75 per cent. silicon in his No.

2 pig-iron purchase. Now, as a matter of fact, it is perfectly proper for the furnace to ship 2.25 to 2.75 silicon iron when 2.50 is specified, for the limitations of blast-furnace practice make this allowance necessary. This does not mean that the several pigs of a car load will vary that widely in composition, for that should not be the case. But no furnace will have a preponderance of metal with one analysis, and to satisfy all customers some leeway is necessary. It is essential, however, that a foundryman specifying 2.50 silicon and having metal with 2.35 shipped to him, should know this. He can then mix his charges accordingly. But with a range of 1.75 to 2.75 he is simply groping in the dark and taking big chances.

In view of the fact that all these furnace association specifications basing grade numbers on analysis ranges will eventually fail, even when metal is sold to the less progressive foundries, they need not be recorded here. If pig-iron salesmen were instructed to help the foundryman buy the metal he needs on its analysis, the onus, if anything goes wrong, will fall upon the foundryman, for he will have gotten what he has asked for.

The composition of the pig irons entering the foundry vary very widely. The general characteristics can best be judged by studying the recommended analyses for the classes of castings described in Chapter VII. From these it will be seen that the silicon percentages are most important, in view of the carbon conditions desired. Next, that certain classes of castings require the use of high-phosphorus irons, others high-manganese. In general, the particular work of the foundryman will differentiate the particular brands of iron he can use very sharply from those otherwise available by reason of good freight rates. The foundryman will narrow the selection down to some half a dozen brands, and select the silicons he may want, merely giving upper limits for sulphur, and possibly manganese if this is apt to run too high.

The ordinary range of composition of foundry pig irons is as follows:

Silicon, from	0.75 to 4.00
Manganese, from	0.50 to 2.00
Sulphur, from	0.02 to 0.08
Phosphorus, from	0.10 to 1.00
Total carbon	3.25 to 4.00

What might be termed the extraordinary range of the elements in pig iron available for foundry purposes, is given herewith:

Silicon, from	0.10	up to	14.00
Manganese, from	0.20	up to	4.00
Sulphur, from	0.005	up to	0.15
Phosphorus, from	0.02	up to	3.50

It will be noted that the above figures include what are still known as the forge (gray forge—a very poor gray iron), mottled and white irons. This on the descending scale of silicon content. Also, on the ascending scale, the silvery irons, softeners, Scotch irons, and ferrosilicons of low silicon ranges. In these days of enlightenment, there is no particular need for these designations, though they are still adhered to in trade reports and statistical tabulations. Foundrymen are now generally familiar with the chemical compositions of the irons thus designated.

In purchasing pig iron, the progressive foundryman first makes up his mind about the selection of high-grade metal, such as the charcoal irons (cold- or warm-blast), or particular brands known for their quality. He next runs over the specimen furnace-cast analyses submitted by the salesmen, and selects brands having the phosphorus and manganese within his requirements—indicating that the ores used are likely to keep these elements fairly constant for the run of the contract to be made. Then the foundryman will specify his silicon and limit the sulphur.

For instance, the author in his extensive practice did the following: For ordinary gray iron castings, he selected brands in which the phosphorus ran between 0.40 and 0.70; manganese from 0.60 to 0.80. The silicon was then specified at 1.75, 2.00, 2.25, and 2.50 for the various tonnages required, and sulphur was limited to 0.05 for all of them. An exact record of the metal received, with furnace analysis, as well as that melted was kept, so that the stock on hand was known from day to day. At the end of the month the situation was gone over with the purchasing agent, and the requirements forecasted. With reasonably steady production conditions it was essential to hold the stock piles of pig iron for each of the four silicons called for up to given percentages of the whole. Thus, the 2.50-silicon irons might form 50 per cent. of the whole stock, and the 1.75 but perhaps 10 per cent. By watching this matter closely the accumulation of irons of compositions but rarely used was avoided, and the interest charge kept properly down.

The author may state here that while he had his irons regularly analyzed by the works laboratory, the furnace analyses, except in the very first years of the change from fracture grading to purchase by analysis, were found quite reliable, and the metal could always be piled from the furnace cards. The peculiar method he used for piling pig irons in the yard took care of irregularities, and as he rarely had less than 5,000 tons on hand at one time, the method by which several thousand tons were stored under one analysis may be of interest.

In the first place, all brands were kept separate, but not carload lots. That is, a "Hinkle" iron, or a "Warwick" would not be mixed together if of identical analysis. It is too important to have the product of each furnace rest on its own merits and to be able to trace troubles to given brands of iron. The silicons being ordered for say 1.00, 1.25, etc. (for malleable castings), as each car came in the silicon was taken from the shipping card and if 0.15 above or 0.10 below one of these specification points, it went on the respective brand pile. The first car load was spread along the ground carefully, the next of its kind went right on top in the same long row, and so on until the piles were as high as a man could lift comfortably. Such a pile, say if "Hinkle" with 0.75 Si, was labeled "C" or any other letter of the alphabet, and kept on the books until used up. In drawing from this pile, the pigs were taken from the most convenient end and kept rolling down to the ground. In this way a perfect mixing of the different car loads of the same analysis took place, and variations were thus equalized, as a number of pigs were always taken from each pile used for furnace or cupola charge. Thus possible furnace irregularities giving poor metal for several successive casts were discounted, and a very even melting practice provided for.

It is well know that foundrymen have found it best to use at least three brands of iron in their mixtures, to care for possible poor metal in any one of them. With the method above outlined, of piling large stocks of pig iron, it is perfectly possible to use the output of one furnace only—the author himself did this again and again—and to get as good results as when more brands are made use of. The separate furnace casts get scattered so widely in the several piles, that it is the same as if a number of brands had been used.

There is no reason whatever why even smaller foundries should not pile their metal in this way, as most of them find it advisable to stock up during the summer months. Small lots for particular purposes, of course, will have to be kept separate, though every foundryman knows how hard it is to get identical results in specialty work when but one car of the special iron is being used at a time.

Returning again to the specifications of pig iron, the author recommends the Standard Specifications for Pig Iron of the American Society for Testing Materials in making purchases. These specifications are being extended for international use, and are so simple and fair to seller and buyer that both parties should be satisfied. What follows below is taken from them, as well as from the comprehensive "Standard Methods of Sampling and Analysis of Pig and Cast Iron," prepared by Dr. Hillebrand, of the U. S. Bureau of Standards, for international as well as domestic use, and adopted by the above-named Society. For a fuller context the reader is referred to the documents in question reprinted in the "Appendix."

Specifications.—The foundryman must first make up his mind as to which elements of the five given below he should specify in making his purchase contracts. To facilitate commercial transactions it is recommended that he select from the specific figures given in the tables, agreeing to the variations allowable in delivery; the furnaceman, in turn, under such specifications and contract, giving delivery within the maxima and minima as well as the variations allowable.

Silicon.—0.50 – 0.75 – 1.00 – 1.25 – 1.50 – 1.75 – 2.00 – 2.25 – 2.50 – 2.75 – 3.00 – 3.25 – 3.50 – 3.75.

The allowable variation is 0.25 silicon either way. Thus, if 2.25 silicon is called for, the delivery of 2.00 to 2.50 is binding.

Sulphur.—0.02 – 0.03 – 0.04 – 0.05 – 0.06 – 0.07 – 0.08.

These are maximum percentages. Hence, if 0.04 sulphur is specified, the delivery may have from nothing up to 0.04, but not over this figure.

Phosphorus.—0.20 – 0.40 – 0.60 – 0.80 – 1.00 – 1.25 – 1.50.

The allowable variation is 0.20 phosphorus either way.

Manganese.—0.20 – 0.40 – 0.60 – 0.80 – 1.00 – 1.25 – 1.50.

The allowable variation is 0.20 manganese either way.

Total Carbon.—(A specification for this element is sometimes desirable in the case of pig irons for specially soft, or very hard chilled work.) 3.00 – 3.20 – 3.40 – 3.60 – 3.80. These are minimum percentages. That is, if 3.40 total carbon should be specified, the pig iron shipped may not run below that point, though possibly up as high as 4.00.

In order that the foundryman may be certain that he receives what he has ordered, and similarly that the furnaceman may have a square deal, it is highly important that the methods of sampling the shipments, as well as the actual analyses, be made under standards accepted by both parties to the transaction. The work must therefore be capable of duplication with concordant results, and also be readily carried out under ordinary conditions.

Sampling.—1. One pig is to be selected at random for each 4 tons of iron, and 10 such pigs (representing 40 tons of iron) to constitute a "unit" of sampling.

2. The surface of each pig taken to be cleaned carefully and skin removed with an emery wheel, at the center of the upper face of each pig. Drillings to be taken from one hole made with a ¼-in. twist drill from top to bottom of each pig.

3. Drillings from the entire unit to be weighed, sifted to two (or three) portions of different fineness, the portions weighed, and proportional parts taken in making the required determinations.

Analysis.—"The Standard Methods for Determining the Constituents of Cast Iron" adopted by the American Society for Testing Materials (or eventually those of the International Association for Testing Materials) are to be used by furnace and foundry, as also for umpire determinations in the case of dispute.

Reference should be made again to the testing of pig iron by the foundryman, so that he may feel safe in using new brands of iron presented to his notice. In Chapter V the safest method—that of melting in crucibles—was given, standard test bars being cast and comparison made with the results of other irons of similar compositon. Otherwise, a small test cupola will give information of value, provided the tests are made scrupulously comparable. As few foundries, however, are provided with crucible and test-cupola melting facilities, the most practical method is to run a few charges—the bulk of which should consist of the new pig iron, in the first part of the day's heat, collect the sprues and defective castings carefully, let these form the scrap of similar charges for the next day's trial charges, and so on until the car load has been used up. Daily test bars from these charges—omitting the first day's results—will give an excellent comparison with the results from the regular brands used in the establishment.

Returning again to "treated" pig iron as presented to the foundryman, the author can only caution against paying much attention to these hybrids. They are all the result of some form of oxygen addition, whether actually blown partially in the converter, ore-treated, or by passing air through the molten metal with or without suspended chemicals. The author has been called upon to investigate some of these processes professionally and invariably found that the change in fracture appearance produced by the "treatment" disappeared entirely on remelting in the cupola under test conditions, the standard bars made showing no differences in composition or strength. Indeed, the peculiar fractures and closing up of the grain of the metal which so encouraged the inventors of the processes could be regularly duplicated by the author by the simple expedient of an impaled raw potato forced down into the molten metal to thoroughly "boil" it—a procedure that will recall personal reminiscences on the part of most of our older foundrymen.

Mention has been made (Chapter VI) of the use of "direct" metal for pouring molds in foundries. This is done at every furnace plant for such castings as may be necessary about the establishment. The open structure of the metal, however—identical with that of pig-iron fractures—makes it undesirable for the regular run of the foundry product. In fact, the use of direct metal is particularly prohibited in some specifications, as for cast-iron pipe, on account of likely porosity, shrinkage spots, etc. Hence, the recommendation of the author to allow the stream of furnace iron to pass over white-hot steel scrap to incorporate this before getting into the ladle, or to add such steel scrap, previously heated up white hot in soaking pits, in the furnace ladle in order to reduce the total carbon, cut out the kish, close up the grain of the resulting metal, and make it for all purposes equal to the remelted foundry product. In some European pipe foundries they try to get around the direct-metal prohibition by running it into partially filled ladles of cupola metal. One can easily see how elastic the method may become if the inspector is not examined for his eyesight unexpectedly by his employers on occasion.

About the only use for direct metal in commercial castings is the making of ingot molds for steel mills. These are large, heavy, simple castings with but a little machine dressing of the bottom. A low sulphur content being essential, as the scrap molds are used in the steel-making processes, direct metal covers the situation better than remelted pig iron where a furnace making the proper metal is close enough to the foundry making the molds. With the ever-increasing necessity for shop economy the time will come when the producers of water and soil pipe, machine builders and other foundrymen turning out enormous tonnages daily, will find it highly desirable to own their own blast furnaces. To use their direct metal they need only have a set of mixers, apply the necessary corrections to the molten metal to fit the requirements of their castings, and save themselves much if not all of the remelting expense.

Scrap.—This is remelted stock, and is divided into two general classes. The first is what might be called "domestic" scrap which consists of the sprues, gates, defective castings, "over-iron," metal from the cupola drop and gangways; in fact all metal that has come from cupola or furnace which for one reason or another must go through the melting process again. It can be assumed that the foundryman knows the composition of this material within reasonable limits, and if he runs several mixtures at the same time, he will keep these sprues, etc., carefully apart.

It should be the aim of the foundryman to use up his domestic scrap as fast as it is made, for accumulations become an uncertain factor if the heat analysis has varied considerably from standard at the time this scrap was made. Again, in the event of trouble with the metal, through undue oxidation, bad coke, and the like, such sprues and defective castings are apt to be stocked up separately for future use when things are running right again. Instead, however, of feeding this dubious material into the mixtures a very little at a time, the origin of the scrap may have been forgotten and heavier proportions used—with consequent risks to the product.

The percentage of domestic scrap made in foundries varies very considerably, depending upon the nature of the castings, the degree of molding and melting efficiency, and the shop discipline. As this material is always covered with burnt sand when gathered in the shaking-out process, it should be sent through the cleaning room for rumbling. Less slag in melting will thus have to be cared for together with cleaner iron obtained in case of dull heats.

It should be the special care of the foundryman to produce as little of this domestic scrap as possible. He will realize this when he remembers that every pound costs him at the rate of molten metal in the ladle plus melting loss when again remelted. There is hardly a foundry in existence where much of this domestic scrap cannot be saved, either in reducing the diameter of the sprues (it is height that gives ferrostatic pressure and not diameter), spilled iron in the gangways and about the sand-heaps—most of which could be returned to the reservoir-ladle—and holding down the percentage of "over-iron" to the lowest safe limit.

Better to make fewer molds and have them perfect, than to fill the shop with the molder's handiwork and lose a big percentage through imperfections resultant from haste and carelessness. If shop conditions are such that a few molds can stand over until the next day, so much the better, as this cares for all the iron melted. Otherwise, the foreman will have to use his best judgment in estimating the metal required from the molds still to pour, just before the completion of his charging programme.

In the case of the domestic scrap coming from air-furnace iron, where a number of these (or of open-hearth furnaces) are in operation daily, it is very important that a thorough mixture should be brought about, as otherwise the making of inferior iron in any one of them may be accentuated by the return of its own scrap in the next charge. In properly run establishments this scrap is gathered in shaking-out and sent to the cleaning department from all parts of the foundry floor at the same time, so that in passing through the mills a very good mixing is had. This work is preferably done at night and the cleaned scrap returned to the furnace platforms or floors after weighing, in readiness for the next day's heats.

It is a common practice as already mentioned for the malleable-castings industry in case of severe trouble with the cupola or furnace iron, to clean out all the sprues from the shop and begin anew with an all-pig iron heat and thus gather a fresh crop of gates, etc. This will eliminate the effect of a poor metal (in the shape of bad sprues) in the mixture for the time being, and give the foundryman a breathing space while searching for his fundamental trouble—usually found in defective charging and melting methods. The melting department of the foundry should always be overhauled at the first signs of poor work not directly traceable to bad sand. This will often save so radical a step as the removal of all the domestic scrap to the yard and making a new start.

Foreign Scrap.—This embraces all scrap materials brought from without, as well as the accumulations of the establishment itself of stock not previously melted in the foundry. There would be three natural classes of foreign scrap, namely: steel (and wrought iron) scrap, malleable scrap, and gray iron scrap. The subdivisions of these classes can be best taken up by a ventilation of the whole scrap situation as it affects foundry melting practice.

Steel Scrap.—Only medium sectioned material should be considered in the foundry, as the descent of the charges in the cupola is so rapid that complete melting of large pieces will not take place before a zone of lower temperature and high free oxygen percentage has been reached. Hence, the heavy steel-melting stock of the scrap market is out of question in ordinary foundry practice. Again, very light steel scrap should also be avoided as the relation of surface (liable to be exposed to oxidizing influences) to weight is too great. Unfortunately even with the most careful attention to charging, a certain amount of air will travel up along the cupola lining, light the upper charges of coke and raise any thin steel scrap present to white heat. What will be left of this by the time it gets down to the melting zone can be imagined.

Furthermore, steel punchings and very small pieces—particularly of high-carbon steel—should be avoided, as these may roll through the charges and eventually lodge directly before the tuyère openings. The result will be badly oxidized metal and castings that are porous and full of pin holes and shrinkage spots. One has to but observe the wonderful display of scintillating sparks that appear at the slag spout of a cupola, into which much light steel scrap has been charged, to realize what is going on within and worry about the results. Steel borings also come under this category, as perhaps the worst material to use.

In air-furnace practice charging heavy steel scrap retards the heats unduly and hence should be avoided. Light scrap is also bad as it is subject to the oxidizing influences of the products of combustion passing over the hearth. Unless very heavy percentages of steel scrap are to be used in an air furnace or open-hearth heat it is best to melt the gray iron stock first, and get a slag cover on the bath, then to charge the steel in shape of rail ends, splice bars, angles, etc., a little at a time to allow it to be assimilated and remain under the slag cover. This prevents all oxidation and gives the best results.

While the author has many times run cupola heats with 60 per cent. steel scrap which included very heavy pieces—such as large projectiles, dies, scrap-steel castings, etc., this meant an unduly heavy fuel bed and hence was not altogether economical. Right here might be mentioned the proper charging sequence in good cupola practice. On top of the coke layers, there should first go on whatever limestone flux is used, as this has to care for the ash of the coke principally. Next comes the steel scrap, well spread over the surface, then the pig iron and heavy-sectioned scrap, and finally the light gray iron scrap. We have to deal with a higher melting point in the steel portion of the charge, a greater heat absorption necessity in the pig iron, and a comparatively quick melting of the gray iron light scrap. By arranging the charge as above stated every portion will begin to melt at the same time, as the lower portion naturally gets the heat first. Moreover, any thicker and hence unmelted steel may be washed away by the stream of metal coming from above.

Again, the author has made many heats of very thin steel scrap, such as tin cans, bed springs, etc. Only the use of enormous fuel ratios (1 coke to about 2 steel) allowed this without freezing up the cupola, or oxidizing the metal completely, cutting away the lining, and sending a foaming slag out of the charging door. Hence, it will be seen that almost everything is possible with the cupola in the way of melting, but whether economical or not is another question.

Foundrymen should therefore try to use steel scrap between ¼ and 1 in. thickness only, in pieces no longer than about 3 ft., and not as small as punchings or little boiler-plate clippings. Scrap angles, tees, beams, rail ends, and the like are best. The lower the carbon content of the steel the better, as high-carbon rails, files, and tool steel give trouble when exposed to high temperatures in the presence of even a little oxygen.

Wrought-iron Scrap.—This is not recommended for foundry use on account of extreme melting difficulty. Unless charged as above stated much of the wrought iron may get too low in the bed and eventually burn with damage to the melt from dissolved oxide of iron. This situation is more real than is generally supposed. Many regions of the country still have scrap wrought-iron horseshoes in abundance. The cupola laborers very naturally charge them with the light gray iron scrap. In descending in regular manner the gray iron scrap melts away leaving the horseshoes intact, they remain under the coke charges above and melting proceeds as usual, the horseshoes finally melt away perhaps some 5 or 6 in. below the proper point. There is little wonder that casting will come out porous when machined.

In the air furnace this is not so serious as there is more time for proper melting, hence also there is no difficulty with steel couplers, knuckles, crop ends, and the not too heavy classes of steel or wrought-iron scrap. The use of steel turnings will be taken up a little further on.

Malleable Scrap.—It is necessary to go into the constitution of this material somewhat to understand its behavior when subject to melting action. The malleable casting was originally a white-fracture, hard, glassy, low-silicon cast iron, which when annealing for a long period at a high temperature became converted to a soft, strong and tough material unique in the iron industry. This change is brought about through the conversion of combined carbon (no graphite being present) to "temper-carbon" or the carbon of annealing, and in addition, to the removal of some of the carbon from the exterior portion of the castings. So that the actual skin of the annealed casting may contain only 0.10 carbon, at a depth of 1/8 in. there may remain say 0.60 carbon, another 1/8 in. inward the carbon may be 1.70, while about 3/8 in. from the surface the full carbon percentage of the original piece—say 2.75 to 3.50—will be found remaining. But of the whole of this total carbon but very little is in the combined state.

The varieties of material, as it were, in the malleable casting, from skin to core would run from low-carbon steel in the skin, then higher-carbon, tool steel, and finally cast iron (but of an entirely different nature than the ordinary gray iron product). The effect of this on the melting point is obvious. The higher-carbon center melts at a lower temperature than the low-carbon skin, and the author has often observed large malleable castings float on the bath of molten metal in his open-hearth heats. Indeed, it was one of his discoveries that by crushing malleable castings under the hydraulic press, to expose as much of the interior fracture as possible, that this material would melt as well as pig iron, and as a consequence he often made heats of malleable castings with as much as 80 per cent. of this annealed scrap in the charge, a thing inadvisable with uncrushed malleable on account of the time necessary for melting and the resulting inferior work.

We have to thank the railroad authorities for a very close separation of the many types of scrap, as in this way they have found it possible to realize enhanced returns. The prospective buyer could thus make a better selection of material suited to his purpose, and hence could afford to pay more. As a concrete instance, the author recalls using malleable scrap taken from the lists of large railroad customers at a price $2 a ton less than the pig irons used in this class of work, when the trade paper quotations were several dollars below even this reduction. The price that could be paid was carefully determined from the records of melting loss, etc., and this shaded to a safe margin on general principles.

In general, malleable scrap is divided between railroad and agricultural. The nature of the latter scrap is evident from its designation, being the remains of agricultural machinery, usually badly rusted. It should not but usually does contain scrap pipe fittings, steel bolts, and other foreign material. The value for the foundry is not high and it usually goes into annealing pots and other low-silicon (white-fracture) castings intended for the application of high and long-continued heat. Railroad malleable scrap can be divided into two classes, the large material such as couplers of the early types and heavy car castings. The second class contains the lighter car castings, air-brake fittings, etc.

Malleable scrap is not bought by the ordinary foundry, as it is very low in silicon. As, however, much of it finds its way into ordinary gray iron scrap as received from the majority of scrap dealers, it is well to know something about it. The maker of malleable castings, of course, buys heavy tonnages, to cheapen his mixtures, as also in the making of his pots and boxes for annealing purposes. The balance in the market goes into the basic steel furnace.

Gray Iron Scrap.—A variety of materials would come under this head. Taking the best of it first, this consists of broken pieces of machinery in cupola size, no item to be over 100 lb. in weight. So far as the foundryman is concerned this should be excellent for his purposes, as the stock represents what was at one time a series of good castings, and hence within reasonably close limits of chemical composition. It is perfectly safe, therefore, to assume a representative analysis to cover this class of scrap in making up the mixture, and as the silicon is most important in the calculations, this may be assumed to be 2.00 per cent. The original castings forming the gray iron scrap in question must have been intended to run between 2.00 and 2.25 in silicon. This will, of course, not hold in the second variety of gray iron scrap. Here we deal with pieces heavier than 100 lb., such as engine beds, big flywheels and pieces of heavy castings. The purchaser is supposed to break them up smaller himself if he wishes to, or else uses them direct in the air furnace. The silicon of such castings is unquestionably lower than 2.00 per cent., and hence for important work every heavy piece—for air-furnace charges—has an analysis made for silicon and sulphur.

It may be mentioned in passing, that "cupola size" means no larger than will go into the charging door, and also can be handled by one man.

The enormous tonnages of gray iron scrap entering the foundry today is rapidly compelling a greater degree of refinement in its classification. Proposed specifications are under consideration and practical tests which will differentiate "machinery" scrap from other varieties. Every piece of scrap under the designation of "machinery" will have to show evidence of having been machined—either planed, turned or drilled.

The first division is to consist of pieces under 100 lb. each. The second to consist of the scrapped machines in unbroken state. These two divisions are to be further differentiated into "light" (under ½-in. section), "medium" (between ½ and 1 in. section), and "heavy" (over 1 in. section).

The elimination of "machinery scrap" leaves a variety of kinds of gray iron scrap, other than special kinds as car-wheel, agricultural, etc., and these are to be summed up as "rough" scrap. The same division into pieces less than 100 lb. and unbroken pieces, as well as light, medium and heavy, hold good here also.

The serious point in connection with the use of gray iron scrap in the foundry is the accumulation of the sulphur. Since the majority of castings made in the foundry eventually arrive there again as scrap after the machines and structures they were part of have served their purpose, it is important to see what happens to the metal on remelting. Some of the silicon and manganese is oxidized away. To get molten iron of the proper composition it is, therefore, necessary to select pig irons with enough of these two elements to allow the burning out of that which would be lost by the scrap as well as of the pig itself. The resulting castings would then have practically the same silicon and manganese as the scrap (or originally castings) contained. Now as to the sulphur and phosphorus. These do not oxidize out in the melting, but would concentrate in the metal the weight of which has been reduced slightly by the loss of silicon, manganese and iron (melting loss). In the case of sulphur the situation is even worse as a considerable amount is added to the iron from the coke. Hence, by reason of this periodic remelting of almost the entire cast-iron stock of the country, the sulphur content has gradually gone up, and where some 35 years ago one could count on 0.05 as the sulphur in gray iron scrap, today it is nearer to 0.12.

While it has been necessary to counteract the evil effects of high sulphur by an increased manganese content—incidentally helping the ore situation of the country—and particularly overcoming hardness in castings high in sulphur by rational melting practice (by not forming dissolved oxides of iron or possibly Porter's oxy-sulphides of this metal), yet there remains the fact that what is needed in the near future in the foundry is a cheap and effective de-sulphurizing process. It is well known that by melting at the highest temperature possible in cupola or furnace, and allowing the molten metal to stand, the sulphide of manganese formed will rise, and can be partially removed, thus cutting down the sulphur considerably. Prince has worked out a process in which air is forced through the ladle of metal, which after a few minutes is skimmed and shows a substantial reduction in sulphur. If, now, this metal could be put into an electric furnace and reheated—and given time to remove the oxidation effects, the process could be recommended. As it is, however, there is the chance of trouble from oxidized metal which shows itself quickly in the machine shop.

The problem is commended to the attention of our iron metallurgists, as the foundry needs de-sulphurized molten metal. It also needs de-sulphurized fuel, if such a thing can be brought about without destroying other necessary properties. The fact that it is perfectly possible to make machinable castings with over 0.20 sulphur by melting without oxidation does not mean that every foundry can do this safely. Hence prevention of trouble by being careful in the selection of melting stock. Unfortunately, the days of charcoal as a fuel in the cupola and charcoal irons as the bulk of the mixture have gone by, so attention should be turned to the problem of de-sulphurization.

Agricultural Scrap.—The quantity used annually in the United States is sufficient to call for a separate division. Care should be taken to keep out steel, malleable pieces, and chilled plow points.

The gray iron scrap thus selected forms the first class of agricultural scrap. The second class consists of plow points and other chilled material, and is much lower in silicon.

Stove-plate Scrap.—This is the product of the junkman's labor and embraces old stoves, radiators, clothes-wringer parts, sad irons, kettles, more or less of pipe fittings and pipe ends left from plumbers' repairs. It is about the cheapest and worst grade of scrap that can still be used in the foundry where small castings are the rule. Most of the stove remains are unfortunately associated with more or less burnt grates—a material which is so much poison in a foundry mixture—and these should be specifically excluded in the contract for the purchase of this class of scrap. As it will be found in the delivery anyhow, the burnt grates should be carefully picked out, piled up separately and put at the disposal of the scrap dealer, the value being deducted from the invoice.

Considering the percentage of rust paid for as iron, the high phosphorus content, and the huge melting loss involved in its use, the foundryman would do well to leave stove-plate scrap to the manufacturer of brake shoes and sash weights. For the former purpose this material is invaluable on account of its cheapness, brake shoes being used up in service and the iron though returned to the earth it came from, lost for future service to man.

Radiator, furnace and stove foundries, while they may have to take back their own product as scrap in exchange when making new installations, would do well not to purchase this grade of scrap so conducive to defective results, but to use only their own scrap and sprues and fill up the balance of the mixture entirely with pig iron.

Car-wheel Scrap.—Broken and discarded wheels in railroad service constitute this material. The bulk of it goes back to the wheel foundries, some to brake-shoe plants, plow works and wherever a low-silicon and somewhat high-sulphur metal is no objection. A distinction is occasionally made between railroad and trolley car wheels as the two are made for different service requirements. Formerly when only charcoal iron went into car wheels this class of scrap was very desirable where chilled work was made, but as coke iron has gradually replaced the charcoal and the repeated remelting of this stock has raised the sulphur to a pretty high figure, car-wheel scrap must now be used with considerable caution.

Grate-bar Scrap.—This refers to the scrapped grate bars of the railroads principally, in fact, is usually known as "raildroad grate-bar" scrap. Much of this is good material and if the burnt portions are broken away, can be used in ordinary castings mixtures. As a rule the railroads give out orders for these bars to local foundries on their line, by way of reciprocity in freight matters, and hence the stock is apt to be of the same grade as the regular run of castings made for machinery and the like. This situation was formerly the case with brake shoes, but with the advent of a powerful corporation consolidated from the principal brake-shoe manufacturing interests, and giving the study of the brake shoe and its function in railroad service the most exhaustive attention, the railroad interests could do no better than turn over their requirements to this specializing aggregation of important foundries.

If a de-sulphurizing process for gray is wanted anywhere, it is in the wheel foundry, for the tonnages melted are enormous though the plants are comparatively few.

Brake-shoe Scrap.—This material is divided into two classes: the scrap brake shoes without steel inserts, and that with. Neither is good for the general foundry and their value is evidently correctly gaged in the open market for the selling price is very low. The bulk of this uncertain material wanders back into the brake-shoe foundry, and most of it ought to go into sash weights.

Cast Borings.—We come now to the final item in the iron scrap list, and with this might also be discussed the steel turnings, and the mixed cast iron and steel borings made in the shops where this waste from machining is swept up indiscriminately.

No one item of scrap has bothered the foundryman more than the disposal of his borings, if he has a machine shop connected with his establishment, or the very tempting figures quoted for borings as compared with pig-iron prices which he would like to take advantage of if at all possible. The author has been in touch with about every form of using this material in Europe and America, and can conscientiously state that no method yet tried has given perfect satisfaction, though there are two that can be and are used daily in foundries which approach this state to a greater or less degree. Considering the importance of the subject a review of the situation will be of value.

From the time of the first machine shops this question has no doubt engaged the attention of the blast-furnace operator. Borings, not being as plentiful as at present (the estimated production of New York State alone being 1,000 tons daily) were stored in the yard until rusted and if used at all would wander into the blast furnace. In the neighborhood of puddling furnaces these would make use of limited quantities. The bulk, however, eventually found its way into the steel furnaces where common merchant bars were rolled for the market. The loss in the conversion was necessarily very high—considerably over 25 per cent., and hence the price paid was correspondingly low. The further away from the steel centers the lower the quotation on account of freight rates.

The first trials made in the foundry consisted in boxing the material in wooden containers. These served to hold the borings together until the wood had burned away, which was low enough down to allow sintering together and melting more or less successfully. The interesting feature of this method was that with good melting practice—that is, proper charging and coke and blast proportions—there was not sufficient free oxygen present to burn the wood, and oftentimes charred pieces remained in the cupola drop. Foundrymen would use this method when they wanted to close up the grain of their castings, the partially oxidized borings hardening the metal by raising the combined carbon. The method, however, proved too great an expense with wood and labor at the figures they were. Hence, one rarely hears of it today, and even then the castings made are questionable when machined.

The next method in vogue at a period some 30 or 40 years ago in the anthracite region of Pennsylvania, and probably elsewhere, was the use of borings in powder cans. These were usually filled up three-quarters and the top battered over to close up the can sufficiently to prevent the escape of the material into the cupola until sintered together previous to actual melting. These cans full of borings were thrown into the cupola on the bed or during the charging, and seemed to have melted all right. The scarcity of cans eventually caused the abandonment of this method.

Other methods of charging borings directly in the cupola have all failed because these would find their way downward into the zone of free oxygen and not only burn up, but by entering the metal as an oxide, ruin the heat. The machine shop would perhaps lose ten times the money saved by using the borings in the foundry.

An interesting development in this connection is a method by which the borings are forced into the cupola a little above the melting zone through the side, by suitable machinery. The intention is to get the material into sintering heat without a chance to drop loosely among the pieces of the charges. Good results are claimed, but the process has evidently failed to satisfy every requirement, as one does not hear any more of it. Unfortunately the material is pushed into the cupola just where some free oxygen travels upward along the lining, and moreover it would seem impossible to supply the necessary additional fuel at the place and time when needed to melt this extra stock. The results must therefore be ununiform and hence not satisfactory.

The first of the really successful processes—if one is satisfied with the results as obtained—is the Prince method of melting borings in tubes. Here sheet-steel stove-pipe in 2-ft. lengths, and perhaps 10 in. in diameter, is used to make up a tube from the bed to the charging door (Prince places two of them in his cupola) and this is filled with the borings, preferably from an upper floor charging door, so as not to interfere with the regular charging of metal and fuel about the tubes. After blast is put on and the charges descend the tube goes with them, and in order to add to its length a bucket of water is thrown through the charging door over the cupola filling which effectually quenches the flame for a few minutes and allows a man to slip on another tube length. This is then filled with borings in the usual manner, and the heat progresses.

As can be imagined, there are advantages to this process and disadvantages. For the former it may be said that if everything goes right, the results are fair. The borings of a shop are used up and the melting loss runs from 12 to 18 per cent. Steel can be added to the borings and thus mixed material as well as straight steel turnings be disposed of. The disadvantages are, however, quite numerous. They are the following: A long tube is difficult to hold in proper position throughout the heat, and hence occasionally opens up, thus allowing the borings to stream out into the charges. This is quickly noticed at the charging door, and subsequently in the machine shop where the castings made are finished up. Heavy losses result from such a tube difficulty and where much machining is done and pin holes are not tolerated in finished surfaces, the method will have few friends. While practice makes perfect, the author remembers having made ten 50-ton heats with this tube method, and through tube difficulties considered only four of the heats as reasonably satisfactory. Subsequently, the author changed the method of placing the tubes, alternating positions on the intermediate coke layers as charging proceeded (at every change the bottom of the tube was provided with a cap to hold the borings) and got less trouble from shifting tubes. There was another object in doing this, however, and that will be seen from the following:

It stands to reason that when such a long tube full of borings is placed on the coke bed, and descends in this same position all through the heat, there is no possibility of replacing the coke directly under it and hence it must push down into the bed some distance. This is aggravated by the fact that borings melt with much greater difficulty than straight cast iron, on account of the air spaces between each chip and within the cracks of each chip. The bottom of the tube, which first becomes red hot, sinters together and then melts off, must necessarily get into a region where there is some free oxygen, and suffers accordingly. Hence, the author's experiment in shifting about the tubes as the heat went on—to enable the bottom to stay out of the danger zone better. The purpose of the steel tube is to hold the chips together until sintered, steel having a higher melting point than cast iron. This purpose is evidently anticipated by the powder-can method above described.

The next disadvantage of the tube process is its expense. In ordinary times, the cost of the sheet steel and labor to form the tubes runs not less than $1.15 per ton of borings melted, and if caps are added, as in the author's tests, this expense goes up still higher. Perhaps, however, this is not so serious an item as one cannot expect to obtain a valuable result for nothing. Another disadvantage—inherent to all borings processes—is the greedy absorption of sulphur from the gases and undue loss of silicon and carbon in melting. The nature of the case accounts for this. The great proportion of surface to weight means greater oxidation in melting, and the breaking up of the chip as it is machined off means a serious loss in loose graphite.

The final disadvantage of the process is the unhandiness. Melters do not like it. It is a nuisance about the place, and this may account for the very poor results obtained in some places as against the comparatively good ones in the foundry of the inventor. Were it not too expensive, the old powder-can method would be best in using borings loose, as these could be charged just like large pieces of scrap.

Other processes brought out just after the tube method make use of core binders to consolidate the borings into briquettes suited for cupola charging. Results vary between good and bad here also. Probably where the briquettes have held together until they got into the melting zone, and at the same time could be kept free from oxidizing action through good melting practice, the results were fair, but where these conditions did not intervene the results must have been no better than obtained by charging borings directly into the cupola.

The best method so far brought out is that of briquetting under enormous pressure. This requires no binder whatever, if properly carried out, and gives excellent results where excessive machinability is not absolutely essential. Mention of this process has been made in Chapter VI, under the head of "Specific Gravity." The process was developed by Ronay, the underlying idea being to apply pressure in successive stages and thus allowing the entrained air to escape in great measure before extreme power is applied. The amount of work is thus reduced and power correspondingly cheapened over that required for the same degree of pressure applied at one stroke. Ronay uses no binder whatever. Another inventor, Weiss, to overcome the Ronay development, adds lime-water as a binder but beyond increasing the expense the difference in value of results is not noticeable.

Another, very recent process uses the explosive force of the gas engine to produce a briquette at each impulse. As such a blow cannot allow the entrained air to escape there is little to commend the operation unless the briquettes made be very small. Considerable quantities can, however, be handled this way. A small briquette is an advantage as it melts faster than a large one. Unless, however, the briquettes can withstand the rough usage of cupola melting—the very process being against this desideratum—the melting results will be no better than where borings are charged direct.

The advantages of the briquetting method are the following: A consolidation of the borings to a point which reduces the relation of surface to weight enormously, and hence offers less chance to oxidation effects. The pressure being about 35,000 lb. per sq. in., if the borings are first ground up and cleaned, a briquette is made that is almost as solid as pig iron. If the borings are used raw the melting results will be identical with those of the Prince process, some losses going as high as 17 per cent. This, however, is due to the composition of the borings in great measure, some of the cleanest in the market showing not over 85 per cent. in actual iron content.

Another advantage is the fact that the briquettes are charged directly into the cupola just as pieces of pig iron. They are not at all unhandy, in fact quite the opposite. While the installation of a plant is quite expensive, the operating cost is less than $1 a ton of borings briquetted, and this accounts for the fact that in Europe where the process was originated, there are more than 25 central plants taking the borings from the surrounding regions and supplying the foundries with briquettes as a custom operation. The foundries being all financially interested in the plants, send their borings on and receive their own metal back in shape of briquettes.

The disadvantages of the process are the following: The great cost of the presses precludes investment by the individual foundryman, and very large concerns usually have specialty work which requires the utmost attention to ease in machining. The second disadvantage is connected with this fact. In Europe they make their castings of the right kind of metal for the purpose required, irrespective of what the machine shop may say to this. In America the foundry is in trouble the moment the machine shop sends word that the castings are hard to machine. As previously stated the physical condition of the individual chip of cast iron is such that in melting—even if enormously compressed as in these briquettes—the silicon will drop about double as much as in melting pig or solid scrap, the sulphur will go up perhaps double also, and the total carbon will be reduced on account of the original loss in graphite in machining and the further burning out in the melting. The result is a harder, if stronger metal, which offers more resistance to the tool than where briquettes are not used. Overcoming this by silicon increases means more expensive pig iron in the mixture, and hence the use of cast-iron borings briquettes will be better adapted in America to the making of heavy machinery castings—where, indeed, trials so far made have fully borne out the contention.

The use of this material, however, is bound to come in time particularly as additions of steel scrap to foundry mixtures, thus increasing strength by a reduction in the total carbon content, are coming more and more into general use, and machining is provided for by cutters which will stand the wear of harder material without special difficulties.

In order to make use of soft steel turnings in the briquetting process, it is necessary to cut these up by feeding them into shears or punching presses with enough strokes per minute to make the operation a very cheap one. When it is remembered that steel and gray iron borings or chips can be easily mixed up and pressed into briquettes, this method will be seen to offer a solution for the effective and advantageous disposition of thin steel scrap.

If the steel turnings are of high enough carbon content to be brittle, they may be fed into a Hardinge or Krupp mill. If desired, the chrom-steel balls may be replaced by scrap ends of billets or other chunky material. Large tonnages can be thus broken up for subsequent briquetting.

A final word of warning in connection with briquetting processes, to save disappointment. The only mechanical contrivance to give the high pressures required successfully is the hydraulic press. But even with this apparatus it is necessary to give the material compressed time enough to allow the entrained air to escape. If this is not provided for the briquettes will be weak and actually go to pieces within a few days. Much disappointment and money loss has resulted from such a situation. It is therefore best to compress in steps, allowing an interval of time between the load applications. By combining the several pressure applications in a press provided with a revolving table these may be carried through simultaneously, and the necessary time given for successful work.

Ferro-alloys.—The use of ferro-alloys in the foundry is not to be recommended as a general proposition, for this form of high-percentage elemental addition to the mixture or molten metal is necessarily expensive. It is usually cheaper, and certainly better, to make the proper selection of pig irons in the first place, than to add the required element later on in the ladle. That this is not always the case, however, is shown by the possibility of running comparatively low-silicon heats for general casting work, and adding ferrosilicon in proper proportion to the molten metal for pouring specially soft or light work, and doing this quite economically. It is unquestionably true that with the extending use of the electric furnace the production of the ferro-alloys will be systematized and cheapened. The foundry will then be confronted with the problem of utilizing the advantages offered or else missing an opportunity for economy in operation. The solution of the problem, however, will lie in getting these ferro-alloys into the molten state before adding to the ladles, so that no heat may be lost and casting difficulties thus avoided.

In general, it may be said that ferro-alloys should not be melted directly with the mixtures in cupola or furnace. The chances for oxidation are too great and the losses in the particular element involved serious. In the case of the air furnace the ferro-alloy may be introduced into the bath under the slag cover, the metal rabbled well and, when sufficiently hot, promptly tapped out of the furnace. In the cupola, however, this cannot be done and the most effective method of introducing the ferro-alloy is to sprinkle the powdered material on the stream of molten metal right at the tap-hole, so that as the metal runs into the ladle it has not only heated the ferro-alloy red hot, but may have incorporated it completely. This method is better than placing the ferro-alloy in the ladle and letting the stream of molten metal impinge upon it. The material will usually float and become red hot in the presence of the air, thus oxidizing some of the elements contained. Further, it is not easy to get a thorough incorporation of the material that way.

For the lower grade of ferro-alloys, such as 15 per cent. ferro-silicon, silicospiegel, spiegeleisen, etc., the above described method of introduction at the tap-hole of the cupola, or adding to the ladle in the cold state will not do, as the quantity required to make the desired correction in the metal to be poured will be too great. Hence, melting in the cupola is essential unless the air furnace is making the heat in question. In melting in the cupola, the lumps of the material should be fairly large, the fuel bed high, and plenty of coke between the charges—to avoid oxidation as much as possible. In Bessemer steel practice "spiegeleisen" (if this is used) is melted thus, and quite successfully.

One case may occur in foundry practice where it is necessary to add the ferro-alloy to the ladle after this has been tapped out. This is where a chill test is taken from the ladle to see whether the metal requires correction by ferromanganese, ferrosilicon, or silicospiegel additions. The proper amount to be added in such cases will depend upon the indications given by the chill test pieces, and is a matter of practice.

To understand the peculiar sensitiveness of ferro-alloys to oxidation in melting, it must be remembered that in their production it is necessary to attain very high temperatures and to use a great fuel excess. Oxygen is so firmly united with manganese, titanium, silicon, etc., that it is not only difficult to pry them apart, but they reunite at the slightest provocation. The blast-furnace man, accustomed to his regular casts of 100 or more tons of metal, can hardly believe his eyes at first when burdening for ferromanganese. His taps give him but a little pool of this highly expensive material. Those who know something of the metallurgy of tin will understand the situation best, for here we have a shaft furnace full of incandescent charcoal necessary to reduce the comparatively small charges of tin ores introduced at intervals, the product being a thin stream of the glistening clean metal. Hence the greatest care must be taken to protect the comparatively expensive ferro-alloys from undue oxidation, as the costly elements are thus partially converted to comparatively cheap ores and go into the slag.

Ferrosilicon.—As the most important of the ferro-alloys used in the foundry, this will be discussed first. The range of silicon in pig irons begins with a trace and ends with almost 100 per cent. of this element. For practical purposes, however, ordinary pig irons do not contain more than 3.50 silicon, and between this and 7.00 they are sometimes called "Scotch" irons, or "softeners"—though a simple specification of the silicon desired will enable the furnace to select the proper cast from its stock. From 7.00 to 12.00 per cent. silicon pig irons are known in the trade as "silvery" and are thus quoted in the trade reports in advances by 1 per cent. between the limits given. "Bessemer ferrosilicon" is also quoted by 1 per cent. advances between the limits of 9.00 and 16.00 per cent. This will not run over 0.10 in phosphorus and 0.05 in sulphur.

The standard ferrosilicon for foundry use is supposed to contain 50 per cent. silicon. Actually it may run as low as 40 per cent., and prices are agreed upon per unit of Si for variations either way. A special brand is made up to 75 per cent. in silicon, with similar provisions for variation per unit either way. These foundry grades are all made in the electric furnace, and the 75 per cent. alloy is recommended where a considerable increase in silicon is wanted in the metal before pouring, as this cools the ladle least. Unfortunately the element silicon, which is made in the electric furnace and has a silvery appearance, is infusible under ordinary foundry melting temperatures.

Ferromanganese.—Originally used by Outerbridge in the production of high-grade car wheels. He had found that the use of very small percentages of manganese strengthened the metal and reduced the chill somewhat. Unquestionably this was due to a de-oxidation of the metal only, as sulphur was not in evidence so seriously in the early days.

As stated previously, ferromanganese is sometimes used as a corrective where it is necessary to produce castings of a given quality—as indicated by a chill test made on the ladle full of iron previous to pouring. A more marked reduction in the chill—meaning softer castings when poured into the molds subsequently—is obtained by using manganese combined with silicon. Probably the most important use of ferromanganese at the present time is for de-oxidation purposes where steel scrap is added to the cupola mixture. This is the cheapest method of getting rid of the gases in iron, as well as the oxide of iron present which gives rise to the subsequent formation of gas by a reaction with carbon even during the actual pouring operation. Where heavy steel percentages are used—up to 50 per cent. of the entire heat—the addition of ferromanganese may be considerable, experience teaching the right amount, namely, that which after using up enough manganese for de-oxidation purposes, leaves about 1.00 in the casting. The limit for this addition in the ladle is naturally indicated by the loss in temperature allowable before the metal must be poured. Cases in which over 2 per cent. of the standard 80 per cent. Mn ferromanganese have been added are common knowledge, though when the oxidation is so serious, such de-oxidizers as metallic aluminum are probably better.

The standard ferromanganese in the market contains 80 per cent. manganese, and is the kind to be used in the foundry. There is much of this alloy in the market, however, that runs below the point given, and practically every percentage down to 30 per cent. can be obtained under the name of ferromanganese.

Another use of ferromanganese is found in making high-manganese castings for crusher purposes. The bulk of the manganese is preferably obtained by selecting high-manganese pig iron (Mn from 2.00 to 4.00). Any deficiency can be made up by adding the necessary quantity in the ladle in the form of 80 per cent. ferromanganese.

Spiegeleisen.—Sometimes abbreviated to "spiegel," or called "specular" pig iron. This is a wonderfully crystallized and colored metallurgical product, and runs from 10.00 to 30.00 per cent. in manganese. It is used principally for steel-making, as the foundry is seldom called upon to make castings for which this material would be melted, the manganese ranges being much lower, and better results obtained from straight high-manganese pigs.

Silicospiegel.—In the above given ferro-alloys the controlling element is that which gives the name to the product, and the percentages of the elements other than iron, besides the important one, are inconsequential. Hence ferromanganese contains little silicon, phosphorus, sulphur, etc. As it is sometimes very important to add both silicon and manganese to the ladle, a ferro-alloy called "silicospiegel" is in the market, the analysis of which runs about 6.00 to 12.00 in silicon and 17.00 to 22.00 in manganese. In spite of the advice by the author given above—that ferro-alloys should not be melted in the cupola, he will confess doing this very thing on one occasion when he had to produce about 50 tons of castings daily without a pound of pig iron in the yard. Three per cent. of silicospiegel added to miscellaneous cast scrap made up the mixture run through the cupola and gave perfectly successful castings. The silicon of the ferro-alloy took care of that lost in melting the gray iron scrap, and the manganese of the silicospiegel helped with the sulphur and oxygen taken up. Fortunately, the freight embargo was broken after 3 days of this and pig iron came in again, otherwise trouble from oxidized metal would certainly have come with the heavy percentage of sprues returned to the heats and no clean pig iron to carry the bad effects away.

Ferrovanadium.—This alloy is not only a de-oxidizer but when used in sufficient quantity adds strength to cast irons of high combined carbon content (see Chapter IV). It is now produced with fairly high percentages of contained vanadium, from about 15.00 to 45.00 being the range.

Ferrotitanium.—This is also a de-oxidizer and of more particular use for burnt gray iron. For foundry purposes—on account of the lower melting temperatures prevalent—the lower grades of ferrotitanium are recommended, as the higher ones are almost infusible in the ladle and too expensive to run through the cupola.

About 9.00 to 13.00 per cent. titanium in the ferro-alloy would cover the case.

Ferronickel, Ferrotungsten, Ferromolybdenum, have hardly any application in the foundry, though the last-named has been successfully used in car-wheel manufacture, and lately ferrotungsten in automobile engine valves. They are too expensive, and hence purchasers will do better to use steel castings in the first place.

Ferrosodium, Ferroaluminum and eventually *Ferromagnesium* would serve as de-oxidizers, but too little is known of their efficiency as yet. *Ferrophosphorus* is a valuable alloy where high-phosphorus irons are to be made in foundries not stocked with stove-plate pig iron. Art castings, for which the molten metal must be extremely fluid, can be undertaken by foundries having the fine grades of molding sand. Very little of this alloy, however, gets into the general foundry. The phosphorus content usually runs about 10 per cent.

Deoxidizers.—The following available elements (practically all in form of ferro-alloys) can serve the foundry by removing dissolved iron oxides when added to the molten metal. They are given in the order of their relative efficacy: Titanium, aluminum, manganese and silicon. The others are either too expensive or not sufficiently known. Aluminum is now cheap enough to add in its metallic state rather than as a ferro-alloy.

The author would again state in this connection, that it is far better to melt the foundry mixtures under conditions that preclude undue oxidation than to subsequently correct the trouble by adding de-oxidizers. As an extra precaution, however, or insurance, particularly in making highly expensive castings such as jacketed gas-engine cylinders, there is no reason why metallic aluminum or ferrotitanium and vanadium may not be added to remove occluded gases and dissolved iron oxides. The proper amount to add has been found by experience to be 0.1 per cent. of the element in question, or 1 lb. for every 1,000 of the charges.

FUELS

Beginning with the original form of fuel, *wood,* we find this now used only for lighting up cupola or furnace, and for drying out the ladles. Practically any kind of scrap wood about the foundry will do, though the best results are obtained from hardwoods cut specially for the purpose and at the proper season (maple, etc.).

Even this fuel is being replaced in many foundries by fuel oil on account of the smoke nuisance. As, however, most foundries accumulate a lot of scrap wood from worn-out flasks, the pattern department and shipping room, a compromise is usually effected, the cupola being lighted up with oil and the ladles dried out in the open with wood.

Charcoal.—This is the residue obtained by the dry distillation of wood. It was the earliest metallurgical fuel used, being easily made. So far as the foundry is concerned, it is no longer made use of for melting purposes, as it is too expensive and the waste is very great. The highly developed cellular structure of charcoal and the ease with which it burns promotes the rapid formation of carbonic oxide (or incomplete combustion of carbon). This means lower temperatures and indifferent melting results. Hence, to accomplish anything in the way of good melting a great excess of fuel must be used, and this is costly (see Chapter V).

The records of cupola melting with charcoal, as practised in Sweden in the early foundry days, are of great interest. The earliest pseudo-cupolas (Réaumur tilting cupolas) melted 100 lb. of iron with 55 to 75 lb. of charcoal—the melting loss being 5 to 9 per cent. of the metal. The more modern constructions did not do so much better either, for Karsten mentions 50 lb. of charcoal as melting 100 lb. metal ordinarily, but when the pig iron was fusible with difficulty, it took 66 lb. of charcoal. An East-Prussian charcoal blast furnace, when used as a cupola for simple melting, did its work with 36 lb. charcoal per 100 of pig iron. The experience gained indicated that the higher the cupola, the better the melting ratio, or just what we know today with our coke-fired cupolas.

Charcoal is used in the foundry today as a cover for the molten iron held in ladles, to protect the metal from surface oxidation and too quick a loss of temperature. Where charcoal is cheap enough, it is used for heating up the ladles and also for the little stoves put into molds for skin-drying purposes.

The composition of charcoal (hardwood) would be about as follows:

Moisture	4.50
Volatile matter	5.50
Fixed carbon	89.00
Ash	1.00
Sulphur and phosphorus below	0.05

Bituminous Coal.—For metallurgical purposes only the best grades of gas coal find their way into the foundry. They are used for air-furnace melting and, where cheap enough, for firing annealing ovens. The ordinary grades of coal of the region go into the boiler room.

It is important to watch the analysis of coals used for air-furnace purposes, as well as the general appearance, for it is difficult enough to get and hold very high temperatures even with the best of firing practice without having to contend with poor coal in addition.

A typical analysis of good gas coals would be the following:

Moisture	1.00
Volatile matter	37.00
Fixed carbon	56.00
Ash	5.00
Sulphur	1.00

There is, of course, a considerable variation from the above figures permissible, but after all "the proof of the pudding is the eating" and certain coals, such as the "Westmoreland" varieties, have attained an enviable reputation for quality in air-furnace practice.

The essential characteristics of a good gas coal for foundry melting are low moisture, ash and sulphur, with high volatile matter and fixed carbon. In times of coal shortage, when almost any kind of gas coal has to be used or the plant shut down, the moisture has been known to run up to 2.50, ash up to 10.00; and the sulphur over 2.00 per cent. The metal produced has naturally suffered badly, for where ordinarily the sulphur in castings would not exceed 0.06, it has risen to 0.24 under such poor coal conditions. The volatile matter of a coal should not be allowed to drop below 35.00, and the ash held below 7.00 if possible. The lower the sulphur the better, many coals having but 0.40, and this may be either in combination with organic matter or present as a calcium sulphate (gypsum).

Bituminous coal is usually bought as it comes from the mine, or as "run-of-mine" coal. This means lumps and a certain percentage of "slack" or fine material, the latter usually more or less heavily charged with slate or dirt. Since it is very difficult to burn slack coal—special step grates being required for this—as the air used for combustion cannot circulate through it freely, it is important to retain the coal bought in lump form as much as possible. Hence the objection to conveying machinery in handling the grades used for the air furnace, there being so much breakage connected with the installations as ordinarily carried out.

Many gas coals run up to 40 per cent., in volatile matter, and the so-called "cannel (candle) coals" may even show 70 per cent. volatile matter. In burning all these gas coals a long flame is obtained, thus carrying the actual process of combustion far beyond the fire-bridge, and almost to the end of the furnace proper. This allows a practically uniform heating up of the walls and roof of the furnace and the consequent radiation of these incandescent surfaces of their heat upon the iron on the hearth. Melting and superheating of the metal is thus accomplished. On the other hand, the low-volatile coals yield no long flame and consequently their heating value is confined to the firing end of the furnace more particularly, with very poor results at the stack end. The details of efficient firing will be taken up in discussing air-furnace melting.

The softest variety of bituminous coal—*lignite*—has not yet found an extended metallurgical application in America, though many tests have been made to render this source of heat available in view of the rapidly diminishing coal resources. Germany, however, has done much in this direction, and the author personally saw the successful application of raw slack brown coal (lignite), on mechanical stokers, to the annealing-oven system of a large malleable-castings establishment.

The composition of lignite—of which immense deposits exist in the United States and Canada—varies considerably, the volatile matter running up to 50 per cent., ash from 1 to 10 per cent., and sulphur often as high as 3 per cent. It is ordinarily a very moist fuel (up to 25 per cent. moisture) and hence is dried before use. The methods of briquetting lignite involve extensive drying apparatus. The material usually goes to powder on the removal of the water content. Superheated steam is then applied and the bitumen content of the lignite begins to run. This serves as a natural binder for the material when put under high pressure while in the heated condition.

Anthracite.—This fuel was formerly used in cupola melting in the eastern part of the United States from the time that the foundry became an independent industry until very recently. It is still used today where freight rates allow it and it is not essential to have big tonnages of molten metal in the shortest time possible. It was the natural fuel to use, with the example of the blast furnace at hand. As coke, however, came into use in the furnaces, first in admixture with anthracite, and eventually altogether in the regions away from eastern Pennsylvania, the foundry followed suit, and but little anthracite is used at the present time. Where foundries still cling to it, and tonnage is wanted badly, this fuel goes into the bed, and the subsequent intermediate fuel charges consist either entirely of coke or else alternate with anthracite.

The density of anthracite and its entire freedom from a cell structure makes it burn much slower than charcoal or coke. Hence, the melting rate for a given diameter of cupola is smaller than when coke is used. On the other hand, the sulphur trouble is not quite so bad when anthracite is used, and hence light castings get the benefit of this. Where, however, tonnage is essential —which means that the time for "blast on" must be pushed as late in the afternoon as possible—coke is the only fuel to use.

The composition of anthracite coal would be about as follows:

Moisture	2.00
Volatile matter	5.00
Fixed carbon	83.00
Ash	10.00

Sulphur would run about 0.70, but may go up to 1.50 at times.

Coke.—This is the product of the dry distillation of certain kinds of bituminous coal. That made for metallurgical purposes should be hard, porous, and strong enough to carry a burden of ore or metal dumped upon it from some height. There are two kinds of "standard" coke used in the foundry: bee-hive coke, and by-product coke. A third variety is seen occasionally in plants where extreme heat is required, namely petroleum coke—the residue of the distillation of crude oil.

Mention was made of the earliest coke-making, in England (see Chapter I). The first records available on the subject for the United States have it that coke was "made on the ground" in Fayette County, Pennsylvania. In 1825 Wm. Strickland was sent to England to study the status of the iron industry and coming back reported on coke-making. As the result of this, trials were made in western Pennsylvania furnaces. 1841 seems to mark the beginning of the bee-hive oven, which became a regular producer by 1855. Since then coke-making has jumped to enormous proportions.

The original method of making coke was undoubtedly along some charcoal-burning system—that is in heaps or mounds. Indeed, the Cambria Iron Co. developed their mound system to a pretty high state of perfection in the Allegheny Mountains. The waste attending this method, and the unreliable results caused its abandonment for the bee-hive oven.

The by-product oven system of coke-making is comparatively recent in date, but is rapidly expanding where tar and gas can be disposed of profitably, for economy in natural resources is the order of the day. There are a number of improvements on the bee-hive oven in operation at present, in connection with a partial recovery of by-products, and labor-saving appliances to reduce the number of men required. With all the good these developments bring about, they will all have to yield eventually to the straight by-product oven, once capital is available in very large blocks, and the prejudice of the bee-hive coke operators and consumers have been overcome.

Petroleum coke is a still more modern article. It is almost as porous as charcoal, burns remarkable free and with intense heat, and hence is used where much steel scrap is added to the mixture. Freedom from high sulphur and a very low ash makes it a very desirable fuel, provided the cost is not too high in comparison with regular coke.

To understand the coke situation from the foundry standpoint, it is necessary to discuss the methods of coking to some extent. When the so-called "coking" coals are heated very highly, either by setting fire to them or by confining within retorts and applying fire from without, most of the volatile matter is driven off in form of gas and tar—the remainder is cracked up to carbon and gas and increases the coke yield. Some coals yield a very light and porous coke while others result in a very dense and heavy material. The heating process produces a cellular structure which may run from 37 to 59 per cent. of the mass (U. S. Geological Survey tests). The denser varieties are better adapted for foundry melting as they do not catch fire so readily in the upper charges of the cupola, will burn with less carbonic oxide formation than the lighter varieties, and finally, will support the metal burden better. A cellular structure of 40 to 45 per cent., in combination with normal ash content, fills the requirements best. Light coke is more desirable for blast-furnace operation, as here a rapid conversion to carbonic oxide is required for the proper reduction of the iron ore. Again, with a knowledge of the principles underlying rational cupola melting, even the lightest of cokes can be made to serve, though as stated, the denser cokes are more desirable.

Whether coal is charged into the bee-hive oven or into the by-product retort, it enters a chamber of red-hot brickwork, and immediately has set up within it a destructive distillation from the top and surface contact inward. Heavy yellowish vapors are driven off which burn with a smoky flame when allowed to pass into the air, as in the bee-hive oven; but are caught and washed for by-product recovery in the retort oven process. The coal gradually becomes red-hot and, air being excluded, remains so until all gases have passed away. The coke is then quenched before or while removing from the ovens, and is ready for sorting and shipment.

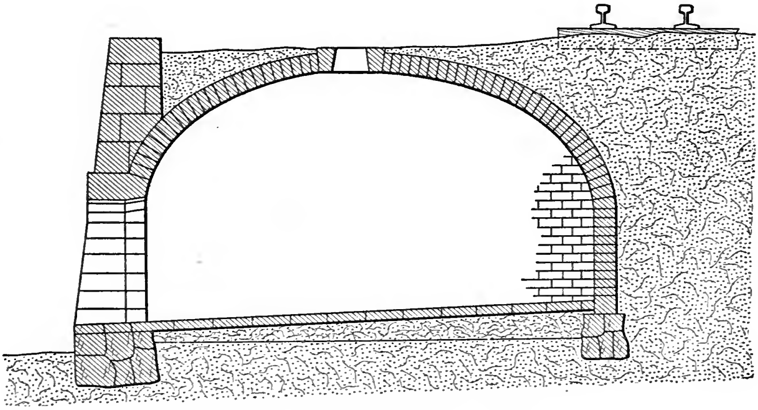


FIG. 23.—Section of bee-hive coke oven.

Taking up the bee-hive product first: Fig. 23 shows a section of the ordinary oven construction, from which will be seen that the coal is dropped through the roof, and the door being partially bricked up, can readily be spread out evenly with suitable iron bars. The inner walls and bottom being at a dull red heat, gas formation takes place almost at once. When the stream of gas is strong enough, this catches fire and burns from the roof with a smoky yellow flame, as may be seen any day or night in passing through the coking regions of the United States. This burning gas represents the loss of enormous values and fortunately is steadily decreasing as the by-product installations for coke-making increase. One does not find the bee-hive oven or the old coking mound or pile in Europe any more.

As the process of coking proceeds from the top downward it is apparent that the leveling process after charging must be carried out conscientiously, and also that the coking process itself should be completed before quenching, as otherwise there will be an excess of "black-butts" or poorly coked coal from the places where the charge was left too high. It will also be realized that the thicker the charge the longer it will take to coke it properly, so that one can make 24-, 48-, 72-hr. or more coke at will, and do it successfully. The author has often seen ovens—in times of over-production—charged so full of coal that they could safely be held a week and yielded a magnificent product, the columns being 3 ft. high where the ordinary coke is but 18 in. long.

After coking has been completed some of the bricks are removed from the oven door, to introduce the perforated pipe for water-quenching. Only enough water is used to lower the temperature of the mass sufficiently so that the coke will not burn when brought out in the open. With this small quantity of water and the practical exclusion of fresh air from the oven there results a fine silvery appearance of the coke fractures, in contradistinction to the dull blackish appearance of the by-product variety which suffers a severe drenching as it is withdrawn from the retorts. The little globules and silvery filaments seen in coke are the result of the carbon deposition taking place during the distillation process.

The physical structure of the coke exhibits further characteristics. The top of the charge having been exposed to air currents to a greater or less extent, some of the material will have burned away, and hence the ash content of the tops will be high. The central portions of the coke column are the best, being fine, normal material. The bottom of the mass, resting on the floor-tiles of the oven, is naturally under lower temperature conditions than the rest of the charge and hence may not be coked as completely. It will retain some volatile matter, and, being light and open in structure, will dissolve in the cupola or furnace gases and give little effective service. Hence the demand of the purchaser that he receive a minimum only of black-butts or ends in his shipments. Hence, also, the care taken by the coke producer to give the foundryman only the central portions of the oven product, reserving the material at the door and along the side walls for blast-furnace consumption.

From the nature of the coking process the only advantage offered by 72-hr. coke over the ordinary 48-hr. variety lies in the length or height of the coke column. The percentage of sound, high-grade material in the longer pieces, as compared with shorter 48-hr. columns, is naturally greater, and hence this coke commands a higher price. When the foundry demand, however, exceeds the supply, the foundryman gets the selected 48-hr. product, and will not be the wiser unless the lumps can be pieced together in a fashion to get at the length, or rather height of the coke column.

Again, the cell structure of a coke is an important physical characteristic. This structure is formed in the early part of the coking process. It depends a great deal upon the continuity of the cell system whether in quenching much of the water used will be retained. Under the temperature conditions in the oven the gases in the cells are so attenuated that the sudden cooling results in sucking in water, and this remains as part and parcel of the coke until used. The "moisture" of a coke analysis is really made up of two things: the water contained in the cells that can only be driven out in the melting operation; and the surface moisture from rain and condensation, all of which dries away when coke is stored. A coke, therefore, which has come in from the road in an open car may analyze 14 per cent. in moisture, but on drying out under the shed drops back to the normal up to 2.50 per cent. This for bee-hive coke. In the case of the by-product oven variety, the system of flooding the red-hot coke as it is withdrawn from the oven results in a normal moisture of up to nearly 5.00 per cent.

From the nature of the charges in the bee-hive oven, the fractured pieces may be taken out as large as the charge was deep; whereas in the by-product retort oven, heat being applied from both sides, there is a plane of separation in the center—the fractured pieces being but half the width of the retort. Hence by-product coke is short and chunky as compared with the bee-hive variety which is long and pillar-like. In addition to the peculiar fracture of bee-hive coke, certain coals (notably the Connellsville) yield coke which shatters into finger-like pieces, called "finger-coke," and this causes the "breeze" or fine coke, which is useless in foundry melting. In the by-product process, which requires the coals to be ground fine, and allows the mixing of coal varieties, these features are not as annoying, for there is usually a market for the fines in domestic service, and "finger coke" is rare. Fig. 24 illustrates the cleavage system of both classes of coke.

The coke operator can do very much toward producing a high-grade product for metallurgical purposes. Not only can he grind and wash the coal even for the bee-hive process and thus get less ash and sulphur content and more uniform composition and structure, but by mixing his coal varieties he can get the physical and chemical characteristics of the resultant coke more adapted to the requirements of his customers. Coke-makers, as a rule, watch these things and strive to give the foundrymen the best they can considering their mining, water, and labor conditions.

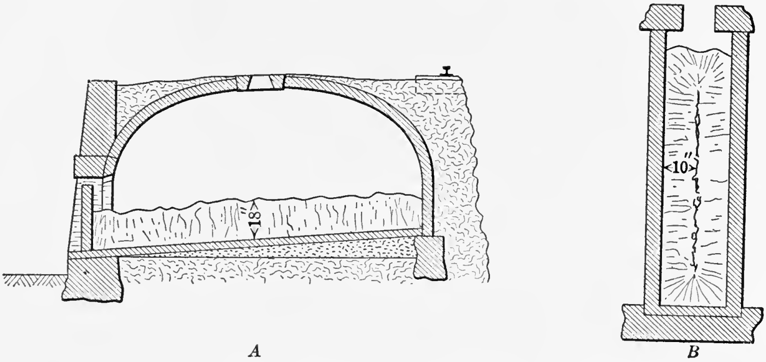


Fig. 24.—*A*, Coke in bee-hive oven; *B*, coke in by-product oven.

In discussing the by-product process for coke, this much can be said: The degree of skill required is far beyond that for bee-hive practice, and hence a higher grade of operatives is required. The disadvantage of the situation, however, is that the principal values of the distillation process, other than the coke itself, are gotten in the first 15 hr. of the operation. Hence the temptation to draw the oven and fill in a fresh charge. The best metallurgical coke—so far as its physical structure is concerned—is gotten when the process is made to occupy about 30 hr., or double the time necessary to get the by-products, which means cutting the capacity of the plant in half. Progressive by-product people strive for a mean between the two courses, and carefully classify the product for its structure, giving the foundrymen the best. The mixing of coals, allowing about 25 per cent. volatile matter as the best average, means a pretty uniform result which in turn has given well-made by-product coke so good a reputation that in some regions it commands a premium and is preferred by foundrymen over the bee-hive product. The future will undoubtedly see developments in by-product practice, in the way of fuel purification, etc., which will help the foundrymen overcome melting difficulties now gradually becoming more acute.

Coke breeze is the fine material rejected by a fork with prongs about 1½ in. apart. It can be used for heating core-ovens and on the molding floor. Coke should be handled as little as possible to save breakage and consequent increase in the percentage of breeze. On the other hand, it is not good to charge very large pieces of coke, as it makes the course of the blast somewhat irregular. The best form of coke for cupola melting is in lumps in size between the double fists and an ostrich egg.

The tendency of coke to break up in transit and in rehandling has led to many attempts to overcome this trouble to some extent, and as a measure of the friability of the material the so-called "shatter test" has been devised. Blauvelt has worked out a system in which a given weight of coke at the ovens is placed in a box with drop bottom, and the charge is allowed to fall a certain height. This is repeated a given number of times, the coke then passed over a screen of given mesh and the material passing through weighed. It is intended to reproduce conditions of loading and unloading in transit, and of weighing and charging at the cupola. The percentage of breeze produced in this test determines the availability of the coke for foundry use—from the physical standpoint. Where this test is used at the producing plant, experience has shown the dividing line between coke fit for the foundry and that which must be relegated to domestic use. The test itself has not been developed to an extent allowing it to be added to specifications, but may eventually arrive there. Coal is still too cheap in the United States to cause the consumer serious concern with quality details he thinks trivial. But the time is rapidly coming when economy will have to be carried to the utmost of detail, and then very strict specifications will differentiate fuels, among many other things, into classes for which the prices paid will be regulated by the intrinsic values.

The question of standard specifications for foundry coke is constantly becoming more acute, in view of the diminishing supply of high-grade coking coals. Foundrymen naturally want the best, but the coke producer has to reckon with the proper utilization of his reserves of coal. Specifications should therefore be reasonable and not based upon fancy requirements. The author recommends the use of the Standard Specifications of the American Society for Testing Materials, from which the following is abstracted:

Sampling.—The car load is taken as the unit. As unloading is impossible before definite acceptance without serious damage to the stock, the exposed surface must be taken for sampling operations. This is done by knocking off a piece the size of a walnut every 18 in. along three lines of the car from end to end, one passing through the center and the other two each 2 ft. from their respective sides. The total quantity of the sample to be not less than 2 pecks. This sample is now broken down and quartered, as described in the specifications, until a laboratory sample of 5 lb. is obtained. Special precautions are involved in the "moisture" situation.

Analysis.—The Standard American Methods of Analyzing Coke of the Society in question are to be used. The following are the limits allowed, "moisture" being cared for by adjustment of the invoice price, the car being weighed at the time of sampling, and any water over 3.00 per cent. deducted from the weight thus found.

Volatile matter, not over	2.00
Fixed carbon, not under	86.00
Ash, not over	12.00
Sulphur, not over	1.00

Fuel Oil.—This is a very concentrated form of fuel, and being liquid, is easy of application. Consisting principally of rich hydrocarbons of the paraffin or asphaltum base type, the calorific value is about one and one-fourth times that of coal. In view of the high value of the lightest constituents of the crude oil as it comes from the ground, this is now always put through a process of distillation to remove the gasoline and kerosene (carbon oil) for power and domestic uses. The residue is the fuel oil of commerce.

An analysis of fuel oil (Best) would give the following:

Carbon	84.35
Hydrogen	11.33
Oxygen	2.82
Nitrogen	0.60
Sulphur	0.90

For purposes of calculation, in making comparisons of oil with other fuels, its weight may be taken at 7.3 lb. per gal., and an average calorific value of 18,750 British thermal units (B.t.u.) per lb. A barrel of oil contains 42 gal. The gravity of fuel oil runs around 25°Bé., and the vaporizing point at about 130°F. for the paraffin base oils and 225°F. for those of the asphalt (California) base type.

The point of principal interest to the foundryman, in connection with the composition of fuel oils, is the sulphur content. In the ordinary uses for oil about the foundry, for heating core-ovens, annealing and crucible melting furnaces, and where economical for raising steam, a high sulphur content will not matter. But when melting is to be done, with the flame in contact with the metal, such as in air and open-hearth furnaces, or as developed lately, in the cupola, a low-sulphur fuel oil is essential. Fuel oils may run up in sulphur as high as 3 per cent., and certainly such a fuel cannot be used safely for melting purposes. As a consequence of this situation there is a commercial division into low-sulphur and high-sulphur fuel oils, and when the price allows it, the former is a very desirable material.

The use of fuel oil is growing rapidly in importance in those regions of the United States where coal and coke are highly expensive. Fortunately, nature has provided oil in or within reasonable shipping distance of these very regions, so that using it becomes a question of careful study and proper application in order to realize a full success. The use of oil is very hard on furnaces, as the heat can become highly localized. A high degree of atomization and a proper combustion space are essential to get a proper calorific effect, and as the author has been identified with the early applications of this fuel in iron melting and annealing, having used thousands of cars of fuel oil, a short review of the difficulties encountered may not be amiss.

Perhaps the original method of burning crude oil was that practiced in the oil regions in firing boilers. A series of pans, stepped over one another at the fire-door, were kept full of crude oil and this burned in the current of air that was drawn in between the pans. This method, though effective, was rather wasteful as combustion was incomplete and regulation imperfect. When the rich yellow oils of Pennsylvania became scarcer and the dark, evil-smelling product from the Lima district in Ohio had to find a market, an energetic campaign was undertaken to replace natural gas in industrial plants by this form of fuel. The author remembers the first contract being made for a period of 6 months at 2.4 cts. a gallon. The result of the campaign in question can be best seen from the fact that every 6 months the price went up, until, after passing 4 cts. a gallon, it became necessary to either revert to natural gas, make producer gas from coal, or use the latter fuel direct where possible.

In the meantime a number of burners and oil-gas processes were brought to the attention of the iron industry. Among the first was the *Archer* process, in which steam was made to carry the oil through a coil of pipe imbedded in incandescent fuel. The superheating of the steam and vaporization of the oil gave a gas which worked very well in melting and annealing but when the generating apparatus was choked up with gas-carbon and the lighter constituents of the crude oil had been distilled off before the cars came into the plant, the reliability of the process suffered, and eventually the high cost of steam caused attention to be directed to other methods of operation.

Next came the atomization of oil by steam or high-pressure air. This introduced a flood of "patent burners," some of which have survived to the present day. Steam or compressed air, at about 80 lb. pressure in each case, carried the oil—which was kept at 45 lb. pressure in the system by means of an automatic pump between the storage tank and the burners—into the combustion chambers of the furnaces and ovens. Steam was also allowed to circulate in very small quantity in the underground storage tank to keep the thick portions of the oil fluid and prevent clogging the system, and a special strainer was inserted in the oil line just before each burner. These systems also worked successfully, and many are in operation at the present time. The author, working at these problems in connection with the foundry fuel development, was not satisfied with the high cost of steam or compressed air, and developed a system in which the oil was kept under a steady pressure of 40 lb., and air was blown past the nozzle outlet at a 3-oz. pressure, by fans, and the oil thus sufficiently atomized to give a long flame, just as wanted in furnace and oven work. No burners whatever were used—unless a

2-in. nipple with a chunk of white iron cast around it, and easily replaced when burned off, can be designated thus. The results were excellent and the method cheaper than where steam or high-pressure air was used, particularly when the air for combustion was preheated.

It might be mentioned here that the atomization of oil in the burning apparatus must be thoroughly understood, in order to get out proper furnace designs. With compressed air or steam, in properly constructed burners, the atomization of oil is very quickly accomplished, and combustion is complete within a very short distance from the burner. Hence this form of oil-burning should be used where a highly localized heat is wanted, and extremely high temperatures must be reached. The brass-melting furnace, heating furnaces for rivets, bolts, etc., would illustrate the point. On the other hand, the use of oil sprayed into a combustion chamber by low-pressure air means a very poor atomization—though all the oil will be carried in—and combustion takes place for a considerable distance from the burner or nozzle. Hence it is necessary to have plenty of combustion space, otherwise the results will be very inefficient. With a good combustion chamber, however, excellent results are obtained and there is not a localization of extreme temperatures such as would manifest themselves in the burning out of a hole in the furnace roof. This method of burning oil is the proper one for melting iron in furnaces, for it means a very long flame and the carrying of heat to all points of the furnace hearth. W. N. Best adapted the air furnace for oil-melting in just this way and coal-firing can be done away with. Considering that not even natural gas will melt iron in the air furnace properly, unless an elaborate regeneration system is employed to give highly heated air, this is indeed an achievement.

The earliest melting with oil in the open-hearth furnace carried on by the author was with a burner arrangement (plain nozzles) and low-pressure air arranged on each side of the furnace, one set at each port bridge wall. With the air there was introduced a very small current of steam as a burner protection when the air and oil were turned off at each reversal. This small volume of steam was allowed to flow constantly, and prevented the burning off of the pipes when struck by the hot gases coming from the burners on the opposite side. The burners were set at an angle and slightly downward, so that the sweep of the flame commanded the entire bath. It is doubtless better, however, to use the present method of introducing the oil directly into the ports, from the back of the furnace, and swinging the burners out of the way on reversal. It gives a longer combustion space for the proper utilization of the oil fuel.

In passing from the subject mention might be made of the final tests made by the author in burning oil direct by dropping it on tiles suitably placed in the furnace hearths. No steam or air was used, and apart from a considerable carbonization (gas-carbon formation), which, however, was knocked off and pushed into the hearth and burned, perfect success was achieved. One point had to be watched specially, however, and that was the hearth level at the point where the oil drops landed. Unless this was kept sloping away from the ports at all times, some of the oil surplus (regulation of the flow not being controllable to such a degree of accuracy) would run backward into the ports, and a raging combustion would ensue in the shaft from the checker-chambers upward. The result was the melting down and out of all the brickwork in the vicinity and expensive repairs.

The fluctuating price of fuel oil in the eastern regions of the United States will militate against the steady use of this admirable source of heat. It should, however, aid in the upbuilding of the industrial systems of the far West. Foundrymen should, therefore, keep their eyes on fuel oil, particularly as gas, whether from coal or oil, will undoubtedly be the fuel of the future. The application of fuel oil to cupola melting practice will be discussed in the chapter on "Melting Processes."

There are other liquid fuels that might deserve consideration, such as tar and the oil from carboniferous shales, gas coals, etc., but these products are comparatively limited in volume and it would hardly pay the foundryman to give them his attention at the present time.

Fuel Gas.—This form of fuel is easiest of application, as it need only be piped to the point required and burned with the proper admixture of air. Gas or air, or both, may be either cold or highly preheated, as necessitated by the purpose in view.

The following kinds of fuel gas require consideration: natural gas, producer gas, and by-product process gas. Oil gas has already been discussed, and the several city and special gases such as water gas, acetylene gas, "blau" gas, etc., need not be gone into here. They could be used as fuels but have proven too expensive in actual practice.

Natural Gas.—This is one of nature's choicest gifts to man. A collection of rich hydrocarbon gases, of high calorific power and low in sulphur, this gas is particularly adapted for metallurgical use. It is highly prized for melting and annealing in malleable and steel-castings practice. Coming from subterranean cavities or porous geological strata, its pressure is sometimes enormous and in the early days of its discovery it was wasted shamefully. Many districts have therefore been exhausted long ago, and what is now available is carefully husbanded for manufacturing and domestic use.

Natural gas varies somewhat in composition for the different regions in the United States as well as in foreign countries. It consists principally of marsh gas (CH_4), and the following ranges of the content by volume will give a fair idea of its constitution:

Marsh gas (CH_4)	92.50 to 95.40
Hydrogen (H)	..... to 2.30
Olefiant gas (C_2H_4)	..... to 4.10
Carbon monoxide (CO)	..... to 0.50
Carbon dioxide (CO_2)	0.10 to 2.00
Nitrogen (N)	2.00 to 4.00
Oxygen (O)	.... to 0.35
Hydrogen sulphide (H_2S)	.... to 0.20

The last four items are the undesirable constituents of natural gas. The lower the percentage of these, the better. The heating value of this gas and comparison with other fuel gases will follow later.

A glance at the composition of natural gas will quickly show what a dangerous situation may result in case of leaks. An explosion is usually accompanied by fatalities when in the immediate neighborhood of human beings. At any rate the burns inflicted are horrible. This is in contradistinction to producer-gas explosions, which are rarely as serious. The author was once in such an explosion, and was surrounded by the flames for the moment. The only effect experienced was as if sand had been thrown into his face and over his hands very sharply and suddenly. Producer gas, by the way, is but one-ninth the calorific value of natural gas, and contains about 63 per cent. of inert gases by volume. Moreover, the flame temperature is much lower than that of the natural fuel.

There are two methods of burning natural gas properly. The first is to provide a "gas-mixer" back of the nozzle outlet. This regulates the air supply and effects a more or less efficient mixture previous to burning. In Fig. 25 the arrows show the direction of gas and air supplies. The gas is throttled by a globe valve, and the air supply drawn in by the gas current is adjusted by reducing the size of the inlet orifices of the mixer.

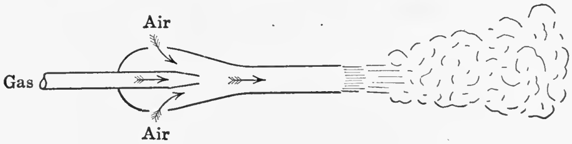


Fig. 25.—Line section of "mixer" for natural gas.

The second method is used in the case of the open-hearth furnace, or where gas may still be used in firing boilers, as in the oil regions. It is of the utmost importance to so design the gas and air inlets that the gas comes in below the air. The air going straight forward and the gas rising, a good mixture is made and the firing is even. If the arrangement is reversed the gas will travel above the air and the results are discouraging. The author remembers a boiler fired by natural gas, the wrong method of gas and air inlet being used. The firing actually consisted of a series of light explosions resulting in a rocking of the boiler and smoke from incomplete combustion belching from the stack. Changing the inlet arrangement to air over gas at once corrected the trouble.

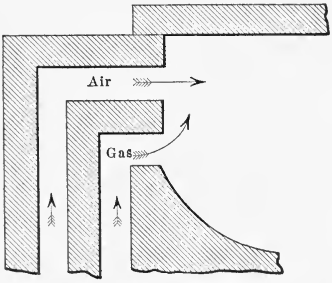


Fig. 26.—Section of open-hearth furnace ports, showing mixing of gas and air currents.

Fig. 26 shows the proper arrangement of the ports of an openhearth furnace. The arrows show the direction taken by air and gas under the influence of the stack draft. This for either natural gas or producer gas under regeneration. When natural gas is not thus used, it is allowed to enter either from the sides of the furnace or through the back, but in any case at a point below the port openings, so that the gas must rise to mix with the air. This gives the best results.

The very richness of natural gas makes it possible to operate the open-hearth furnace without preheating the gas, sending the air through both air and gas chambers being sufficient. When, however, it is desired to get the gas hot also it is necessary to use a special precaution, to prevent the deposition of carbon in the gas-box and pipes—due to heat radiation backward from the gas valve. All light hydrocarbon gases are peculiarly sensitive in this direction. A small jet of steam is therefore allowed to enter with the gas and this holds the temperature down sufficiently to prevent decomposition and carbon deposition until the gas has passed through the valve into the gas flues. Whatever may deposit there is subsequently burned when, on reversal, the surplus air and products of combustion pass through these flues and up the stack.

The efficacy of preheating both natural gas and air in the open-hearth furnace may be judged from the experience of the author, who, in making malleable heats in 10-ton furnaces obtained them in as short a space as 1 hr. and 50 min. from end of charging to tapping. The ordinary method, preheating air only, takes 2½ hr. It may be stated, however, that under the first-mentioned conditions the action of the furnace was so rapid that tapping out had to be gotten through with as quickly as possible, otherwise the end of the heat would Bessemerize in the bath, and be unfit for use through oxidation. Moreover, the crown and ports of the furnace would begin to soften under the intense temperature existing, and this had to be constantly checked to save the furnace. Whereas, therefore, poorer gas must be regenerated for effective melting, in the case of natural gas it is better not to do this, but, as previously stated, to allow the air used to pass through both checker-chambers, as the heat obtained is amply sufficient for the purpose.

In spite of the high calorific value of natural gas it is not possible to bring about so perfect a combustion that the flame temperature suffices for proper melting of iron in the air furnace. Whiteley, however, succeeded in getting reasonably good results after installing a series of pipes in the throat of his furnace—on the "economizer" principle—and forcing the air for combustion through this before it burned the gas. In this way the preheating effect of the open-hearth furnace was approached for the air. Red hot pipes, however, are not very permanent, and hence the experiment did not find imitators.

Similarly, natural gas has never been used for cupola melting.

There is no reason, however, why this should not eventuate in replacing oil in the Stoughton cupola oil-melting process, to be described later.

Natural gas is very light, the specific gravity being 0.520 and upward, air being unity. The composition by weight would be about 72.34 carbon, 24.09 hydrogen, and 3.57 oxygen. One pound of natural gas (25.143 cu. ft.) has 25,160 heat units B.t.u., as compared with the best bituminous coal, a pound of which runs about 14,860 B.t.u. Natural gas, therefore, has about 1.69 times the heating value of coal.

Producer Gas.—This is the gas made by blowing air (in modern practice in admixture with steam) through a thick bed of incandescent fuel. Any carbonaceous, solid fuel will do, such as charcoal, anthracite, coke, lignite, etc., but bituminous coal is employed almost universally. The flexibility of the process is shown by the fact that in Sweden a coal with but 20 per cent. carbon is gasified successfully, and in spite of the enormous ash content.

Since the producer-gas process is so closely allied to both the blast-furnace and the cupola operation, it is necessary to study the details somewhat in order that the subsequent discussion of rational cupola melting may be better understood.

Producer gas is made in a large, brick-lined combustion chamber filled with fuel. Air is blown in near the bottom, or drawn in by the action of a steam jet and carried through the system by the stack draft of the furnaces. A minimum amount of steam is used, as this is only intended to hold the temperatures down a little—in fact, in the latest type of gas producer, the "slagging" type, almost no steam is used at all. Grates are provided at the bottom of the "producer"—the brick-lined combustion chamber—in order to facilitate the deflection of the ash outward and allow the distribution of the blast. The bottom of the producer being in a water-sealed tank the ash may be readily removed without danger of gas escape or explosions.

The operation of the producer may be best understood by glancing at Fig. 27, which illustrates one of the older types (Duff). Coal is charged into the hopper, covered, and the bell allowed to drop—just as in the blast furnace. A series of pokeholes in the top allow the introduction of bars to break up the clinkering of coal, and afford passage to the gases. Indeed, in some types of producers the upper portion is made to revolve and thus break up the bed automatically. This is highly important in gas-making, for as the carbon dioxide formed near the grates passes upward, and should find plenty of incandescent carbon to pick up, to form carbon monoxide—which is the gas wanted; the presence of great clinkers or aggregations of coke not only retards this chemical action, but also compels the gas to seek the shortest way out with consequent "air-channels." The analysis of the gas quickly reveals this situation, for instead of the oxygen percentage being about 0.50, it may rise to over 2.00 per cent.

It will be noted, further, that unless the bed of fuel is quite thick, the carbon dioxide formed just beyond the grates will not have had an opportunity to be converted to carbon monoxide completely before it has passed through the producer, and hence the normal percentage of CO_2, of about 5.00, may be considerably increased. Thus there are two items in the analysis of producer gas which at once show whether the process has been carried on properly or not.

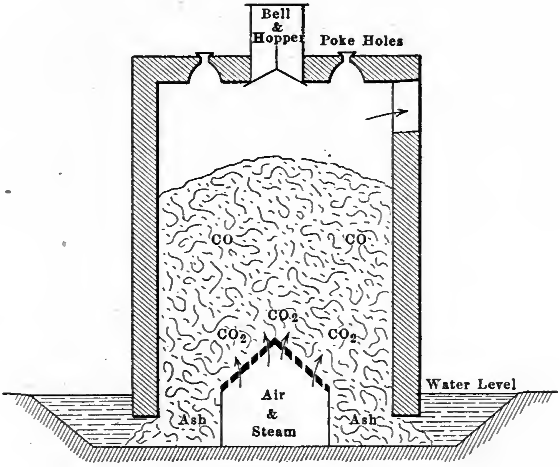


Fig. 27.—Line section of a gas producer.

These two points are of interest in connection with operating the cupola, for the formation of channels in the charges, allowing the blast to pass through only partially consumed, means the presence of oxygen higher up where melting is done, with consequent deterioration of the metal. Further, with too high a bed much of the carbon dioxide—at maximum temperature—will have been converted to carbon monoxide—with considerable reduction in temperature—and melting is slower and fuel wasted.

The reduction in temperature when too much fuel is used is not always understood by the foundryman, and hence a few words on the subject of combustion will not be amiss. The reactions will be best understood when only the elements carbon and oxygen are considered. In actual practice it must be remembered that coal and coke contain a considerable quantity of ash, and hence their calorific values are reduced correspondingly. Further, in bituminous coal the presence of rich hydrocarbons involves hydrogen-oxygen reactions which counteract this reduction in heat value. Again, fuels are not burned with pure oxygen, but with air, and this consists of 23.1 per cent. oxygen and 76.9 per cent. nitrogen, by weight (20.9 oxygen and 79.1 nitrogen by volume). Nitrogen is entirely inert in the process of combustion, and passes through the cupola unchanged—taking with it, however, a lot of sensible heat as it passes beyond the charging door.

There are two reactions between carbon and oxygen going on when combustion takes place. The first is that in which "carbon dioxide" is formed, expressed in chemical terms, as follows:

$$C + O_2 = CO_2$$

Here 1 lb. of carbon has been combined with 2.66 lb. oxygen (29.8 cu. ft.); using 11.517 lb. air (142.44 cu. ft.). The result has been the formation of 3.66 lb. carbon dioxide (CO_2, 29.8 cu. ft. in volume), and the passage of 8.857 lb. nitrogen (112.64 cu. ft.) through the process unaffected chemically. Finally, there will have been developed 14,544 B.t.u. of heat.

The second reaction invariably accompanies the first, namely—as previously stated—the taking up of extra carbon from the incandescent fuel by the carbon dioxide gas. The reaction given in chemical terms, is as follows:

$$CO_2 + C = 2CO$$

As between CO_2 and CO, it will be seen that 1 lb. of carbon takes up only half as much oxygen in the second case, or 1.33 lb. (14.9 cu. ft.), thus using 5.759 lb. air (71.22 cu. ft.). The result of this reaction is the formation of 2.33 lb. carbon monoxide (CO, 29.8 cu. ft. in volume), and the passage of 4.429 lb. nitrogen (56.32 cu. ft.) through the process unaffected chemically. The heat units developed in this case, however, are less than one-third as much as in the first reaction. Heat is rendered latent and only given out again when the carbon monoxide is burned, which in the cupola happens above the charging door—where it is useless for melting purposes. The first reaction (burning to CO_2) is therefore called a "complete" combustion, and the second an "incomplete" one.

The foundryman should see the bearing of this very readily. It is impossible with ordinary methods to achieve complete combustion, there will always be more or less of the incomplete kind coexistent where fuel is burned. Hence the cupola should be so charged and operated that the coke bed is just high enough to have the melting done at a point where there is present a maximum of carbon dioxide, a minimum of carbon monoxide, and but little or no free oxygen remaining.

From the foregoing it will be noted that in melting iron the cupola should be run for as complete a combustion as possible (CO_2), all the heat the fuel is capable of yielding being wanted for stock heating and melting purposes; the gas producer, on the other hand, must be handled in the opposite manner. Here a maximum of CO is wanted, or an incomplete combustion—just as in the blast furnace. The heat thus rendered latent is recovered again when the gas is burned subsequently where required.

In the oldest and simplest type of gas producer, the Siemens, which is a simple shaft furnace full of incandescent fuel, air being admitted at the bottom by natural draft of the system, the gas produced consists of practically half carbon monoxide and half nitrogen. This is a very good fuel gas, there being very little hydrogen to cause troubles noticed when too much of this element is present. The manner of ash removal is very simple, two sets of round grate bars being used, the upper row is forced into the bed when this has burned past the point in question. By withdrawing the lower set of bars everything between the two points drops into the shallow pool of water maintained in the ash pit. Replacing the lower bars and removing the upper ones allows the fuel charge to settle down sufficiently to permit adding fresh fuel. The process is thus made continuous and gives little trouble.

The amount of air entering such a producer is, however, dependent upon the stack draft of the furnaces taking the gas, and considering all the leakages of air into the system on the way, is unsatisfactory for rapid production. Hence the old Siemens producers have given way to the modern forced-draft gas-making systems. The author remembers seeing the last of these producers in operation in the Pittsburgh district, these having been brought there to replace the waning natural gas. They, however, quickly yielded to the newer types of producers.

In addition to keeping close watch on the analysis of the producer gas made in regular operation, the ash should be carefully inspected while being taken away, to see that little or no ungasified carbon has remained. If this should not be the case, the producer has worked irregularly and better attention must be given the stoking of the coke crust formed near the top of the bed, gas channels destroyed within the bed, and the steam injection and air distribution looked after. In carrying out this routine, the experience of the author may serve, as he had the gasification of large coal tonnages to look after, and the use of some 7,000,000 cu. ft. of producer gas per 24 hr. for melting and annealing purposes to control. Gas samples were taken at 6-hr. intervals and the ash taken out inspected at the same time. The regular method of making gas analyses was shortened to avoid taking cognizance of the comparatively small percentages of marsh gas and olefiant gas present—these appearing in the analysis with the hydrogen and carbon monoxide. Thus, with little trouble and loss of laboratory time a perfect check was kept on the operation of the gas plant, the operatives of the plant being furnished with copies of the reports for their own guidance. Before adopting the rapid (and necessarily somewhat inaccurate) method of analyzing producer gas, a comparison was made with the accurate method for some time, and the following averages will be of interest.

	Rapid	Accurate
Carbon dioxide (CO_2)	5.88	5.88
Carbon monoxide (CO)	24.80	21.80
Hydrogen (H)	14.54	14.17
Oxygen (O)	0.08	0.08
Marsh gas (CH_4)	......	0.10
Olefiant gas (C_2H_4)	......	1.09
Nitrogen (N)	54.70	56.88
Heat units per cu. ft. (B.t.u.)	137	146

The only changes of note are in the carbon monoxide and hydrogen content—due to the breaking up of the marsh and olefiant gases. Carbon dioxide and oxygen remain the same, and the nitrogen is gotten by subtracting the volume of the other gases from 100. The fact, however, that the B.t.u. capable of development are not far apart would indicate that the rapid method of analysis answers the purpose of a daily check fairly well.

The percentage of carbon dioxide should not run over 5.00 in good work. In the average analyses just given, this is 5.88, showing that the bed of fuel was too thin at the time the samples were taken. On the other hand, the percentage of oxygen is only 0.08, which is exceptionally good, normal practice having this item at about 0.50. Since the coal used was the best Pittsburgh gas coal, and the producers were constantly stoked, there was little trouble from air-channels. The free oxygen from the air blown in and from the decomposed steam was also used up in spite of the thin bed of fuel. By way of information it may be added that the average analysis above discussed was made up of items which gave the range of CO_2 as from 5.52 to 6.23, and the oxygen from nothing up to 0.20.

While the undesirable constituents of producer gas form the best criteria of the practical operation, the two valuable items are the carbon monoxide and the hydrogen. In spite of the very much higher heating value of hydrogen (62,032 B.t.u. per lb.) over that of carbon monoxide (4,450 B.t.u. per lb.) this is not as real as it seems, for the analysis of gases is always given by volume, not by weight. Recalculating to find the heat units by volume, hydrogen comes out as having 348 B.t.u. per cu. ft., while carbon monoxide has 349 B.t.u. per cu. ft., or very nearly the same. The apparent value of hydrogen is further reduced very seriously by its behavior in the furnace itself. This is highly important and shows why developments in producer-gas making should lie in the direction of increasing the carbon monoxide and not the hydrogen. When hydrogen burns at the ports of the open-hearth furnace water-vapor is formed, and much heat is evolved by the combustion. However, at the high temperatures prevailing, water-vapor is possible of decomposition again, into hydrogen and oxygen, with the rendering latent (absorption) of just as much heat as was given out in the combustion process. Hence there will be more or less of a continued association of hydrogen and oxygen, and dissociation directly after, with alternate giving out and taking away of heat, until the temperature drops to a point at which water-vapor is no longer dissociated. Here the heat given out will remain out. As this point is reached only after the gases have left the hearth of the furnace, not very much gain will have been made for direct melting from a high percentage of hydrogen in the gas used. Steel melters are therefore prone to operate their producer systems with the least amount of steam possible, to hold down the percentage of hydrogen in the gas.

The latest development in producer-gas practice is the so-called "slagging" producer. The best example is the Servais producer, which gasifies nearly four times as much coal in an installation as large as the ordinary types. Almost no steam is used—just sufficient to prevent burning off the admission pipes. Preheated air is sent into the fuel bed under pressures of up to 5 lb. per sq. in., and the intense combustion and high temperatures produced at the point of maximum carbon dioxide is counteracted, so far as the lining of the producer is concerned, by a water-jacket belt having but a thin face of refractories. A suitable flux is charged with the coal, and consequently the ash is melted to a slag which is tapped off regularly, just as in the blast furnace.

Curiously enough the reactions are so complete that any oxide of iron present in the ash of the coal, or from blast furnace flue dust that may have been added, is reduced to iron, and the high temperatures also promote the reduction of silicon from the silica present. Hence, when tapping out the slag, a ferrosilicon comes with it (about 12 per cent. Si), thus adding to the revenue of the process. When the author was at Bochum, Germany, with Servais, to go over the situation, breeze coke was used as the fuel, and flue dust from the blast furnaces was fed directly into the producer. Ferrosilicon was tapped out with the slag regularly, and the gas made was of an astonishing quality, the analysis showing the following:

Carbon dioxide (CO_2)	1.5
Carbon monoxide (CO)	34.0
Hydrogen (H)	8.0

The objections to producers of this type—that they take away too much sensible heat, which is lost before the gas reaches the melting furnaces, the extra deposition of soot, etc. are cared for to a great extent by allowing the gas to preheat the air blown into the producer, by a recuperative system arranged for in building the flues.

The other direction of improvement made in gas-producers lies in the recovery of some of the by-products from the coal used. The Smith producer not only takes away the tar and thus makes the gas peculiarly fit for glass production, but is built sectionally in batteries, thus saving space and radiated heat. In the case of the Mond type of producer, where the use of steam is at a maximum, the producer temperature is held so low that the by-product recovery is very marked and it is possible to recover the ammonia, benzol, etc.

The foundryman will, however, not be interested so much in these phases of the situation as in the actual use of the gas about his establishment. Compared with the heating value of natural gas (1,000 B.t.u. per cu. ft.) that of producer gas (125 B.t.u. per cu. ft.) is quite low, and hence enormous volumes must be employed. This means carrying conduits built on a large scale, the usual diameter of the flues being about 4 ft. The most convenient method is to conduct the gases underground, but this has the serious disadvantage of leakage through expansion, contraction, and consequent failure of the flues. The brickwork finally caves in and the flow of gas is partially stopped. Overhead flues of steel, lined with second quality refractories (as the temperature is not very high) are most satisfactory, and should be well provided with manholes and explosion covers which drop automatically. Sand makes the best gas-seal, and provision should be made at both ends of the system and its branches to burn out the soot lodging in the flues by way of the most convenient chimney.

Reference has been made to the relative heating value of natural gas as contrasted with producer gas. There is still another gas that may come into prominence for foundry use, and that is *coke-oven gas* from which the by-products have been removed. Large steel works are beginning to appreciate the advantages of having their own by-product coke plants in connection with blast furnaces, and here the surplus gas question is one which either affects the domestic interests of the nearest towns, or else the gas will be used for melting and other works purposes. The analysis of such a by-product coke gas would be about as follows:

Benzol (C_6H_6)	0.69
Olefiant gas (C_2H_4)	2.48
Marsh gas (CH_4)	37.55
Hydrogen (H)	46.27
Carbon monoxide (CO)	11.19
Carbon dioxide (CO_2)	0.81
Nitrogen (N)	1.01

This gas has high illuminating powers as well as heating value. The very high hydrogen, however, is objectionable for melting purposes, as was previously explained. The relative calorific values of the three gases discussed may be set down as follows:

Natural gas	1,000 B.t.u. per cu. ft.
Producer gas	125 B.t.u. per cu. ft.
Coke gas	570 B.t.u. per cu. ft.

FOUNDRY FLUXES

When pig iron and scrap is melted in the cupola with coke or anthracite as the fuel carbon unites with the oxygen of the blast and goes off up the stack. Molten iron is tapped away from the spout, and there remains within the cupola whatever sand and clay may have adhered to the metal and the ash of the fuel. When melting has progressed for some time, this refuse—which in itself is very refractory—begins to give trouble in obstructing the proper passage of the blast and eventually "bungs up" the cupola. Hence it is necessary to get this material into a fluid form in order to remove it during the run if it accumulates to an annoying extent.

In actual practice there is always a certain amount of iron oxide, in the shape of rust, on the metal charged, and as the oxide of iron is a very powerful base—sand being acid and ash at least partially so—a slag is always formed in cupola melting whether the heat is fluxed or not. With poor cupola practice, which promotes the oxidation of the sound metal charged, there may be enough iron oxide at hand to make a very thin and corrosive slag, which affects the lining of the cupola very seriously. Every foundryman knows of cases in which the lining of the lower part of the cupola was cut away in a single heat. Also the accompaniment of a "foaming" slag which may be large enough in volume—though very light in weight—to be lifted clear out of the charging door by the blast.

Rational cupola practice holds down the oxidation of iron to a minimum, and hence if only clean metal is used and the fuel contains only the normal percentage of ash, it is quite possible to run heats of several hours without fluxing at all. Under ordinary conditions, however, a considerable amount of sand and dirt is introduced. It may not be possible to obtain machine-cast pig iron, and hence a greater or less quantity of sand goes in with the charge. The very allowance of 28 lb. for pig iron "sandage" speaks for itself. Again, the author has often had to melt with coke containing 14 per cent. of ash, and was present at one run which gave cold metal and a ruined day's work which was afterward traced to the coke with an 18 per cent. ash content. Under conditions of this kind ½ hr. without fluxing would mean the dropping of the bottom.

In furnace practice the problem is comparatively simple. There is no fuel ash to care for, and if the sprues of the previous day are tumbled before charging, and as much of the pig iron used as possible is of the sandless variety, there is so little slag formed that it is sometimes necessary to either add slag from previous heats, or better, to thin down the slag present with fluorspar additions, in order to get a protecting cover for the metal in the earlier stages of the melting operation.

The principal fluxing agent used in the foundry is limestone (a carbonate of calcium). Lime is a powerful base which unites with silica to form a slag. It also takes up clay, iron oxide, etc., and if in proper quantity makes a fluid, easily handled slag which is tapped out of the cupola from a special spout placed at the top level of the molten iron held in the crucible. There are other fluxes which can be used, but lime is the cheapest and most available agent, besides being the best—if of sufficient purity.

The forms in which lime is available to the foundryman are the following. The earliest use of lime was in the shape of oyster shells. These are thin, pure, and flux very easily. In summertime, however, their use is out of question for sanitary reasons, unless they have been weathered and lost their organic accompaniment. If charged directly into the fire, oyster shells will send off spalls of their hard interior face with a crackling noise. These pieces may be seen to fly upward, the finer portions being carried off altogether. When charged in the usual manner, however, on cold coke or metal, there is no difficulty. Oyster shells are probably the best form of limestone flux.

Next would come the more or less pure mineral calcite, now entering the eastern markets of the United States. This mineral accompanies a variety of metal ores, and being hoisted to the surface and picked out in the process of ore-dressing, is thus made a profitable by-product of mining or quarrying operations. When transparent and free from sulphides, this is a very desirable form of lime.

Marble spalls are next in order, this rock being a very pure carbonate of lime. In cities of large population much of this waste is available for foundry fluxing. Dolomite can be included here, as this is handled in many marble yards. This mineral has part of the lime replaced by magnesia, the latter also being an excellent fluxing material, though less widely distributed.

Finally limestone itself requires consideration, as this is not only the most frequently used material for fluxing, but is found in all degrees of quality, some very valuable for foundry work, and again some that is absolutely worthless. Limestone is supposed to be practically pure carbonate of lime. An analysis would show the following, in round numbers:

Calcium carbonate	96.7	98.8	82.8
Magnesium carbonate	....	....	13.2
Silica	2.0	0.5	1.4
Alumina	0.8	0.4	1.5

The carbonates of calcium and magnesium are the effective agents in fluxing, the silica and alumina (clay matter) are the objectionable impurities. These analyses are examples of good limestones, the impurities not running over 3 per cent. Blast-furnace practice allows up to 5 per cent. Unfortunately, however, the limestones sometimes found in foundries run as high as one-third their weight in clay matter, sand, etc., and these are not only worthless for fluxing, but actually an added burden in the cupola, withdrawing a very appreciable amount of heat in fusing them from effective metal-melting. Every particle of sand or clay that is contained in a limestone requires almost three times as much of the lime present to flux it. Only the balance of the lime left is available for fluxing the impurities of the charges. Hence, while it is desirable to hold the impurities in foundry limestones below 3 per cent., the limit should be placed very strictly at 5 per cent.

Another of the undesirable constituents of some limestones is gypsum, or the sulphate of lime. This is also often the case in the ash of coke, and while the action in furnace and cupola has probably not been investigated very extensively as yet, the presence of such a sulphate under high temperatures, in contact with liquid iron, is certain to mean an absorption of some sulphur by the metal. The foundryman is therefore cautioned in regard to the limestone bought, so that he may have the analysis carefully watched and accept only the best, even if at high figures. The presence of 5 per cent. silica and clay means the using up of 14 per cent. of the lime present to neutralize them. What would happen with 20 per cent. impurities can therefore be imagined, and such cases are by no means rare.

All limestone fluxes should be of a handy size, not in large lumps as is oftentimes seen, but just small enough to be undisturbed by the blast pressure. Egg size is probably best, and in charging it should preferably go on the coke, evenly distributed, but some 6 in. away from the cupola lining. The quantity to be used will be discussed later on under "Melting Practice."

Perhaps no thing is so annoying in cupola practice where light work is made as the charging of the sprues and gates just as they come from the floor. The amount of burnt molding sand thus introduced into the cupola is astonishingly large, and as this material contains some 20 per cent. clay, which is very difficult to flux away, an unusually heavy percentage of lime must be available for fluxing. If the foundryman will remember that his burnt sand corresponds somewhat in composition to his cupola lining, and imagines himself charging fire-brick into the cupola, he will probably tumble his gates, etc., before charging them with the mixture.

Fluorspar is another important fluxing agent. This is the fluoride of lime (calcium fluoride—the mineral "fluorite"). It is extremely active and is used to thin the slag. It is also very corrosive and cuts into the cupola lining very badly if used in too great a quantity or too close to it. Fluorspar is also supposed to act favorably in sulphur removal. Good fluorspar should run at least 90 per cent. calcium fluoride. Ordinarily, however, it is much mixed with calcite, and may therefore not run over 50 per cent. Nevertheless, this is good fluxing material, but the price should be adjusted accordingly, the pure article being quite expensive.

The subject of foundry fluxes cannot be closed without reference to the patent medicines and "cure-all's" sold to innocent and trusting foundrymen subject to hypnotic influence on the part of clever salesmen. One has but to turn to the advertisements still to be seen in reputable trade journals—though fortunately the grosser frauds have long ago yielded to the general foundry enlightenment. There is no question about these materials so far as fluxing is concerned, for they are usually nothing more than fluorspar cleverly colored with iron ore, etc., but the price asked and the claims made for excellence in results constitutes the disturbing feature. Rational melting practice, clean and high-grade meterials charged, and brains, will bring results as near perfection as is possible without the use of patent or secret fluxes. The author urges foundrymen to be from "Missouri" and never buy anything the content of which is not honestly disclosed by the seller. The foundryman can then tell whether it is worth the trial.

REFRACTORIES

The subject of refractories for foundry use is more important than is generally thought to be the case. How often does the foundryman complain that his cupola brick are melting away too fast, when an investigation shows that he uses the product of local clay pits as his bond and daubing material. There is little wonder—as such conditions are pretty general—that a great waste is going on in the foundry industry along this line. Again, even high-grade refractories necessitate study so that the proper quality may be selected to suit the service required of them. A clay brick should not be taken where a silica brick gives better service, and a coarse-grained brick will not answer as well as a finer-grained one where corrosive action is to be withstood.

Refractories, though this term is generally applied to heat resisting brick and tile, cover a much wider field, and embrace sand and clay, as well as heat-resisting products of three distinct types. These are the acid, basic and neutral materials forming the basis of the industry in question.

In general, 2,750°F. is taken as the point below which no first-class refractory should soften. As a matter of fact, however, few grades of fire-brick or other manufactured refractories will withstand this temperature successfully at all times. Whether through addition of old brick from torn down furnaces, or from lack of uniformity in the clay used, it occasionally happens that furnace crowns soften dangerously under ordinary temperatures of melting practice. As a consequence, certain clays have acquired a special reputation for reliability, and crucible makers particularly are extremely cautious in changing to new brands.

Even molding sand will not stand as much heat as could be expected from this class of refractory material. Whereas 2,500°F. ought not soften a sand, few varieties will stand more than 2,200 without showing signs of fusion. The feldspar content, of course, explains the situation. Fortunately, however, even if the molten metal is highly superheated, contact with a damp mold surface, or even a dry-sand mold surface, lowers the temperature sufficiently to avoid serious trouble. Nevertheless, very fine sand rich in undecomposed feldspars should not be used for molds requiring the passing of much metal at given points.

The group of acid refractories are best represented by sand and fire-clay.

Sand.—When pure, this consists of silica only (SiO_2), and is found in nature as the mineral quartz (rock crystal). When disintegrated by weathering and rounded by wave action, the sand of river bottoms and sea beaches, as also the deposited beds of sandstone and the cemented silica rocks, may have had many impurities introduced. Thus, an examination of sea sand under the microscope may reveal a dozen or more distinct minerals in admixture with the rounded quartz grains. Hence the important points to be considered, so far as the heat-resisting properties of a sand are concerned, are the percentage of silica and the character of the admixtures.

Silica itself is infusible under ordinary furnace conditions, requiring the temperature of the oxy-hydrogen blowpipe, or the electric arc to melt it. The admixture of lime, magnesia, iron oxide and the alkalies (potash and soda), however, lower the fusing point, and hence the presence of minerals containing such elements—as for instance the feldspars, iron ores, calcite, fluorite, apatite, etc.—lower the refractory qualities of the sand considerably. In selecting molding sand for the steel foundry, fire-sand for furnace bottoms, or in admixture with fire-clay for ladle linings, etc., a very pure sand is essential. Nevertheless, a small percentage of fluxing material is of value in sticking the sand grains together, as for instance in making silica brick, which consists of ground silica rock (ganister) to which about 2 per cent. of lime is added, the brick formed, dried, and then fired at very high temperatures. The added lime fuses the grains together. An analysis of silica brick would be about as follows:

Silica (SiO_2)	96.20
Alumina (Al_2O_3)	1.42
Lime (CaO)	1.98
Alkalies (K_2O, Na_2O)	0.50

Any small percentage of iron oxide is included in the alumina figures, and whatever magnesia is present would be found in the lime content. Silica brick expand on heating and due allowance must be made for this fact to avoid trouble in furnace construction. Fire-clay brick, on the other hand, contract at high temperatures, and hence precautions are necessary here also. Silica brick have been found very advantageous for furnace crowns and sides, as they can stand the highest temperatures for fairly long periods of time without softening seriously.

The sand used for furnace bottoms, called fire-sand, or latterly "silica-sand," should run up to 98 per cent. in silica. Such material, however, is not very common, and hence poorer grades are often taken. Many foundries use sea sand for their furnace bottoms, though a lake sand is usually a much better material. The alkalies and iron oxide are the worst of the fluxes.

For lining converters and the small hearth construction of the miniature open-hearth furnace, lumps of sand stone (very pure material) may be used direct. This makes a perfectly satisfactory and very cheap lining, which can be patched up by smaller pieces just as the cupola can be patched up with flakes of mica-schist. The binding material is fine rock mixed with high-grade fire-clay.

In recent years the natural rock "mica-schist" has come much into use for the daily patching up of the cupola lining at the melting zone. This rock, originally stratified sandstone and shale subsequently metamorphosed by eruptive conditions, splits off in flat pieces of any desired size and thickness. Being highly refractory in addition, these flakes can be made to replace the regular and split brick and "bats" which would otherwise have to be built in and are more costly. The special precaution to be taken is the necessity of a very careful drying out of the moisture in the clay-mortar used behind the flakes. Otherwise when blast is put on steam is generated so rapidly that the flakes are blown off, have to be fluxed away by the limestone charged, and still worse, expose the damaged lining at that spot to further cutting away.

The use of mica-schist is to be recommended as furnishing a ready and cheap means of keeping the lining of the cupola straight from top to bottom, whereas it would otherwise be allowed to burn away at the melting zone until the first ring of blocks or brick have been cut through. A straight lining makes for good melting conditions so far as the descent of the stock is concerned.

The sands containing clay in admixture, and making up the great division of molding sands—so far as the foundry is interested in them, will be discussed separately. These were formed in nature in a different manner from the silica sands, and require special study.

Fire-clay, when theoretically pure, is a silicate of alumina, and would contain 45.87 per cent. of alumina and 54.13 per cent. of silica. The nearer the analysis of a fire-clay approaches this, the more refractory will it be. Thus, a high-grade Pennsylvania fire-brick is quoted to have the following analysis:

Silica	52.93
Alumina	42.69
Iron oxide	1.98
Lime and magnesia	0.71
Alkalies	1.55

Other analyses show much higher silica percentages, with corresponding reduction in the aluminum content. Probably the best fire-clay in use is the "Klingenberg"—famous for the crucibles made from it. The author has made many investigations along this line, and gives an analysis of the above-mentioned clay, as follows:

Silica	61.04
Alumina	35.02
Iron oxide	1.87
Lime	0.46
Magnesia	0.43
Alkalies	1.09

The percentage of fluxing components amounts to but 3.85, or less than that of the fire-brick just given. The silica content runs higher, however, and as this component of fire-clay may run up to 70 per cent., it would seem wise to keep track of the analysis of the refractories used where the amount bought annually warrants it and the Standard Methods involved will be found in the "Appendix."

The analysis of a fire-brick, however, does not constitute the sole guide to its availability for the service required. The items that require consideration in making the selection are the following: (1) Resistance to high temperatures; the crowns and ports of open-hearth furnaces, bungs of air furnaces, the lining of the cupola at the melting zone—localities subjected to very high heat, long applied. (2) Resistance to abrasion. One of the best examples would be the cupola lining, particularly near the charging door. Not only are the bricks subjected to heavy pounding during the charging operation, but as the charges descend the comparatively friable material is scored, ground and crushed by the heavy pieces of metal pressed against it. (3) Resistance to corrosion by the slag. The melting zone of the cupola illustrates this nicely. The cutting action of iron oxide, lime and magnesia is very hard on refractories, particularly when also unable to resist high temperatures.

The physical structure of the fire-brick has a direct bearing when considered from the above standpoints. A brick may be very open and porous as one extreme, and quite dense as the other. The structure may be coarsely granular to very finely so—with low melting points the grain structure may have been entirely obliterated and a glazed fracture results from the firing process. In the process of manufacture more or less of old material is ground up with the clays used, for economy and to lessen the contraction. Then also, the brick may be burned light, medium, and hard. All these conditions affect the service given under the three requirements mentioned above, namely: successful resistance to high temperatures, abrasion and corrosion.

In selecting fire-brick for the several classes of construction about the foundry the following points will be of value: A fine-grained, hard-burned brick will serve best for cupola linings and the side walls of furnaces. A coarse-grained, medium-burned, softer brick does better for crowns and furnace bungs. Only the most refractory grades should be used, as the heat requirements are most severe. Even then it becomes necessary, in the case of the open-hearth furnace, to periodically check the heat in order that the extreme temperatures do not penetrate the brick beyond a few inches, as otherwise there is danger of collapse through undue softening. This is arranged for by checking the gas supply the moment a heat is ready to tap. During this period, and the subsequent patching and recharging of the furnace the interior lining has a chance to cool down a little, and is thus able to stand a renewal of extreme heat when melting and refining goes on again.

In the case of the cupola, the melting zone has no such chance, and for continuous melting it is important to have a very thick lining, to stand much cutting away before the steel shell becomes affected. Ordinary practice, with runs not over 2 or 3 hr., can be so regulated by careful charging and operation that but a few inches of the lining—the most intense heat of the melting zone—is seriously affected, and daily patching should readily handle the situation.

For annealing ovens and heating furnaces in which a lower range of temperature will do, a less refractory brick can be used. It is customary, however, to select the so-called "second-grade" brick, which are really of the same refractory character, but in the process of manufacture there is omitted a second pressing (after drying) and thus a cheaper brick becomes available where accuracy of shape is not so essential.

Going down the line still further, the interior surfaces of chimneys, and flues for waste and producer gases can be made of "flue" brick. These need not stand more than 1,100°F., and hence are made of less refractory clays. They are correspondingly cheaper than fire-brick. For the outer shell of annealing furnaces and drying ovens common red brick will do very well, as also for foundation work below the refractory bottoms.

Cupola linings must be very refractory, hard and dense. There must also be considerable toughness manifested by the brick or blocks. Hence fine grinding of the clay and careful burning to great hardness. This situation also cares for the corrosive influence of the slags formed during melting operations. The fewer the hair cracks and spaces between grains, the less chance for the entrance of slag and molten iron. Tough brick will withstand the pounding given in charging better than coarse-grained material. Fortunately manufacturers of fire-brick are giving these matters their serious study, and hence the foundryman is fairly well protected—provided he watches the quality of the clay used for bonding.

The worst point of the air furnace and open-hearth is the slag line. Here the corrosive influence of slag is seen in its most destructive aspect. The walls of the furnace become undermined and seriously weakened, and hence particular care should be given this part of the furnace in patching up after a heat. Chrome brick have been used at the slag line to overcome this cutting action but without success, as the rapid temperature changes cause them to spall off rapidly. Similarly chrome brick were tried in the melting zone of the cupola lining, but failed here also as contact with incandescent carbon results in the formation of chromium carbide which is volatile at these high temperatures.

As mentioned previously, it is highly important that the clays used for bonding the brickwork of furnaces and the cupola lining be equal in refractoriness to the brick itself. Otherwise the joints will melt out and the slag flowing over the walls injure the surfaces. The safest procedure is to use a clay identical with that put into the fire-brick. This will leave every part of the construction equally resistant to heat. The author can cite case after case in which the extremely rapid cutting out of the lining of cupolas was traced directly to the local clays used for bonding up and daubing. The fluxes ordinarily contained in common clays run so high that not only the day's repairs but also an added inroad into the lining itself is made during the heat. When it becomes necessary to reline the entire melting zone after the seventh heat, things are surely in a bad way. The foundryman is therefore advised to see that whatever he lines up his ladles with, the cupola should receive special consideration. Finally come the fire-clays used for lining up ladles and shanks, botting up the cupola after tapping, etc. Since the temperature of the superheated molten iron does not usually exceed 2,450°F., it is not essential that the highest grade of fire-clay be used for these purposes, and hence cheaper varieties will serve. All that is necessary is to observe that the clay is really a "fire-clay" and that it is fat enough to do the work required of it. A "fat" clay, in contradistinction to a "lean" one is a clay with high bonding power, or adhesiveness. A very lean clay has almost no bonding power, and while useful in pottery and chinaware establishments, would not serve the requirements of the foundry.

It should be remembered, however, that the more refractory the clay used, the thinner the ladle linings may be—it being understood, of course, that only enough clay is added to the fire-sand forming the body of the lining material, to give a resulting mixture with the least shrinkage when dried. A pure fire-sand, mixed with a very fat and highly refractory clay, gives a comparatively thin but very serviceable ladle lining much appreciated by the men having iron to carry to many molds. In general, therefore, unless the cost of high-grade and fat fire-clays is excessive at a given location, it pays to buy the best material even for the ladle linings.

Of late a special grade of fire-brick is being made in which "bauxite" forms the chief constituent. This is the ore of aluminum made use of in the production of this metal, being the hydrated oxide. Bauxite is calcined after grinding, to remove the water of crystallization and thus reduce the subsequent shrinkage. It is then mixed with a good fire-clay for bonding and fired as usual. While this brick cannot stand sudden changes in temperature without spalling somewhat, it is extremely refractory, strong and tough. An analysis would run about as follows:

Alumina	56.00
Silica	39.00
Iron oxide	2.50
Lime and magnesia	1.50
Alkalies	1.00

The iron foundry has so far had but little to do with basic refractories, these being important only in the steel-making industry. Nevertheless, mention should be made of this class of heat-resistant materials in view of the coming growth of the electric melting industry.

Of the three available basic materials—lime, magnesia and iron oxide—the latter can only be used where comparatively low temperatures are the rule, as in heating furnace bottoms and in the puddling furnace. With higher temperature ranges the presence of carbon brings about a reduction of iron, and the lining goes to pieces. Lime has the difficulty of slacking after calcination, by moisture and carbonic acid absorption, unless kept at a high temperature. Lime and magnesia—as dolomite—is better in this respect, and hence is used extensively for furnace bottoms in the basic open-hearth steel process. Unquestionably, however, calcined magnesite is the best material for basic linings. Magnesite is the mineral carbonate of magnesia, which when burned to magnesium oxide—magnesia—slacks but little. The small impurities contained in the mineral used for the purpose of making refractory brick is sufficient to bond it when fired in the usual manner, after the calcined magnesite has been molded into bricks. A good magnesite brick contains over 85.00 magnesium oxide, around 5.00 of lime, perhaps the same in silica, and but very little iron oxide. Bauxite really comes under the head of basic materials too, but as mixed with fire-clay for brick-making purposes, the percentage of silica runs so high that the basic properties are negligible.

Neutral refractories are necessary to make a separation between the acid and basic varieties in furnace linings, otherwise these will melt together. Chrome iron ore is the material generally used. It is highly refractory and is used either as made up into bricks or crushed. The analysis shows about 50.00 chromium oxide, 35.00 iron oxide, and the balance consists of silica, lime, magnesia and alumina.

Perhaps the best of all refractory substances is carbon. In the form of graphite it is known to all foundrymen, whether they use it for finishing mold surfaces or see it in their graphite crucibles. The fact that a mixture of graphite and clay gives crucibles capable of withstanding the temperatures and corrosive influences existing in crucible steel-making is highly characteristic. Even crushed coke is useful in this direction, foundrymen using this very material in their "blackening" for cores.

The so-called "gas carbon" and that made in the electric furnaces form very refractory varieties of this element. When ground fine and bonded with pitch or tar very good bricks can be made. Indeed, it is a question whether the solution of the "permanent mold" problem may not be found in this direction. And if not this, then at least the "long-life" mold. With a surface so dense that no iron or slag may enter between the particles, and the molten metal so free from gases (possibly cast under a vacuum) that venting is unnecessary, a profitable field would seem open for the experimenting metallurgist.

MOLDING SAND

One of the most important items in the production of iron castings is the material used for making properly shaped containers (molds) to hold the molten iron until definitely set. This material must answer a variety of requirements, such as refractoriness, strength, porosity, cheapness, etc.—points that require extended discussion and study. The ancients found that clay fashioned over the desired pattern, and this either removed before baking or destroyed in that operation, would hold molten metals safely and give the desired results. From those times until the present there has simply been an extension of the range of molding material from all clay with little sand to much sand with little clay.

The molds of today rammed up about the patterns, which serve as the containers for molten iron, are therefore made with a variety of sand carrying sufficient clay to make it plastic enough to serve the purpose. Such a sand is termed a "molding sand." At the outset the author wishes to state his definition of the ideal molding sand as *"a sand consisting of uniform-sized rounded grains of silica, each grain evenly coated with the thinnest necessary layer of the most refractory and fattest clay to be had."* The reasons for the definition as given will appear from the discussion to follow.

To understand the nature of a molding sand fully it is necessary to study the requirements of a perfect mold. First of all, the mold must be able to withstand the high temperature of the metal, applied until proper setting, without damage to the surfaces of contact between molten metal and sand. This means that the silica grains above mentioned must be pure and hence practically infusible. Also, that the coating of clay binding the grains of silica together must be sufficiently low in fluxing ingredients to resist softening or change of shape at least until the metal has fully set. The molding sands provided by nature do not all fill this requirement equally well, for while the silica grains are practically pure the clay substance is by no means so, and hence the time required for the metal to set forms an important factor. Thus a thin casting may come out all right from a mold made of sand carrying a heavy percentage of fluxes. There is simply no time for action on the sand as the metal cools and sets too quickly. With a heavy casting, conditions would be different and the surfaces resulting would not look good.

Granted that a molding sand is of such a composition that its refractory qualities are satisfactory. It is next necessary that the finished mold is strong enough to withstand the ferrostatic pressure of the molten metal without yielding. A casting must come out "true to pattern" or it is useless. Further than this, the sand itself must be adhesive, or strong enough to remain intact after being rammed about the pattern, this withdrawn, cores set, and the parts of the mold closed. The sand in the upper part of the mold—the cope—must not drop, corners should not break nor edges crumble. The mold surfaces must not suffer from the cutting action of the molten metal flowing against them. This means that there must be enough bond between the grains of silica—whether through much comparatively lean clay or little fat clay—when the molding sand has been properly wetted down or "tempered" and rammed just right, to successfully resist destruction as a proper container for the molten metal.

Then comes the ability of the mold to quickly free itself of the steam generated on contact of the molten metal with the damp mold surfaces. This steam should pass outward through the mold and not have to find its way through the molten metal. Again, any gases carried in the iron and liberated at the moment of set must be able to pass through the sand, as also any air pocketed within the mold by the rising metal.

To satisfy this condition a molding sand must have a good grain structure and only sufficient clay to bond properly without closing up the spaces between the grains too seriously when rammed. This property of allowing air and gases to pass through the mold is called "permeability." Naturally, the more uniform and round the grains the better, for fine material chokes up the spaces between the larger grains. Further, the fatter the clay, the less required.

Another requirement is the ability to destroy a mold easily on "shaking out" the casting. If the sand were baked too hard through the action of the molten metal upon it, an expensive situation would result. Moreover, but little of the sand should be "burned," or have its bond destroyed permanently, so that the removal of whatever sand may adhere to the casting as shaken out (subsequently finished in the "cleaning room" and thrown away) should leave the remaining sand of the mold available for subsequent use. These two requirements are fulfilled when the clay bond of a molding sand is of a highly refractory character. It will not be affected seriously by the heat conditions it is thus subjected to. A sand with high fluxing percentages, on the other hand, will bake together somewhat, particularly if the casting is heavy, not only because it cannot successfully resist high temperatures long applied, but also because this high heat is rapidly spread to the portions of the mold further away from the metal.

Finally, a mold should leave the casting made in it with a smooth surface. The coarser the grains of silica in the sand, the rougher the surface of the casting. The finer the grains the smoother the casting made in it. But as the finer-grained molding sands will not do for heavy work, for other reasons, the grain of a molding sand should be carefully selected to suit the work in hand.

The above are the more salient requirements of a perfect molding sand. The minuter details will develop as the chemical and physical properties of molding sands are gone into more fully. To get a better general view of the subject it is well to glance at the manner in which the natural molding sands were formed.

Typical granite is composed of quartz, the feldspars, and the micas. Occasionally the micas are replaced by hornblende and its allied minerals. When such a rock goes to pieces in the weathering process of the ages, there remains a sandy clay—eventually becoming a soil. All rock is more or less permeable by water. This enters first along the natural planes of cleavage, and on freezing shatters the structure little by little. This can be noticed by anyone in an abandoned stone quarry the face of which has been left exposed for years. The piles of broken rock at the base of the Palisades are a good instance. Again, the percolating water also carries acids taken from vegetable matter and the air, and this acts upon the ingredients of the rock susceptible to them. Thus, in a granite rock, the feldspars are decomposed, as also the micas, and the quartz grains—which are not affected seriously by this action—are set free.

The feldspar group of minerals consists of aluminous silicates of potash, soda, lime, and soda-lime. In the decomposition there is leached out the potash, soda and lime, leaving the mineral kaolinite, a hydrated aluminum silicate—the essential constituent of clays. Unfortunately this decomposition is rarely complete, and hence the highly refractory kaolinite contains admixtures of undecomposed feldspars—which, being fusible, form the fluxing ingredients of molding sands.

The micas are hydrated potash-aluminum silicates and are more or less subject to decomposition also. Where a mica has resisted this action successfully, the molding sand will exhibit shiny particles. As the micas are quite fusible, they are undesirable constituents in the sand heap. Where hornblende (the amphibole group) is present in place of a mica, the decomposition is very complete, and as this mineral carries much iron, the molding sand may be dark in color.

Where such a granite has been weathered in place, and hence the resultant products have not been moved away, the sand grains will be angular, be imbedded in more or less pure kaolin, and yield a rather strong molding sand. The weathering action being more marked at the surface than deeper down, the grains will be finer above and quite coarse down below. If, on the other hand, the weathered material was subsequently subjected to the action of wind and water, the ingredients will have been changed somewhat so far as their physical structure is concerned. As the crystals of quartz are rubbed against each other by waves or flowing water, they become rounded. Kaolinite, when scoured out of position, mixed with water and carried away to quiet bays or lakes, will settle out as clay. The action of the great ice sheet covering the northern countries meant so much grinding and rubbing, with streams of water at the terminal boundary washing and mixing, forming temporary lakes, developing beds of clay and molding sand. The margins of such lakes were particularly adapted to the formation of sand and clay mixtures, wind and waves keeping up the process of sizing and freeing the bed from the friable and undesirable mineral constituents, the micas, hornblende, etc., and storing up for the foundries of the future vast supplies of molding sand, making it so cheap that until very recently it has escaped the scrutiny of the investigator. Now, however, molding sand has come in for detailed study, for the foundry has about decided that it is cheaper to spend more for sand to get perfect molds than to chance the loss of labor and castings through defective or deteriorated sand heaps.

The sum and substance of the previous discussion is that molding sand consists of three essential ingredients: sand, clay matter, and fluxes; that is, grains of quartz, fully decomposed feldspar, and undecomposed feldspar, mica and other minerals. With this in mind the so-called "rational" analysis of a molding sand will be understood, as it consists of three items only, namely: quartz, clay substance and feldspar. The item "feldspar" embracing all the undecomposed minerals other than quartz, as these are fluxes, or fusible, in contradistinction to quartz and clay which are both practically infusible. It may be stated in this connection that the ordinary analysis of a material is the "ultimate" one, that is the elements or their chemical combinations are separated from each other, and the percentages determined. Thus, in a molding sand, the ultimate analysis would show the percentage of silica, alumina, iron oxide, lime, magnesia, potash, soda, etc., from which the percentage of the actual elements can be readily calculated if desired.

A third method of determining the constituents of molding sand is by "mechanical analysis." This consists of a thorough separation of the clay substance from the quartz grains by means of some deflocculating reagent, such as caustic soda, ammonia, etc. Careful washing is necessary to effect this separation completely, and if carried out over a set of sieves it is possible to get a good fineness test of the sand grains at the same time.

The author has made extended investigations on American molding sands for the American Foundrymen's Association, the results of which were duly given to the foundry industry. The data were further turned over to the U. S. Bureau of Standards for further study with a view of standardizing the subject. This means the preparation of ideal artificial sands for various classes of castings, both iron and of other metals, so that natural sands may be studied with regard to their preparation and improvement. The 76 molding sands tested by the author were well known and extensively used from the Mississippi to the Atlantic seaboard north of Alabama. Rational analyses were made through the courtesy of H. E. Field. They are classified by regions, and averages are given where over a single sample.

Region	No. of samples	Quartz	Clay substance	Feldspar
Albany, N. Y.	23	58.82	18.99	22.16
Kentucky	13	64.53	24.77	10.69
Ohio	14	71.02	23.79	5.17
Missouri	10	64.10	24.36	11.54
Pennsylvania	9	67.21	21.99	10.79
New Jersey	4	81.38	15.49	3.13
Illinois	1	70.82	16.65	12.53
Georgia	1	77.37	17.94	4.69
Tennessee	1	74.53	21.11	4.36
Grand average	76	65.53	21.73	12.74

This grand average, recalculated to the ultimate composition, gives the following:

Silica	84.26
Alumnia (and iron oxide)	13.59
Lime, alkalies, etc.	2.15

A study of the above table shows some very wide variations in the rational analyses of molding sands. The ranges of the three constituents of these averages are summarized in the following, and with them are given the ranges of the individual analyses that make up the averages.

	Range in averages	Range in individual sands
Quartz	58.82 to 81.38	45.77 to 88.70
Clay substance	15.49 to 24.36	13.38 to 41.20
Feldspar	3.13 to 22.16	2.45 to 32.43

As might be supposed, the ranges are wider for the individual sands than in the averages for the regions indicated. The fact that all the sands are in daily use and are giving good results for the particular classes of castings being made in them—when things are going right—would show that a very wide range of composition is possible. Taken in connection with the well-known variation in percentage of molding losses found in foundries making the same class of castings with the same varieties of sand, however, it would seem that a much narrower range in composition would be far better and insure safety from losses directly chargeable to poor sand. It would be highly desirable, therefore, to establish a system of testing which can be used by the foundryman to ascertain whether his sand heaps are within the safe range of composition at all times. He will thus know of trouble ahead before it actually faces him in the shape of lost castings.

Referring again to the author's definition of an ideal molding sand, in connection with the figures above given, it would appear that the lower the feldspar content, and the smaller the clay percentage of high bonding power with low feldspar residues, the better. So that if it were possible to get high strength, refractoriness, uniform grain size, etc., in a molding sand with a composition of about 84.00 quartz, 13.50 clay substance, and 2.50 feldspar, it would be pretty near the ideal American average. The actual range, from the averages previously given, runs about

65.50 quartz, 21.75 clay substance, and 12.75 feldspar, or a material overloaded with a clay that leaves much to be desired.

The published analyses of foreign sands are unfortunately given as "ultimate" instead of "rational," except in the case of some English sands. Here, however, the accompanying ultimate analyses, on recalculation to the rational (that is apportioning the silica belonging to the alumina to make the clay substance as also the alumina and silica belonging to the alkalies, lime and magnesia, to make the feldspar) give such discordant results that either the ultimate, the rational, or both analyses are unreliable, or else were made on different samples.

The author has recalculated the analyses given below, for comparison with the American average rational analysis of molding sands.

	Quartz	Clay substance	Feldspar
American average	65.53	21.73	12.74
French sand, Paris region	84.45	10.68	4.69
German sands:			
Brandenburg	87.31	10.19	2.50
Freyenwalde	58.63	15.77	25.23
Lueneburg	85.72	7.71	6.89
Hannover	86.57	7.52	6.44
British sands:			
Worksop	74.01	12.60	8.88
Mansfield	73.36	5.90	12.39
Erith	73.47	14.48	11.40
Kidderminster	75.40	7.71	13.28
Stourbridge	64.76	10.53	23.46
South Staffordshire	77.21	6.99	13.03
Clyde	78.23	7.03	12.80
Glasgow	89.47	4.70	4.18
Wordsley	73.34	11.76	11.12

From which it will be seen that there is just as much divergence manifested in these sands as there is in the American. Indeed, some of these sands are said to require additions of clay-wash to make them bond satisfactorily. A further noticeable point in a number of the so-called "red" sands is the very high percentage of iron oxide—this rising up to 7.50 in some English sands. In one case near Vienna a sand is used with over 11.00 iron oxide, and again another sand with nearly 12.00 lime. Both of these ingredients are bad, as they are fluxing, but it is interesting to note that a moderate percentage of iron oxide, if distributed over the surfaces of the quartz crystals as a stain and encrustation, is not objectionable to a serious extent, as it serves as a base to hold the clay more firmly to the otherwise smooth surfaces of the sand grains, particularly if they are well rounded.

While on the subject of the analysis of molding sands, that of the material used for "loam molding" should also be given. This is a natural mixture of fire-clay and sand deposited alluvially, is very plastic on account of the heavy clay percentage, and to be useful should be quite refractory. The fundamental requirements of a good loam are that when dried in the oven it should bake hard and strong, and not show any signs of shrinkage in the material.

Hence there should be sufficient clay in a loam to give strong bonding, as well as sufficient sand to overcome the natural shrinkage in the clay when the loam is baked. Much will naturally depend upon the character of the clay constituent, for if this is lean and enough sand is added to overcome the shrinkage, the mass may not be able to resist the cutting action of the metal as well as the ferrostatic pressure in the mold. Hence artificial bonds are added in shape of cow-hair, hay and straw rope, horse-dung, and similar organic material which incidentally help in proper venting. Another way to correct the trouble is to add more clay, but of the very fattest kind, in the shape of clay-wash, with just enough sharp sand to care for the increase in shrinkage otherwise resulting.

The foundryman therefore has it in his power to apply the proper remedy in case his natural loam does not quite fill the bill. In fact, in loam molding, it is important to differentiate between the interior and the surface material. The former must be of good bonding power but well vented, hence rather richer in clay than absolutely necessary—the passages for gas and air being carefully kept unobstructed—while the mold surfaces should have a higher proportion of sand. This in order to successfully resist the intense heat applied as the molten iron remains in contact with it, at least until a sufficiently strong shell of metal has formed to preclude any further danger of shrinkage in the mold surface. Thus the loam for the interior of a mold may run 34 per cent. quartz and 66 per cent. clay substance and fluxes, whereas the surface finish may be but little richer than a strong molding sand.

Loam must naturally be mixed with water some time before use, so that the moisture may permeate it thoroughly. Then it should be put through the mill for thorough kneading and mixing. The presence of organic matter, either natural or by admixture, is beneficial, as in baking the gases formed create channels in the material which afterward assist in venting.

Next to the composition of a molding sand, the grain size is of special importance. The clay content of the material is in a very finely divided state, but the quartz grains are easily distinguished under a low-powered microscope and may be angular or rounded, small or large. The sizing of a molding sand is carried out with a set of sieves of given mesh sizes, and is performed on the sand while dry. It is necessary to rub the sand grains apart where the clay substance is fat, and the real object of sizing is to determine to what class of casting work the sand is best suited.

It has so far been customary to separate the sand sizes by sieves in which the number of meshes per inch run 20, 40, 60, 80 and 100. So that the material would be divided into sizes larger than 20, between 20 and 40, 40 and 60, 60 and 80, 80 and 100, and all that would pass through the 100-mesh sieve. This method is quite satisfactory, the only question remaining unsettled is the sandardization of the sieves. This is being worked out under the auspices of the U. S. Bureau of Standards, and while not specially important for foundry purposes, it is very much so in other industries.

The ideal sand should be of uniform grain size and round. The reasons for this will be understood when a moment's thought is given the matter. Small grains will pack between large ones whether they be round or angular. In the latter case the spaces are apt to be filled more completely by reason of the compacting action given the sand in making the mold. All this means reducing the permeability of the sand, and venting is interfered with to a very serious extent. Hence the importance of a uniform size of grain.

The reduction in the permeability is, however, also brought about to some extent in the case of sands of uniform size if the grains are angular. In ramming up the mold the quartz slivers and angular pieces are driven into close contact with each other, and the comparatively small spaces left between them are filled up with the clay substance. This is not the case with round grains of the same size. No amount of pounding will bring them closer together if they are true spheres. It is only necessary to have a very fat clay in amounts too small to fill the voids between the spheres to have an actually "fool-proof" molding sand which can be pounded as hard as wanted and yet vent properly. There is another point to consider. In ramming up deep molds, the action of a blow upon sharp sand (angular grains) is to drive the particles together very closely at the point of delivery, but the force thus expended is not transmitted very far beyond. In the case of round grains, however, a blow is not only effective at the point of application, but is transmitted from grain to grain, straight ahead and sideways, so that the ramming action results in a uniformly compacted mold even around the deep pockets. With angular grains in a sand, the points furthest away from the rammer are apt to be too open and the castings will be swelled at those places.

This situation will be better understood when preparing the molds for the standard test bar. The author uses a mold slightly different from that described under the standard specifications in his experimental foundry. Instead of using a section of pipe and ramming up two patterns side by side, he has prepared a large number of cylinders of perforated sheet steel, provided with a bottom of the same material. These cylinders are 4¼ in. in diameter and 16½ in. high. The pattern, when rammed up in vertical position, thus has 1½ in. of sand around and below it. After drawing the pattern the mold is dried in the oven and a lot of these molds are parked ready for pouring whenever required. As the bar is but 1¼ in. in diameter and is 15 in. high (vertical pour directly into the top), it takes skill to make the mold properly, as the ferrostatic pressure has to be reckoned with. Many a high-class molder will bring his first bars out looking like Indian clubs, the bottom having swelled so badly. With sharp sands the ramming up has to be performed with very thin layers at a time to avoid this trouble, as the ramming force is not transmitted very far into the sand. With round-grained sands this difficulty is not so noticeable. The crux of the whole situation is that the strength of the molding sand should be obtained through the fatness of the clay and not the sharpness of the quartz grains, and good venting conditions through uniformity in grain size.

Mention has been made of the grain size determining the class of castings for which the sand is suitable. As a general proposition, the finer the grain the smoother the work produced. The highest grade of art castings are made with the finest molding sands. Indeed the clay mold for the most delicate bronze work is of material perhaps 250-mesh fine. Coarse grains of sand in the mold surface mean the entrance of iron between them, thus leaving a rough surface. Castings from certain cities in America are notorious for their poor surface—though otherwise very high class for quality—simply because the sands used are coarse-grained and ununiform.

On the other hand, the finer the sand, the poorer the venting power. Hence, the selection of a sand for a given line of castings should be made for the finest grain size possible, with safe venting of the molds. This will mean the smoothest surfaces on the castings obtainable without special finishing methods.

After sieving a molding sand to divide it into the several meshes and getting the percentages, it is desirable to calculate out an "average" fineness for purposes of comparison of this sand with others. Such a calculation is necessarily very arbitrary, as the division is not by actual grains but by groups of them, running in size from say 40- to 60-mesh, etc. The hypothetical standard for fineness—or 100 per cent. fine—is one in which all particles pass through the 100-mesh sieve (100 meshes to the running inch of the brass gauze used, or 100 × 100 equals 10,000 openings per sq. in.). By multiplying the percentage of sand passing through each sieve by the mesh number, adding these products together, and dividing the whole by 100, the percentage of average fineness is obtained. Thus, for a New Jersey sand the folalowing figures obtin:

95.40	per cent. passed through	100-mesh × 100, equals.......	9,540.00
0.24	per cent. passed through	80-mesh × 80, equals.......	19.20
1.40	per cent. passed through	60-mesh × 60, equals.......	84.00
1.32	per cent. passed through	40-mesh × 40, equals.......	52.80
1.44	per cent. passed through	20-mesh × 20, equals.......	28.80
0.20	per cent. retained by	20-mesh × 0, equals.......	0.00
100.00	per cent.		9,724.80

Dividing the sum by 100, this sand will show an average fineness of 97.25 per cent. The separation of the molding sand into sizes incidentally shows it to be a very uniformly fine one, as but a very small percentage of the material is coarser than the bulk. This is not indicated by many of the sands used in daily practice. For instance, a sand from Kentucky shows the following fineness:

19.12	passed through	100-mesh
6.52	passed through	80-mesh
17.60	passed through	60-mesh
34.92	passed through	40-mesh
21.64	passed through	20-mesh
0.20	retained on	20-mesh

This sand has an average fineness of 53.19 per cent., when calculated out by the method above given. It is a comparatively coarse sand, the bulk of the quartz grains grouping around the 20- to 60-mesh points, while the clay substance passed through the 100-mesh. This sand would have been better had the bulk of the quartz grains run closer together, say 20 to 40, or 40 to 60. The fineness test just given, however, shows just how such a sand could be improved; namely, by running the carefully dried and ground sand through a sieve which would reject everything not passing the 40-mesh. This would cut out the 21.64 and 0.20 items, bulk the quartz grains together better, and make a somewhat finer molding sand. As the majority of the 19.12 item is clay, the removal of over 20 per cent. of the coarser quartz grains might leave the balance of the sand too clayey and hence an equivalent of 40- to 60-mesh silica sand—round-grained as possible—could be mixed with the molding sand in the original grinding (separating the sand grains from each other) to restore the proper composition.

While the above-described method of obtaining the average fineness of a molding sand is arbitrary and rather crude, yet it serves very well for purposes of comparison. In the tests made by the author for the American Foundrymen's Association, the sands examined could in this way be classified into the "fine," "medium" and "coarse" varieties. Averages between 90 and 100 per cent. fineness were called "fine" molding sands, those between 80 and 90, "medium," and those below 80 were designated the "coarse" varieties, as indeed they were. Attention, however, should be called to the fact that in the Kentucky sand above mentioned only the scattering of the grain sizes over a wide range which included much fine material brought the averages of fineness up to 80 per cent. If, therefore, the natural sands should be corrected either by the removal of the fine material between the clay portion and the coarse quartz grains, or else by the addition of more coarse material and bonding clay, the classification will undoubtedly have to be revised, so that the "fine" molding sands would probably run between 80 and 100, the "medium" between 60 and 80, and the "coarse" below that point.

In the meantime, however, the following table of fineness is presented to show how the grain size of the three classes run for the American sands investigated. To save multiplicity of figures, averages only are given.

Grade	No. of samples	Over 20-mesh	20- to 40-mesh	40- to 60-mesh	60- to 80-mesh	80- to 100-mesh	Through 100-mesh
Fine.........	18	0.03	0.29	3.32	3.50	3.46	89.42
Medium......	10	0.29	3.16	7.89	11.36	13.12	64.18
Coarse.......	48	1.85	17.49	27.07	14.90	8.39	30.40

It will be noted that the distribution of the material is very good for the fine sands, the coarser particles being so scarce until 40-mesh is reached that the gray iron or brass castings made should have very smooth surfaces. To understand the situation better for the medium and coarse sands, it will be of interest to deduct the percentage of clay substance and feldspar (averages) as these materials are finer than 100-mesh in the case of fine and medium sands, and certainly finer than 80-mesh in the coarse sands. In fact, only a small portion of the feldspar in the coarse sands will run less fine than the clay. The following figures give the information in question:

Grade	No. of samples	Average per cent. clay substance	Average per cent. feldspar	Total
Fine...........	18	22.22	14.26	36.48
Medium........	10	18.49	18.81	37.30
Coarse.........	48	22.22	10.98	33.20

The table of fineness above given recalculated to give the quartz grains only would then look as follows:

Grade	No. of samples	Over 20-mesh	20- to 40-mesh	40- to 60-mesh	60- to 80-mesh	80- to 100-mesh	Through 100-mesh
Fine.........	18	0.03	0.29	3.32	3.50	3.46	52.94
Medium......	10	0.29	3.16	7.89	11.36	13.12	26.88
Coarse.......	48	1.85	17.49	27.07	14.90	5.49	

The fine sands again show up well with the clay and feldspar removed. The medium sands show up badly, being scattered about in grain size from 40-mesh to very fine—over one-quarter of the quartz grains being smaller than 100-mesh. The coarse sands, however, are not so bad as the quartz grains are grouped between 20- and 80-mesh. As previously stated, there is room for much improvement here in reconstituting these sands so that the grouping of the quartz grains is brought within much narrower limits.

An interesting point in the figures presented is found in the remarkable agreement in the clay substance and feldspar averages for the three grades of sand. This would argue for a pretty even distribution of the minerals in the decomposed granites from which the molding sands were derived.

In studying the physical character of the grain structure of molding sands the microscope is indispensable, not necessarily with high-power lenses as for metallographic work, but arranged for enlargements of say 18 diameters. This gives a clear view of the sand grains, allows the making of serviceable photomicrographs, and the application of polarized light to distinguish many of the minerals contained. An ordinary pocket microscope will quickly show whether a sand is sharp or round-grained, uniform in texture or badly mixed as to grain size.

The minerals found in molding sand are also of interest as they give a clue in regard to the probable refractoriness. The following have been observed in the sand tests above referred to. The tests were made by D. Dale Condit, through the courtesy of the Ohio State Geological Survey.

Quartz:
The Feldspars:
  Orthoclase
  Microcline
  Plagioclase
The Amphiboles:
  Tremolite
  Actinolite
  Hornblende
The Micas:
  Muscovite
  Sericite
  Biotite
The Pyroxenes:
  Diopside
  Enstatite
  Hypersthene
  Augite
Tourmaline
Zircon
Apatite
Rutile
Garnet
Corundum
Magnetite
Chlorite
Serpentine
Hematite
Limonite
Pyrite
Kaolinite
Pyrophyllite
Sillimanite
Andalusite
Cyanite
Spinel
Calcite
Dolomite
Siderite
Monazite
Titanite
Epidote

A truly long array of minerals which have their effect on the refractory properties, color, bond, strength, etc., of the sands they are found in.

The bonding power of a molding sand is the next point to be considered. The more and fatter the clay substance, the stronger the bonding power of a sand. On the other hand, the smaller the venting power such a sand will have, owing to the closing up of the voids between the quartz grains. Hence the desirability of testing sands for their bonding power in connection with the ability to pass air and gases through them.

The foundryman is much interested in this phase of the subject, as it is important to him that copes shall not drop, or the mold surfaces be cut by the stream of molten metal. At the same time the sand must be open enough for his purposes. It is necessary, therefore, to test not only the sand shipments as they arrive, but also the sand heaps on the floor, to see that these remain up to standard. To handle the subject intelligently the range of bonding power required of the sand should be definitely established. That is, the point should be determined below which the sand gives trouble from undue weakness. Again, an upper limit is also good, for any unnecessary strength on the part of the sand in the heaps means a corresponding loss in venting power. These limits can best be gotten by actual observation, and tests made on the sands under such conditions of undue weakness and strength will fix the actual figures. If, now, in one week say the first, third, fifth, etc., sand heaps are tested for bond; and the next week the second, fourth, etc., heaps are examined, the foundryman will know exactly in what shape his molding sand on the several floors is. Any sign of weakness can be promptly corrected by increasing the supply of new sand, while over-running the upper limit for bond means wasting new sand.

This question is more important than it looks. The author has repeatedly been confronted with the following situation. Large foundry corporations operating a number of plants, when checking up production costs, find that for the identical line of castings, and using identical molding sands, one foundry may use two or three times as much sand per ton of work produced as another. Even if molding sand is still a very cheap commodity in the United States, this situation is not a proper one. It is possible, of course, that the sand shipments may not have been uniform in character, but it is likely that more sand was used than necessary in order to keep the discounts down. On the other hand, the conditions of waste disposal may be such at a plant that the foundry foreman stretches a point to use his sand to the limit. Unfortunately, when such a limit has been reached —as shown by the growing discounts—the sand heaps are in such a deplorable condition that the temptation to remove them bodily is very great, and only the application of clay-wash to the heaps from day to day, in addition to the new sand, will save the situation.

The author has observed many cases where it was necessary to add so much new sand to the heaps daily, to keep them up to standard, that in addition to the burnt sand taken away from the heaps with the castings freshly shaken out, it was necessary to remove perhaps 10 per cent. of the heaps themselves. The bond of the sand was so low in value. Here the use of a better grade of molding sand—that is, of greater bonding power—will save much labor and material otherwise going to waste, and emphasizes the value of testing the sand heaps at stated periods.

The test of the bonding power is a very simple one. It seems that the "fat" clays have a greater power for absorbing dyes than the "lean" ones, and this property has been made the basis of the method of determining the bonding power. An aniline dye of great brilliancy is taken in given quantity, dissolved in a given quantity of water, and a given weight of sand added. After agitating long enough to get a perfect mixture, the material is allowed to settle until a clear solution remains above. The lighter the color the greater the dye absorption and hence the better the bonding power. The dye called "malachite green" was used until the recent investigations of Saunders and Franklin indicated that "crystal violet" gave better results. Comparison is made with a standard solution of the dye itself and thus a basis of valuation of the bonding power arrived at.

To get an idea of the bonding value of the "clay substance" in the tests of the several sand regions previously mentioned—not the bonding value of the sands themselves—a series of calculations was made by the author on the individual results in question, and comparison made with the clay bond of the Albany series, this being the lowest in value. These results will show how variable the bonding powers of the clays contained in molding sand are when subjected to close investigation.

Region	No. of samples	Relative bonding value
Albany	23	1.0
Ohio	14	2.2
Kentucky	11	2.0
Missouri	10	2.3
Pennsylvania	9	1.4
New Jersey	4	1.7
Illinois	1	2.6
Georgia	1	1.4
Tennessee	1	2.2

There are many theories to account for the "stickiness" or bonding power of clay. Whatever this "colloidal" (glue or jelly-like) condition of the hydrated aluminum silicate is due to, the driving off of the chemically combined water by heat also deprives the clay of its bonding power. "Burnt" molding sand has but little bond remaining. This is the sand adhering to the castings as shaken out after the molds have been poured off. In the malleable foundries this material is taken from the hard-rolling room, mixed with water to a stiff paste and applied to the annealing boxes as a luting to close up the joints. Sometimes also as a cover where cast-iron plates (white fracture) are not used. There is just enough bond remaining in the burnt sand to hold the material together, and the high-silica percentage prevents the formation of shrinkage cracks.

The above-mentioned chemically combined water of the clay begins to pass off at about 500°F. Saunders and Franklin give some results in connection with the loss of bonding power when a molding sand is heated to different temperatures for equal spaces of time. A sand with the bonding power expressed by the number 480 (according to the method used by these investigators) was thus treated with the following losses in bonding power.

Temperature (degrees F.)	Bonding power—number
212 (100°C.)	480
572 (300°C.)	380
932 (500°C.)	260
1,292 (700°C.)	260
1,652 (900°C.)	160
1,832 (1,000°C.)	120

Continuing the heating operation at the highest temperature given resulted in the complete destruction of the bond. The above emphasizes the necessity of removing all the adhering burnt sand with a casting from the sand heap when shaking out.

Also, the sooner a casting is shaken out after pouring, the better, provided the temperature has dropped low enough to avoid air chilling with the accompanying setting up of interior strains.

Incidentally contact of the sand with the molten metal has another effect. This is the splitting up of the quartz grains into slivers and angular pieces to some extent, a material not good to remain in the sand heap. If to this production of fine material and the loss of bond there is added the graphite blacking rubbed into the mold surfaces, the condition of the molding sand can be imagined at the point where a molder has removed a flask and scraped the red-hot sand from the casting to have a look at the surface. Every foundryman knows how bad this is for the sand heap, and yet this very thing happens in the large establishments having conveying systems for handling the castings as they are shaken out. Here so much burnt sand is taken off in transit and gets into the hot good sand going to the retempering apparatus that a serious castings discount from small surface defects results. Sometimes it becomes necessary to add a very fat clay to the sand to bring it up to the necessary bonding requirements again. Hence, such establishments should give their sand heaps the closest of attention.

The question of the strength of molding sands comes up next. This is intimately connected with the amount of clay present, the bonding power of this clay, and unquestionably the degree of roughness of the quartz grains present. Mention has been made of an iron stain as promoting this roughness, with consequent greater ability of the clay to adhere to the quartz surface. It must make some difference whether the grains present a polished surface or one like that of a sheet of ground glass.

For a rough test the foundryman has the habit of grabbing a handful of the tempered sand, balling it up and breaking the lump to see how strong it is. Where the molding sand is purchased under the dye-absorption test, as also the sand heaps are carefully watched, there is no need of a special strength test. It will be interesting, however, to see what has been done by way of comparing the strength of molding sands when tempered and rammed up into test specimens.

One of the simplest methods of testing the comparative strength of the molding sands presented for trial is to ram up inch square test bars a foot long, upon a plate of polished marble or glass. The bars are then slowly pushed over the edge and the length of the overhang noted as they break off. A more satisfactory test, however, is the breaking of a sand bar supported at both ends by a centrally applied load a test similar to the transverse breaking of cast iron. In the comparative tests made by the author, many of the sands being rather weak, it was necessary to place the 6-in. bars on supports 4 in. apart and even then some of the bars would break of their own weight. The bars were 1 in. square in section and the load was applied centrally by running bird shot into a little aluminum bucket suspended from a knife edge of magnesium resting on the bar.

Everything, of course, depends upon how the sand is tempered and to what extent it is compressed. In the first place, the amount of water required to temper molding sands properly varies somewhat, and hence three standards were used. The minimum taken was 5 per cent., medium 7½ per cent., and maximum 10 per cent. After mixing these quantities of water with the previously dried sands, they were allowed to stand for some time under a rubber blanket to allow a thorough diffusion of the moisture. The results justified the trials with varying amounts of water, for some of them were stronger with the larger amounts whereas the general tendency was the other way. Tests were also made with sand bars after drying in the oven, and the general averages obtained are given herewith:

Quality	No. of samples	5 per cent. water, pounds	7½ per cent. water, pounds	10 per cent. water, pounds	Dry, pounds
Fine	18	0.13	0.16	0.15	1.28
Medium	10	0.76	0.22	0.11	1.68
Coarse	48	0.42	0.31	0.24	1.88

In the finer sands the higher water averages seem to serve best, which is natural when the greater surface areas to be covered is considered. In the coarser varieties excessive moisture renders the sand soggy and weak. The great increase in strength in the dried test bars shows the value of dry-sand casting work over green-sand so far as the integrity of the molds themselves is concerned.

The method of ramming up the bars is also most important in judging the value of the strength tests. A separable frame of hardwood 1½ in. thick, arranged with spaces for the bars, is filled and heaped up over the top an inch high. The sand is then compressed with a hand-rammer to ¼ in. over the top of the frame, and this is struck off flush. Strips of wood the size of the bars, and ½ in. thick, are laid on the sand over the spaces and these pressed flush with the frame. This compresses the already slightly packed sand to 1 in. thickness, and the whole procedure corresponds to what happens when ramming up a mold on a machine. The separable frame is taken away, and the test bars are ready for use.

While the transverse strength of molding sands when rammed up into molds is of value in judging the chances of copes holding up properly, a good crushing strength is equally desirable as indicating the probable resistance of the mold, when properly made, to the ferrostatic pressure of the molten metal poured into it. While making the sand bars for the transverse test, those for the crushing test (as also for the permeability test) were made in the same frame under the same conditions. These bars—used as columns—were also 1 in. square and stood 1½ in. high. The weight necessary to crush them is given in the following table:

Quality	No. of tests	5 per cent. water, pounds	7½ per cent. water, pounds	10 per cent. water, pounds	Dry, pounds
Fine.............	18	3.11	2.97	2.48	7.82
Medium..........	10	4.03	3.28	2.38	13.70
Coarse...........	48	4.82	3.43	3.68	14.29

These results show a similarity with those of the transverse test. Individual tests, however, give some surprising figures. One sand running as follows: With 5 per cent. water, 3.57 lb.; with 7½ per cent. water, 2.76 lb.; with 10 per cent. water, 3.32 lb.; when tested dried, 60.30 lb.

As previously stated, in spite of the interesting figures obtained by subjecting molding sands to the transverse and crushing tests, the purchase by and routine testing of the bonding power of a molding sand is quite sufficient for the purposes of the foundryman if he knows the limits between which he must work.

There remains the venting power of the sand when properly rammed. The effect of grain fineness and quantity of clay substance on this property of a molding sand has already been discussed. The degree of moisture added for tempering purposes and the closeness of the structure gotten through ramming also have a decided influence on the results obtained from the sand.

The moisture situation in itself is not usually serious as if not too wet commercial sands will vent properly. Unless, therefore, the molder uses his swab too freely and thereby causes the metal to boil at the point affected, or if too much water has been applied in finishing up the mold surfaces, troubles from excessive moisture will generally be due rather to hard ramming, with neglect to use the vent wire freely. Steam generated at the mold surface by contact with the molten iron cannot get through the mold but is forced into the iron.

To test the venting power of molding sands, the author made inch-thick blocks, rammed up with the test pieces for strength, and forced air through them by means of suitable apparatus. There was noted the time necessary to force a gallon of air through an orifice of ¼ in. diameter placed against one side of the block—the other being free to the atmosphere. Over and above the time necessary to run a gallon of air through the apparatus without having the sand in place, the following embraces the averages of time observed:

Quality	No. of tests	5 per cent. water, seconds	7½ per cent. water, seconds	10 per cent. water, seconds	Dry, seconds
Fine	18	1.65	1.75	2.71	1.29
Medium	10	0.68	0.85	1.10	0.93
Coarse	48	0.89	1.34	1.79	0.97

These figures would indicate that, apart from the very fine sands, the sparing use of water in tempering gives even better results than for dry-sand tests. Evidently a slight moistening brings the particles closer together. The use of much water, however, seems to close up the spaces between the particles very materially and obstructs the passage of air and gases. The figures again emphasize the desirability of round and even-sized grains of quartz in molding sands, bonded with only small amounts of very fat clay.

The foregoing studies on the characteristics of molding sand will naturally find their best application in foundries having laboratories connected with them. As but few of the existing foundries are so equipped, however, a set of rough tests requiring no apparatus of refinement will be of interest to the practical foundryman. Such tests are, of course, comparative ones only—that is, making comparisons of new sands offered with those in use and well understood. First, the magnifying glass—this will show the size and shape of the grain structure of the sands. Next, a cupful of each sand is placed in a separate fruit jar or preferably a small-diameter, high bottle. To this is added an exact amount—say a pint—of the dye solution previously made (either malachite green or crystal violet). The bottles are now shaken up very thoroughly for say 5 min. and allowed to stand. In a minute or so the sand will have settled and the relative amount of this as compared with the clay portion which settles out later can be noted. After standing over night, the tint of the solution above the sand will indicate the bonding power of the sand—the lighter the better the bond.

While this is a very rough test, the author has nevertheless used it oftentimes when no laboratory was available. The results have always been borne out in the foundry when the sands thus compared were put to actual trial under molding and pouring conditions.

CORE SANDS

Since cores are bodies of either dry or green sand placed in molds to form corresponding cavities in the castings, their function is identical with that of the molds themselves. Instead, however, of containing the metal as in the mold proper, the cores are themselves partially or nearly wholly surrounded by the molten metal. As this situation makes the demands upon a core much more severe than on the mold, special attention must be given the materials and methods of making this rather expensive adjunct to the molder's handiwork.

In general, cores require more strength than molds as they are subject to more and rougher handling during transportation and placing into position. Further, as the cores project into the molten metal they have not only to withstand severe bending strains through the ferrostatic pressure, exerted, but the gases formed within them must be given every opportunity for rapid escape without "blowing" into the metal. Finally, as the cores must be removed after shaking out the molds and getting ready to finish up the castings, the bond of the cores must be such that it is readily destroyed by the heat of the molten iron after this has set.

The green-sand core can be dismissed at once as it is made of ordinary molding sand, just as the mold itself. The molder makes it right on his bench or floor, ramming it up on an iron arbor designed for strength and to suit the work in hand. He gives the venting problem special attention, and it really is a molding problem.

To give the best possible venting power a core sand should have uniform-sized and round grains. Since any clay substance present would bake the grains together and thus make it difficult to remove the core after casting the metal about it, the required bond should preferably be a substance with strong adhesive powers, so that only little need be used, and be able to withstand heat long enough to prevent the metal from cutting the surface as well as entering into the pores. Enough of the "binder" or bonding material must be used to allow the core to be transported and handled without too great a degree of care. Core binders are usually organic substances such as flour, linseed oil, rosin, etc. They will be discussed separately.

For his core sand the foundryman will therefore look about to the nearest supply of reasonably clean bank sand, unless he has specially fine work in hand. In this case he will do well to obtain the wonderful lake sands or wind-driven varieties, such as the Ottawa, Michigan City, Toledo, etc. Where very large quantities are used the sand merchant can afford to grind and wash the sand for core-making purposes. This not only removes undesirable clay matter, roots, etc., but also breaks up large grains and means an improvement in surface of the metal cast against the material.

Perhaps a word in regard to the disposal of waste sand would not be amiss here. The cost of handling refuse core and molding sand in foundries is a burdensome item, and should really be added to the first cost of the sands themselves to get a line on the economy of possible sand recovery. The problem is particularly serious in the large cities and for the great foundries in outlying districts.

Lane, who did more work in this direction than any one else—being at one time engaged by the automobile interests of Detroit for this purpose—unquestionably solved the problem of sand recovery from the technical standpoint. He found, however, that every situation demanded special treatment as indicated by local conditions and the grades of sand used. This would mean more or less complicated installations for dry or wet cleaning, the cost of which might mount pretty high, though the net expense per ton of sand thus treated would be comparatively low.

Swan, who also investigated the subject, particularly from the laboratory standpoint, found that the principal difficulties encountered in the subsequent use of this "recovered" material were to be found in the presence of sea coal previously used in the facing sand, which injures the bonding power in the molding sand heaps. In the case of core sands, the individual grains of the burnt material are coated with a porous carbonaceous layer coming from the binder. Such material will therefore absorb considerable new binding material when used again, give weak, soft cores, and prove less economical than expected.

The author has also made many tests in this direction and while having had success so far as the actual recovery of material was concerned, found it inadvisable to introduce such a separate enterprise into the foundry unless warranted by peculiar local conditions, such as heavy cores the greater part of which could be picked out unaffected by the molten metal, etc. Under ordinary circumstances the undertaking would soon become a side issue, but little attention being given the operatives. What should be an economy in the general system finally either only pays for itself or actually becomes a leak.

FACING MATERIALS

Under the specific term "facings" there would be included all those materials which are used to give the skin of the mold a smooth finish, so that when in contact with the molten metal this—after setting and cooling—may "peel" easily. In the general sense, however, the specially prepared sand riddled on the pattern, and arranged when rammed up to form a layer of about an inch in thickness next to it, is also called the "facing" sand. This material requires a more extended discussion.

Since only that portion of the mold eventually to come into contact with the molten metal need exhibit all the qualities so essential in the production of good work, it is customary to use two classes of sand in the molding operation—the facing sand above mentioned and the "backing" sand, or that of the molder's sand pile. After the mold has been poured and the casting is shaken out, the latter is removed to the cleaning room with whatever sand may adhere to it. What remains in the broken mold is eventually mixed together when retempering the heap. In this way the good facing sand not affected by the heat of the molten iron is supposed to strengthen up the sand pile, instead of obtaining this result by a direct addition of new sand thereto.

It will be quite evident from what follows that the current practice mentioned is by no means a good one, and many a foundry has found it very costly when the sand piles deteriorated so badly that the bond became almost nil. From the earliest days of the foundry it has been customary to add a considerable percentage of a finely ground rich gas coal to the facing sand. This material is termed "sea coal" to the present day, its history being traced to the mining of coal under the ocean in Wales. Indeed, this high-grade material is mined there and shipped to foundries of Europe today. The philosophy of adding a carbonaceous material containing over 25 per cent. volatile matter, and so finely ground that contact with molten iron means the practically instantaneous generation of gas, is still a matter of speculation. Authoritative tests have not yet been made to settle the question. It is evident, however, that with only 1 part sea coal to 10 of sand, or thereabouts, but little of the coal comes into actual contact with the molten metal and hence the gases formed cannot well blow into the iron unless the mold has been rammed too hard.

Two things can happen to such a facing sand. Either the gas formed may act as a film or layer just an instant before passing through the mold, but long enough to let the iron glide by without eating into the sand; or, the heat of the molten metal throws out carbon from the rich gases, thereby "smoking" the mold long enough to do the work desired. Such a carbon deposit will quickly disappear, being either taken up by the metal or else burned away. The chances are that both things happen and it is even claimed that such a refractory form of carbon as graphite will—when ground very fine—burn and make gas enough to form the film in question.

Experience has shown that the heavier the castings the richer the facing sand must be in sea coal, if this material is used at all. Too much sea coal, however, will cause the surfaces of the castings to take on a "veined" appearance, or as the molder would call it—"grape-vined." These castings do not need it, and as the sections increase sea coal is used in proportion of 1 to about 15 parts of sand. For cylinders, etc., of some thickness 1 to 10 may be used, and for very heavy work the proportion can be 1 to 7. The thoroughly hand-mixed sand and sea coal, after tempering, is best run through a centrifugal mixer to obtain greater uniformity.

As an inch or more of this facing sand surrounds the pattern after ramming up the mold, it will be seen that a considerable portion will not have been affected by the molten iron, and going into the sand heap is intended to strengthen it. Unfortunately, sea coal has no bonding value whatever, and also partially destroys the bonding power of the clay present. Hence, instead of improving the molding sand, it may actually deteriorate it. The modern tendency, therefore, in view of the existing excellent finishing materials for the mold surfaces, is to get away entirely from the use of sea coal and facing sands, and to have but one kind of molding sand for the mold, finishing the surfaces by applying graphite, etc.

In view of the information now available on the characteristics of molding sand this tendency is to be encouraged, as the elimination of the expensive material—usually bought by the car load—means simplifying the molding operation, puts the sand heaps under closer attention, saves money and labor and marks a distinct advance in the art. As the use of sea coal, when abandoned, means closer attention to the finishing operations upon the sand faces of the mold, this subject should be investigated thoroughly with a view of ascertaining which materials and how applied yield the best results.

Since the only reason that sea coal is added to facing sand is to enable the formation of gas instantaneously as the metal flows by, care should be taken in purchasing it to get a very high percentage of volatile matter, low sulphur and low ash. The best results are obtained with the famous Westmoreland coal, a gas coal used extensively for firing air furnaces. Where the maker of facings uses the run-of-mine coal and not the cheaper "slack" the ash content will not run over 10 per cent., and the volatile matter at least 35 per cent. Since slack coal contains much slate, unless this is washed to remove most of it, the ash content of the sea coal may run up to 16 per cent., which is paying good money for ground slate.

The materials used for finishing the mold surfaces may be either carbonaceous or mineral in character. When carbonaceous, such as graphite, coke, charcoal, etc., they are called "blackings."

When ground silica, talc, soapstone, cement, etc., they are called "mineral facings." All of them are ground to an impalpable powder in the ball mill, and should be capable of application dry by means of the dust bag, if desired.

BLACKINGS

Graphite is unquestionably the most important of the facing materials for mold surfaces. It is a naturally greasy mineral of very high refractoriness, and in its best form (Ceylon graphite) has a large flaky structure lending itself admirably to the covering of surfaces without adding thickness to an appreciable extent. Its very greasiness, however, prevents it from adhering to the mold surface unless held there by some binder. This difficulty is not so noticeable with the poorer, more amorphous forms of graphite, which when finely powdered will enter the pores of the sand and adhere as the pencil mark does to paper. Unless the flakes of graphite are made to stick to the mold surface they will be lifted off by the current of molten iron and pushed ahead to gather at some point with disagreeable results to the surface of the casting.

The manufacturers of foundry facings have this situation in hand and prepare their graphite facings with suitable binding material to give good results under varying degrees of dampness of the green-sand molds. The damper the sand, the less binder the facing may contain, otherwise it will not "slick" well. The greater the percentage of the flaky high-grade graphite the facing can be made to carry, the better the results will be. But this graphite must adhere to the mold, otherwise it is wasted. The facing is either dusted on and then slicked off with the tool, or else rubbed on with the hand and the excess blown away.

In the case of very small plate work, after dusting on the graphite some powdered charcoal must be dusted on also and the pattern "returned" or "printed back." This will press the graphite into the mold surface, and the charcoal addition prevents the graphite from sticking to the pattern The result is a very fine surface on the casting, especially desirable for stove work. Graphite is also laid on the mold surface with a fine brush, care being taken not to disturb the integrity of the sand structure. All this refers to the finishing of the green-sand mold, the natural dampness of which is counted on to make the prepared graphite adhere. Where there is not sufficient dampness present, the application of a fine spray of molasses-water will be of great assistance.

For dry-sand work the graphite is applied wet, in form of a wash. The liquid used may be either molasses-water, sour beer, or any vegetable substance having adhesive qualities. The soluble vegetable rosins existing in the waste liquor of the pulp mills, which when neutralized and concentrated are especially good. The material comes into the market under the name of "glutrin" and is much used for cores. Usually the blackings applied to the dry-sand mold surfaces are mixed with fire-clay to make a syrupy material which is applied with a swab. After drying—the application being made while the mold is still warm—the surface is slicked down smooth and occasionally finished by a wash of molasses-water. The fire-clay added forms an excellent medium for binding the graphite to the mold surface.

Mention has been made of poor grades of graphite. The mineral itself runs from the highest type, the flaky Ceylon variety, so pure that it goes into pencils, to material so lacking in the greasy, flaky characteristics of the mineral that it shades into the variety of coal called graphitic anthracite. The foundryman is offered all these shades and qualities at the highest prices they will stand, and hence there is an urgent necessity for a thorough investigation of the subject to get it on a rational basis. The good grades may be adulterated seriously and still be better than the poor ones. Soapstone, coke, anthracite and even bituminous coal is ground up with graphite to cheapen the mixture. It is practically impossible to trace much of this adulteration in the laboratory for coke and coal are carbon just as much as graphite is. There is furthermore so much gangue in mineral graphite that on burning away the carbon a very respectable amount of ash would remain in any case, and 20 to 30 per cent. of this is common as things go, though very expensive for the buyer. The preparation of suitable specifications, based upon reliable tests is, therefore, one of the urgent problems of the foundry, so that manufacturer as well as foundryman may be protected in the preparation and use of this important article.

Graphite is also known as plumbago, black-lead, silver-lead, and Ceylon lead. When pure it will run up to almost 100 per cent. carbon, with very small amounts of silica as the impurity. From this, it may run down to 60 per cent. carbon, and 40 per cent. silica and still preserve some of the desired properties. The foundryman will readily see that paying freight on silica, or sand, at graphite rates and prices is not a very desirable procedure.

Ground Coke.—This makes an excellent core blackening, when applied in the shape of a wash. Also for dry-sand molds. Good hard coke, with low ash and sulphur, is selected and ground up very fine in the ball mill. Mixed with molasses-water, with or without additional fire-clay, it is painted on the surfaces in question and brush marks avoided as much as possible.

Ground gas carbon is even better than ground coke for the purposes above mentioned, being short only to graphite. It is more costly, however, and hence coke is used where graphite is not absolutely required. Gas carbon undoubtedly has a future ahead of it for the foundry, as it seems to be eminently suitable for purposes of long-life molds, if not the much looked-for "permanent" article.

Ground charcoal is very useful for dusting over other blackings which would stick to the tools in slicking. Mention has been made of its use where patterns are to be "returned." For very light work it also proves valuable in place of the usual "parting" sands between cope and drag of the mold. The best varieties are made from hardwood.

Ground anthracite is mentioned here merely to complete the list, as it forms a constituent in some of the blackings made where this fuel is cheap.

MINERAL FACINGS

Soapstone is probably the best known of the mineral facings. It is a compact variety of the mineral group known as *talc.* The specific mineralogical name is *steatite,* another common name is *French chalk.* The talc minerals are silicates of magnesia and on account of the high percentage of magnesia they have the soapy touch—in a smaller degree but similar to graphite.

Soapstone is applied to the mold surfaces as a facing with the idea of letting the molten metal slip by without cutting. Also that contact between the mold and metal after setting may result in a smooth surface to the casting. Unfortunately, however, the talc minerals are fusible at high temperatures giving off some water just previous to softening. Hence, while no difficulty is experienced with thin castings—the metal cooling too quickly to cause trouble—in heavy work great care must be exercised when using soapstone in the facing mixture.

Soapstone, like graphite, has no bonding power, and hence must be attached to the mold surfaces by some binder, whether by fire-clay or a vegetable substance. If soapstone becomes loosened from the mold surfaces it is carried along with the iron and imprisoned as it sets. Spots result in the metal which consist of a nasty mixture of iron, molding sand, slag-like soapstone facing, and this interspersed with bubbles from the steam generated by the expulsion of the water of combination in the soapstone. Then also shrink-spots will come from irregularity in setting on the part of the metal, and all in all, a bad mess is the result of what might otherwise have been a good casting. Since soapstone is always found in nature mixed more or less with earthy material, some deposits of it will be more easily fusible than others, and the founder takes a chance when he buys it.

Soapstone is often mixed with graphite by the foundryman himself, in order to save money. When he gets a good grade of graphite this will stand a considerable adulteration and yet give good results. This, however, not because of the soapstone addition, but in spite of it. An equal amount of a good refractory fat fire-clay will be found even better, as this, when applied to the damp mold surfaces, will increase the adhesion of the graphite to the sand. The author therefore feels that he cannot recommend soapstone specially to the foundryman in view of the much better results obtained with graphite.

Silica flour, while used more particularly in facing up molds for steel castings work, is sometimes applied in the gray iron foundry for finishing up dry-sand molds. A good binder, however, is necessary to attach the powder to the surfaces applied—dextrine or flour being used, and the water used for the wash should contain either molasses or glutrin in addition.

Cement is often dusted on mold surfaces to finish them up. This material has refractory qualities and probably assists in forming a crust of the surface with the silica grains of the molding sand. The application of heat from the molten metal destroys the crust after the iron has set and the casting peels fairly well. Just how valuable the application of cement to the mold surface may become when excessive dampness is present is a question. There is no doubt, however, of the value of cement as a binder in core-making. Mention of this will be made later.

Carborundum (SiC), carbide of silicon, is used to some extent in steel-making, for purposes of adding carbon and silicon to the metal. The high temperatures prevailing in steel-casting practice, however, are not equalled in the gray iron foundry, and hence a much smaller percentage of the carborundum used will be taken up by cast iron, and even then it must be very finely divided. There are some cases, however, in gray iron-casting practice where a hard surface on a soft casting is a very desirable condition, and here the application of carborundum powder to the mold surface, when attached with a suitable binder answers very well. The author has made a number of trials in this direction, portions of the same casting being thus treated and others not. They always showed greater surface hardness, the high silicon of a soft casting being probably augmented at the skin by extra silicon from the carborundum, thus acquiring the hardness of a ferrosilicon.

This "case-hardening" of cast iron is also brought about by using powdered ferromanganese on the mold surface, as mentioned previously, except that in this case a manganese chill is looked for in the skin of the casting made.

PARTING MATERIALS

"Parting" sand, or the material sprinkled on the joints of a mold to keep the parts from adhering to each other, is a round-grained fairly fine sand without any bond whatever. When used on the lower half of the mold before ramming up the upper half, there being no bond in this sand between the two, they can be taken apart without damage. While round-grained sand of pure silica gives the best all-around results, any sand without bond, such as "burnt" sand from the cleaning room, will also answer.

Lycopodium powder is used as a parting medium for the finest classes of castings the molds for which require particularly fine joints. This vegetable substance—the spores of a certain variety of club moss—rejects moisture successfully and hence is ideal for separating two planes of damp sand. Where the parting is very deep it is a great help in preserving the integrity of the mold. Lycopodium is highly inflammable, a property which should not be forgotten by the molder.

Mention has already been made of powdered charcoal as a parting medium, owing to the absence of any bonding power in it.

CORE BINDERS

The general functions of core binders are: (1) To hold the individual grains of sand together so effectively that the core remains intact and rigid until sufficient of the liquid metal in the mold has set for safety. (2) To lose the bonding power after prolonged heating by the metal after setting, so that the core sand can be shaken out readily. Specifically, core binders must be available for many and varied requirements, brought about by the character of the metal poured, its temperature, duration of destructive heat, etc.

Ordinarily foundrymen would divide core binders into the "dry" and the "liquid," but according to Lane, who studied this subject most exhaustively, the best classification would be as follows:

Water-soluble binders
Paste binders
Colloidal and allied bodies
Gums and pitches
Oils

Perhaps the most satisfactory way of discussing these binders is to take them up in succession and note their behavior under service conditions.

Water-soluble Binders.—Molasses is about the best known of these. That of the sugar-cane is most effective, particularly if fermentation has not yet set in—in which case practically half the binding power would be sacrificed. The molasses of commerce is thinned down with water before using, in proportion of 1 part in 15 to 30 parts of water, depending upon the quality of the molasses. As this binder boils up just before setting, cores made with it have the disagreeable property of softening at the first application of heat, with consequent liability of deformation. The syrups obtained from the sugar-beet are not serviceable, as cores made with them absorb water and disintegrate.

Sour beer and distillery refuse contain dextrine and similar compounds of high binding power, and hence are used to good advantage wherever obtainable.

Glutrin, the neutralized and concentrated sulphite liquor of the paper pulp process, carrying the soluble vegetable resins of the wood, is an excellent binder. A peculiar tendency is noticed in applying it, the glutrin solution working out to the surface of the cores. Further, as the water evaporates and the contained glutrin concentrates it draws to the point of contact between the sand grains giving a very strong bond with good venting. Since, however, the tendency to concentrate at the surface means a hard skin but soft interior for the cores made, the introduction of a colloid substance, such as clay, is to be recommended, as it keeps the distribution of the binder uniform. Like molasses, glutrin of commerce must be thinned with water to the proper consistency before using.

Glue, hydrol and water glass (silicate of soda) are binders used occasionally in core-making, but as they all have undesirable properties either in the making of cores or after the molten iron touches them, they are not to be recommended.

Paste Binders.—*Flour* is the oldest and best known of these binders. The gluten present is the adhesive portion of the material, and the more of it a flour has, the better it is as a core binder. Wheat flours are better than rye, and as there is a great variation in the gluten content of flours, the foundryman, in testing samples presented, makes a small ball of flour paste by mixing with a very little water, and judges by the stretch exhibited.

Unfortunately, the use of flour in the cores gives rise to a penetrating acrid smoke when the molten iron touches them. This smoke is highly irritating to the eyes and hence foundries with poor ventilation have particularly to suffer. This smoke problem, as well as the notorious swelling of cores when excessive amounts of flour are used, have given the material a poor reputation and foundrymen are prone to replace it by the "compounds" in the market. Much of the trouble has come from using the car sweepings of flour shipments, moldy and spoiled material, cheap varieties containing but little gluten, instead of purchasing a good article rich in gluten on definite specifications.

As an interesting sidelight on human nature, the author remembers the attention that had to be given in his own core room, where much flour was used, to the girls that worked there. Their nimble fingers turned out great numbers of little cores daily, and as this work was paid for at various rates per thousand cores, it was essential that the core sand should stick well. The amount of flour that was smuggled in by the operatives and worked into the sand brought to the benches was astonishing. An increase of a few per cent. in the flour of a mixture might be the cause of pretty bad cores.

With good ventilation in a foundry and proximity to milling centers, flour will continue to be an important factor in core-making, and hence some attention should be given the subject. Without going into the preparation of flour from the grain, it may be stated that the "bran" part is of no value to the foundryman. The poorer grades of flour offered, however, contain much of this which, after regrinding, will have given the flour a yellowish color. Another portion of the grain gives grades of flour called "shorts" much of which is sold to foundrymen. The remaining portions of the grain give the high-grade flours, which are rich in gluten and starch. The "shorts" or "offal" flours show relatively high percentages of fiber, fats and mineral matter on analysis, and can be eliminated by proper specifications. The bran can be seen by the naked eye. Hence there remains the starch and gluten situation. Of the two the gluten is more powerful as a binder. This, however, is subject to rapid decomposition under bad weather conditions, whereas starch is fairly stable. Decomposed gluten means inferior binding power, hence "musty" flours are not very valuable.

Evans, who has given most attention to the matter, has worked out specifications on the subject, from which the following is given: Starchy wheat flour is wanted, without adulterants, either vegetable or mineral. This cuts out "sweepings." When slicked out smooth, no appreciable amount of bran particles should be visible to the eye at a distance of 15 in. from the flour. On analysis, the following should govern:

Mineral matter, or ash, not over....................	1.35
Crude fat (ether extract), not over..................	2.50
Crude fiber, not over............................	1.25

The flour should not have a "musty" odor.

To show how the above requirements work out, Evans gives the following figures:

Grade of flour	No. of samples	Moisture per cent.	Carbohydrates per cent.	Mineral matter per cent.	Protein per cent.	Crude fiber per cent.	Crude fats per cent.	Cost per 100 lb.	Strength in pounds 1 to 30–	1 to 60
Low-grade starchy flour..............	5	11.44	72.80	0.67	12.31	0.73	2.05	$1.87	55.24	42.13
"Offal" flours.......	2	10.08	65.42	1.74	15.62	2.66	4.48	1.81	35.65	25.35
Adulterated flours.....	5	5.72	46.72	38.05	6.61	0.97	1.93	1.31	24.70	13.35

For strength tests Evans used a medium fine silica sand. The cores were made 1½ in. square and 10 in. long, and tested on supports 8 in. apart. Two batches were made from each sample, one with 30 parts sand to 1 of the flour, with 4 parts water; and the other 60 to 1, with 4 parts water. The results are given in pound required to break the cores.

The low-grade starchy flours were the only ones to pass the specifications and showed an average increase of 95 per cent. (1 to 30) and 143 per cent. (1 to 60) over the averages of those flours which had not passed the specifications. Similarly, these good flours showed increases of 55 and 66 per cent. respectively over the "offal" flours, and 120 and 216 per cent. respectively over the "adulterated" varieties (sweepings, etc.). Finally, the binding value of flours passing specifications were worth in dollars and cents just two and a half times as much as those failing to pass. These tests certainly tell the story.

The *starches*, when prepared in form of a liquid paste, work very well and draw down to points of contact between the sand grains. In the raw state they are of little value. *Dextrine* is one of the best binding materials of this group and forms the basis of some of the high-class dry-core compounds on the market. It has the further advantage of holding the core in shape while green.

The disadvantage of the entire paste group of binders, however, is that when exposed to dampness for a time, the cores will gather moisture and become soft. Hence they must be kept dry, be used fairly prompt after making, and not be allowed to stand in molds long before pouring.

Under the head of "*Colloidal and Allied Bodies*" will be found those materials which owe their binding power to the colloidal nature of one or more of the ingredients contained. Clay, when used in quantities small enough to prevent loss in venting power, is a core binder. When used in connection with flour it is of no mean value for heavy classes of cores, and has the advantage of keeping out moisture. Milk of lime, magnesia, aluminum and iron compounds also come under this head. *Manures* owe their value to the colloidal (glue or jelly-like) condition of some of the ingredients, which when milled with loam for pipe cores, give the clay present a greater bonding power.

Rosin is the principal item in the class of "*gums.*" This, when powdered and used for a binder, melts during the baking process and flows between the grains of sand, thus sticking them together.

On cooling, the rosin becomes hard again and makes a solid core. Rosin is commonly used in connection with flour as it has no binding power until heated to melting and then cooled. An old and well-tried mixture would be about the following:

New core sand	12
Old core sand	6
Flour	1
Rosin	1

Where molding sand enters the mixture, and hence the clay content acts as a binder, rosin alone may be used, but the core will be weak, as a rosin core has no strength when hot. In any case but a limited percentage of molding sand could be used with the bulk of clean core sand on account of proper venting, and hence a rosin core of this kind should be strengthened with a further addition of binding material. On the other hand, rosin cores are easily broken up in the cleaning process, as the high temperatures, particularly when long continued (thick sections of iron surrounding the cores), result in driving off of the bulk of the rosin from the core.

Rosin, when heated highly, decomposes and throws off a dense black smoke. Hence, for some classes of work powdered rosin is dusted on the mold surface in order that when struck by the molten iron or brass, the sand may be "smoked" heavily. This results in a smooth casting of good color. At about 645°F. rosin is decomposed into rosin oil and a rosin pitch. The former has little bonding power and hence if used at all in core oils is present as an adulterant. At higher temperatures the above-mentioned destructive distillation and smoking takes place.

The *pitch* used for core compounds is the variety coming from the by-product ovens in coke-making. Its composition differs very much from that of the resins, in having a much higher carbon percentage. Consequently, when surrounded by molten iron a coking process ensues making the core harder than it was originally. This pitch, coming from the distillation of coal tar, is the basis of the so-called "black compounds." As cores made with this material give considerable trouble in the cleaning room, there is usually added a considerable amount of "sea coal" (finely ground bituminous coal). This overcomes the difficulty by reducing the hardness due to the coking tendency. Strictly speaking, however, this is an adulteration of the core binder which is allowable only if the price paid is adjusted accordingly.

The last class of core binders are the *oils.* There are two divisions to be considered: First, the so-called "drying" oils of the paint trade. Linseed oil is the most important of these. Then would come Chinawood oil, soya-bean oil, cottonseed oil, fish oils and many vegetable oils. The second class are the "filling" oils, really adulterants of the first class. Here are the petroleum oils, tar oils, oils from the distillation of coal and wood, and resin oil.

The action of core oils of the first class is a development of the binding power through oxidation. The oil itself does not evaporate but in oxidizing becomes sticky, drawing in between the points of contact of the sand grains, and finally hardening. The introduction of a "dryer" in the oil—a catalytic agent (such as a manganese compound), which intensifies the action by transferring oxygen from the air to the oil without being affected itself—is advantageous and brings about astonishing results. The author has often seen radiator cores made with an oil ratio of 1 to 100 sand. Here, of course, machinery was employed to rub the thinnest possible effective film of oil evenly over each sand grain. Ordinary practice makes the ratio more nearly 1 to 30.

The second class of core oils dry down and become more or less sticky. This would mean such oils as the asphalt base variety of crude oil of the West and South of the U. S. The more these have been heated to remove the lighter volatile matter the better will be the result. The solution of gums and resins in petroleum also comes within this classification. As can be imagined, the drying is slow and, if anything, detrimental to a good oil of the first class when mixed with it. The undesirable adulterants of the good core oils emphasize the necessity for testing this class of foundry supplies regularly, as well as writing proper specifications for their purchase.

With good ovens, good sand and high-class oil, there can be no question of competition on the part of cheaper oils. The foundryman must, however, give the good material every chance in the way of preparation and equipment to show what it can do.

Dry and Liquid Core Compounds Compared.—Opinions among foundrymen vary widely on this subject. In general, a dry binder is more desirable for the heavier classes of cores, on account of the tendency of an oil to migrate to the surface and form a hard impenetrable skin. Further, the question of drying in the oven is much simpler than where a liquid binder is used. On the other hand, the amount of binder used is proportionally greater, as the distribution of a dry compound is not effected as readily as that of a liquid one. This is overcome in some measure by mixing the required quantity of core sand and binder a day ahead of time. This allows the binder to soften thoroughly, and on putting through the mixing machines just before use, a very uniform distribution is obtained.

Small cores, on the other hand, can be made more readily with liquid binders, such as linseed oil, glutrin, etc. The drying is completed so quickly (by oxidation of the oil) that but little migration to the exterior surface of the core takes place, and good strong cores result with relatively smaller percentages of binder.

Foundrymen should test their binders regularly to assure themselves of their strength. Lane recommends a small cement testing machine, the grips for the test piece being of hardwood instead of steel. By using the standard sand (Ottawa) of the U. S. Bureau of Standards, a given quantity of the compound, mixing under standard conditions, and baking at temperatures carefully selected for best shop conditions, information is obtained showing what is gotten for a given investment of money.

Cement.—Mention has been made of cement used as a core binder. The author at one time devoted six months to testing out this binder for small and very large cores in the production of perhaps fifty tons of castings daily. One part of cement was used to nine parts of sharp sand, with just enough water to dampen the material and allow the cement to set. The cores after being rammed up were not baked but set aside for 24 hr. to harden and then—if not used at once—stored in a warm and dry place. Excellent results were obtained in the foundry and the cost was exceedingly low. The cores could be kept for months as they did not deteriorate—being practically cement blocks of great porosity. The disadvantage of the process, however, was found to be the effect on the hands of the operatives, the caustic properties of the cement being serious unless rubber gloves were made use of. There is no reason, however, why such a cement binder core-making system should not work out well with the core-machine, as the material need not then pass through the bare hands of the workmen. Cement is cheap and the absence of a core-oven a desirable economy. The idea of using cement as a core binder came from John Smith, one of Pittsburgh's pioneer builders, with whom the author worked out the problem to the perfect satisfaction of everything but the effect on the hands of the girls and men making the cores in question.

The smaller supplies used about the foundry, such as chaplets, molder's nails, white metal for patterns, lubricating oils, gasoline for core-blacking, and the many odds and ends usually wanted very badly when wanted at all, do not seem to require a special enumeration and discussion. It pays to have a good storeroom well filled with these things, and it also pays to see that they are not wasted.

CHAPTER IX

THE TECHNOLOGY OF COMBUSTION

Combustion is chemical combination attended with the evolution of heat and light. In the ordinary sense combustion is understood to be the union of the carbon and hydrogen of a fuel with the oxygen of the air. In the more scientific aspect of the case, however, oxygen need not be present, for the introduction of phosphorus or antimony into chlorine gas produces a combustion also attended with the evolution of heat and flame.

If any form of solid fuel is heated in the presence of air, any gases coming off will catch fire as soon as the temperature of ignition has been reached. As time and space are necessary for the gas and air to mix and burn, a flame is produced which is more or less luminous. The remaining coke or other form of solid carbon, not being able to mix with air, will be consumed by surface contact, glowing brightly but without flame.

Continued contact of the carbon dioxide formed with the solid incandescent fuel results in the taking up of carbon from it, making carbon monoxide gas. This reaction is assisted by rising temperatures, contact with greater fuel surfaces (cell structures), and slower rate of travel.

In ordinary practice these things occur side by side, and hence what is required for a good serviceable combustion of the fuel used is plenty of air and sufficiently high temperatures. Since the ideal conditions, however, are rarely if ever obtained, the result is more or less imperfect combustion, smoke and consequent fuel waste. In the case of wood, which is a poor conductor of heat, the distillation of the tarry vapors and gases is comparatively slow. Moreover, they are heated highly by passing through a layer of incandescent charcoal forming on the surface of the sticks shortly after combustion has commenced. It is therefore possible to obtain a good mixture of gases and air and with reasonable care but little smoke is made. At first, however, burning wood is most trying to lungs and eyes. One has but to enter a foundry while the ladles are being dried out with wood fires to realize this, and the sanitary codes of many States and municipalities now contain provisions prohibiting this practice within the foundry proper unless suitable well ventilated locations are arranged for.

With bituminous coal the question is not so simple. On opening the fire-door and throwing in a shovelful of fresh coal, this falls upon a bed of incandescent coke and practically stops the passage of air through the grates at that spot. There is a sudden evolution of gas and tarry matter from the coal and a drop in the temperature of the fire-box. The result is that part of the tarry vapors, particularly the upper portions, condense into little globules before reaching the real zone of combustion. The burning of these globules is greatly retarded on account of the high carbon and nitrogen constituents present, and there is necessary quite an excess of oxygen and very high temperatures for complete gasification. In the absence of enough oxygen more or less pure carbon separates out in the form of soot. This is in addition to the tarry matter above mentioned. Smoke is therefore a combination of tarry matter and soot suspended in the flue gases.

The solution of the smoke problem, so serious to foundrymen located in built-up sections, would seem to lie rather in preventing the formation of this objectionable product than in consuming it after it has been evolved. Instead of scrubbing the sooty and tarry gases or passing them through chambers filled with incandescent brick, etc., it is better to arrange the firing process in such a way that the temperature of the gases made is not lowered unduly. This may be done by preheating the air, providing a combustion chamber lined with high-grade refractories, firing frequently instead of at long intervals—in fact having the gases pass off at as uniform a rate as possible. In boiler practice this is accomplished by using mechanical stokers and grates. In metallurgical work, particularly in the air furnace, much remains to be done yet both in furnace design and practical operation.

Probably the best means of ascertaining whether the combustion attained is of a high degree of efficiency for the fuel involved, is to analyze the flue gases. The composition of these shows up the firing practice quickly. For instance, in the ordi-

Carbon dioxide	14.10	
Carbon monoxide	none	
Oxygen	6.20	
Nitrogen	79.70	(Wagner)

nary fire-brick lined house stove, the preceding analysis would show good firing:

Here the air supply was sufficient to turn any carbon monoxide formed into the finished combustion—the temperatures attained in the fire-brick lined combustion space permitting this. Where fuel comes into contact with iron parts, as in the water-back of the kitchen range, it is impossible to get perfect combustion at such places.

The same situation is observed in boiler practice, where it is also necessary to have a considerable excess of free air entering the fires. The following analysis of the flue (chimney) gases shows a rather smaller excess of air than is generally used, but is very good nevertheless:

Carbon dioxide	15.45	
Carbon monoxide	0.17	
Oxygen	3.86	
Nitrogen	80.52	(Jacobus)

On the other hand, driving a boiler with an insufficient air supply, producing much smoke, having very hot chimney gases, and burning out a set of grates a week, resulted in the following analysis of the flue gases:

Carbon dioxide	10.36	
Carbon monoxide	8.20	
Oxygen	1.47	
Nitrogen	79.97	(Moldenke)

Increasing the height of the chimney 50 per cent. gave a stronger draft and corrected the practice at once. It may be stated that in this case the highest type of water-tube boiler was used, and that a large fire-brick lined combustion chamber gave an opportunity for the gases passing over the bridge to combine properly. The absence of sufficient excess air, however, could not be overcome even with the good mechanical stoker used.

The air furnace would be the next problem in combustion to be considered. Here only the best varieties of gas coal should be used, as it is essential to get a long flame. As the highest possible temperatures that can be gotten by simple combustion must be had, in order to raise the fire-brick surfaces of the furnace sides and roof to incandescence, so that heat may be radiated upon the metal charge, the smallest amount of excess air which will still give almost smokeless combustion should be arranged for.

A somewhat different situation is met with here as compared with boiler practice. Apart from the water-vapor formed by the combustion of hydrogen and hydrocarbons from the gas coal, the stack gases would run about as follows:

Carbon dioxide	16.00
Carbon monoxide	2.00
Oxygen	2.00
Nitrogen	80.00

Whereas, however, in the case of the house stove and boiler the firing process is not pushed more rapidly than would leave the chimney gases retain a temperature of about 450°F., the balance of the heat of combustion going into heating the rooms or raising steam, in the air furnace the firing process is pushed very much harder. Here the temperature of the chimney gases is so high that in the case of comparatively short stacks, the flame itself may be seen to issue from them—just as in puddling furnaces. It is necessary to heat the furnace lining to the maximum temperature possible practically up to the point of stack entrance. As almost nothing has been published in this direction, the gas analysis given above is assumed.

In the open-hearth furnace the preheating of the air used for combustion means very much higher temperatures in the hearth with a clear flame, but avoiding too much excess air. The stack gases would give a similar analysis as that for the air furnace, except that carbon monoxide would be practically absent.

Finally, in the case of the cupola, this, if properly charged and operated, shows a complete consumption of the oxygen introduced in burning up the fuel. If the height of the fuel bed has been such that at its upper level the oxygen of the air blown in has been entirely used, this would mean a maximum of carbon dioxide formed and at the same time the maximum of temperature. If, now, the hot gases come into contact with the metal charge on the bed under such conditions, enough heat will be given up to the iron to melt it and also superheat the drops of metal as they fall downward. The balance of the heat in the gases going upward should not be enough to let them take up much carbon to form carbon monoxide and thus interfere with the efficient utilization of the fuel.

This reduction in temperature is, of course, very desirable as the stock of metal charged should take up all the heat possible, and not let too much pass up through the stack. However, the action is tremendously swift, and the first few fuel charges above the bed will suffer somewhat by contact with very hot carbon dioxide. Hence the gases taken for analysis at a point just below the charging door will invariably show some carbon monoxide. They should, however, show little or no oxygen. The following are examples of good cupola melting practice:

	1	2
Carbon dioxide	16.40	16.70
Carbon monoxide	3.00	7.30
Oxygen	none	0.10
Nitrogen	80.60	75.90
	(Osann)	(Stoughton)

On the other hand, examples of bad practice are given in the following:

Carbon dioxide	5.10	9.20
Carbon monoxide	21.20	16.60
Oxygen	1.20	0.40
Nitrogen	72.50	73.80
	(Stoughton)	(Osann)

Here it is quite evident that two things have happened. First, that some of the air has passed up the cupola unconsumed—probably along the lining. Second, the bed was so thick that the reactions of the gas-producer took place; namely, a partial change of carbon dioxide to monoxide owing to the additional incandescent fuel encountered by the carbon dioxide gas before striking the metal to be melted.

The subject of combustion has been briefly discussed in Chapter VIII under the title of "Producer Gas." The two reactions going on when burning carbon in air are the following: 1 atom of carbon takes up 2 atoms of oxygen and makes 1 molecule of carbon dioxide (1 lb. of carbon with 2.66 lb. of oxygen, making 3.66 lb. carbon dioxide gas). This is called "perfect" combustion, there being generated 14,544 B.t.u. of heat.

The second reaction is the combination of the above molecule of carbon dioxide with another atom of carbon (from available incandescent fuel), making 2 molecules of carbon monoxide. This would correspond to a union of a pound of carbon with but 1.33 lb. oxygen, making 2.33 lb. carbon monoxide. This is called "imperfect" combustion, for there is developed but heat enough to yield 4,450 B.t.u. Hence the poor economy in running a cupola with too high a bed.

This carbon monoxide, however, in taking up another atom of oxygen can be burned to the original carbon dioxide again, and in doing so gives up the heat rendered latent when the carbon monoxide was formed. That is, the difference between the 14,544 B.t.u. and the 4,450 B.t.u. above mentioned, or 10,094 B.t.u. are recovered. In the case of the cupola, this is unfortunately above the charging door where the entrance of the air current burns the carbon monoxide coming from below. The heat thus generated passes out of the stack without benefit to the process other than helping the draft. Naturally this is only the case when the percentage of carbon monoxide is sufficient to allow ignition of the gases.

It will thus be seen that the analysis of the chimney or stack gases gives a very good idea of what is going on within the furnace, and also serves as an indication for proper correction of the firing practice. The whole smoke question in cities finds its solution not in smoke consumption, but in smoke prevention by applying proper methods to insure perfect combustion.

Hydrogen and hydrocarbons in general must also be considered when discussing fuel combustion, for fuel oil, natural gas, producer gas, and the rich gas coals fired directly are frequently met with in modern foundry practice. In the case of hydrogen, 2 atoms unite with 1 of oxygen of the air to form water vapor, and in doing so give out 62,032 B.t.u. per lb. of hydrogen consumed. This is 4.28 times as much as can be obtained in the perfect combustion of carbon, and accounts for the tremendous effect obtained from the oxy-hydrogen flame. The limitations of hydrogen as a metallurgical fuel, however, have been described under "Producer Gas."

Olefiant gas (C_2H_4), one of the important hydrocarbons, gives out 21,344 B.t.u. per lb. when burned. Natural gas (practically marsh gas, CH_4, and nature's most efficient fuel) is credited with 25,160 B.t.u., and fuel oil, in which the proportion of hydrogen is lower, averages about 18,750 B.t.u. per lb. (see Chapter VIII).

The importance of the hydrocarbon content in bituminous coal is seen from the fact that in spite of an ash content of nearly 10 per cent., the average heat evolved corresponds to about 14,860 B.t.u. per lb., as against 14,544 for pure carbon. Average quality bituminous coal does not give first-class results for air-furnace firing. It requires the very best grades of rich gas coal to do this. The extra hydrocarbon content these contain makes this difference.

The subject would not be complete without mention of another line of fuel playing an important part in the metallurgy of iron. The production of internal heat in molten metal is brought about by exposing this to oxidizing influences. The silicon, manganese and carbon contained, in burning out during the so-called "refining" of the metal, give out heat enough to raise the temperature of the bath very much. Indeed, unless checked by the introduction of cold material, or removed from the hearth by tapping, this process may go on to the point of burning up (oxidizing) the iron itself, and a dense brown smoke will come from the metal and even issue from the stack. This situation is well understood in air-furnace practice when dealing with low-silicon irons. It is customary to skim off the slag after the charge is fully melted and well rabbled, to allow a better heating up previous to pouring. This at the same time permits oxidation of some of the manganese and silicon, and if continued, also the carbon. When sufficiently hot for tapping, the composition, as judged by the fracture of a test plug, must also be right and pouring may commence. It is the business of the man in charge of operations to have the mixture such that the composition and temperature are both right at the same time. As this is not always the case, a second skimming may be necessary to remove the slag formed as the result of the exposure and oxidation of the bath due to the first skimming. Incidentally, it may be stated that better metal would be obtained by heating through the slag cover of the bath, if time permitted, instead of taking advantage of the production of internal heat through oxidation by removing this. Here is one of the reasons why open-hearth metal is better than the air-furnace product. The greater temperatures prevailing in the hearth of the first-named process allow the metal to be superheated through the slag cover and thereby limit the bad results coincident with an oxidation process. The addition of steel scrap in the original mixture will balance the strength otherwise gained by "refining" a heat.

Probably the easiest understood application of an internal-combustion process is the act of Bessemerizing. Here the blast of air sent into the converter oxidizes the manganese, silicon, carbon and some iron. In the basic-converter process the phosphorus in oxidizing out also serves as fuel. The same oxidation exists in both acid and basic open-hearth processes, but the reactions in the latter are slower. It might be added that even the cupola process is in a measure an oxidizing process as from 0.20 to 0.25 silicon is oxidized out. Manganese goes to the extent of about 0.15 per cent., and in very bad charging practice, with low-silicon metals, the author has often observed the brown smoke of oxidizing iron pass out of the cupola stack.

That the heat of combustion of some of these elements is not small may be seen from the following table:

One pound of silicon, oxidized to SiO_2 develops	11,450 B.t.u.
One pound of manganese, oxidized to MnO, develops	2,975 B.t.u.
One pound of iron, oxidized to FeO, develops	2,110 B.t.u.
One pound of phosphorus, oxidized to P_2O_5, develops	10,600 B.t.u.

The air supply necessary for proper combustion would seem to be the next consideration. Oxygen is the active component of air; the other, nitrogen, is inert and plays the unavoidable rôle of rendering the combustion process inefficient by taking along an amount of sensible heat up the stack corresponding to its volume and temperature. The percentage of oxygen in air is as follows:

	By volume	By weight
Oxygen	20.9	23.1
Nitrogen	79.1	76.9

The minimum air required for the combustion of 1 lb. of a fuel is the weight of oxygen necessary (as found from the combustion equations) divided by 0.231. This weight of air can be converted into volume by dividing by 0.0808—the weight of 1 cu. ft. of air in pounds at normal atmospheric pressure and at the freezing point.

The following table shows the comparative weights and volumes of oxygen and minimum necessary air for the combustion of a pound of the several fuels given:

One pound fuel	Oxygen required		Air required	
	Pounds	Cubic feet	Pounds	Cubic feet
Hydrogen	8.00	89.626	34.632	428.61
Marsh gas (CH_4)	4.00	44.813	17.316	214.30
Olefiant gas (C_2H_4)	3.43	38.427	14.848	183.76
Carbon to CO_2	2.66	29.800	11.517	142.44
Carbon to CO	1.33	14.900	5.759	71.22

It should be remembered that hydrogen, particularly, is exceedingly light and a pound of it occupies an enormous volume. Hence, the large volume of air required for the combustion of 1 lb. of this gas does not seem so great after all. At 1 atmosphere and 32°F. the figures bearing on this subject are the following:

One pound of hydrogen occupies	178.83 cu. ft.
One pound of marsh gas (CH_4) occupies	22.20 cu. ft.
One pound olefiant gas (C_2H_4) occupies	12.58 cu. ft.
One pound of natural gas occupies	25.14 cu. ft.

Since foundrymen are becoming interested in the use of the oxy-acetylene welding and cutting process, and the future may see some of the lighter condensible hydrocarbons from natural gas (kept liquid under pressure) substituted for acetylene gas, in spite of the higher temperatures obtained with the latter, the following figures will be of interest:

One pound acetylene (C_2H_2) requires	3.077 lb. oxygen.
One pound ethane (C_2H_6) requires	3.733 lb. oxygen.
One pound propane (C_3H_8) requires	3.636 lb. oxygen.
One pound butane (C_4H_{10}) requires	3.586 lb. oxygen.

The cubic feet per pound are not given as acetylene is compressed and absorbed by liquid acetone before shipment, and the other hydrocarbons (best obtained by refrigerating processes) are kept liquid at ordinary temperatures under pressures of about 2,000 lb. per sq. in.

As the pound when used in connection with gases does not convey the information given as clearly to the mind as cubic feet, the following table will be simpler to understand:

One cubic foot hydrogen requires	0.5 cu. ft. oxygen for combustion.
One cubic foot marsh gas requires	2.0 cu. ft. oxygen for combustion.
One cubic foot ethane requires	3.5 cu. ft. oxygen for combustion.
One cubic foot propane requires	5.0 cu. ft. oxygen for combustion.
One cubic foot butane requires	6.5 cu. ft. oxygen for combustion.
One cubic foot olefiant gas requires	3.0 cu. ft. oxygen for combustion.
One cubic foot acetylene requires	2.5 cu. ft. oxygen for combustion.

All the figures for the amount of oxygen and air required for combustion so far given represent the minimum quantities theoretically necessary to accomplish this purpose. Practically it is necessary to give an excess of air to insure smokeless and in fact efficient results, as the stumbling block lies in the "perfect" and "imperfect" combustion possibilities of carbon. The formation of carbon monoxide is too easy and cannot even be avoided in the most efficient of melting processes—the cupola.

It will be of particular interest to compare the theoretical volume of air required for cupola melting with that observed necessary in actual practice. Assuming that the coke charged is burned perfectly—that is, to carbon dioxide. For practical purposes a pound of coke contains 0.88 lb. carbon, and this times 142.44—the amount of air necessary to burn a pound of carbon to CO_2—means a requirement of 125.35 cu. ft. of air. Since the melting rate in a cupola under practically perfect conditions of charging and with the lining thoroughly heated up can be taken at 11 lb. metal to 1 of coke—not counting the bed—a ton of iron will be melted with 182 lb. of coke. This multiplied by 125.35 gives 22,813 cu. ft. as the volume of blast required to melt a ton of iron.

To obtain the heat units developed by 1 lb. of coke burned under such ideal conditions, the following calculations must be made: 0.88 lb. carbon in every pound of coke, when burned to CO_2, gives off 0.88 times 15,444 B.t.u., equals 13,590 B.t.u. Hence, 182 lb. coke, required to melt a ton of iron, would develop 2,473,382 B.t.u.

Unfortunately, however, such ideal conditions do not exist in practice. As previously stated, it is impossible to burn carbon in air without producing some carbon monoxide, and as the imperfect combustion of carbon uses up less air than the perfect, the more carbon monoxide is formed the less of air will have been used. Putting this into practical form; the result of blowing into the cupola a given volume of air, through the incandescent fuel bed, will mean an economical consumption of carbon where the bed is of proper height, and a consumption of an excess of carbon where it is too high. The latter situation is accompanied by a lowering in temperature, as previously explained. The foregoing will be understood better from the examples of combustion in the cupola given herewith:

Taking the best analysis of cupola gases of common practice to contain

Carbon dioxide (CO_2)	18.00
Carbon monoxide (CO)	3.00

or six-seventh of the former and one-seventh of the latter, by volume. This, recalculated to percentage by weight, gives 25.56

per cent. CO_2 and 2.71 per cent. CO. The relative content of carbon by weight would be the following: $\frac{3}{11}$ of 25.56, equals 6.97 per cent. carbon in the CO_2; and $\frac{3}{7}$ of 2.71, equals 1.16 per cent. carbon in the CO. The relation is therefore 6 to 1 in weight of carbon contained.

Six-sevenths of the carbon in every pound of coke ($\frac{6}{7}$ of 0.88, equals 0.754), burning to CO_2, requires 0.754 times 142.44, equals 107.41 cu. ft. of air. The other seventh of the carbon in every pound of coke ($\frac{1}{7}$ of 0.88, equals 0.126), burning to CO, requires 0.126 times 71.22, equals 8.97 cu. ft. of air. This makes a total of 116.37 cu. ft. of air as against 125.35 required under conditions of ideal combustion.

Since a melting rate of 10.5 to 1 would be applicable in this case, 190 lb. coke, requiring 190 times 116.37; equals 22,110 cu. ft. of air would be the blast volume to melt a ton of iron. Continuing the calculations to get the total heat units developed in burning 190 lb. of coke to melt 1 ton of iron when six-sevenths of the carbon goes to CO_2 and one-seventh to CO, the following figures are obtained:

C to CO_2—$\frac{6}{7}$ of (0.88 times 190 lb. coke) times 15,444 B.t.u. equals 2,208,492
C to CO —$\frac{1}{7}$ of (0.88 times 190 lb. coke) times 4,450 B.t.u. equals 106,290

Total B.t.u. developed—2,314,782

This iron will come down snow white in color, and is obtained only in exceptionally good cupola melting practice.

Taking now the more common results obtained in cupola melting—as given by the following two typical analyses for CO_2 and CO:

Good practice { CO_2—16.00 by vol.
CO — 8.00 by vol., or 2 to 1.
Poor practice { CO_2— 8.00 by vol.
CO —16.00 by vol., or 1 to 2.

Recalculating to percentage by weight and getting the relation of the carbon content in the CO_2 and CO in each case, the following results are obtained:

Good practice, CO_2 to CO, carbon content as 2 is to 1.
Poor practice, CO_2 to CO, carbon content as 1 is to 2.

In the case of good practice, two-thirds of the carbon in every pound of coke ($\frac{2}{3}$ of 0.88, equals 0.587) burning to CO_2 requires 0.587 times 142.44, equals 83.61 cu. ft. of air. One-third of the carbon, burning to CO requires 0.273 times 71.22, equals 19.44 cu. ft. of air. Total 103.05 cu. ft. of air per lb. of coke. When running a cupola with twice as much CO_2 in the waste gases as CO, the melting ratio is not as good as the previous cases, and 10 to 1—not counting the bed—would be about right. Hence, instead of using 190 lb. of coke to melt a ton of iron, 200 lb. would have to be used between the metal charges to hold the bed up properly. The total air used to melt a ton of iron would then be 103.05 times 200, or 20,610 cu. ft. The B.t.u. developed under these conditions amount to 2,069,320.

When running so poorly that the carbon content of the CO_2 to CO in the stack gases is 1 to 2, or the reverse of the foregoing problem, it is impossible to melt better than 8 to 1—not counting the bed. So that fundamental principles may be kept in mind, it should be stated that the very reason for so poor an analysis of the waste gases is too high a bed and too heavy intermediate coke charges. The cupola becomes a gas producer.

To return: Under the poor conditions of melting mentioned, with 250 lb. of coke charged to melt a ton of iron, the cubic feet of air required amounts to 20,173 and the B.t.u. to 1,782,002.

Recapitulating the results of the several cupola operations given, the following table obtains:

Melting ratio	Coke used between charges, pounds	Carbon in CO_2 (and coke)	To melt 1 ton of iron (2,000 lb.)		
			Carbon in CO (and coke)	Cu. ft. air required	B.t.u. developed
11 to 1	182	1–(182 lb.) to	0–(none)	22,813	2,473,382
10.5 to 1	190	6–(163 lb.) to	1–(27 lb.)	22,110	2,314,782
10 to 1	200	2–(133 lb.) to	1–(67 lb.)	20,610	2,069,320
8 to 1	250	1–(83 lb.) to	2–(167 lb.)	20,173	1,782,002

This table shows some interesting features, and should not be understood to represent the operations of the same cupola supplied with a constant volume of air, but the effect of good and bad charging practice in any cupola insofar as the composition of the waste gases is concerned. The causes will be gone into fully under "cupola melting," further on. The table merely gives the requirements of air and coke to melt a ton of iron under the combustion conditions obtaining, and a fair idea of the temperature of the molten iron may be obtained by observing how the heat units developed from the fuel have dropped in spite of the increase of the amount used. While the first example is that of a theoretically perfect combustion of the coke, impossible of actual reproduction in the cupola, the others are actual examples of what can be done and is being done in daily practice, good and bad. The higher the bed is raised by using more coke between the charges, the smaller the amount of air necessary to gasify it. In other words, with a constant blast volume, the greater the coke supply, the greater the solution of carbon by the carbon dioxide formed in the lower part of the bed and consequent locking up of heat units in the resultant carbon monoxide. A further result is the dropping of the heat units developed to an extent that makes for colder iron with excessive coke.

Once the cupola gases coming from the melting zone reach the charging door level the inrush of air allows the carbon monoxide to burn and the heat units locked up are given out again—when too late to do the charges of iron any good. Hence, every effort of the foundryman should be directed to the operation of his cupola in such a manner that his fuel bed is of the right height to locate the metal charges at the point of maximum carbon dioxide one by one as they come down, the intermediate coke charges serving to maintain this point in a relatively constant position.

In order to observe the dropping of the heat units developed in the several phases of cupola operation given above to better advantage, let it be supposed that these operations were carried on in a cupola 48 in. inside the lining, and that a constant volume of air to melt 8 tons an hour under proper conditions of operation was introduced. This volume, ordinarily taken at 30,000 cu. ft. per ton of iron melted is really somewhat lower as there is more or less leakage in the blower, escape through the imperfections of the blast pipe and wind box, and finally blast traveling up along the lining of the cupola and therefore doing no effective work in melting. 24,000 cu. ft. of air may be taken as the actual air doing the melting of 1 ton of iron under first-class conditions of fuel and charging methods. For purposes of calculating the capacity of a blower to supply a given cupola, it is, however, essential to use 30,000 cu. ft. of air as the unit necessary to melt a ton of iron. For a cupola 48 in. inside diameter the desirable melting rate is 8 tons per hr., hence the blower must be capable of delivering 240,000 cu. ft. per hr.

Recalculating the above table on the basis of obtaining 1 ton of superheated molten iron with 182 lb. of coke—on the supposition that all the carbon goes to carbon dioxide, the following relative amounts of coke will have to be consumed in the same period of times (1/8 hr.) to use up the oxygen furnished by the blast and produce the waste gases the table is based upon.

Blast volume, cu. ft.	Carbon ratio CO_2 to CO	Cu. ft. air per lb. coke	Coke per 1/8 hr.	Melting ratio	B.t.u. produced
22,813	All—None	125.35	182	11.0 to 1.0	2,473,382
22,813	6 to 1	116.37	196	10.2 to 1.0	2,392,889
22,813	2 to 1	103.05	221	9.0 to 1.0	2,290,808
22,813	1 to 2	80.69	283	7.1 to 1.0	2,020,840

The introduction of the element of time—a constant volume of air throughout the heat—gives a clearer view of the conditions resulting in perfect, very good, fair, and very bad melting practice. The carbon ratio in the waste gases is the key. It will be noticed that the increase in coke charged is serious and with it a corresponding drop in the melting ratio. The B.t.u. developed, which after all tell the story, indicate that the greater the coke consumption the less the actual heat available for melting purposes. In normal practice the consumption of coke is practically 200 lb. per ton of iron, or 10 to 1. An average gray iron suitable for machinery castings requires 1,075 B.t.u. until molten and superheated—975 B.t.u. when just melted—per pound of iron. Per ton, these figures would run 2,150,000 and 1,950,000 B.t.u. respectively, which shows that it would be just possible theoretically to melt iron in even the worst case quoted, if there were no losses to consider.

While considerable allowance must be made in basing conclusions upon the figures given, for they are theory and practice considerably mixed together, it is quite evident that the cupola melting process can be made a very efficient one. The items that would affect the results are the following:

The Blast.—The theoretical 125.35 cu. ft. per lb. of coke (0.88 C) necessary to give perfect combustion is not a practical figure. Much more air is used. The higher the pressure, within reason, the better the penetration of the blast into the body of the bed and the smaller the loss of unused air along the lining.

The Coke.—Some coke is better than 0.88 carbon, with consequent greater B.t.u. developed in combustion.

The Waste Gases.—These do not always fully indicate the condition below. If, for instance, a light coke is used it is quite possible that the percentage of CO_2 at the point of melting is very good, but in rising through the upper layers of coke extra carbon is dissolved and a high CO percentage shown. The cupola waste gases referred to are taken at a point sufficiently below the charging door to avoid contact with the air coming in at that point.

The Melting Ratio.—With imperfect charging methods, this will vary considerably within the same heat. The higher the intermediate coke weights for the same quantity of iron, the lower the ratio.

The B.t.u. Developed.—Some of these are lost in the waste gases, as it is impossible for the metal charges to absorb all the heat passing by them. A smaller quantity goes into the lining to render this incandescent at the melting zone. More goes into the formation of slag. On the other hand, the oxidation of silicon, manganese and iron add to the heat developed.

The Melting Rate.—With excessive coke, the B.t..u developed go down as shown. The result is that the iron will not only melt colder, but it will melt slower. In melting slower, however, time is given to burn away carbon, and the bed goes down. The result is a higher CO_2 percentage in the gases, higher temperatures at the point of melting, and quicker melting. Where the stream of iron is kept running steadily, this change in temperature can often be noted. Unfortunately, however, the next intermediate coke charge coming on the bed (in the case of excessive coke charges) raises this unduly again, the cupola becomes a gas-producer temporarily and the iron melts slower and colder until the bed is lowered again. Thus a very unsatisfactory situation results. Where the charges of metal are very large for a given cupola diameter, the change in temperature of the iron as one charge melts at a time can be distinctly noted in the tap. The beginning and end of the melt in each case take place at different bed levels. Hence, the importance of small metal charges, with corresponding small coke charges. The temperature of the molten metal will be more uniform.

While the efficiency of the cupola is usually quoted as around 50 per cent., it looks very much as if this can be improved upon when the proper operating methods are fully understood. The figures of the tables, even subject to modifications to come closer to the real facts, show this quite plainly. It must be evident that if it is theoretically possible to melt a ton of iron with 182 lb. of coke, and that this is actually done with 196 lb.; when melting is accomplished, even if poor, with 283 lb., there must be a great waste. It must further be remembered that the temperature of the waste gases below the charging door is not as high as would be supposed when observing the roaring flames at this entrance for air. In good practice the cupola gases will not be hot enough to light until some time after putting on blast. Only when the stock has been heated up sufficiently to allow the gases to pass out at about 1,000°F. will there be ignition, and even then the gases must be rich enough in carbon monoxide—over 12 per cent.—to light at all.

The study of the cupola is not simple, for not only is it essential to obtain a good efficiency from the operation, but also good quality from the metallurgical standpoint.

Flame Temperature.—This is the next point of importance, particularly in air-furnace practice, for unless a very high flame temperature be obtained as the gases burn over the hearth, melting will be slow and the molten metal inferior in quality.

The following table of partly observed and partly calculated flame temperatures of gases, when burned in air and in oxygen, will be of interest to foundrymen. The great difference observed when a gas is burned in air as compared with its combustion in oxygen is due to the large amount of nitrogen to be heated up during the process. The latter is inert and forms 76.9 per cent. by weight of the air used. The absorption of heat for no useful purpose, is therefore very serious and accounts for the effort being made to enrich the oxygen content of air blown into the blast furnace, etc., in connection with the exploitation of liquid-air processes. This subject is, however, not so important in the foundry as the cupola melting process, if conducted efficiently,

FLAME TEMPERATURES

Fuel	Combustion in air (Le Chatelier)	Combustion in oxygen (calculated after Richards)
Carbon (C) to carbon dioxide (CO_2)	3,700°F.	6,685°F.
Carbon (C) to carbon monoxide (CO)	2,335°F.	6,045°F.
Carbon monoxide (CO) to carbon dioxide (CO_2)	3,810°F.	5,400°F.
Hydrogen (H) to water-vapor (H_2O)	3,585°F.	5,775°F.
Marsh gas (CH_4) to carbon dioxide and water-vapor	3,360°F.	5,760°F.
Olephiant gas (C_2H_4) to carbon dioxide and water-vapor	3,735°F.	6,450°F.
Acetylene (C_2H_4) to carbon dioxide and water vapor	4,390°F.	8,030°F.

gives amply superheated molten metal, and where furnace iron is desired, the open-hearth answers the purpose very well as regards high temperatures.

Some reduction in the calculated figures must be made for actuality. It is well known that carbon dioxide dissociates at very high temperatures, and hence the theoretical figures are never fully reached. Nevertheless, the importance of burning carbon to carbon dioxide rather than to carbon monoxide will be seen from the above table of flame temperatures just as much as in the calculations for the heat units developed.

In this connection it will be of interest to note the flame temperature of burning producer gas, owing to the importance of the open-hearth furnace in the foundry. According to Le Chatelier this gas, with a carbon monoxide and hydrogen content of 20 and 10 per cent. respectively, when burned cold, gave a flame temperature of 2,460°F. When, however, both air and gas had been preheated in the checker-chambers (regenerators) of the open-hearth to 1,800°F., the flame temperature rose to 3,900°F. This would correspond to the maximum theoretical temperature of the cupola melting zone.

In some tests made by the author in open-hearth glass-pot furnaces, where it was desirable to introduce the Le Chatelier pyrometer thermocouples through the roof, the temperatures just under this were so high that the platinum, platinum-rhodium couples dropped off melted as fast as pushed through the cracks (platinum melts at 3,190°F.). Further down, the temperatures were considerably lower and could be measured from the sides of the furnaces without difficulty. Figures given by Le Chatelier and Damour corroborate this and show the following:

Temperature of gas leaving the producer	1,325°F.
Temperature of the gas leaving the gas regenerator	2,200°F.
Temperature of the air leaving the air regenerator	1,800°F.
Temperature in hearth (average)	2,820°F.
Temperature in bottom of flue to stack	575°F.

Unquestionably the upper layers of the gases passing through the flues to the chimney are much hotter. Indeed tests made by the author gave all the way from 1,000° to 1,800°F., depending upon the time between reversals that these were made.

It is unfortunate that nothing definite is known about the temperatures existing in the air furnace when run with maximum efficiency. It is quite certain that the application of waste-heat boilers in the chimneys of these furnaces would not be such tempting propositions if the design and operation of this so common type of hearth furnace were better understood.

The drop in flame temperature when carbon instead of burning to carbon dioxide goes into carbon monoxide shows very plainly why it is not desirable to have the fuel bed of the cupola too high and why it is important to melt in the zone of maximum carbon dioxide.

Air Necessary for Combustion.—As has been stated, the difficulty in attaining the perfect combustion of carbon is so great, the adjustment of the fuel bed so delicate, and the formation of carbon monoxide so easy, that for reasonable efficiency it is necessary to furnish an excess of air for ordinary firing purposes. The boiler is a good example of this, for up to 100 per cent. excess air is admitted under the grate bars to get satisfactory results. This means a considerable dilution of the carbon dioxide formed, with consequent smaller chances for making carbon monoxide. The flame temperature is reduced and consequently the tendency of carbon dioxide to dissociate under very high temperatures effectively retarded. Since the relatively larger volume of lower temperature products of combustion, in passing around the iron tubes filled with water, give up their heat to good advantage before going up the chimney, the results are fairly efficient.

In the case of the air furnace, however, it is not a question of heating water for making steam, but melting iron, in fact superheating the molten metal. Hence the highest possible flame temperature consistent with efficient combustion is absolutely necessary. The degree of dilution of the products of combustion must therefore be held to a minimum. This means a corresponding reduction in the percentage of excess air used in firing. Upon this situation, as well as the selection of the best-quality gas coals yielding high flame temperatures, will there rest the efficiency of the melting process as well as the quality of metal produced.

An example will perhaps show the situation up best. Assuming that the theoretical flame temperature of carbon burning to carbon dioxide with the theoretical amount of air necessary is 3,700°F. With the following percentages of excess air used to obtain good combustion, the flame temperature will have been reduced as given below:

Carbon to carbon dioxide with theoretical air only	3,700°F.
Carbon to carbon dioxide with 10 per cent. excess air	3,450°F.
Carbon to carbon dioxide with 25 per cent. excess air	3,170°F.
Carbon to carbon dioxide with 50 per cent. excess air	2,790°F.
Carbon to carbon dioxide with 100 per cent. excess air	2,250°F.

The above are theoretical figures and are never realized for reasons previously given. Inasmuch as it is necessary not only to melt iron in the air furnace but to superheat it considerably before tapping out, so that the required temperature will be close to 2,500°F., an excess of 50 per cent. of air above the theoretical requirement for perfect combustion will in all probability not heat the furnace enough to give the desired result unless aided by internal combustion of silicon, manganese and carbon in the bath. This is actually the case where the heats are unduly long. The combustion due to poor firing is so imperfect that the period of melting drags along, and instead of tapping 4 hr. after charging, it may take 7. This means oxidized metal, blow-holes in the castings, and other troubles coincident with "lifeless" molten iron.

It will be necessary, therefore, to limit the excess air for combustion to no more than 25 per cent. of the theoretical requirement. This will give a reasonable assurance, if the firing is even and free from inrushes of cold air at intervals, that the flame temperature will be sufficient to keep the hearth interior (laboratory) highly incandescent and yield quick and satisfactory melting results. If the excess air can be held down to 10 per cent. the situation will be still better.

The necessity of having a long flame sweep over the hearth, to distribute the high temperature gases in combustion well over the interior of the furnace body, precludes the use of such fuels as coke and anthracite. Gaseous fuels bring up other problems and cannot be successfully used unless the air is preheated—in which case the open-hearth furnace might as well have been used in the first place. Recently oil has been applied successfully, but only through atomization and combustion in a special chamber for the purpose, the long flame then passing over the bridge wall into the furnace body.

A good high-volatile gas coal gives the best results, for unless a long flame is obtained the development of heat is more or less of a local character. The intensity of the fire in a limited portion of the cupola melting zone, as seen by the cutting of the lining; also the local heat of oil burning with atomization by high-pressure air, and the consequent holes burned in the crown of the furnace give ample evidence of this situation.

In the air furnace, the passage of the air and products of combustion is slow when compared with the cupola. Time is thus given to burn the tarry portions of the volatile matter and the heat values obtained. The excess air used tends to retard the formation of carbon monoxide, and if the introduction of air is adjusted with nicety—so that there is just a little smoke coming from the doors off and on, there will be a non-oxidizing atmosphere with the furnace, the flame will be nearly clear and not cutting and the results satisfactory. The same situation holds for the open-hearth furnace, a good melter always liking to see little puffs of smoke come from the peep-holes in the charging doors.

In the cupola, from the nature of the melting process, combustion is carried on without an excess of air. All the air blown in will be consumed if the bed is made of proper height. If made too high, efficiency is lost as the imperfect combustion of carbon eventuates, as in gas-producer practice. If the bed be too low—that is, the metal charge put on before the bed has been made high enough unconsumed oxygen will be present, corresponding to the use of excess air, the flame temperature is lowered, metal is oxidized and troubles result. Since the point of minimum free oxygen corresponds to that of maximum carbon dioxide, minimum carbon monoxide, and incidentally the point of maximum temperature, this point, or rather plane, should constitute the top of the bed and be kept there by the subsequent intermediate fuel charges throughout the heat.

Preheating the Air Supply.—This subject is of more particular interest in open-hearth furnace practice, for here it is vital. As, however, many attempts have been made to operate air furnaces and even cupolas with preheated air supply, a few words in this connection will not be amiss.

The natural source of the heat for the purpose under discussion lies in the waste gases before they pass up the stack. Some of this heat is either stored up in the checker-chambers of the furnace and given off to the products of combustion and air currents alternately as they pass out and in, or else the waste gases are circulated about coils or other apparatus through which the air for combustion is made to pass, and some of the heat is transferred. The latter method is continuous and was used for air-furnace and cupola purposes in the more or less successful melting attempts referred to. The result is a preheating of the air for combustion and a consequent higher flame temperature.

While the preheating of the air is successful, in fact essential, in the open-hearth furnace, there are objections to this procedure in the case of the air furnace and cupola. First, from the practical standpoint. Those who have used castings under conditions of red heat to preheat air that is passed through them, know how short their life has been. The old cast-iron stoves of blast furnaces are excellent examples, and where this class of scrap has eventually landed to plague the foundryman a trail of lost foundry product has been the result. Not only will cast iron used under such heat conditions grow, warp and crack, but it will oxidize so heavily that burnt grate bars may be called good by contrast. The consequence is that the air preheating coils used in the chimney end of air furnaces for utilizing natural gas as fuel soon give out and the operation becomes costly and unsatisfactory. The use of steel coils in place of iron castings does not improve matters very much, the metal in any case is almost a dead loss when the apparatus fails by burning through in some spot.

The other consideration is more of a scientific nature. Unless the air to be used is delivered to the preheating apparatus of the furnace cold there will be inefficient results. Foundrymen have always noticed that if the blower draws the cupola air from without the building the melting results will be better than if the shop air is used. Similarly, in cold weather the results are better than in hot. It comes down to the actual pounds of oxygen available in a given volume of air used. Hot air contains less oxygen by weight than cold air, per cubic foot. Since the weight of oxygen drawn into the furnace by the chimney draft is dependent to some extent upon the original temperature of the air as it enters the furnace, the matter is important enough to be carefully watched.

The author, while operating a number of open-hearth furnaces one summer noticed that the heats were getting too long and the results were unsatisfactory. Investigation showed that the shop air was peculiarly hot and vitiated as the result of practically continuous pouring. Piping from the air valve of the worst furnace to the atmosphere without the foundry remedied the trouble at once, and suitable arrangements were then made for the other furnaces. The chimney draft could not get enough oxygen into the furnace for efficient combustion until comparatively cold air was available.

While some attention is given this subject in cupola installations, nothing seems to be done for air furnaces. It would not be amiss, therefore, to connect the ash pit with an outdoor air supply where chimney draft is depended upon. The coal consumption would be more effective with consequent higher flame temperatures and better all-around results.

If it becomes desirable, therefore, to preheat the air for combustion in any cupola or furnace tests to be made, this should be done between the blower and the furnace, so that the weight of oxygen calculated upon to do the work of melting may not be reduced. For intermittent melting, as in cupola and air-furnace practice, the colder and purer the air the better.

Transmission of Heat by Radiation and Conductivity.—A final word on the transfer of heat from the products of combustion to the metal to be melted. In shaft furnaces, the cupola in particular, this transfer is quite direct. The hot gases are in intimate contact with fuel and metal charged with the good and bad results that follow. Melting is the result of the conductivity of the iron, the heat applied at the surface being passed along inward until the melting point is exceeded and the metal drops off. But little radiation is possible from the heated lining of the cupola as the charges are in close contact. Indeed, what little radiation of heat exists applies to only a very small portion of the charge.

As the gases in the cupola pass upward heat is absorbed by the stock above, and the more heat absorbed by the charges before they get down to the bed, the higher the degree of superheating at the final melting. On the other hand, the hotter the fuel the greater the loss in carbon by solution in carbon dioxide with consequent formation of the undesirable carbon monoxide which burns above the charging door. Hence, a medium course is desirable and usually obtained when the height from cupola bottom to charging door is between 15 and 20 ft.

In furnace melting the situation is different. Whether in the plain hearth, or air furnace, or in the better open-hearth operation, the flame cuts through the charge to a limited extent only if this is loose and heaped up near the crown or furnace roof. In the heating up and final melting down of the charge the flame also renders the roof and sidewalls of the furnace incandescent, and the most effective work is done by radiant heat from the interior surfaces of the furnace. It is highly important, therefore, that every square inch of the interior surface be in good repair and heated up to the highest temperature attainable. Loose doors, the refractory lining of which is partially gone, a coating of slag over the surfaces instead of the highly radiant face of the original brick, open firing doors, and other defects calculated to drop the high temperatures existing or diminish the power of radiation on the part of the refractory furnace lining, should be watched closely.

In the air furnace, as well as the open-hearth furnace, melting is accomplished by conductivity and radiation combined until the gradual disappearance of the metal under the slag-covered bath precludes much more transmission of heat by conductivity, and radiation takes up the full work of melting through the slag cover or the surface of the bath of metal, and accomplishes the necessary superheating as well.

A review of what has been said in this chapter will show how fundamental and vital the question of efficient combustion is to the foundryman. Unless he gives his special attention to the charging and operation of the cupola, or the proper firing of his air furnace, he will be handicapped at the outset by molten metal inferior with respect to quality and temperature. The defects thus commenced with will injuriously affect his pouring, his method of gating the molds, in fact, every department of his activity. Prevention is better than cure in every case, and attention in starting off right means half the battle.

CHAPTER X

MELTING PROCESSES

The remelting of pig iron and scrap used in the production of gray and white iron castings may be carried out in the crucible, air-furnace, open-hearth furnace and electric furnace. Of these the cupola and air-furnace melting processes must be considered in greater detail. The crucible melting process has become obsolete in the iron foundry, for, in spite of the excellent product made, the cost is prohibitive.

Some attention must, however, be given the open-hearth and the electric furnace processes, as the former yields the highest grade of metal in one operation, while the latter can best be used in purifying the molten metal coming from the comparatively cheap cupola melting process.

The cupola is a simple form of shaft furnace. It consists of a vertical cylinder of boiler plates lined with fire-brick, the top open to receive alternate charges of fuel and metal, with blast introduced near and molten metal drawn off at the bottom. First-class iron can be obtained with good economy by melting it in an old boiler set on end, top open, and lined with fire-clay. At the proper distance from the bottom holes are punched to allow the introduction of pipes to act as tuyeres. An opening at the lowest point of the prepared bottom permits the tapping of the molten iron. Such an apparatus, when operated with sound knowledge of the melting problem, will yield equally as good metal as the most elaborate construction. It will be more troublesome, however, to run in regular practice. When one, therefore, sees the derelict cupolas in some foundries operated day after day, it is possible to understand that good castings can be made with them; not because of the decrepit state of the melting apparatus, but in spite of it. The air introduced is made to burn the fuel and give the necessary heat for melting just as in the best-built cupola.

Fig. 28 shows the vertical section of a cupola. The cylindrical shell consists of steel plates riveted together, with rings of angle iron bolted on at intervals to support the fire-brick lining. A door (or more than one of them) is cut in about 15 ft. from the bottom plate, thus allowing the introduction of the fuel and metal charges. Near the lower end of the shell there is provided an annual chamber encircling it, into which the blast from the blower is made to enter, circulate and penetrate into the cupola through a series of tuyères ranged about the ring of lining at regular intervals. The operation of the tuyères may be observed, and they may be cleaned through "peep-holes" cut through the outer shell of the "wind box."

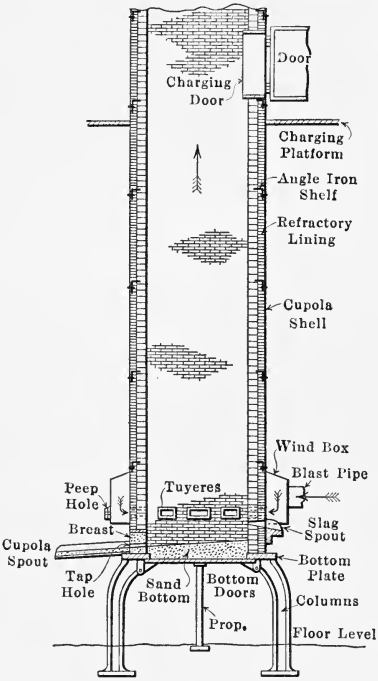


Fig. 28.—Section of Cupola.

Just below the tuyères and directly opposite the cupola spout, which is the front of the cupola, there is placed the slag spout used to relieve the bed of slag accumulating during the running of long heats. The cupola spout itself is arranged to be at the lowest point of the sand-bottom, at which place an opening is left in the shell which when rammed up with sand and clay makes up the "breast" of the cupola and holds in the molten metal until tapped out through the "tap-hole" left for the purpose.

The illustration shows the "sand-bottom" in place for charging. It is made on the swinging doors hinged to the "bottom-plate" supporting the whole cupola structure. The doors are held up by the "prop" as shown. The cupola proper rests upon columns set on concrete foundations laid several feet below floor level. The parts of the cupola will be taken up in detail, the constructions explained and the functions studied.

The Shell.—This is made up in cylindrical sections riveted together as in the case of an iron smokestack. The thickness of the sheets runs from 3⁄16 to 3⁄8 in. ordinarily, depending upon a number of conditions. Thus, the higher the cupola stack (as this should extend over the top of the buildings about 10 ft. for reasons of safety and proper draft) the thicker the lower plates to sustain the weight. Then again, the lining of the upper part of the cupola is renewed comparatively seldom, whereas the portion below the charging door is put in at least every 9 months of running—the lining within the zone of actual melting oftener still. This necessitates the support of considerable weight by the lower sheets during the relining operation. The rings of angle iron bolted to the cupola to serve as shelves assist in giving security to the brickwork, and in case of accident to the lining localizes the trouble.

The lowest course of sheets must be the heaviest, as this suffers most in the operating process through heat, dampness, rust, as well as the removal of much metal to accommodate the breast, the tuyères and slag-hole. Ordinarily there is no requirement of extra strength to resist strains tending to disrupt the shell, but if the lining is not put in properly this may occur, and is often seen in badly managed foundries. Here also there may be observed the effect of running the lining too thin, the plates becoming hot and buckling from the superimposed weight.

Above the charging door the stack of the cupola can be reduced in diameter in the case of large units, as it saves money, gives better draft, and reduces weight. Where this is done it is better to begin the reduction at a point one ring of sheets above the door to assist in the proper ascent of the gases. Whatever may be the thickness of the lining below the charging door, this can be reduced to 4 in. over the angle shelf above it. The actual reduction in shell diameter is effected by a ring of conical shape, as will be readily understood.

In the case of small-diameter cupolas, such as 42 in. inside the lining and below, it will not pay to reduce the diameter, which is therefore kept the same all the way to the top. The lining, however, is held to the 4-in. minimum over the charging door.

In congested districts it is customary to top the cupola with a spark arrester, or hood provided with iron netting to catch sparks and glowing coke pieces. The delapidated appearance of these hoods after a time shows how desirable it is to avoid putting them on at all. If the cupola is carried high enough to overtop the surrounding buildings by at least 10 ft., there will be little trouble encountered unless the melting practice is exceptionally bad and excessive fuel has to be used. Then the flame will belch from even high cupolas, sparks and glowing cinders will fly around and endanger property, cause suits at law and embitter the residents against the foundry in question.

In some of the congested European cities, where it is absolutely necessary to maintain foundries the cupola gases are carried downward into the sewer. This can be readily done by closing the top, except when charging, and forcing the gases through an outlet at the side either by steam or air jet. The system is naturally expensive but may be compelled by the circumstances.

In order to charge the cupola conveniently the necessary doors are provided above the platform. In the case of small cupolas a single door will do. It is put about 2 ft. high and directly above the slag-spout, as a rule, though whatever position is most convenient should be selected. The melter can then throw his charges just where he wishes them and get level layers. For the larger cupolas it is customary to provide two charging doors, one at each side, and the location above the platform depends upon the method of charging to be used. For hand-charging the doors can be at floor level or perhaps 6 in. above, for safety. If the doors are large enough, this will prove more convenient than to put them up the usual 2 ft., though in the design of the melting house the platform should be located with a view of giving the proper height of "bottom to charging door" for the cupola.

The subject of mechanical charging will be taken up specially, for this is very important in view of the constantly increasing cost of labor. Unless the principles of rational charging are thoroughly understood, serious consequences will result from the installation of improperly designed mechanical charging devices—of which there are quite a number in existence at the present day.

The doors themselves are hinged to a frame of cast iron which extends into the cupola slightly beyond the lining. The lower portion of the frame—the sill, or charging shelf—should be substantial, to avoid breakage, and be wide enough to protect the brick lining below it. The doors may be iron castings, and should in that case be lined with fire-brick. Or else they may be skeleton frames covered with heavy wire screening.

The further function of the charging doors is to assist the cupola draft—this, particularly, in the early stages of the "lighting-up" process. It is good to keep them almost closed after charging is complete, for a strong draft will help the melting operation and keep the charging room free from gases. The cupola can, however, be run with the doors wide open if desired, which shows that they are not actually essential.

Mention has been made of the "height from bottom to charging door" of the cupola. This is an important dimension as it fixes the amount of heat that can be extracted by the melting stock from the ascending cupola gases. The higher, naturally, the better the absorption of heat. The value of high stocks of material in a cupola is seen particularly in the case of continuous melting, as in car wheel, pipe and Bessemer cupola work. Perhaps the general custom of rarely exceeding 15 ft. for the dimension at issue has come from desire to limit the heat to about 2 hr., as also to keep the platform below the ordinary roof trusses used. Again, with very small cupolas the chances of bridging are greater than with large diameters, although this can be obviated by breaking the pig used to proper size. That this trouble is more imaginary than real (unless the pig charged is actually too long) is shown by the fact that a cupola is in daily operation in Europe (as told the author) which has a diameter of 1 meter (39.36 in.), the charging door of which is 50 ft. above the bottom. The melting results here are said to be wonderful. It may be stated that the height in question was fixed by the location of the railroad high above the town.

Modern foundry structures being much higher than was formerly the case, particularly as heating and ventilating systems are now part of the regular programme, there is no reason why the cupola platform should not be at a level giving 30 or more ft. to the column in the cupola. Indeed, with the mechanical charging device designed by the author, and described later on, there need be no charging platform at all, and the height of the column in the cupola can be fixed at the most economical point.

A number of items would enter into the fixing of this point. If the heat is short, it would not pay to have the cupola so high that almost the whole tonnage is charged before blast is put on. It is only in long heats that high cupolas show their value. Again, there is a limit to economical heat extraction from the waste cupola gases. These gases grow colder as they ascend through the stock. On the other hand, the stock grows hotter as it descends. So far as the metal part of the charges is concerned, the hotter this gets the better; for the coke, however, this is another matter. The hot carbon dioxide gas passing upward dissolves carbon from red-hot coke. If, therefore, the coke charges become incandescent pretty far up there is serious danger of loss of heating value from carbon monoxide formation (particularly in the case of very light cokes). To avoid this it is sometimes even desirable to thoroughly drench the intermediate coke charges with water—never the bed coke—after they are weighed, so that they may arrive at the lower levels with less loss in carbon.

On the other hand, the gases ascending upward grow colder by giving up their heat. The colder, the slower the cooling process and consequently the lower the efficiency. Moreover, it is necessary that the gases going out of the cupola top be hot enough to have at least enough velocity to keep them from coming out of the charging door. Indeed, the entrance of fresh oxygen at the charging door enables the cupola gases to burn freely when rich enough in carbon monoxide. Hence the evolution of more heat with consequence draft improvement. Unfortunately this is at the expense of cupola melting efficiency, for the percentage of carbon monoxide should be held as low as possible.

The selection of the "height of bottom to charging door" would therefore depend upon many things. As not all of these things can be foreseen, and a cupola must be installed before any operations can commence, the foundryman usually turns to the tables furnished by cupola builders for the heights recommended. Here he sees, for instance, that a 36-in. diameter (inside the lining) cupola should be 13 ft. high; a 54-in. cupola 15 ft., and an 84-in. cupola 17 ft. high, from bottom to charging door. Now, after all, the ability to give off heat to the stock depends upon the velocity of the cupola gases. In other words, for the same velocity the cupola height in question should be identical whether the internal diameter is 36 or 84 in. With slower gas velocities, of course, the height can be smaller, and *vice versa*.

The author has prepared the following table showing the relative gas velocities in cupolas assumed to be empty. The actual velocities in the fully charged cupola while in operation are naturally much higher, as the volume is almost filled with metal and fuel—the gases having to travel in the spaces left between the individual lumps and pieces. If, for instance, the interior of the cupola is filled by the charges to the extent of 75 per cent., then the gases will travel four times as fast as given in the table below. The relation of the velocities of the different cupola sizes to each other will, however, not be changed.

The melting rates—in tons per hour—are those which daily practice has found best suited for the cupola sizes in question. The ordinary figure of 30,000 cu. ft. of air per min. to melt a ton of iron is the basis of the blast calculations given.

Cupola diameter, inside lining, in inches	Tons of iron melted per hour	Cubic feet blast per second	Relative velocity of blast, feet per second
18	½	4.17	2.36
24	1½	12.50	3.98
30	3	25.00	5.09
36	4½	37.50	5.30
42	6	50.00	5.20
48	8	66.67	5.30
54	10	83.33	5.24
60	13	108.33	5.52
66	16	133.33	5.61
72	19	158.33	5.60
78	22	183.33	5.52
84	26	216.67	5.63
90	30	250.00	5.66

It will be noted that with the exception of the two smallest sizes—in reality little test cupolas—the velocity of the blast in feet per second does not vary very much. In fact if the 30-in. cupola be omitted, the variation of the other, larger, ones is very little indeed. This would indicate that the ordinary tables quoted by makers for different heights of cupolas, as based on their diameters, are incorrect.

That much defective practice exists on this point is patent to anyone going about the foundries of the country. Oftentimes one sees small-diameter cupolas the charging doors of which are but 6 ft. above the bottom. Then the foundrymen wonder why their melting ratios are so low. In view of the above table, it would seem that cupolas—even as small as 30 in. inside the lining

—should all be at least 15 ft. high, since experience has shown that good economies can be had with that figure. On the other hand, for continuous operation, particularly with large tonnages, 25 ft. and over would be preferable.

The *wind box,* or air chamber, of the cupola consists of a steel belt attached to and surrounding the cupola shell at its lower extremity. The purpose of this chamber is to distribute the blast delivered by the blower uniformly in pressure and volume through all the tuyères entering into the cupola, as far as this may be possible. Many constructions have been used to arrive at the desired result. Air chambers have even been built inside specially boshed cupolas, though this method is fundamentally wrong and the chances for leakage are greatly increased. The simplest method is to rivet on and caulk the steel plates to the outer surface of the shell just where required, and to allow the blast to enter through the top by means of two vertical pipes, one on each side of the cupola. This construction gives the most satisfactory results.

The *blast pipe* can also be allowed to enter the wind box horizontally on a tangent. Unless, however, the area of the latter is made quite large as compared with that of the blower outlet (three to four times), the tuyères next to the blast-pipe outlet are apt to pass more than their share of the air. As the width of the wind box cannot be made less than 6 in. nor more than 12, ordinarily, the area required must be gotten by a suitable height. Hence, in modern construction of large cupolas, the wind box usually commences at the bottom plate and extends considerably above the tuyère level. Since modern melting practice entirely discards the upper tuyères of less recent times, the cupolas of the future should have air chambers of more simple construction.

One of the difficulties of a wind box extending to the bottom plate is the almost certain entrance of slag and molten iron by way of the tuyères. Even the most careful melter is apt to be caught some time, particularly when iron is melted faster than it can be carried away. He forgets that he has only to shut off the blast completely to stop melting, and if he drains the cupola and partly opens one of the tuyères, to keep up enough draft to hold the blast pipe clear of carbon monoxide gas (and thus prevents a subsequent explosion), the heat may be held *in statu quo* for a considerable period.

To overcome trouble from molten slag and iron in the wind box, one of the tuyères called the "safety tuyère," is set a little lower than the others and below it in the bottom plate there is placed a fusible plug. This is supposed to melt and let the blast drive out the molten material at least sufficiently for observation and prompt correction of the trouble by tapping out. Occasions have been known when this device actually worked; in fact the author observed it once in the course of his life experience. The usual situation, however, is that in picking out the lining for the day's run refuse drops back through the tuyères, so that the safety plugs are covered and will not react when hot slag or iron enters the air chamber. For that reason cupolas are always provided with two or more cleaning doors, suitably placed, allowing the melter to remove extraneous material from the wind box previous to lighting-up. How conscientiously this work is done is shown by the author's observation in many foundries of several inches of solid iron frozen tight within, if not actually enough slag to fill the space level with the tuyères. Then the foundryman wonders why his cupola works one-sided. With the reduction of the cross-section of the chamber the uniformity of wind distribution cannot help but suffer.

In order to observe the operation of the tuyères from without the cupola, as also to introduce the cleaning bar during the running of a heat, peep-holes are cut into the outer shell of the wind box opposite them. These orifices are closed by swinging covers provided with mica centers. When swung shut and clamped the peep-holes will not leak air and enable the melter to see what is going on—provided he keeps the mica sheets clean at all times. The peep-holes further serve the purpose of allowing air to pass up the cupola during the lighting-up process.

There are a number of things about a cupola shell which indicate the experience of the builder. Melters oftentimes complain of the trouble involved in cleaning the wind box and working about the cupola and slag spouts. The arrangement of the frames and plates can give maximum to minimum trouble, and as the cupola must be attended to on practically every working day, it pays to look into the smaller details of construction with this in mind.

Tap-hole.—This is a round straight orifice of small dimensions left in the breast of a cupola through which the molten metal is drawn off. The "breast" is a mass of refractory material rammed into an iron frame let into the cupola shell at the bottom end. It forms part of the cupola lining for the time being, the frame being made large enough to allow plenty of working room and ribbed to hold the breast from being blown out. The breast is broken out after every run and made anew, the frame construction preventing damage to the cupola lining proper at this point. As on occasion a tap-hole will freeze up and it becomes necessary to cut out a new one without delay, the breast must be large enough to allow this readily.

The tap-hole of a cupola is usually placed in the front, or directly facing the observer as he stands in the foundry looking at this furnace. Any other position may, however, be taken to facilitate the proper removal of the molten metal. Where the tonnage is heavy and molten metal has to be diverted to a foundry "lean-to" at one side or behind the cupola, a second tap-hole is provided at the side, and both are operated at a time—the "bottom" level being arranged accordingly. Suitable spouts are provided to carry off the metal. The manner of making the tap-hole will be gone into more fully in discussing the preparation of a cupola for melting.

The Spout.—This is a cast-iron channel provided with flanges to bolt it to the cupola shell. The casting has the proper slope to facilitate the running of the metal without giving too much force to the stream. It is made sufficiently large to allow lining out with either split brick or a mixture of fire-clay and fire-sand. The spout may be long or short, as the exigencies of the foundry may dictate. A fairly long spout is safer and allows more working room. The cupola must be set high enough to allow it to be applied. A short spout saves heat but is good only with small cupolas from which the metal is taken off in hand-ladles.

The construction of the cupola spout becomes a serious consideration in the case of large foundries making pipe fittings, etc., in which the metal is taken off in small units by hand or trolley, and it is necessary to run all day long. Here the slag problem must be met, for it is not always possible to prevent the tap-hole from running dry and letting through slag when it is hardly botted up during working hours. In such a case the cupola spout is made quite deep, to provide a small basin just beyond the tap-hole in which the metal remains long enough to allow any slag present to rise and flow off at the side. The outlet of this basin is below the surface of the metal within it, and from here the stream flows on over the spout. At the side of this basin a small tap-hole is provided to drain it when operations cease. Fig. 29

illustrates the "slagging cupola-spout" in question. It will be noticed that the spout is deepened at the cupola end to provide the above mentioned basin for molten metal coming through the tap-hole in the breast. A bridge of fire-brick is laid across the spout as shown, thus effectively damming up the metal as well as skimming it as it passes underneath and over the rest of the spout, the bottom level of which at the bridge being regulated by the melter to provide the desired level of the molten metal in the basin. If it is intended to slag the cupola by means of this spout altogether, the level in question must be held low enough to allow the slag to flow out of the cupola tap-hole with the iron. If, on the other hand, the usual method of slagging out the cupola through the slag spout just under the rear tuyères is carried through, and the molten iron is only intended to clear itself of small amounts of entrained slag, the basin level is held a little above the cupola tap-hole. The removal of the slag is provided by the side notch shown in the spout at the basin. A special tap-hole is put at the lowest point of the basin to drain out the metal when required. This whenever the cupola has to be botted up for some reason, and at the end of the heat.

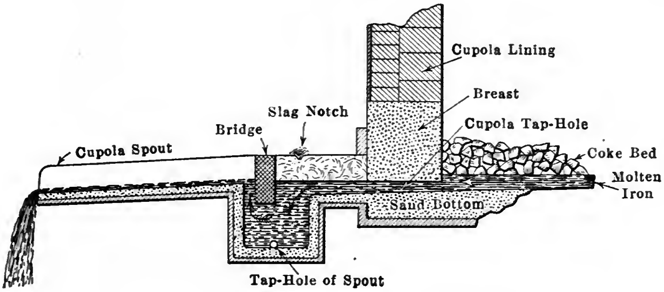


FIG. 29.—Section of slagging cupola spout.

While such a slagging spout arrangement on the cupola looks attractive to the foundryman troubled with slag inclosures in his castings, it should be applied only in extreme cases and not for general practice. There is considerable trouble involved in the upkeep of this piece of apparatus and at best it is cumbersome. If in any cases other than the ones mentioned the foundryman gets dirty castings, the slag keeps on rising to the top of the big ladles for too long a period, or the cupola spout is befouled with stringy, pasty slag in spite of the usual care in tapping and botting up, it is quite evident that the charging and melting practice requires immediate attention. Iron is oxidizing by melting on too low a bed and the temperatures are too low to let the iron clear itself of the slag properly before leaving the cupola.

Instead of applying a slagging cupola spout the bull-ladle into which the iron runs before distribution in the shop can be of a self-skimming type. But even this is applying a corrective measure instead of attacking the evil before the damage has resulted.

The *slag-spout* is a channel casting bolted to the cupola for the convenient removal of the slag through the cupola perforation made for this purpose. It is in effect a cupola spout on a smaller scale, and is placed directly opposite the cupola spout in order to divert the stream of slag from that of molten iron as effectively as possible. If required, however, the slag-spout may be placed at the side of the cupola or wherever the exigencies of the case may demand it.

The *slag-hole*, or perforation in the cupola intended to furnish the slag made within a proper exit, should be located with special reference to the level of the molten iron held in the crucible of the cupola (the space below the tuyères). If it is intended to gather a considerable quantity of molten metal before tapping, the slag-hole is placed high enough up to be in operation only when this is the case, and consequently must be closed after drawing off the metal, otherwise too much air will escape through the opening. On the other hand, if the stream of molten iron is kept running continuously, and hence but little is held within the cupola, the slag-hole can be located quite near the bottom. The actual operation can be readily understood when it is remembered that slag is much lighter than molten iron and hence remains on top of it. As melting progresses and iron and slag trickle downward into the crucible there will be a layer of slag over the layer of molten metal. As the metal rises the slag goes up also, and if an opening is provided through which the slag may be forced by the blast within the cupola, it will travel that way. Gradually the liquid slag will work backward and escape through the slag-hole until the iron level goes above this, and the shower of sparks behind the cupola tell the melter that he must tap out.

The slag-hole of a cupola must be kept sufficiently below the tuyères to allow the removal of the slag before it can run into them. It must be large enough to care for the slag before the iron appears, and be kept open while the slag is at that level.

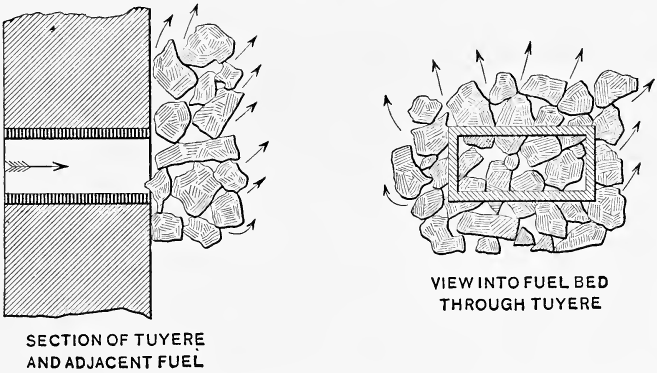
The position of the slag-hole being dependent upon the iron level within the cupola aimed at, the location of the tuyères becomes a serious question. Ordinarily, a foundryman is given his cupola by the maker with the tuyères (the lower, if two sets are furnished) 20 in. above the bottom plate. The foundryman may now change the position of the sand-bottom by making it thin or thick, as he wishes and thus vary the tonnage of molten metal he can hold before the slag-hole is reached—or if this is kept closed, before the slag enters the tuyères. If, however, the foundryman operates his cupola on definite lines day after day—so far as holding iron within it is concerned—and 20 in. is an unnecessary height, it becomes irksome to build up the bottom and thus save coke. He should either have ordered his cupola with the tuyères at the proper height above the bottom, or else place them there afterwards. A few inches of extra height do not look serious, but when the extra coke used day after day is figured, especially in the case of large-diameter cupolas, it becomes a matter of moment.

The slag-hole is therefore placed very low in the case of continuous operation (as in stove shops) and the tuyères as well. On the other hand, where great castings are produced and it is necessary to have big tonnages of molten iron available, the slag-hole, and consequently the tuyères also, are placed very high—3 ft. not being uncommon.

Where the heats taken off are short and the cupolas are small, the slag-hole is often conspicuous by its absence. A moment's thought will explain this. As the iron melts and slag is formed, they both trickle downward into the space below the tuyères and collect in separate layers between the coke filling. As the metal is tapped off, the slag remaining behind begins to accumulate and the layer becomes thicker. If the thickness of this slag layer is insufficient to overflow into the tuyères by the time the heat is run off, there has been no damage done and the material is removed in the "drop." With sandless pig iron and well-rolled sprues the amount of slag is so small that a fairly long heat can be run without difficulty, and there is no necessity of opening the slag-hole, or even having one. In the interest of economy, however, and clean and efficient operation, so that the tuyères may be at the lowest safe point, a slag-hole should be provided and operated after the heat has progressed far enough to show a slag accumulation when tested at the slag-spout.

The time at which the slag-hole must be opened will depend upon the percentage of foreign material which must be fluxed away, the amount of the flux used to do this and the rate of melting. If no fluxing material is charged, the foreign substances, such as sand, rust, dirt, and fuel ash, must get together as best they can—usually resulting in a thick pasty slag which clogs the charges and retards melting. With good limestone and a thin, hot slag which finds its way to the bottom quickly, combustion will be better and the melting rate of a cupola increased.

The *tuyères* are openings in the cupola body through which the blast is forced into the fuel bed. From this definition it may be judged what a simple affair the tuyère really is—merely an opening to let air blow through it. And that is all the most complicated, wonderfully constructed and widely advertized tuyère can do. A moment's consideration of the situation as it actually exists at the tuyère opening into the cupola will show how little faith can be placed in the claims of the "patent tuyère" experts. Fig. 30 illustrates the condition of things as the blast enters the cupola. It matters not whether the blast enters through horizontal or inclined tuyères, the moment the coke pieces are struck by the air, the deflection is so varied and great that the original direction is lost and the air current seeks the easiest outlet—namely in a curve to the outlet on top.



SECTION OF TUYERE AND ADJACENT FUEL

VIEW INTO FUEL BED THROUGH TUYERE

FIG. 30.—Blast entrance into the fuel bed.

The degree of penetration, or the sweep of the curve inward to the center, depends upon the velocity of the air as the blower forces it through the tuyère. The smaller the area, for the same volume of free air taken into the blower, the higher the velocity and consequently the greater the penetration of the sweep of air turning inward and upward.

It will be further evident from the illustration that there is a serious obstruction to the flow of air offered by the pieces of coke that lodge against the tuyère, thus reducing the effective area very materially. This has the same effect as the introduction of a short piece of say an inch pipe into a 2-in. line. The result would be a material decrease in the volume of air delivered if a fan were used, but in the case of a positive blower it means an increase in the horsepower consumed with constant delivery of air. Further, there will be a higher pressure registered the more serious the obstruction.

The logical conclusion derived from a study of the situation is that the effective area of the tuyère is really determined by the air channels through the fuel bed right at the tuyère opening. This will always be smaller than the smallest cross-section of the tuyère, and since these channels cannot be measured or even estimated, it is simplest, for purposes of calculation, to take the smallest cross-section of the tuyères and compare the sum total of these with the cross-section of the cupola. The real area of air inlet into the coke will be smaller but impossible of determination.

Experience has shown that a certain relation of tuyère area to cupola area is necessary to obtain proper penetration of the blast. If this is not correct, one of two things will eventuate: With the tuyère area too small, the penetration, by reason by extremely high velocity of the air will have a good penetration toward the center but the tuyères will soon show black coke and mask the proceedings within, while the power consumed by the blower will be unnecessarily high. On the other hand, if the tuyère area is too large, the velocity of the air will be so low that instead of penetrating into the bed sufficiently it will travel upward as soon as it enters and hug the lining too much. The result will be a cone of unconsumed and non-active coke in the center of the cupola which may extend through the ordinary position of the melting zone.

Following this line of argument, the ratio of the areas in question should be small for small cupolas, as penetration is not so essential here, and large for the big cupolas. To put this in figures, a 36-in. cupola should have the sum of the cross-sectional tuyère areas about one-fifth that of the cupola, whereas an 84-in. cupola may have this only one-tenth. The intermediate sizes should run in proportion.

The fundamental requirement in cupola melting is the introduction of a constant volume of air irrespective of what the pressures may be during the melt. That is to say, if a 54-in. cupola is to be operated on a normal production of molten metal, or 10 tons per hr., it is essential that the necessary volume of air per hour, or about 300,000 cu. ft., be taken in by the blower and delivered through the tuyères, whether the pressure be 5 oz. or 5 lb. If the tuyère areas are about one-seventh the cross-section of the cupola, the pressure will run from 7 to 10 oz., depending upon the state of affairs within the cupola itself during the melt. When started, the pressure will be lower than after the cupola becomes bunged up, the fuel covered with slag and the tuyères possibly partly clogged. Toward the end of the heat the pressure will drop down again as the column within the cupola is diminishing in height and consequently does not offer the same obstruction.

The above is dwelt upon specifically to show the foundryman that in purchasing his cupola it is not necessary to call for a pressure gage, but very essential to have a "volume" gage, or "pitot tube" so that the performance of the blower may be checked up. In these days of purchased current the fluctuation of the voltage is often serious enough to give a variation of 10 per cent. in the speed of the motor driving the blower. This, in turn, is sufficient to affect the melting results enough to be noted by the eye in respect to temperature and melting speed.

The further conclusion is that with due respect to the faithful fan of the olden times in foundry work, this is not reliable enough for modern establishment as an absolute blast volume is demanded.

The general conclusions as to the shape of the tuyères may be summed up as follows: The contact point of tuyère and fuel bed being the governing factor, it is necessary that from this point backward to the windbox the tuyère be enlarged if anything, so that loss of power through undue friction be avoided. Similarly, that the windbox be ample in cross-section and the blast pipe be large enough for the blower—as previously mentioned. The placing of obstructions in the tuyères is therefore undesirable, and they should be of equal area of cross-section or enlarged backward instead of *vice versa.* There is no objection to changing the profile of the tuyère section from rear to front. In fact, it is quite desirable to have the contact point of the tuyère with the fuel form a rectangle but a few inches high but very wide. The reason for this is not only that it keeps the tuyère free from materials that do not belong there, but there is a chemical requirement that must be considered.

As the air is blown in there is formed carbon dioxide, and this is made all the way up in the fuel bed until the oxygen content of the air is exhausted. At the same time, however, the carbon dioxide will pick up carbon from the fuel and make carbon monoxide—a very undesirable thing. Hence it is important to confine the process of combustion to the narrowest limits of fuel thickness possible. To go into this more fully: Suppose a tuyère is narrow and high—say 12 in. high instead of only 4. The oxygen of the air coming in through the upper part of the tuyère is consumed in say about 24 in. of the bed above. The oxygen of the air from the bottom of the tuyère will be consumed at a point about 12 in. above the tuyère top, leaving another 12 in. of bed to go through and make the undesirable carbon monoxide. The result is an inefficient combustion.

Mention is made of this situation because one occasionally sees cupolas with these narrow high tuyères still in operation in very old establishments. The principle being entirely wrong, these should be changed to the usual flat and wide tuyères of modern practice.

The further bearing of this situation is found when the subject of a second row of tuyères is considered. Modern cupola methods have proven the upper tuyère to be unnecessary, in fact, detrimental. The argument as given for the high tuyère holds good, the practical effect being the establishment of a second smaller melting zone above the regular one. This means unconsumed oxygen where it is not wanted with chances against the best quality of metal made. Foundrymen have realized this situation instinctively, and in going about the country today one rarely sees the upper tuyères used any more in daily practice. They are usually built up solid.

The idea of the upper tuyère was originally the furnishing of additional air to burn up any carbon monoxide present in the melting zone and thus get the full calorific value of the fuel. Theoretically fine, but practically imperfect of operation. The carbon monoxide and extra oxygen do not seem to get together as they should, the passage of the gases being too rapid. The idea of the extra air was worked out to its logical conclusion by the construction of the famous Greiner & Erpf cupola, an illustration of which may be found in almost every book on foundry practice. Here the extra air was added through small pipes built into the lining in a spiral, winding up around the cupola. Very little air was used as it was not intended to do more than burn the carbon monoxide. Too much would have started new melting points. Results of analyses made at the Krupp works indicated a material reduction of the percentage of carbon monoxide in the waste gases, and the melting ratio was excellent. It was found, however, that identical results were obtained in ordinary cupolas without this extra air addition, and as the system was cumbersome and if not operated just right resulted in oxidizing iron and wasting fuel, it was finally abandoned, living at present only in the text books.

The tuyère situation thus narrows itself down to a single row of openings with little height and a combined width to make up the area of proper proportion to that required for the cupola diameter, as previously explained. If, for instance, in a 54-in. cupola—the cross-sectional area of which is 2,290.2 sq. in.—the combined tuyère area is to be one-seventh of the cupola cross-section, or 327.2 sq. in. If, again, it is desired to have the tuyères 4 in. high, then the combined length of these tuyères would be 81.8 in.; and if it would be desirable to have six separate tuyères, each one would be 13 in. long, or 4 in. by 13 in. This is about the actual situation found in practice in foundries where the upper tuyères have been eliminated and the lower ones rearranged to give the best melting results.

The matter can be carried still further. If it is good to have tuyères of little height, the proper area being obtained by arranging the width to suit, then the logical conclusion is to make the combined width extend around the whole circumference and work out the height accordingly. That is, to have the so-called "continuous tuyère" and make this high enough to give the area wanted. In the case of the 54-in. cupola above cited, this height would work out as 2 in. In practical construction this would have to be increased somewhat on account of the high friction with so thin a slit.

Fig. 31 shows such a continuous tuyère. The crucible of the cupola can be made a little larger in diameter than the lined shell. This keeps the shaft straight, allows nothing to drop into the tuyère, and if the construction is sufficiently rigid makes an ideal cupola. There are no clogged tuyères to care for, the drop is straight and clean, and it is a wonder that more of such cupolas are not in daily use as they are perfectly successful here and abroad. It will be noted that there is nothing "patent" about the tuyère.

This cupola is the old Mackenzie type, originated by a foundryman of that name in Newark, N. J., with the difference, however, that the lining is not boshed above the tuyères. Where this is done—any deviation of the lining from a straight line being incorrect, as explained in the discussion of cupola and blast furnace, Chapter V—there will be much trouble from slag sticking to the bosh thus built into the cupola. The result will be a gradual thickening of the layers (unless carefully chipped away daily), and every chance for bridging of the stock during the heat.

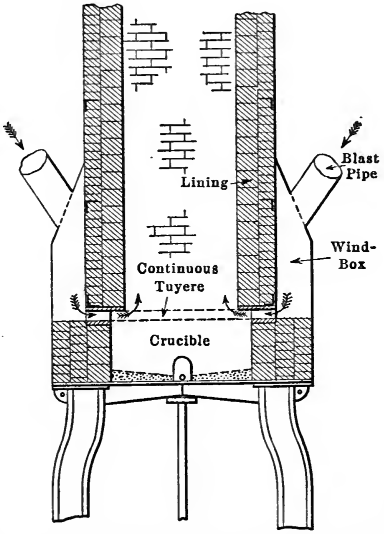


Fig. 31.—Section of cupola with continuous tuyère.

One of the later developments of the continuous tuyère cupola is met with occasionally in Europe, namely the Herbertz cupola. Advantage is taken of the slitting up of the structure to make the crucible removable. Blast is provided by a steam jet at the top, the cupola being closed and arranged for top-charging. The air is thus drawn into the cupola through the continuous tuyère. When the heat is finished, the bottom is simply drawn away, cooled and prepared for the next day's run. There is no necessity of going into the subject further as the high cost of operation by reason of the steam jet limits this cupola to congested districts where the gases must be sent into the sewer. It is quoted, however, to show that the tuyère arrangement is a perfectly satisfactory one.

A final word as to tuyères. As previously stated, the actual state of the fuel bed into which the blast is to be forced is such that most scientifically planned tuyères will give no better results than a number of straight pipes of proper combined area—provided that rational charging and melting methods are employed. This is known by every foundryman who has had occasion to operate a variety of cupolas fitted with the various tuyères in the market. There is no reason, therefore, why each man may not use the tuyère that suits him best—provided it conforms to the requirements for low height and proper proportion of total area to that of the cupola cross-section. If this relation is correct and the blast volume corresponds to that giving the best melting rate for the particular cupola, the results will be good.

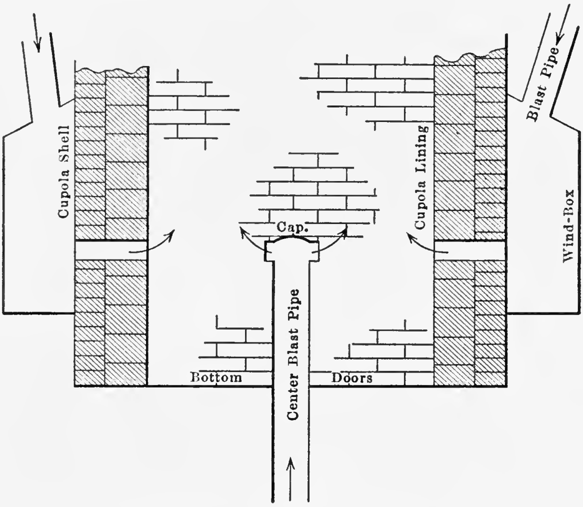


Fig. 32.—Outline section of West's center blast tuyère.

Even for very large cupolas the penetration will be sufficient to obviate the use of a center blast. This idea originated in Massachusetts in the 40's (from information given by Dr. Edward Kirk) and later was used in English cupola constructions by W. Ireland and others, to the exclusion of the side tuyère. It did not give satisfaction until so modified by West, in 1893, that it amounted to a continuous side tuyère set into the middle of the cupola at the regular tuyère level.

Fig. 32 shows a section of West's center blast in outline only, to show the air currents produced. The central pipe, provided with a cap, is placed upright in the ground and connected with the blast pipe. The cap is fastened in such a manner that the opening beneath it is almost continuous all around, thus allowing the blast to come out in every direction horizontally. The swinging doors are cut out to pass the pipe. Within the cupola the apparatus is covered with refractory material. West used this device successfully in his large cupolas, and the author also made use of it for a time, and successfully. Since, however, no very noticeable gain could be recorded over the ordinary method, with proper blast relations, the upkeep of the apparatus proved cumbersome and expensive, and the melter eventually took particular care to see that molten iron got in and ruined it. It is another case of a scientifically as well as practically good development, but not necessary enough to compel its use.

The Cupola Lining.—This is the refractory material, of uniform and ample thickness, built up within the cupola shell to form the container of the fuel and metal charge for melting purposes. In reality the lining is the furnace proper, and the cupola shell merely holds it together.

The first requirement of the cupola lining is refractoriness. The temperatures existing in the hottest portion of the melting zone are among the highest met with in metallurgical operations. Hence, whatever material is used must be first class in this respect. Again, the nature of the shaft-furnace melting process, whether in blast furnace, cupola or smelter, means pressure and abrasion from the descending stock, which must be successfully resisted by the lining. Finally, the action of the slags formed is of a chemical nature, and the lining must withstand this also.

The choice of materials then becomes much more limited than is generally supposed, if the cost item is to be kept within good economy. This will be better understood when considering the nature and cost of the daily repairs to the lining at the melting zone. The author has repeatedly met with cases where the lining at that point was so badly eaten into daily that relining was necessary every week or two. Investigation regularly brought out the fact that an inferior daubing clay was obtained in the neighborhood and this melted off in the early stages of the heat, exposing the lining proper to further cutting. Summing up costs it was always found excellent economy to purchase, and bring from a great distance if necessary, the very best grades of fire-brick and fire-clay to be obtained.

Hence, while it is possible to use mica-schist, sandstone, basic material, or ground refractories mixed up and rammed into place, nothing excels the fire-clay brick or cupola block. This is selected for high resistance to heat, and of a fine enough grain to stand abrasion and chemical action well. Mention has been made of this situation in discussing foundry raw materials, in Chapter VIII.

It is first necessary to decide upon the thickness of the lining. This must be at least 4 in. in small cupolas and 6 in large diameter ones. Experience, however, indicates that it is very poor policy to skimp with the material used, and hence the lower limits had better be placed at 6 and 9 in. respectively. The upper limit can be made anywhere desired.

Inasmuch as most foundries grow in the course of time it is always better to purchase the cupola large enough to care for a much heavier tonnage than is contemplated for the start. This is then lined down to the required diameter, to give a run of 1½ to 2½ hr. As the demands upon the foundry grow, the lining is reduced in thickness and the blast volume increased. This increases the melting rate and gives the metal required without disturbing the shop routine.

Until more recent times the cupola lining was built up with standard fire-brick, that is, units 9 by 4½ by 2½ in. The weight of each brick is 7 lb. and a cubic foot 145 lb. As the brick are set on end in the cupola a more desirable form is the arch brick, the surface planes of the sides of which will more or less intersect the center line of the cupola. So-called circle brick are still better, being made to build up true rings.

Of late, however, and in line with specialization where large tonnages are involved, brick when used for cupola lining have been enlarged to tiles called "cupola block." Two of the ends form arcs of circles suited to the cupola dimensions, the other two are radial, the thickness is 4 in., the depth 6 in. and the length of the outer arc is 9 in.—the inner one being of varying lengths as necessitated by the internal cupola diameter. Larger block are made as special sizes.

Fig. 33 illustrates the various ways of arranging the cupola lining. For small cupolas, a single lining is shown in both brick and block, the former being 4½ in. thick and the latter 6 in. It is better, however, to use the double lining shown, in which a course of "splits" are put against the shell first, and the brick or block next. This is an added protection to the shell in case of burning through the first row of brick in spots, or the falling out of sections of the lining during the heat.

For large cupolas two methods of putting in a double lining are shown, though the thickness can be made as desired. In setting up the brick or block a space of about ¾ in. should be left between it and the shell, this to be filled with sand as the work proceeds. A cushion is thus formed to care for any expansion taking place in the lining as it is heated up. Unless this is done, trouble is sure to ensue and the rivets will become subjected to excessive shearing stresses.

The brick or block should form close joints to prevent the entrance of metal and slag. The grouting should always be of the same material as the brick itself—that is, have the same refractory qualities. A course is laid breaking joints between the several rings, each brick being dipped to cover the sides that are to touch the brick it is placed against. When the course is complete, grout is poured over the top and worked into all the cracks. The next course is put on, with joints breaking, in similar manner. The space between brick and shell is filled as the work goes up. Above the charging door, where but a single lining is required, circle brick should be used and laid against the shell, a cushion being unnecessary.

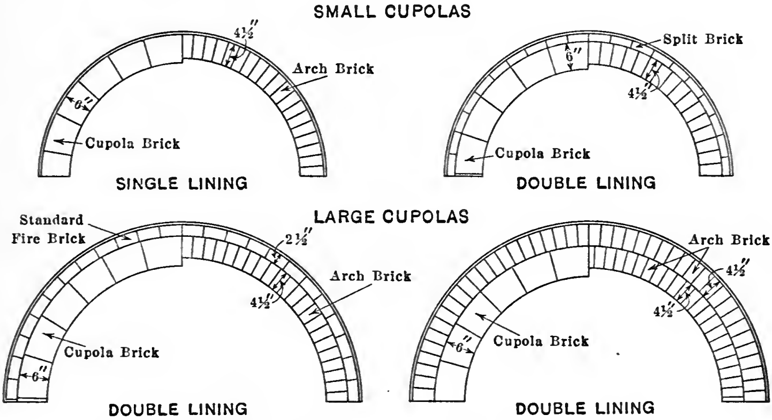


Fig. 33.—Cupola lining plans.

In good cupola construction shelves of angle iron are provided, as already explained, to hold the lining at courses not over 3 ft. apart. The integrity of the lining is thus maintained even if sections fall out from accidental causes. Occasionally one sees cast-iron cupola block used at a point opposite and slightly below the charging door. These block are intended to protect the lining from being smashed by rough usage in charging the cupola. It is a better policy, however, to train the crew so that rough usage of the lining is reduced to a minimum. If the men are made to take the trouble to see where they throw the pigs and scrap, they will probably put the pieces where they belong and the melting will be better for this. It is not good to put cast-iron block into the cupola lining near or below the melting zone in any case, for it can only result in chilling the slag that may touch them and remove heat from the molten metal in some slight but unnecessary manner.

After the cupola has been lined up it becomes necessary to dry it out thoroughly before starting on the regular melting programme. Unless this is done the effect of the first regular heat, with extremely high temperatures rather suddenly applied, will be a very unequal expansion of the brick—wet on one end and red hot on the other—and much spalling off and flaking of the outer surfaces. This is particularly noticeable where the denser and harder brick are used, the soft ones allowing the steam generated to pass away more readily. Again, with such preliminary drying out, the cracks and holes appearing can be patched up properly before molten iron or slag may enter, and this prolongs the life of the lining very much.

For "drying out" a cupola lining the bottom doors are closed and a regular sand-bottom made. Shavings are charged on this and wood placed on it loosely, the longer pieces standing against the side walls. Then coke is dumped in, the shavings lit at the open breast and the fire allowed to burn through. A slow fire lasting preferably several days effects a thorough drying out of the brickwork, and the cupola is ready for its first heat.

At this point it is well to take up the subject of the cupola "fore-hearth," much used in Europe, but seldom met with in America. The fact, however, that some of the most progressive foundries of the country are taking the matter up and, where properly designed, are getting excellent satisfaction from its application, indicates that a future is ahead of the device when its functions are better understood.

Primarily the fore-hearth of the cupola is a continuation of the bottom by means of a very short, covered spout to a covered receptacle serving as a reservoir for the molten metal, from which reservoir this metal is tapped out as wanted. To understand the functions of the device properly and study its advantages and disadvantages, reference is made to Fig. 34, which shows a section of the lower part of a cupola thus provided. This is practically a Krigar construction (Hannover, Germany), and is typical of the fore-hearth cupolas of Continental Europe. The Ireland, and the more modern Stewart (Glasgow, Scotland) cupolas are similar in construction and represent British fore-hearth cupola practice.

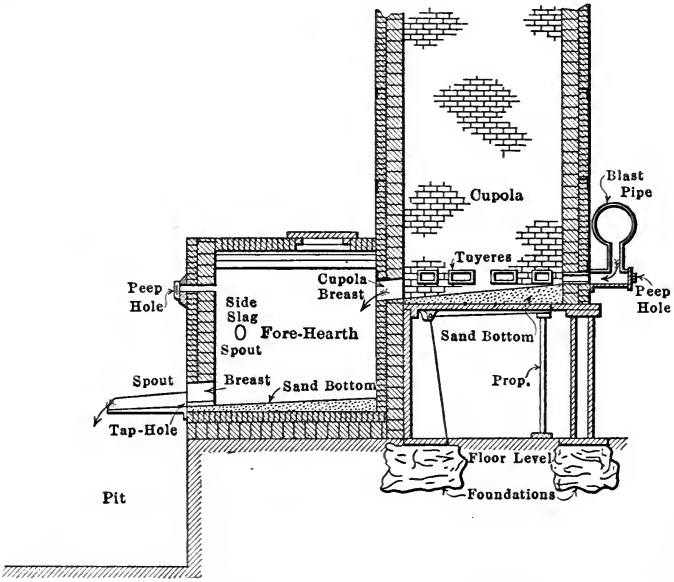


FIG. 34.—Section of cupola with fore-hearth.

It will be noticed that the tuyères are practically at the bottom, for no molten metal is held in the crucible of the cupola, iron and slag flowing directly into the fore-hearth as fast as melted. If the tuyère area is properly proportioned with respect to the cross-sectional area of the cupola, melting will be as perfect as if the tuyères were the usual 10 in. or more above the bottom.

The breast of the cupola is not made up as a tap-hole is not necessary at this point, the molten iron being drawn from the fore-hearth spout. Slag is collected on the molten iron and this accumulated until the side slag-hole is reached, when this is opened and the slag blown out. The fore-hearth being a closed container, there is no interference with the blast and the same pressure exists in it as in the cupola wind box. Peep-holes are provided in the tuyères as usual, and in addition at the front of the fore-hearth in line with the cupola breast location.

The cupola should be placed pretty high in order to catch the stream of metal conveniently, or else the fore-hearth spout may discharge into the ladles placed in a pit, from whence there are taken away by crane. The fore-hearth should be preferably of the diameter of the cupola and not high enough to exert too much ferrostatic pressure upon the breast, otherwise this may be forced out. Probably 2½ to 3 ft. should be sufficient. This is rather important as much of the poor success gotten from fore-hearths was due to making this reservoir for molten metal entirely too large for the cupola it served.

The advantages of the fore-hearth are the following:

1. Removal of the molten metal from continued contact with the incandescent fuel. This prevents further possible chemical reaction after the globules of iron have passed through the zone of melting. Where heavy steel charges are used less carbon may be absorbed, and with high-sulphur coke it will help keep this injurious element down a little.

2. Collecting the metal in one pool instead of subdivision of the mass by simply filling the interstices between the lumps of coke or coal. This makes for better mixing, the metal as finally tapped into the ladles having passed over two spouts, as it were.

3. Opportunity for the metal to clear itself of entrained slag far better than if kept in the crucible of the cupola.

4. Similarly, better opportunity for manganese sulphide formation, this rising to the top of the iron and under the slag.

5. The collecting of greater quantities of molten metal than is convenient in the cupola crucible.

6. The saving of an appreciable quantity of bed coke daily by reason of the dropping of the tuyères to the bottom. This is probably the most evident advantage derived from the use of the fore-hearth. If the removal of iron and slag, as fast as melted, into an ordinary bull-ladle were attempted in order to drop the tuyères to the bottom, much trouble would result from cold iron. Hence, unless the metal melted under such conditions is carried away and poured into molds as it comes over the spout —which must be of the "slagging" type—a fore-hearth becomes

imperative. In the absence of such a reservoir attached to the cupola the tuyères are always put at an appreciable height above the bottom, and a tap-hole is left in the breast so that iron can be held in the cupola if necessary, and the slag forced out through a slag-hole in the cupola rather than to allow it to come out into the ladles and mess them up.

There are, however, decided disadvantages to a cupola fore-hearth, particularly if this is poorly designed.

1. The crucible of the cupola is cold enough, because it derives its heat only by convection from the incandescent material in front of the tuyères, and the heat of the molten metal collecting on the bottom. The crucible of the cupola is therefore considerably colder than the molten and highly superheated iron dropping into it, at least in the beginning of a heat. The conditions in the fore-hearth, unless this has been highly heated by oil previous to running the heat, are probably worse, and the chances for cold iron are greater. If this is accentuated by having too big a fore-hearth for the melting rate of the cupola, as would be the tendency in foundries making castings of big tonnage, the situation is worse than if the metal had been held in the cupola. Foundrymen of America have therefore, as a rule, never taken kindly to the idea.

2. The use of the fore-hearth means the preparation of two "bottoms," or an increase of the labor item. The upkeep of the walls of the fore-hearth is offset by the repairs on the bull-ladle or stock-ladles ordinarily used.

3. In the event of using several mixtures during the heat a considerable transition period must be allowed for—that is, castings made which can safely take either mixture or a blending of both in varying proportions—this more so than in the ordinary cupola.

From the above it will be seen that the real objection to the fore-hearth is the undue cooling of the superheated metal as it drips through the melting zone. For that reason the English constructions have aimed at diverting some of the cupola gases through the breast into the space above the molten iron held in the fore-hearth, by connecting the cover of the latter with the cupola at some point below the charging door by means of a flue. This brings about a circulation of hot gases and helps the heating problem. It were much better, however, that this heating be done by means of oil burners, for the diversion of some of the blast going through the fuel bed must necessarily change the melting conditions above and make the zone of effective melting an uneven one.

The application of oil or gas burners to heat up the fore-hearth has led to the development of a number of hybrid cupolas, some of the melting being done in the fore-hearth. Metal charges placed in the cupola have been melted with greater or less success by the sweep of the flame from the fore-hearth, this flame coming from either oil or producer gas. All these methods have, however, failed for they attempted to combine the quality of air-furnace melting with the cheapness of cupola work. Air-furnace melting is notoriously expensive, and the combination referred to proved so complicated that neither cheapness or quality was obtained. The open-hearth furnace, which yields better metal than the air furnace, and ranging in cost between this and the cupola, offers the simplest solution of the situation, and hence space need not be wasted in recounting the numberless trials which are best classed with ancient history. The use of oil fuel in the cupola will be dealt with specially, as it has distinct advantages for certain lines of melting.

The subject of using preheated air and returned cupola gases may as well be disposed of here also. The objections have been mentioned in Chapter IX, so far as hot air is concerned. The melting zone of the cupola gives ample superheating of the metal with a cold blast, and the refinement of economy by using hot blast is overbalanced by the wear and tear of the equipment necessary for this purpose. In the case of "dry" air, the advantage gained in melting is more than counterbalanced by the enormous cost of the equipment—cupola melting being intermittent, and interest on capital working 24 hr. a day. The return of cupola gases with or without steam, however, has always looked good to some foundrymen and special cupolas have been brought out for the purpose in even very recent times. Unfortunately, however, the necessity of using fresh supplies of oxygen in air to burn the fuel limits the quantity of waste gases that can be utilized. These contain a lot of nitrogen, as does the new air used. Any carbon dioxide thus used takes up carbon from the bed and this hurts the operation, while the carbon monoxide taken from the waste gases, if it burns at all in this dilution, plays but a small figure in the processes that are based upon its presence. All such attempts, especially if complicated by the presence of steam, have failed to make good. They are mentioned merely to cause new investigators to pause and study the reactions involved before wasting their time.

A final point relative to the cupola lining. In the discussion of the blast-furnace profile versus that for the cupola (Chapter V) the reasons why the latter should be perfectly straight have been given. As the cupola simply melts and has no ore to reduce, gangue to slag off, etc., the metal melts as placed, the fuel burns up and but comparatively little slag has to be cared for. Hence, a straight descent of the stock into the melting zone is essential, and no bosh below this to catch and hold dripping slag and thus start the cupola bridging.

Inasmuch, however, as the pieces of coke directly in front of the tuyères have their surfaces at different angles to the streams of metal and slag descending upon them, and these may readily be deflected into the tuyères, it is advisable to provide for a very slight "overhang" above the tuyères—in fact all around the cupola lining. This overhang must, however, not be much over an inch, so as not to interfere with the proper operation of the blast. Fig. 35 shows such an arrangement. It consists simply in putting in a row of "splits" above the line of tuyères, letting them extend into the cupola about an inch and daubing the lining as shown. The effect is twofold The molten iron and slag will not be diverted into the tuyère so easily, and the blast will not seek to travel up along the lining as readily as if the corner were a true right angle.

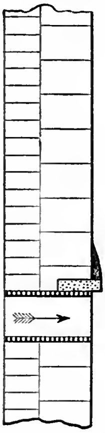


FIG. 35.—Section of cupola lining tuyère "overhang."

To sum up: A cupola with a straight shell, one row of tuyères, convenient arrangement of wind box, the tuyères low and as continuous as possible, a substantial structure, no attempts at boshing or blast-furnace profile; all this is found in the best American cupola practice. The Whiting, Colliau, Newton, etc., as one sees them in progressive foundries after several years' operation have the upper tuyères closed off altogether, and the active lower row as originally shipped or replaced by plain straight box tuyères, any and all of them doing excellent service.

The cupola platform may be considered an integral part of the cupola installation. Its functions are twofold: A working floor to enable the handling of the materials charged into the cupola, and a storage floor to stock up additional supplies for operating the cupola in case of an elevator breakdown.

In modern foundries this platform is usually substantially built, of steel throughout, with the floor-plates riveted to the beams (heads flush) to present a smooth surface for scooping up coke and light scrap. The platform should hold at least 2 days' supplies of metal and fuel, and where possible a separate room should be provided on the platform level and entering upon it, for the storage of a full car load of coke.

As in most modern foundries the charges are all brought up by elevator plied up on small trucks, an industrial trackage system with suitable turntables or switches is arranged for on the platform. Still better, if two elevators are at hand, and these properly arranged so that one or both may be used in connection with the trackage system. This gives the greatest flexibility and allows of a considerable reduction, if not the entire obviation, of the storage materials. With space enough for two elevators, preferably in the rear of the platform at each end of the room, turntables in front of them and a track connecting, storage space can be had behind the track system, thus leaving the entire front of the platform for purposes of the immediate work in hand. It must not be forgotten that as the pig-iron piles in the yard run out, the corresponding irons in storage on the platform must be used and replaced by other metal, otherwise in emergency the available material will not fit in the mixture and the storage was for no purpose.

There is nothing so disconcerting about a foundry as a dirty, littered-up cupola platform. It is just as easy to have the piles of metal and scrap neat and separated; to have no accumulations of unknown age, no sweepings and remnants of lunches, old nails and scrap wood lying about. A platform kept untidy and left untidy after charging is finished for the day is a pretty certain indication that the charging itself is as bad and the weighing records unreliable. It will pay the heads of industrial establishments to make periodical inspections of this somewhat out-of-the way department, to see just what attention the foreman gives to it. This room, as also the sorting room for castings, is one of the vital nerves of the foundry. The question of platform arrangement with mechanical charging will be taken up further on, when discussing the charging operations for the cupola.

A further adjunct to the cupola platform is the blower room. This is a special location (as dust-proof as may be for the benefit of the machinery bearings) for the blast apparatus serving the cupola. For purposes of economy in first cost of blast pipe, and running cost in power, the blast apparatus should be placed as close to the cupola as may be convenient. Where a fan is used, this is in fact essential, as friction of the air in long pipes obstructs the volume delivery of the apparatus. That distance does not interfere with proper delivery of air in the case of the positive blower—although it adds to the horsepower required to drive it—may be seen from an experience of the author. It was necessary to place the blower over 1,000 ft. from the cupola house, the connecting blast pipe being used for other purposes when the cupola was not operated. There was not the slightest difficulty experienced with this arrangement.

Experience has shown that where more than one cupola is operated, each one of them should have its individual blower. These blowers may all be run from a common shaft, provided the revolutions are properly calculated out and maintained constant whether one cupola or more of them are in operation at a time. It is better, however, in these days of the electrical transmission of power, to have a motor directly connected with each blower.

It is customary to have a safety valve for the blower or blast pipe. On general principles this is correct, for an inadvertance of operation may cause a temporary overplus of air, and this must be relieved. Since, however, in modern cupola operation the volume of blast required is absolutely constant, and any diminution of this volume is attended by a lowering of the fuel bed, the weights on the safety valve should be set high enough to prevent blowing-off unless a very serious obstruction occurs. Parenthetically it may be stated that if the blast volume is reduced somewhat this does not necessarily mean bad iron, provided the blast is kept that way. It is only in case the blast volume is restored again during the heat that trouble is likely to occur, for with a lowered bed the metal melted after the full blast volume is put on again will be under the influence of free oxygen and suffer accordingly.

It may be objected by foundrymen who actually change their blast volume during the heat that they get good results. The author has often seen this himself, yet always noticed that the coke charged to maintain the bed—that is the intermediate coke charges—was in excess of that required just sufficiently to make up for the variation of bed height in question. The proper remedy when iron comes too fast, and the foundryman is tempted to reduce the blast volume by either slowing down the blower or letting the safety valve blow off somewhat, is to shut down tight for a while. This stops melting at once, and after the congestion has been relieved, the blower can be started at full speed again. The bed conditions will thus not have been changed and there is merely an arrest of operations. When so shutting down the blower one of the tuyères of the cupola must be opened to maintain a little draft, otherwise the gases may back into the blast pipe and even the blower, and on starting up again an explosion is likely to wreck the installation. A blast gate should be placed in the blast pipe close to the cupola and shut off the moment the cupola is stopped for any cause.

Since the subject of blast volume is all important in cupola melting practice, the apparatus for furnishing the air must be considered here. In the early days of the foundry, when it became separated from the blast-furnace industry—that is, pig iron was remelted instead of making castings from direct metal—the usual blowing engines of those days were used. These were practically air compressors and hence of a positive type. The high power requirement and comparatively small delivery of these machines caused attention to be turned to the mine ventilating fan as a means of driving air into the cupola. Very soon the fan became the standard blowing apparatus in the foundry and the text books of the early times devoted pages to the discussion of the shape of the blades to get the best results.

That the fan did not give satisfaction as time went on is shown by the appearance of the rotary positive blower, the earliest being the Root, Baker, and later the Connersville, Sturtevant, and others. Europe has also furnished several very good types. With these blowers the delivery of air was positive, only a very small percentage of the air escaping through leakage. The manufactures of fans, however, were not idle either and Sturtevant developed a pressure fan which did and still does excellent service. The Buffalo pressure fan is another of this type.

The fact remains, however, that as the cupola becomes clogged up with slag and the blast is obstructed more and more, a fan begins to deliver less and less air in spite of showing a good high pressure in the blast pipe. It can impell only enough air in the direction of the cupola to maintain the maximum pressure it is capable of producing. If the blast gate were to be shut off suddenly, or the obstruction in the cupola be too great, the fan would simply revolve without drawing in more air than necessary to keep up the pressure. The positive blower, on the other hand, continues to deliver the air volume irrespective of the cupola condition. If the blast gate were closed or the cupola obstruction became too great, the safety valve would either lift or the blast pipe burst—if the motor were not automatically thrown out or burned out before.

The positive blower is, therefore, to be preferred to the fan where the latest and safest practice is desired. Another candidate for favor has recently appeared in the centrifugal blower which is really a reversal of the steam turbine. Instead of revolving under the impulse of steam at high pressure, power is applied and the revolving of the blower delivers air at high pressure. The absence of gliding friction in the construction of this new machine accounts for the lower power consumption, and hence the centrifugal blower—which can be constructed to become an actual high-duty air compressor—is to be recommended for foundry use, care being taken, however, that the proper-sized blower is attached to the cupola for which it is bought, and not a larger blower used running it at lower speeds.

It goes without saying that the blast pipe used should be larger in diameter than the blower outlet, to reduce frictional losses. The blast pipe should be absolutely tight, have only very large radius bends, and where branching out to two outlets to the wind box, do this by means of a large radius "Y" construction.

The air inlet pipe to the blower should be arranged so that outdoor air is taken instead of the shop atmosphere. Preferably the air box connecting with the inlet opening of the blower should be carried over the roof and provided with a wire screen to keep out extraneous matter. Where such an arrangement is not provided and the air is taken from the blower room the capacity of the blower is apt to be reduced somewhat. Either the air will be too warm and hence supply a smaller actual weight of oxygen per revolution of the blower than would be the case with cold air; or the inlet area may be reduced by the accidental covering of the screen by newspapers, rags or other material carelessly left about. This so increases the friction by the air entering the blower that a partial vacuum may be formed and the blower simply does not get the proper amount of "free" air to compress and deliver to the cupola. There remains still the adaptation of the cupola for fuels other than the usual coke. In the olden days charcoal was the fuel alone available, and cupolas were operated with this successfully but with terrible waste of heat. This is perfectly natural. The cell structure of charcoal is so minute and the ease of combustion so great that carbon monoxide is formed very quickly after the air has entered the fuel bed. The result is an incomplete combustion of the fuel and consequent use of large quantities with low melting rates. The question has been discussed under "Charcoal" in Chapter VIII, and as the melting ratio was shown to be little better than 2 lb. of iron to 1 of charcoal as fuel, the subject is not worth further attention in these days.

The same thing may be said of bituminous coal as a cupola fuel. Reports of successful runs with this material appear in the technical journals from time to time, and there is no doubt whatever that it is possible to melt iron with this fuel. It is very probable that steam coals—that is low-volatile coals, give the best results, for the nearer they get to anthracite, the less they coke, swell, cake together (and therefore obstruct the easy passage of the gases), the more regular will the melting process be. It is doubtful, however, if any foundryman would care to take the chances of an irregular operation on the part of his cupola certain to follow the charging of so friable, weak, and quick-burning a fuel as bituminous coal. The recorded results all show hot and cold iron, irregular operation of the fuel bed; but also the harder the coal the better the iron made. None of it, however, equals the results obtained with coke or anthracite.

Anthracite coal replaced charcoal for blast-furnace and cupola purposes early in the nineteenth century, and gradually spread all over the foundries that could obtain it readily. About the end of the '60s coke began to appear in the foundry and as it melted faster than coal, soon replaced it in the foundries not directly tributary to the anthracite regions and their railroads. The author remembers still seeing heats run in New York City with anthracite coal in 1900, and 20 years before that time but little coke got into this city. The iron made was very fine and no difficulty was experienced in getting it hot enough. It is naturally difficult to get positive facts regarding the melting rate of cupolas run with anthracite as against coke, because there is no longer any interest in making comparative tests. In the days gone by, foundrymen knew so little about rational cupola melting that their records of coal melting mean nothing to the investigator.

Some facts, however, seem to stand out prominently. First, it is possible to use metal charges of almost twice the weight where coal is used instead of coke—this, because the bed is burned away at but half the rate for coal. Coal has no cellular structure and hence a pound of it occupies but about half the space of the corresponding weight of coke. The lowering of the bed will therefore be the same for both fuels when twice the weight of metal goes on the coal.

The second fact seems to be that using coal solely, the capacity of the cupola is reduced. That is, a smaller volume of air gives better results in a cupola where coal is used than if the fuel is coke. This, of course, means a lower melting rate. Foundrymen who prefer to use anthracite in these days will therefore compromise by putting in a coal bed, and alternate intermediate fuel charges of coke and coal. It will be found, however, that in these days of advanced practice the use of coal amounts to a fad, and is really indicative of either ignorance or a hesitation in using coke. Beyond the statement that if coal is to be used, the hard Lehigh variety gives the best results, the subject may be dismissed.

Oil and natural gas can be taken up next. So far no success has been attained with either natural gas or any other form of a true gas. And only recently has the question of utilizing oil in cupola melting reached a promising development. Foundry literature contains many references to trials made with oil and gas but failure is recorded in practically every case, if one is used to reading between the lines or will follow up the final summation of experience. It is possible to melt the metal, but it cannot be gotten hot enough. This is very easy to understand. Pig iron is so good a conductor of heat that the application of even the most intense oil flame in ample volume will simply melt off the ends touched leaving the adjoining portions soft enough to be pressed together and finally obstructing the passage of the gases. The top of the metal pile may be heated but little. A solution of the problem came through the investigations of Stoughton, who conceived the idea of retaining a small percentage of the coke used as fuel and using this as a heat-insulating medium —so to speak—between small layers of the metal. In this way the pig iron and scrap would be heated about the same as in regular practice because the amount of each charge was limited in weight. Instead, therefore, of the heat being drawn away almost as fast as imparted to the iron, as was the case in all the other attempts of previous experimenters, there was opportunity for not only rapid melting but also considerable superheating. A further advantage was the immediate proximity of incandescent coke which also imparted heat to the molten metal, in fact probably gave it the final increment of heat before it dropped through to the bottom.

The cupola bed is charged the ordinary way and the first metal put on. Instead of putting on the entire intermediate coke charge next, only about one-fourth the usual amount is used. Then comes the second metal charge, then the same small amount of coke as before, and so on. The oil is atomized by compressed air, preferably at high pressure to render the atomization very effective and the flame comparatively short but with complete combustion. As there is a small excess of air present this keeps the coke incandescent, otherwise the fire might be actually put out by the oil blast.

The use of oil for fuel in the Stoughton process is really in combination with a considerable percentage of coke. Where it is essential to keep the sulphur low, however, as in the case of melting the stock to be afterwards blown into steel in the converter, the use of oil is very advantageous. Similarly, where the price of coke is prohibitive and oil is cheap, its use has a great future, as on the West coast of the United States. The process is in constant operation, the author himself having run a number of test heats to learn the requirements for the necessary regulation of oil and air.

The future will show whether the application of oil for fuel, in combination with the insulating coke charges, will work out successfully and economically for melting in every branch of the foundry industry where the cupola is made use of. It is still too recent to have definitely settled upon the best proportion of oil and coke, the exact pressure of air to be used, etc. It is to be hoped that the matter will be studied out fully, as the reduction of coke necessary for melting purposes in regions were it is costly and oil is cheap is a live problem.

Since the subject of coke for foundry purposes has been discussed pretty well in Chapter VIII, no more need be said for the moment. Additional information will be brought out during the study of the cupola melting process to follow herewith.

THE CUPOLA MELTING PROCESS

The cupola melting process consists of melting pig iron and scrap in the cupola under conditions which result in unoxidized and highly superheated molten iron suitable for the purposes of the foundry. The success or failure of the process, as also the efficiency of the melting, will depend upon the degree of perfection with which the conditions in question have been arranged for. Thus, if the fuel bed is held too high, it is possible to get satisfactory metal, but it will be at an excessive fuel cost. If the bed is held too low the iron will be cold, oxidized and if seriously affected, unfit for use. Unless the charging is even, the charges themselves not too large, and unless very many small but important points are carefully attended to, the foundryman will be disappointed with his melting results and the customer for the castings probably even more so.

It is the purpose in what follows to discuss every step in the melting process, from making "bottom" to dropping it, in order that the elements of the problem may be thoroughly understood and every foundryman can compare his own installation and practice with that which the author claims as "standard." The day when every cupola was supposed to be an obstreperous inanimate object requiring careful nursing on lines of its own has passed, and cupola melting can now be carried on upon a scientific basis. The author claims the credit for having first undertaken the scientific study of the cupola melting process—in connection with the Government coke tests at the St. Louis Exposition (1904). The results obtained by running a large number of test heats on a variety of cokes made for the purpose, while showing their value for melting purposes, nevertheless proved so unsatisfying in respect to indicating a basis upon which any coke could be used in any given cupola, that further study was necessary.

The author gave several years to this work and finally outlined a plan of operations to the U. S. Bureau of Mines—then under its first Director, the late Dr. Jos. A. Holmes, who was ever anxious to benefit the foundrymen. This plan was extended and developed in much detail and the tests carried out by A. W. Belden then of the Bureau, and for the first time in the history of founding definite information became available on what happened within the cupola during a heat. It cost the Government much money, but the benefit to the industry is beyond calculation.

The gases within the cupola were taken out at a number of definite points of the bed, by means of suitable water-cooled tubes. These were analyzed, and the work repeated until a very clear idea of gas condition of the fuel bed from lining to center and from tuyère to charging door was obtained. The zone of maximum melting effect was thus established, and the original contention of the author that this corresponded to the point of maximum carbon dioxide and also minimum free oxygen proven. The foundryman who wishes to study the test details will find them in *Bulletin* No. 54, of the U. S. Bureau of Mines.

The first operation in getting ready to run a cupola heat is to chip out the remains of the last one, unless the cupola is new or has just been relined. This operation is more important than is usually supposed, and the greater the care bestowed upon the damaged lining, the more satisfactory the subsequent melting operation will be. With proper melting practice the cutting away of the lining at the zone of highest temperature is quite confined—perhaps not over 9 in. in height. With poor practice in charging, this belt may extend from the tuyères to quite 3 ft. above them. The extent of the cutting in such cases may be so serious that a portion of the lining may require replacement nearly every week. With a proper understanding of the principles of melting in the cupola, and a knowledge of the refractory qualities of the daubing used to patch up the lining after a heat, however, the chipping-out process is not a burdensome labor.

The "dump" or material dropping from the cupola when the bottom doors are allowed to swing open is supposed to be removed as soon as cooled sufficiently by the stream of water turned on it to allow this. Preferably grabhooks are laid on the floor under the doors, and these hooks are connected by chain to a winch bolted to the wall in the rear of the cupola. When the slag and coke left in the cupola fall upon these hooks, and the water has chilled the slag, most of the dump can be pulled away from under the cupola and thus allow the lining to cool faster than would otherwise be the case.

In the morning after a heat, the cupola should be cool enough to allow work within, and the melter first sees that the dump is fully removed and a few pails of water are thrown around the lining from above to lay any dust there. He next has his helper, or he himself goes up to cover the cupola shaft at the charging door with corrugated iron sheets or boards to give protection from falling objects while work is going on below. Before doing this, however, in case the cupola is badly bridged over, bars and sledges are made use of to break a hole through this crust large enough to operate in. The melter now takes his heavier pick to break off all the slag he can conveniently and then uses a smaller pick to systematically clean the brickwork of its adhering coating of slag. The more thorough this is done, the better the daubing of clay put on later will adhere during the firing.

A distinction must naturally be made between the slag coating on brick that has not been eaten into and where the lining has been cut. The slag is to be removed only where it is essential that the lines of the brickwork be restored to their original straightness. Unless this is done, it is only a question of a short time after the heat is running when the slag softens under the daubing and lets this slide down into the bed. Then the cutting of the lining goes on again, constantly enlarging the cupola diameter at that point heat after heat. Not only will a very pasty slag result from the destruction of the daubing, but as the daubing has to be thickened and finally brick must be taken, the quantity coming off during the heat is constantly increased. By cleaning the surfaces carefully of the slag cover it is possible to put on a clay daubing which will be burnt on tight and the lining thus built out with a chance to remain so if the clay was good and the cupola is run right.

In chipping out a badly operated cupola considerable material has often to be put in to build the lining out straight again. The best material is, of course, brick of the same kind as that forming the lining. Thus, for bad spots full-sized brick may have to be put in. For smaller spaces, split brick will prove convenient. Of late a natural stone, called mica-schist, which separates on cleavage planes that allow it to break in the shape of large "flakes," is employed. It is highly refractory—being of very high quartz content—and much cheaper than fire-brick. This gives satisfactory results if care is taken to heat up slow enough to allow the steam formed behind the pieces to escape without blowing them out. The daubing should not be too wet as the formation of steam will injure the work unless very carefully done. The lining being thus repaired at the melting zone, and the little shelf above the tuyères being daubed up properly, "bottom" can be made.

A word about the daubing. It is essential that this should dry without cracks, that it be as refractory as the brick itself, and that it be very adhesive. Since clay contracts very considerably, it is necessary to add a goodly proportion of fire-sand to give a mixture which will dry out and burn without either contraction or expansion. In trying out a new clay it is advisable to mix it with an equal amount of fire-sand. If this gives unsatisfactory results the proportion of the sand must be varied until the right amount is found. Some of the leaner clays require only 25 per cent. of sand while the very fat ones may take up to 75 per cent. The clay and sand are mixed dry and put in large vats near the cupola. Water is added and the material allowed to soak for at least 24 hr. It is then well mixed though with as little water as can be made to do. The surfaces to be coated with this daubing are first wet down with a brush and the daubing then applied. This will make it stick to the clean fire-brick surfaces.

It can be readily seen from the above description that if the melter is conscientious and the melting practice has been bad, the work to be done may be a very serious item for time and labor. As a matter of experience, wherever poor melting practice exists, the chipping of the cupola will also be poorly done and the cutting and the slag problem are things to worry the management. The men are limited for time to get the cupola ready and hence simply pick out a little and slap on the daubing to make the cupola interior look presentable. They know they will have the same duty to perform the next day and that it may be worse. Unless the foreman watches the situation personally, the work will certainly be done perfunctorily and much that should be cut away will be simply covered up.

On the other hand, with up-to-date melting practice, and the scoring of the cupola lining limited to less than a foot of height, things can be kept in order easily, the lining remain perfectly straight, and relining resorted to only at very long intervals of time. The foundryman should therefore keep accurate cost memoranda of the materials going into his cupola repairs. He can soon tell whether the melting is going on as efficiently as it should, and if necessary give his personal attention to the job.

Making Bottom.—First, the doors are swung shut and a prop placed under them. The simplest way is to put up one door and support it with a temporary prop, and then put up the other, setting the regular prop as it should be. Large cupolas may have two props of wrought iron, from 2½ to 3½ in. in diameter. Small cupolas, on the other hand, require but one prop and this 1½ to 2½ in. in diameter. Latches on doors to hold them up are not safe, nor are the props either if not standing on firm foundations. In the case of large-diameter cupolas the foundation for the props must be fairly heavy and be at least 24 in. square and about 6 in. thick. Stone or concrete serves the purpose best. The props are seldom removed from the hot dump at the time they are pulled away and hence must be heavy enough to stand considerable punishment.

The doors being up, small plates of iron are put over any defective spots due to the cutting of molten iron that has gone through the sand at previous heats. These plates are firmly imbedded in clay and all joints are well rubbed with fire-clay to make them tight. The sand for the bottom is now put in and spread over the doors for ramming up. The requirements of this sand are the following: It must be refractory enough not to melt together, have enough clay to keep it from being friable and allow the metal to cut through it and reach the iron doors. On the other hand, the clay content must not be great enough to cause shrink-cracks under fire. In such a case the sand will also be so wet that the steam formed may be destructive. If rammed too strong the metal will begin to boil as it collects. If not rammed enough the bottom will be too open to hold the metal well and it cuts through.

Ordinarily gangway sand is used, that is molding sand which has been burned to some extent. If too weak, clay-wash is thrown over it and worked in. Usually the finer grades of molding sand are best adapted for the purpose, as for instance the gangway scrapings in the light castings shops. Mixtures of clay and fire-sand will also do, but must not be made too rich in the former, otherwise the bottom will bake too hard and give trouble when dropped. The depth of the sand when rammed up should not be less than 3 in. at the lowest point and is obtained by ramming up the material in layers of an inch at a time. The most convenient way of getting the sand into the cupola is to throw it through the opening for the breast. It can be put in by way of the charging door if desired but this gives more trouble.

First the sand is carefully packed against the lining by hand, to insure a tight joint. Then the melter rams up the material in such a way that the bottom slopes upward from the breast backward and sideways on a grade of about ¾ in. to the foot. If less, the iron will not run out fast enough, whereas if the slope is much greater there will be too much force to the stream as it passes through the tap-hole. It is better to use a board as a guide so that the bed may be sloped evenly from back to front as well as from the sides to the middle line, otherwise there will be a chance for the gathering of molten iron into puddles which may be chilled at first and melt later on with interference to the proper mixture. The plan of digging out a small basin in the bottom just behind the breast, met with occasionally in old foundries, serves no useful purpose. Indeed, if this metal begins to chill, it will interfere with the tapping operation subsequently and make it difficult to keep the tap-hole open. The bottom should be so made that it is possible to drain the cupola of all molten iron readily and keep it thus at any time in the heat, if desired.

Bottom having been made it is ordinarily advisable to prepare for the lighting-up operation in order to give the cupola every chance to warm up before blast is put on. Indeed the temperature of the first iron taken off is a great measure dependent upon the length of time the fully charged cupola has stood under heat. It will be readily understood that if it takes the greater part of the heat developed in the cupola to bring the metal up to the point of melting, and then comparatively little heat to do the actual melting, the nearer the lower charges are brought to redness before blast is put on the higher the degree of superheat the first metal will have. The difference between the first metal from a cupola standing under heat several hours and from one operated as soon as charging is under way is known to every foundryman who has tried both ways.

As an extreme case of operating the cupola, in regard to lighting-up and running, the author cites the following method which he has personally seen applied. After bottom was made, the necessary wood (maple) was placed upon it and the full requirement of coke for the bed put on this. The cupola was next charged with metal and coke layers to the door. Then the match was applied to the wood to light up the cupola and blast was turned on. A few minutes thereafter the molten iron began coming down. In a little while the cupola was operating normally. This example is cited to show what it is possible to do with a cupola, not that it should be done so. The risks are too great. Unless the wood burns away uniformly and completely, leaving the coke bed even, at the proper level and entirely burned through, the cupola will operate one-sided during the first part of the heat. As a matter of fact, it is useless to expect wood to be entirely consumed by the time metal is tapped under such conditions, and hence the contact of molten metal on the bottom with unburned wood boils the iron and cannot but damage it. The author actually found that some of the thin castings made from charges averaging nearly 3 per cent. silicon, when melted by this method, came out with a white fracture.

Where wood is to be used to light up the coke bed, shavings and oily waste are first thrown on the bottom and particularly at the opening for the breast so as to facilitate things when the match is applied. The larger flat pieces of wood are placed against the freshly daubed parts of the lining to protect this from the falling coke. Enough wood is used to insure a good heat in the coke bed, one-half to two-thirds of which is dropped on the wood before using the match. Too much wood should not be used, for not only will some of it remain unconsumed—the charred remains often being found in the cupola as bottom is dropped—but the coke may fall on the bottom unevenly and disturb some of the subsequent layers of the materials charged. It must not be forgotten that the only air passing through the bed below the tuyères is that from the opening in the cupola for the breast, and as the tap-hole is prepared while the bed is burning through, the air supply may be entirely cut off from the sides and back of the bottom and prevent the burning up of what wood may still have been unconsumed by that time.

From what has been stated above it will be seen that the wood used should be as dry as possible and not in thick pieces. Where plenty of time is available the hardwoods give best satisfaction as they last long enough to insure a thorough heat in the coke bed. Ordinarily, however, the lighting-up process has to be rushed and occasionally even blast put on to hurry matters, and in that case pine or other light woods serve best. Wherever wood is used, the scrap about the foundry will naturally be taken first and as many foundries are connected with manufacturing establishments plenty of wood is available for the cupola and the ladles.

The careful melter puts the smaller pieces on his shavings (the pattern and carpenter shops supply this), and then the larger ones. In big cupolas he has the material handed down from the charging door and puts it into position himself to insure an even fire and protection to the damp and yielding daubing on the lining. Where the work is done carefully and the cupola stack is above the highest point of the foundry buildings, the smoke evolved is not much of a nuisance and the results are entirely satisfactory. In cities, however, and where wood is scarcer, the smoke problem is gradually causing foundrymen to use the oil torch to light up the cupola with.

The success or failure of the oil torch in lighting up depends upon how the lower part of the fuel bed is arranged. To put the burner against the coke on the bottom—about half to two-thirds of the coke being charged, as in the case where wood is used—would mean a red-hot front and a black interior, or if carried on longer, a hot interior and the front entirely burned away. Hence, it is necessary to take the larger pieces of coke and build a series of channels on the bottom which will allow the penetration of the oil flame at least three-quarters of the distance to the back of the cupola as well as to the sides in several places. This will allow the flame to set the bed afire through the lower portion and the heat will go upward in the usual manner.

It is necessary that the bed coke be perfectly dry—a requirement for good melting results in any case—and that the torch be applied long enough to be certain that combustion will continue satisfactorily. The only objection to this method of lighting-up is the terrific noise of the burner for the 20-odd min. it takes to perform the operation. The cost is very small and as the results are excellent when a proper channeling of the bed is arranged for, the system is to be highly recommended.

As the bed begins to burn through, red spots will be seen on the surface here and there, and these should be evenly distributed. Usually, however, they appear on one side of the cupola—sometimes over the breast as the point of greatest draft. As this, however, is closed up very soon after the torch is taken away, the draft becomes more even if all the open tuyères are clear. In fact, by partially or entirely closing the peep-hole covers of some of the tuyères it is possible to check the combustion and allow the backward parts to catch up. If the fire is too weak or the draft poor on account of weather conditions, blast may be put on for a few minutes, thus stimulating the rate of combustion. As soon as the bed is well burned through—that is the portion already charged—the remainder of the coke intended for this purpose is thrown in and the combustion allowed to proceed.

When the full bed now begins to show red spots on the top surface, and if wood was used to light-up with it is certain that this is all consumed, a measuring rod is used to see that distance of the bed from the charging door sill is correct. This really means that the height of the bed above the top of the tuyères is what it is intended to be. The importance of this measurement will be shown later. If the bed is low, sufficient fuel is spread over the top evenly to bring it up to height. If too high, it may remain so. The peep-holes are now all closed up except one which should be left partially or entirely open to keep a little current of air going up the cupola and thus prevent the gases from backing into the blower pipe. The tap-hole should be left open also to assist this draft. The particular peep-hole left open would be the one at the point of poorest combustion. Charging should now commence.

Making the Breast.—While the fuel bed is lighting up nicely from the draft going through the opening for the breast and the tuyère peep-holes, preparations must be made to put in the cupola breast and form the tap-hole. The opening in the cupola for this purpose is carefully brushed clean and wet with clay-wash, the bottom being rubbed in with wet clay. The rod, pipe or wooden plug intended to form the tap-hole is now put on this bottom in exact line with the slope, and little pieces of coke covered with clay placed about it and pressed together tight. The entire opening may be filled this way, the coke and clay being rammed into place tight, or else molding sand with extra clay or loam and blacking mixed up are used, the material being thrown in and rammed tight little by little. The idea is to have a material that will resist heat and pressure as well as withstand the cutting action of the molten iron.

Ordinarily the melter puts some pieces of fresh coke against the red-hot bed coke at the breast and uses this as a wall to ram the material against. If, however, he puts the material in place in the shape of small lumps he can apply pressure downward until the hole is small enough to close from the front. After the breast has been rammed up completely, the front is cut away toward the tapping hole to make this as short as possible. The slope of the breast as cut away should be easy, otherwise there may be difficulty in stopping-up.

The lining of the cupola spout is a continuation of the cupola bottom and is made of the same material as the breast. For very large cupolas, the spout may be lined with split brick and the clay and fire-sand mixture is daubed on this as a backing. Before the spout is lined the rod or plug that forms the tap-hole is withdrawn and the tap-hole finished up smooth.

There are two ways of improving the above general method of forming the tap-hole. One is to prepare a special dry-sand core with the proper diameter perforation to act as the tap-hole, and imbedding this in the clay mixture forming the breast, and the other is to use two split bricks (cut to size) set across the cupola opening and carefully imbedded in the breast material, the tap-hole being cut into the brick at the line of junction, as shown in Fig. 36. This method gives excellent results, and was originally shown the author by a Swedish foundryman of great ability. It will be observed that the tap-hole is but the thickness of the brick, or not over 1½ in. The difficulty of keeping it clear is very small. It can be stopped up by a bod-stick a foot long when standing to one side of the spout. Similarly, the clay cone, or "bod" used to stop up the tap-hole can be picked away with the pointed end of a file. The particular value of this style of tap-hole is that it can be made and held to exact gage and hence may be arranged just large enough to hold a head of metal in the cupola while discharging a continuous stream of iron as fast as this is melted.

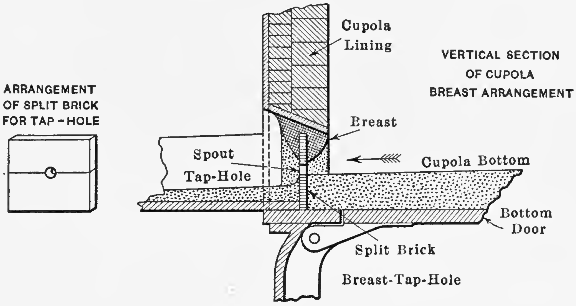


Fig. 36.—Cupola tap-hole.

The use of a dry-sand core is of value also, as it is easily made, has the advantage of being dry in the first place, can be readily arranged to contain two tap-holes side by side, and gives the same service day in and day out. Neither of the two improved methods mentioned above is seen very much in the foundries of the country, which is unfortunate, for the troubles with a poorly made breast and tap-hole are highly annoying.

Occasionally the melter will get too much clay in his material for making the breast. As the heat increases this first dries out and then shrinks badly. The breast may then not only leak, but will sometimes actually blow out, as the author himself has seen. In such a case it is simply necessary to shut off the blast, drain the cupola, and put in a new breast. The bottom need not be dropped, as there is no danger whatever. The insertion of some fresh coke pieces to ram the refractory sand and clay mixture against, and quick work in doing this, will merely mean the delay of not more than ¼ hr.

The properly lined spout is now heaped with small wood and this fired in order to thoroughly skin-dry it as well as the front of the breast. As a lot of smoke is made, it is better to use the oil torch or natural gas where this is available. The tap-hole should be left open as it is of highest importance to get the time of the first iron running over the spout, in order to know whether the fuel bed was of the right height. Furthermore, the blast in issuing from the tap-hole after going through the fuel bed downward dries this out and in fact renders the interior surface red-hot.

The size of the tap-hole depends entirely upon whether the molten metal is to run out continuously, is to be tapped out at short intervals, or whether large bodies are to be held within the crucible of the cupola to be tapped very quickly when required. Further, also on the tonnage to be handled within a given time, or melting rate of the cupola. The minimum diameter of the tap-hole will be that which will care for the iron as fast as it is melted and leave a sufficient head of metal within the cupola to allow slagging-out. About ⅝ in. is the smallest tap-hole ordinarily made. From this it may run to 1½ in. in diameter, the latter orifice caring for big streams of metal tapped out intermittently.

The *slag-spout* of the cupola is lined in the same manner as the cupola spout, and a tap-hole is left in it as well. This, however, is botted up with clay until ready to use, say about ½ hr. after blast has been put on ordinarily. The iron is allowed to accumulate on the bottom until it rises high enough to satisfy the melter that he can open the slag-hole. The blast then pushes the slag floating on top of the molten iron out of this hole in the rear or side of the cupola and slag will run out until the metal rises high enough to come out too, as shown by the sparks and stream of metal. The cupola should now be tapped but the slag-hole left open even at the risk of losing some blast. Usually the slag partially closes up the slag-hole and the melter must dig it out every time he wishes to get rid of more slag. With a thin and fluid slag there is little difficulty, but it means strict attention on the part of the melter to keep things just right.

Charging the Cupola.—The first consideration is the determination of the height of the fuel bed. It is assumed that Chapter IX, on the technology of combustion, has been carefully read. Here the general reactions incident to the combustion of fuel in the cupola melting process have been discussed very fully, and it remains now to apply the deductions made to actual practice.

The position of the proper zone of melting has been stated to be that at which the oxygen of the blast has been entirely consumed, the maximum of carbon dioxide and minimum of carbon monoxide formed, and the maximum temperature attained. This zone should really be identified by observing the scoring of the cupola lining. Unfortunately, however, particularly where the melting practice is poor, this scoring, instead of being less than a foot may extend over 3 ft., in fact almost down to the tuyères. Hence the proper point is masked and it is necessary to have recourse to practical experience in determining the height of the bed.

Special emphasis is laid upon the "height" of the bed, and not the "weight" of the fuel used. In following out the action going on within the fuel bed, it should be remembered that as the air travels upward the incandescent carbon and oxygen unite to form the hot gases in question. This means that a definite distance has to be traversed before all the oxygen is used up. And this distance is not strictly dependent upon the weight of the fuel, for if, for instance, the correct fuel bed on a given day consisted of 1,200 lb. of coke, several weeks thereafter, with the lining cut out badly, this 1,200 lb. would be possible 6 in. lower in the cupola on account of the widening of the diameter. It is a mistake, therefore, to charge a fixed weight of coke for the bed day in and day out. The proper way is to measure the height of the bed, and this is easiest performed by putting a measured rod or stick on the bed just before charging begins and seeing that the top of the stick is level with the sill of the charging door. The length of this rod has been previously determined by holding it against the lining of the empty cupola with the bottom the required distance above the top of the tuyères.

As stated above, the height of the bed is determined by practical experience. This experience indicates that the bed is of proper height when the "first iron" runs over the spout in 8 to 10 min. after the blast has been put on. This time is all important in getting the melting started off right. If the bottom has been carefully made, the charged cupola has stood for at least an hour, the bed is of the right height, and then blast has been put on—the full blast volume of the blast should be used throughout the heat—on looking through the tuyères drops of molten iron should begin to appear in about 6 min. Gradually little streams will flow over the coke to the cupola bottom, and some metal will splutter out of the tap-hole. The time of "first iron" should, however, not be taken until a regular flow of molten metal runs over the spout. The time should be at least 8 min. from "blast on," and preferably not over 10 min. If a little longer, the bed is unnecessarily high, though this is no special detriment particularly for light casting work. Should, however, it take 15 min. to get the first iron the bed is certainly too high and coke is being wasted.

A study of the passage of the blast through the coke bed shows, as the oxygen is consumed and the heat rises, that the desirable zone of melting is to be found in about the top 4 in. of the fuel. Below this there is too much oxygen at hand, which burns the molten metal. Further, the temperature is not quite high enough and hence the iron is apt to be cold besides being oxidized. A low bed is therefore very dangerous to good practice. If the first iron comes at less than 8 min. it is necessary not only to add a little coke to the intermediate fuel charges during the heat, to bring the bed up to proper height and thus get better iron for at least the middle and end of the heat, but the bed must be made higher the next day.

The general rule of procedure is to make the bed extra high for the first time, and observe results. If the iron comes at 12 min., the bed must be made a few inches lower the next day, and so on until the 10-min. point has been reached. Ordinarily, with a proper blast and area of cupola relation, the fuel bed of a cupola varies between 22 and 24 in. in height above the top of the turyères. Where trouble exists and the time of the first iron is not known, it is safer to begin with a bed 30 in. high and see what results accrue. Care must be taken to prevent undue draft while charging and allowing the cupola to stand, otherwise too much of the bed will be burned away.

The author has run such test heats in hundreds of cupolas and naturally found all kinds of relations between the blast volume and the cupola area. In some cases of extreme blast volume—the idea being to force the cupola production to the utmost—the bed had to be made 48 in. over the top of the tuyères, and in spite of such a tremendous development of heat the melting rate remained low, as most of the heat was blown up the stack instead of being absorbed by the metal charges. Hence the economy of melting under conditions that are not too forced. The table given in the early part of this chapter shows the proper melting rate of cupolas of various diameters.

Installations in which too light a blast is used are not met with often, for it is the aim of the foundryman to keep the molders at work as long as possible. Hence short heats in the latter part of the afternoon, with every one busy carrying iron. Where the blast volume is too low for a given cupola, the wind will travel up the lining and as the heat progresses a high cone of inert coke forms in the center. The cupola then really melts only in a ring between this dead center and the lining, the charges as they descend working toward the lining and away from the middle. Such conditions are not economical.

It is well, therefore, to first make a calculation of the blast volume delivered to the cupola, by multiplying the revolutions per minute of the blower by the free air (in cubic feet) taken in at every revolution. This multiplied by 60 min. to the hour gives the total volume of air blown into the cupola per hour. Dividing by 30,000 gives the tons per hour the cupola should melt. Conversely, multiplying the tons per hour the cupola should properly be made to melt by 30,000 cu. ft. of air, gives the total air to be blown into it per hour. Dividing by 60 gives this per minute. Dividing again by the air taken per revolution of the blower gives the revolutions per minute the blower has to run to operate the cupola properly.

The height of the bed having thus been settled upon for the given cupola as operated under the existing or properly corrected blast conditions, charging may now begin. The very first thing to settle now is the weight of the metal charge and that of the fuel charge to follow, these charges to follow alternately until the tonnage required for the day has been put into the cupola as melting progresses.

First Metal Charge.—At the outset the author wishes to state that the very prevalent custom of making the first charge heavier, if not actually double the others, is entirely incorrect. A moment's thought will show the reason. The actual results obtained in the Bureau of Mines cupola melting tests have shown conclusively that only the top of the fuel bed exhibits the conditions necessary for proper melting. A short distance below this there is free oxygen and a lower temperature prevails. It is therefore unsafe to allow the bed to burn away much more than about 4 in. If, therefore, a big metal charge as the first one will permit the consumption of more than this 4-in. layer of coke, the first of the tap may be good enough, but the last of that charge will have melted too low; and, worse yet, the charge of coke following the first metal charge, unless made correspondingly heavy also—which is never the case—will not restore the bed to the original level. A heat may thus begin with a proper bed and yet be damaged by putting on it a first metal charge calculated to drop the bed level below the right point and keep it thus for the balance of the run. Many a heat has been damaged in this manner.

It may be objected that foundries are operated in this way and yet get good result. Investigations of the facts, however, invariably show that the bed has been made unnecessarily high in the first place and is brought to the proper level by the melting of this big first charge; or the subsequent coke charges are all made larger than necessary and the bed is gradually restored during the heat. Furthermore, a trip through the departments of such a foundry, particularly where the castings are machined, will reveal plenty of work showing the effects of oxidized metal, as seen in blow-holes, undue shrinkages, cold-shuts, etc. Europe is far ahead of American in this respect, for one can travel far and wide there and find no instances of cupola charges in which these are not all alike in weight. Foundrymen there never think any other way. The custom referred to must have originated in America from the development of cupolas along big diameters and heavy tonnage melting. It does seem out of proportion to put in a few thousand pounds of coke for the bed and then charge only a ton of metal. Hence the custom has grown up of proportioning the charging bed to first metal charge as about 1 to 4, whereas the subsequent charging must be about 1 to 10. When the metallurgical aspect of the situation is considered the absurdity of such action is manifest.

Weight of the Metal Charges.—Much has been written about small versus heavy charges for cupola melting. If the successes and failures are studied, insofar as the actual facts are obtainable, there is no wonder that experts of the older school are inclined to believe every cupola a law unto itself. Where one man gets success with big charges, another, using the same-sized cupola, does better with small charges. If the truth were known, the operating conditions of both are more than likely very different. The author, who has consistently advocated small charges all his life, has been met with criticism constantly in this regard, but invariably found that the causes of the difficulty were located in entirely different fields. The statement that in the same cupola big charges work faster than small ones has been disproved by him again and again when he got the foundryman interested to hold his watch to the heat and find the bottom dropped in each case within a few minutes of the usual time, earlier or later.

In view of the fact that the principles of rational cupola melting were unknown at the time when these discussions arose, this would indicate that most of the conclusions were worthless, as the facts of operating were not comparable. The author himself, when first advocating small charges could not advance the real reasons as now known, but simply had found better results in his practice when so doing. Today he has no hesitation in saying that one cupola will work exactly the same as any other, provided they are all built on the lines as laid down in the first part of the chapter, and are operated under the same blast conditions, charging, etc. Cupolas are therefore not at all laws unto themselves, if run rationally. If run in defiance of proper principles of charging, blast conditions, interior lining, tuyère arrangement, etc., then certainly they run their own way—usually not that desired by their owners.

Inasmuch as the studies made on the subject have shown that it is not good to lower the bed more than 4 in. every time a metal charge is disposed of, this at once gives a basis for the calculation of the weight of the standard metal charge to be used in any particular cupola. A body of coke 4 in. high and filling a ring of the same internal diameter as the cupola is weighed, and the metal charge will be practically ten times this amount. For instance, if the weight of such a 4-in. coke charge is 200 lb., then the metal charge will be roughly 2,000 lb. Every cupola will therefore have what may be called its standard charge, this depending upon the how much a given coke weighs when piled 4 in. high in that cupola. The question of large or small charges thus falls away absolutely.

In further explanation of the above paragraph it may be stated that to get the weight of a layer of coke 4 in. high for any cupola, the easiest way is to lay out the cupola circle with brick on the platform, and make this 1 ft. high. Fill the coke, weigh and divide the amount by 3. This gives a fairly accurate figure, which of course, is liable to change for every new kind of coke used. In using this figure for the weight of the intermediate coke charges for the cupola, it is best to make it a round number, say an even 10 or 5—that is, not 187, for instance, but 185 or 190 lb.

The iron charge may now be calculated. As stated, ordinarily this is ten times the weight of the coke charge. The following conditions, however, affect this relation: If the coke used has over 10 per cent. ash, it is obvious that there will not only be less carbon to furnish heat, but that a little more of the heat furnished will be used to make a slag of the ash present. Next, in the early part of the melt, much of the available heat passing through the outer portions of the charge is absorbed by the lining in getting this incandescent. For this reason a little less coke is used from the middle to the end of the heat. Where, for instance, the first coke charges are 200 lb., these can be reduced to 190 lb. about the middle of the heat, and perhaps to 180 lb. at the end. Experience is the only teacher in this regard, but there is also a good guide in the extent of the scored lining of the cupola. With a constant height of the fuel bed, this scoring should not extend over 9 in. to a foot in height, and preferably run not more than 6 in. below the original bed height.

If the same quantity of coke and metal is charged throughout the heat, it is possible that toward the end the bed is built up by unnecessary fuel. In that case the melting will slow up for an undue amount of carbon monoxide is formed and the temperature drops. A reduction in the amount of coke charged, holding the metal charge the same, will remedy this.

In ordinary practice, therefore, with a good coke, it is safe to make the metal charge ten times that of the standard coke charge. Where the coke is in doubt, the analysis being absent, or where it has remained in the open instead of being housed under roof, it is safer to begin with a ratio of 9 to 1, and for very light castings possibly even 8 to 1, until the running of a few heats give assurance that the fuel can be cut down safely. It may be mentioned in passing that the question of moisture in coke is so serious a problem that better results are usually obtained by measuring than weighing this fuel. That is to say, a given box, basket or can is filled with the coke in question, but known to be dry, and this is weighed. The same receptacle may then be used on the charging platform in caring for the intermediate coke charges. This method is better than weighing a forkful of coke and then counting the number used.

Attention is called to the fact that while the coke bed is a matter of height, and independent of the weight, the subsequent coke charges are a matter of weight primarily. In the bed it is a question of using up the oxygen in the blast completely, while in the subsequent coke charges it is a matter of restoring a given weight of fuel which in being consumed has given off enough heat to melt the metal charge above it.

The question of the weights of material charges has now been ventilated sufficiently, and the charging operation itself must be looked into. The bed was left as just showing red spots through the top and the measuring rod applied to see that it was either of proper height or, if too low, was made so. The subject of hand-charging would be in order first. The metal charges are supposed to have been brought up the elevator and either deposited on the charging platform, or stored on enough cars to keep the men busy charging while more material is being weighed and brought up on the cars as fast as emptied. The men now either take the pigs of iron and throw them on the bed, passing the door one after the other; or better, they hand the pigs to the head of the gang—who stands at the foor—and he drops them into the cupola properly.

This operation sounds easy but is not always carried out as it should be. The following precautions are to be observed: The pigs should not be dropped in criss-cross fashion. This would soon build up a pile so open in texture that the flame can be seen through 2 ft. of it. The result is a waste of heat, the gases passing through to the top without finding enough metal to impart their heat to it as fully as they should. Hence the pigs should be laid side by side and around the lining, but as evenly distributed as possible. In this way the layer will be compact and still open enough for the passage of the gases. With the pig should be charged all scrap of the same thickness and over. The reason for this is given in the following:

General Sequence of the Metal Charge.—The three principal components of the metal charge are pig iron, gray or other cast scrap, and steel. The action of heat on these can be stated thus: Steel, with its higher melting point than cast iron, would remain unmelted longer than cast iron whether pig or scrap. Pig iron has the same melting point as scrap for like composition. Usually, however, it contains less combined carbon and hence does not melt at quite as low a point as this. At any rate, it is thicker in section and it takes longer to absorb the necessary heat to melt than is the case with ordinary scrap. Hence, the order of melting would be light scrap (which usually includes the gates and sprues about a foundry), pig and heavy scrap, and then steel. If, therefore, the steel is charged first, the pig next and the lighter scrap last, they will melt together. Another reason for charging the steel first is that the melting pig and scrap wash it down. Charging steel last puts it just as much in contact with the fuel as if charged first and has the disadvantage of requiring the next charge of pig to melt it completely, thus upsetting the mixture conditions.

In the order of charging, therefore, if steel is present this goes in first, evenly distributed on the bed, and then the pig. An interesting point comes up in this connection: For a fairly long heat it is a good policy to sort out the steel scrap, separating the lighter from the heavy. While it is not good to use steel scrap lighter in section than ¼ in., and not much heavier than 1 in., in cupola practice, occasionally heavier pieces must be melted. The lighter scrap is then used in the first charges and then the heavier, gradually increasing to the heaviest toward the end of the heat. The reason for this is that the cupola becomes hotter and hotter and the heavy pieces have a better opportunity to absorb heat before they get down too low. The author once ran a heat in which many heavy steel projectiles formed a part. By using the lighter first and the great big ones last, no difficulty was experienced even though the steel formed 50 per cent. of the mixture.

When steel is used, a further precaution must be taken. As this material melts at a higher point than cast iron, it takes more coke to give proper ladle temperatures. The rule of 10 to 1 will not hold here, and depending upon the steel percentage in the mixture the ratio may drop as low as 7 to 1. With thin steel, as for instance a 100 per cent. steel mixture consisting of tin cans, a ratio as low as 2 to 1 may be necessary. The author, however, in running a lot of such heats had no difficulty in converting this poor ratio to 6 to 1 when he had the cans pounded down to flat pieces or lumps. It was simply a case of getting more weight in a given volume to facilitate the absorption of heat from the cupola gases.

With 5 to 10 per cent. of steel in the mixture a ratio of 9 to 1 can be used to start the heat with safety. This means metal to intermediate coke charge, and does not refer to the bed.

Returning to the charging operation, a further precaution in charging the pigs and heavy scrap is to spread them evenly all over the bed, and later on evenly all over the intermediate coke charges, or over the steel in each case if this is used. This condition is emphasized because there are foundrymen who charge their pig around the lining and put the scrap in the central portion of the metal layer. A moment's thought should show the error of this procedure. Metal in the cupola is melted by the gases passing directly around it from the fuel below. With the heaviest portions at the rim and the lightest in the center, and the same thickness of coke below each, the melting ratio for the pig iron might actually have to be 15 to 1, whereas that for the scrap would be very low from an excess of fuel, or say 5 to 1. The result can only be a gradual wasting away of the fuel at the edges without properly disposing of the pig, the dropping of the layers at the edges, cold metal there, and a great waste in the center. When the molten metal arrives at the bottom and is drawn through the tap-hole, a mixture is formed which has an average temperature, and may be hot enough to use, but the metal melted at the rim will have been damaged just the same. Indeed, the author when called to establishments using this method of charging has invariably observed the effects of oxidized metal due to this cause in the machining of the castings made.

The steel and pig with the heavy pieces of scrap, such as the chunks of "over-iron" and broken flywheels, etc., having been charged, the lighter scrap is put in next and well distributed all over the pig, the very lightest going in last. There is a limit to the use of very light scrap, and this is the piece that will just remain where thrown. Smaller pieces, shot, nails, small lumps from the slag-mill, should never be used in the mixture and go into the cupola as long as molten metal drawn from this is still going into castings that are important or must stand machining. Such small pieces are apt to roll between the pieces of coke and will finally land near the tuyères and receive the blast with highly disastrous results.

There is even a limit to the section of pieces of scrap when intended for a cupola mixture. It necessarily takes some time for a heavy piece of iron to heat up to redness and then melt completely. In the meantime coke is burning away and the top of the bed is being lowered, the chunk of metal going down with it. Unless this heavy piece is gone before larger percentages of free oxygen are encountered, there will be burnt metal with all the disastrous consequences this entails. In extreme cases enough of such a chunk of iron may remain to get within range of the blast and either be partially Bessemerized or else cease to melt altogether and fall with the cupola dump. The latter case is often met with since foundrymen are apt to melt such material at the end of their heats to cast floor-plates and the like, or to repig for subsequent use in their mixtures.

Such unmelted lumps of metal are often met with when charging briquettes of cast borings where these have been made exceptionally heavy—that is of large diameter and height. They will get down so low in the bed that the half unmelted remains are dropped with the bottom. One further oftentimes sees pigs of "over-iron" a foot thick, evidently made by scooping out a deep hole in the sand with the shovel (and usually in a hurry) to contain the remnant of a ladle of metal which was too cold to use. These lumps are not calculated to improve the quality of the molten metal, as they also get too low down into the bed before being disposed of. It is just as easy to have a pig bed ready for this material so that the section of the pieces be not over several inches. If desired, small amounts can be poured into a number of compartments of the pig bed, and this iron covered by more in subsequent pours. The separation of the metal in cleaning up the bed will yield scrap of usable thickness.

Incidentally, the above-mentioned "over-iron" may be said in its strictest sense to consist of the additional quantity of iron charged, over and above the estimated amount of metal required for the day's run of work on the floor. This extra amount is melted for safety's sake, so that in pouring an important casting of big weight, as for instance, a 54,000-lb. flywheel, the mold may not by short-poured by just a few hundred pounds. Distressing situations like this are met with occasionally and are difficult to tolerate in any shop. A big casting like the one cited is usually not poured until the latter part of the heat, and hence the foreman has time enough to look over the floor and estimate what remains there. He can then see whether he has charged enough metal while the ladles are filling up in anticipation of the big cast, and if in doubt get some more into the cupola in time.

This additional metal charged to make sure of having enough for the day's run should not ordinarily exceed 5 per cent. of the total melt. In exceptional cases it doubtless runs higher. In any case, however, the moment the last casting has been poured and there is no object in melting any more iron (as for instance, to convert "shot" to pig, etc.), the bottom should be dropped and as much of the extra iron as possible recovered in an unmelted state from the dump.

A further situation to be watched is the charging of scrap or over-iron so large in surface that a considerable percentage of the cupola area is covered. One oftentimes sees plates of metal charged which cover three-quarters of the charge below them. Such a plate will descend intact into the cupola until not far from the melting zone. The result is a diversion of the intensely hot gases going up and forcing them against the lining. Not only will the lining be thus exposed to serious cutting action, but the metal for several charges above this plate will not be thoroughly preheated before arriving in the zone of melting. In the interest, therefore, of proper charging and melting practice, such plates should be broken up.

Finally, a word about indiscriminate charging. The author has repeatedly observed such things as a whole kitchen range dropped into the cupola during a heat. A little thought would make a foundryman hesitate doing such a thing a second time. This stove has to descend some distance before becoming red hot, softening and crushing flat. In the meantime, the material charged on it, whether coke or scrap, falls down on the sides and certainly does not result in a level layer when the stove will have flattened out. The result is an up-setting of proper conditions for a while. In addition, a space of several feet (the height of the stove) will be subject to a sweep of the gases without imparting their heat to much metal, and the efficiency of the melting process thus impaired.

The scrap and sprues having been put into the cupola, the charge of coke is next spread on the metal as evenly as possible. This should be a simple proceeding and need not be discussed further. On this coke charge there is put whatever limestone is to be used.

Perhaps this is as good a place to discuss the fluxing of the cupola as any. Foundrymen hesitate to slag-off the cupola on account of the nuisance this operation usually is about the working space, the interference with tapping metal when and how desired, the loss of blast, the difficulty of keeping the slag-hole acting, and a lot of minor things that prove a burden to the melter. Hence, he will run with his cupola bridged and bunged up, slag coming off with the metal and defiling the spout and every ladle in the shop rather than take the bull by the horns and make a fusible slag from the very start, driving it out of the cupola through the slag-hole as soon as there is enough accumulated to warrant this. Again, in most foundries the melting of iron began with rather small units and as the tonnage became heavier the men grew accustomed to care for the accumulation of slag within the cupola as a matter of course, the management rarely realizing the condition of things existing and the undoubted interference with efficient and metallurgically satisfactory melting operations.

The following points should be borne in mind: For every 100 lb. of coke charged and consumed, there will be about 10 lb. of ash to care for. Every ton of sand-cast pig iron may introduce about 20 lb. of gravel and sand into the cupola. Wide-awake foundrymen tumble all their sprues, gates, etc., to prevent slag formation to that extent at least. But few will take the trouble to clean the pigs of over-iron from the thick layer of sand burned to them. Then comes the rust of the scrap, which in the case of stove plate is a pretty serious item. This goes into the slag. The amount of earth charged with the foundry sweepings is also an item, and finally many a kind of limestone gets into the cupola which contains so much clay and sand that most of the lime is used up for fluxing these before it can act upon the charges. In short, there is a lot of refuse in the cupola charges of metal and fuel which will accumulate at the melting zone and just below it, which if not fluxed away and gotten below the tuyères, will prove a source of trouble as the heat progresses. This refuse, in the absence of lime, magnesia or alkalies is practically infusible, and must depend upon any rust or other form of iron oxide present to become liquid at all. Unless fluxed away, after running about ½ hr.—especially if the cupola is forced—the tuyères show black, a little later bridging begins, and after running say 3 hr. without fluxing and slagging-off, when bottom is dropped, the chances are that but little will fall out. If pigs dropped into the middle do not make a hole through the bunged-up bed, water has to be thrown in from the charging door, and only if this cracks the slag sufficiently to trickle through is there some chance to get the cupola ready on time the next day. Otherwise the situation is doubtful.

In general it may be said that any heat running over ½ hr. should be arranged to permit slagging-off. Since refuse sand, ash, etc., begins to collect from the very beginning of the heat, and if allowed to freeze within the bed above the tuyères from the start is very difficult to get away again, the addition of limestone—preferably a purer calcite, if available, or oyster shells, marble chips and other forms of comparatively pure carbonate of lime—should begin from the very first of the heat. Hence, the fluxing material can be safely charged right on the bed and on every layer of coke thereafter. The best place to charge is on the coke, as the limestone would land there in any case if placed on the metal. It should be spread evenly on the fuel, but preferably a little away from the lining, as lime and clay or silica brick get together quickly to make a slag—which means a bad cutting of this part of the cupola at the melting zone.

The quantity of limestone used need not exceed 1 per cent. in ordinary cases—that is with scrap not over 30 per cent. of the mixture. Where the scrap is dirty and in great excess, the quantity may have to be increased to 2 per cent., and in the case of rusty stove plate and pipe scrap, even higher. An analysis of the limestone should show as high a percentage of carbonate of lime as possible, in order to get effective results.

As the slag is formed and drops down into the crucible of the cupola with the molten iron, it floats on this and gradually accumulates and fills the voids between the pieces of coke. After the cupola has run about ½ hr., the melter should allow his metal to accumulate until he judges the slag to be at the level of the slag-hole, and then he opens this slightly. If any slag is there, the blast will force it out and the hole can be opened altogether. The stream of slag will now issue and run on the floor of the cupola room, the melter aiding the escape by keeping the hole open. When the first iron appears, with the pyrotechnic display this causes, the cupola should be tapped out, and the level of iron and remaining slag within it lowered. This alternate raising and removal of slag and then lowering of the metal bath will serve to remove the surplus material from the cupola, and the melting can be conducted all day if desired.

When using limestone only in the latter part of the heat, there will be black tuyères to deal with and much poking through the peep-holes to give the blast a chance to penetrate into the interior of the bed. Hence the importance of fluxing early to get the slag to pass the tuyères in its downward course. If desired, a little fluorspar can be added to the limestone to thin the slag. This flux is very hard on the lining, and should be used with caution. It is unquestionably good, however, and also removes sulphur to some extent.

Instead of letting the slag run on the foundry floor, it may be caught in steel slag-buggies, or better still in removable tanks full of water. The slag in flowing in is granulated and disposed of at once this way. There is no danger incident to this method, though few foundrymen have tried it out. Where used it is found the cheapest method of handling the situation.

During the intermittent flows of slag, the slag-hole is left open to allow some of the hot gases to pass through it. But little blast is lost in doing this, for the hole naturally becomes clogged with cooling slag and, in fact, a tube is formed outside extendin downward from the slag space some distance, through which the liquid slag keeps flowing if the iron level is held at about a constant point.

The alternate layers of metal and fuel are charged into the cupola until this is full to the charging door and, in case of a short charging space, piled up as high as the men can throw. The subsequent material can be introduced only after melting has begun and the charges already in the cupola descend. After charging as much as can be done, the cupola is allowed to stand under heat as long as possible. During the charging operation the tuyères have been shut off with the exception of one, as already stated. This is now partially closed also, the idea being to have only as much draft in the cupola as is necessary to send the gases up the stack instead of allowing them to back into the blower pipe and possibly the blower itself. Too much draft will mean the consumption of unnecessary fuel before blast is put on, and hence an undue lowering of the bed.

Ordinarily, the charged cupola should be allowed to stand an hour before commencing to melt. Better if this time can be made 2½ hr. This will insure a fine warming up of the metal and lining, and when blast is put on finally, the first iron will be fit to use practically from the very start. This is not the case when blast is put on right after charging, a few hundred pounds of metal being lost for pouring purposes. True, this metal could be used to heat up the ladles, and is so utilized in most foundries, but ladles are better heated up specially by wood or oil fires, and every pound of molten metal not used for pouring is so much material raised in sulphur and lowered in silicon and manganese. It has cost money to melt and is very expensive scrap when the fact is considered that it need not have been wasted.

The difference between operating a cupola which has stood charged for 2 or more hours, and one which has not had any opportunity to stand at all is so striking in its results, that foundrymen should try it out and shape their charging accordingly.

The older foundrymen will remember the excellence of iron castings in the early days. Much of this was due to better pig iron, but at least some can be credited to the custom of piling the weighed amounts of pig, scrap and hard coal on the platform while the bed was burning through. The melter would then throw the material in a little at a time and thus mix it all up—but in proportion to wind up with everything cleaned up and no surplus of either of the three items. The result was that the bed remained unchanged in height, no fluctuation up and down being possible. As fast as a piece of coal would be consumed, another would drop in its place, and so on. If the melter had his bed right, he could not help but make an excellent melting record.

When everything is ready to begin melting, the signal is given and blast is put on. This should be in full volume from the very start. The foreman or melter should time this so that he may know when he got his "first iron." In fact, in the "cupola record" of metal and fuel charged which every foundryman keeps, it would be well to provide for such items as the hour and minute when charging began, when it was complete up to the door and the cupola began to stand to heat up; when blast was put on and when the first iron ran over the spout so that it was necessary to bot-up; then, the time for "drop-bottom." These records give the necessary information allowing a calculation of the melting rate, the melting ratio, and show whether the bed was right. They should be checked up daily in the office and any deviation from normal investigated and corrected. It is further understood that these records should go into the office "undoctored."

As the blast operates within the cupola, metal will be seen falling in drops past the tuyère openings in about 6 min.—they should not come earlier unless much very light sprues have been charged in the first metal put in. The blast coming through the tap-hole will heat this up well, and as some iron begins to show, this must be cleared away to allow a good passage for the blast. If steel has been charged there will be some slag from oxidized metal uniting with the ash of the coke, and this slag is apt to clog up the tap-hole unless removed. Soon the iron comes out stronger and finally a small stream appears of sufficient steadiness to run over the spout. This is the time for taking the number of minutes since putting on blast. The stream is allowed to run just long enough to insure a clean tap-hole, and this is now plugged up.

After the blast has been on long enough to allow the accumulation of the desired amount of molten iron within the cupola, the clay bod is picked away and the stream of metal issues. The tap-hole is cleared by running an iron rod through it and the flow is uninterrupted until the ladle is full or the level of the metal within the cupola is so low that the first signs of spluttering iron show the exit of the blast there. Alternate tapping and closing up the tap-hole now continue until the end of the heat, unless the stream of metal is arranged to be continuous, as previously explained.

When the last iron has been taken out, or it is desired to stop the heat because the molds are all poured off, the blast is shut off. The last iron is now drained from the cupola, and the prop beneath the doors pulled away. The doors swing out, the sand-bottom tears away and the contents of the cupola fall down—unless held up by chilled slag. A stream of water is directed on this heap of incandescent material, called the "dump" and when sufficiently wet down to prevent combustion from going on within the mass, the melting operation may be considered finished for the day.

The dump is picked over the next morning, pieces of unmelted metal taken out and returned to the proper piles—as it is comparatively easy to identify the pigs and scrap. The coke recovered is either sent to the core-ovens or up the platform again, but only for use on the last charges. It is unfit for the bed or the earlier charges on account of the contained slag and water. The author prefers the use of this recovery coke as a cover for the last metal charge. It protects it from loss of heat by radiation upward and helps give a good drop.

It it is desired to change the mixture during the heat, an extra amount of coke put between the two kinds of metal retards the heat sufficiently to insure the melting of the first mixture and its removal from the cupola before the other mixture starts to melt. Usually the intermediate coke charge is doubled the first time such a change is tried. After experience has been gained, about half the charge additional will be found sufficient.

Similarly, when it is desired to run the cupola intermittently, the foreman calculates at about what point the cupola is to be stopped, and arranges for an extra half charge of coke to be down to the bed by that time. The author often ran large heats intermittently during the day in this manner and had no difficulty with results.

Where it is desired to operate the cupola continuously during the day, it is necessary to line down to a smaller internal diameter and use a correspondingly lower volume of blast. That is to say, arrange for a smaller melting rate per hour in order to have a thicker lining to fall back upon on account of the demands made upon this by so long a heat. The cupola must be slagged carefully, and no foundryman should go into this method unless he has two cupolas available, and uses them turn about in his daily work. There are many examples of successful operation in America; indeed, the requirements of the Bessemer converter are responsible for the successful development of the continuous melting problem, as large tonnages used at regular intervals during day and night are essential.

Attention is again called to the necessity of keeping the blast volume constant during the heat. It is, however, possible to decrease this volume safely at any time, but then it should be kept so, as the bed will have been lowered. Naturally the melting rate drops with the blast volume and if attempts were made to increase the blast to normal again without having previously provided extra coke to raise the bed again, there will be oxidized iron and injured castings. Hence the desirability of not experimenting but if the metal comes too fast, simply shutting off the blast entirely for a while. This stops melting and allows the disposition of the ladles full of molten iron for the time being. The opening of one tuyère is necessary when blast is thus shut off—as already explained.

The size of the dump is an important guide to operation within the cupola. Theoretically, the pile of incandescent material dropped with the bottom should be exactly that of the bed put in, if all the iron charged was melted. Practically this is difficult to estimate. Enough, however, will be seen to determine whether the bed was low, about correct or high. This, with the scoring of the cupola lining, helps the foundrymen keep things running properly.

There are many other minor points that have a bearing on successful melting practice, but enough has been given to show that today the charging and melting operations for the cupola are an exact science and not experimentation. With a sound knowledge of charging, melting, the making of mixtures and the proper gating of molds, there is no reason why the losses in the foundry may not be kept to a minimum at all times.

Mechanical Charging.—So far the operations described have been based upon hand-charging conditions. It is now necessary to discuss the advantages and disadvantages of mechanical charging. At the outset it may be stated that there are no disadvantages in mechanical charging, if the principles laid down in the previous discussions are not violated. Since, however, most of these principles are disregarded in the installations—with few exceptions—that one sees in the larger foundries, the results are by no means what they should be.

Essentially, the charging by machine should duplicate the charging by hand in every particular except the requirement of man-power. That is to say, the pigs should be laid on the bed just as if thrown in by hand. Similarly the scrap, coke and limestone. This at once presupposes that the charges must be laid on the charging machine by hand in the yard in the position as wanted in the cupola, and the charges shot into the cupola without change. An examination of most of the devices in use in foundries shows that this is an impossibility. Take one of the earliest, the inclined hoist dumping the stock into the charging door much as in the case of the blast furnace (without the bell, however, and not into the top). The men in the yard throw the required weights of pig into the bucket, it goes up to the charging door and is tilted over, shooting the pig into the cupola from the side. Next comes the scrap, then the coke, etc. None of these layers are level and uniformly thick. In fact, in all these side-charging devices, there is only one position of the charged cupola when there is likely to be a level layer, and that is when the cupola has been filled to about 3 ft. below the charging door. Even here, a charge of flat steel, or scrap of unequal sections is apt to land sideways or at any rate, not level.

As no one pretends to claim that the operatives will see that this peculiar safe point in the cupola is maintained during the charging process, the charging apparatus is run whether the cupola is low or full and indifferent results are obtained. The author has been called in professionally so often to foundries using such side-charging devices that he unhesitatingly condemns them all as undesirable and productive of castings troubles. They will not charge level. They cannot charge as carefully as by hand. This always means the using of more coke than in hand work, to overcome the deficiencies of the system, and in fact in many places the men have to level off the coke charges put in this way by hand before they dare charge the metal again. At one place the author saw a coke charge, instead of going on top of a metal charge, actually roll behind this as the metal charge had not gotten beyond the front half of the cupola (as seen from the charging door). The result was that another coke charge had to be used, and the melting ratio at that plant was 5 to 1 even with 50-ton heats.

As the result of his experience with the charging devices in use in America and a study of those devised in Europe, the author made up his mind that the good engineering talent expended upon them was wasted simply because the constructors did not know much of foundry metallurgy. They would not otherwise have devised a method of charging giving uneven layers of either metal, fuel or both. The author further made up his mind that the first prerequisite to successful mechanical charging was a straight drop for both metal and fuel. The next requirement was a method of putting the charge by hand into the charging receptacle in such a way, and so arranging the receptacle, that the charge as laid would drop unaltered into the cupola. Further, that the handling of pig, scrap and coke by the men must be confined to touching the materials but once, and this once to be the taking up of the material from the respective piles in the yard. After that labor must be confined to moving the receptacles only. Finally, that it was desirable to lay a full charge of pig, scrap and coke, with the necessary limestone, just as was required in the cupola, in the same receptacle. In other words, the advantages of hand-charging must be retained and only the labor replaced. This the author accomplished by designing the following system at the time for one of the largest foundry corporations of the country, operating over a dozen foundries. The preliminary trials with small and then large tonnage proved so successful that the system was worked out to the logical end, and the cheapest method of charging the cupola by mechanical means and at the same time metallurgically correct attained.

To be able to charge the cupola in the yard—for that is what the system amounts to—a steel bucket was made about 4 in. smaller in diameter than the cupola interior. Into the middle of this bucket there was riveted a partition made of two plates far enough apart so that when the two swinging doors fell out they formed a continuation of the partition plates, as shown in Fig. 37. The effect of this construction was to allow an absolutely unobstructed descent on the part of the stock from each half of the bucket. The pig, scrap and coke could therefore be laid into the bucket as carefully as desired—away from heat and in plain open-air sight—and when the buckets were rolled right into the cupola, the drop was instant, straight and without disturbing the arrangement of the contents to any appreciable extent.

To get the bucket into the cupola, this was cut away at the platform level and built out into a chamber, the tracks from the elevator running right on the cupola lining. Above the chamber the cupola was contracted again to the proper diameter stack. The track could be hinged and lifted back when charging was completed, and a door let down to close the chamber. A deep notch was cut into the cupola front to allow the open doors of the bucket egress from the cupola for closing up and latching outside. Suitable wheels were attached to the bucket, making the apparatus substantial and complete. When charging in the yard, the bucket was run to the several pig piles, scrap heaps and under the coke bins, while on a transfer table. A scale was provided on this transfer table, and thus one lifting only of a pig, etc., was necessary for placing into charging bucket, weighing, transfer to cupola and dropping into this. Contrast this with some of the ordinary hand-methods. A pig, let us say,

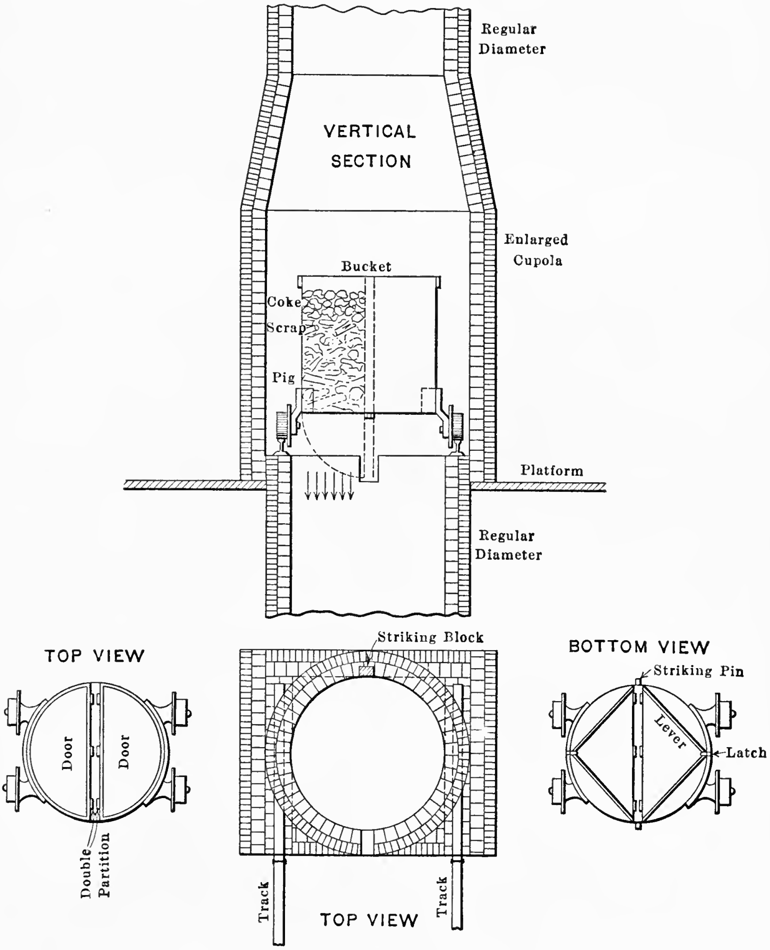


Fig. 37.—Cupola bucket for mechanical charging.

will be lifted up in the yard, placed on a buggy, run on the elevator and up to the platform. It may be taken off and piled up for stock. Again, it may be lifted and put on a scale, or the buggy may be weighed as a whole, and the pigs taken off and piled for subsequent charging—unless there are enough buggies to care for the entire charge. Suppose the charges to be piled for the day. The individual pigs are again lifted up for the purpose of charging them into the cupola. Thus every handling adds to the cost—a thing which few of the molders consider when they throw cold iron on the floor.

The practical result of the mechanical charging device designed by the author was the layering of the charges parallel to each other—there being a slight rise in the middle of each charge due to a little spreading of the material as it struck—the confining space in the bucket being smaller than the cupola to obviate scoring the lining in the descent. The drop was interesting. The pig and heavy chunks put on the bottom naturally went a bit faster than the lighter scrap above them. The coke on top of the metal dropped just a little slower than the scrap, and hence the charge adjusted itself nicely on its arrival below, being practically identical with the arrangement as laid out in the bucket in the yard.

Naturally, such a system means rapid charging and is particularly useful for continuous melting. A bucket of this kind can be charged in the yard, taken up and dumped into the cupola in less than 15 min. Since the presence of but one man is required on the charging platform with this method, and the men in the yard do not get near the heat and gases of the confined cupola charging floor, the sanitary situation has its advantages in addition to the financial and metallurgical.

While the author prefers the arrangement of the track running right on the cupola lining, there are other ways of getting the charging bucket into the cupola. The bucket can be attached to a charging beam which in turn is made to roll on the lower flange of a fixed I beam placed above the charging door. If this fixed beam has a slight drop toward the cupola it will facilitate operations. In this method there will be no parts remaining in the cupola under fire at any time, for the charging beam comes out with the bucket. The cupola need not be built out to a chamber either, but is simply cut out to the middle and just a little larger than the bucket outline, a slot below the sill accomodating the hanging bottom doors. Light doors can be put on the cupola to close up the space cut out when the operation is finished.

In concluding the chapter on the cupola melting process, two items referred to frequently should be mentioned again briefly: first, the melting ratio; and next, the melting loss—these, for any kind of melting. Under the term "melting ratio" there by understood to be given the number of pounds of metal melted is 1 lb. of fuel. Thus, in the cupola, when a ratio of 8 to 1 is spoken of, this means that the total metal charged bore a relation to the total fuel charged as 8 is to 1. This is the custom in America. In Europe, this term melting ratio refers to the total weight of the metal charges (all being alike) to the total weight of the coke charges, exclusive of the coke used for the bed. When one therefore reads of very fine European ratios—such as 14 to 1—these, if true, will mean very long heats with very high cupolas, and the bed coke left out of the calculation. The method is, however, more correct than the American, which includes the bed, for a cupola may be run perfect in both cases and yet a short heat has a poorer melting ratio than a long one.

Under ordinary conditions a ratio of 8 to 1 is considered fair in American practice, this really meaning 10 to 1 above the bed. There is, however, only one proper ratio for each situation, and it is idle to ask the foreman to cut his coke or give a bonus for coke-saving, if the cupola has been run on the principles outlined in this chapter. If the bed is made too low or too high, this can be determined. If the intermediate coke is too heavy or light in weight, this is also shown by the results, by the time of first iron, the scoring of the lining, the size of the dump, melting rate, etc., as already explained.

The *melting loss* in the cupola is the reduction of weight of the metal incident to the melting operation. All melting is accompanied with more or less oxidization. In spite of trying to melt on a bed of fuel at the point of least oxygen there will be enough present to affect the melting metal under the high temperatures prevailing. Hence here, and also while the superheated metal is dropping through the constantly increasing oxygen percentages of the blast, until past the tuyères, there will be a substantial reduction in the silicon and manganese present in the iron. This loss of the two elements is a fairly constant percentage no matter what the silicon content of the mixture may be in ordinary work.

It is a little higher for very high-silicon iron and lower than the average for the very low-silicon varieties. The trait is perhaps more marked in the case of manganese, for melting high-manganese irons is accompanied with more than a proportionally higher loss.

This reduction in the silicon, particularly, is important in making mixtures for these must be just so much higher in silicon content than the castings wanted. The ordinary figure—the melting practice being supposedly the best—is 10 per cent. or roughly 0.20 for the average and lower-silicon ranges, and 0.25 for the upper percentages. In rather poor melting practice, these figures may run 0.25 and 0.30 respectively. It is usually safe to add 0.25 to the silicon percentage of the castings wanted to arrive at the silicon in the mixture. In the case of manganese, the loss is usually held to be 15 per cent., but, as stated, varies somewhat with the percentages in the irons used. It will be noticed, therefore, that if the carbon and phosphorus remain unchanged and the increase in the sulphur content affects the results but little, that the average mixture of say 2.50 silicon and 0.70 manganese shows a loss in weight of 0.30, or 0.3 per cent. in the weight of the metal charged for melting.

The above is highly interesting, for the author made a number of melting tests of machine-cast pig iron with about 2.00 silicon, and the melting loss of this all pig mixture was exactly 0.3 per cent. Where sand-cast pig was used alone, the loss was 1.00—showing the effect of the added sand weighed as iron. This also, when charged in the shape of burnt sand attached to gates and sprues as they come from the foundry floor after shaking-out, may amount to a serious item and account for much of what is called the melting loss. In some lines of work where this is the case melting losses of nearly 10 per cent. are thus expected. The errors introduced by this condition in the calculations of such a foundry can be imagined. Generally, however, foundries in which high percentages of sprues are made and these are not tumbled before remelting again, do not make calculations or try very hard to get up-to-date.

In addition to the loss in silicon and manganese, as well as attached sand weighed as iron, there is the question of rust. Probably the best example of the loss from this cause is to be found in stove-plate scrap. This is all pretty light material which accumulates in the local scrap-dealers' yards, and before reaching its final destination at some foundry may have remained exposed to the weather for years. The coating of rust is therefore heavy. Elaborate tests have shown that 8 per cent. may be considered a good figure for the melting loss of this material. When there are many burnt grate-bars in the collection, the melting loss may run as high as 14 per cent.

The following table gives the average melting loss of the several kinds of foundry metal going into ordinary mixtures:

Machine-cast pig iron	0.30
Sand-cast pig iron	1.00
Car wheels	2.00
First quality machinery scrap	2.50
Light machinery scrap	3.50
Stove-plate scrap	8.00

These melting losses are more important than is generally thought. Many a foundryman finds that he has a 5 per cent. loss, for instance, and is satisfied. If he were, however, to analyze this loss, figuring out from the above table what his loss ought to be he might find that his results are very poor. He might further find, if his results were correct, that the prices paid for his stock do not justify the use of some parts of it. In other words, the material with low melting losses may be carrying the remainder on the cost item.

Poor melting practice will add another set of losses. Thus, the carbon is certain to go down and the iron itself will waste away through oxidation, going into the slag. Every foundryman should know his melting loss with reasonable accuracy. If he arranges to put the work made daily through the cleaning department, there should be no reason why he may not keep in close touch with the situation.

CHAPTER XI

MELTING PROCESSES (CONTINUED)

THE AIR FURNACE

This furnace is also known as the "straight-draft" or "coal" furnace, and is one variety of the type known as the "reverberatory furnace." In general foundry parlance the term "air furnace" is recognized as the conventional one.

The air furnace may be defined as a hearth furnace with firebox and melting chamber separate. The chimney draws the flame over the fire-bridge and through the melting chamber, the gases sweeping over the hearth. These gases partially melt the stock charged but particularly heat the walls and roof of the chamber to incandescence, and the radiation from these interior surfaces do the real work of melting and superheating the metal.

Fuel and metal are therefore not in direct touch, except only where the iron has contact with the gases and the fine ash carried over. Hence, there is an absorption of some sulphur, but not as serious as in the case of the cupola.

There are two general types of the air furnace recognized in foundry practice. The first is found in gray iron foundries and is used for the production of high-grade metal, such as "gun iron," chilled and sand rolls, important steam and gas-engine cylinders, as also other work requiring special physical qualities and great strength. This furnace is not long, fairly high and wide. As it is charged from the end it is possible to introduce entire cannon, rolls and very heavy pieces of scrap. The furnace is therefore built for heavy tonnages, 25 being the ordinary size, while occasionally one sees a 40-ton construction. These furnaces are operated by natural draft, the ash pit being open and the slicing of the fires quite convenient.

The second type of furnace, on the other hand, is very long, narrow and with a low roof. It is used almost exclusively in the malleable foundry, which industry has to do with light sections and hence requires the charging of nothing heavier than pig iron. The roof of the malleable air furnace is, therefore, made removable—consisting of a series of "bungs," and most of the charge goes in from the top. The ordinary size of these furnaces is 12 tons, and should in no case exceed 20 tons, for metallurgical reasons connected with the production of this class of work. Small furnaces of this type—down to 1 ton—are also operated, but these are rather special. Of late years the malleable foundry has borrowed from open-hearth practice, and now it is customary to run a series of heats before shutting down to repair bottom, whereas this was done after every heat in former days. In the case of the furnace for gray iron, shutting down for fixing up the bottom is essential after every heat.

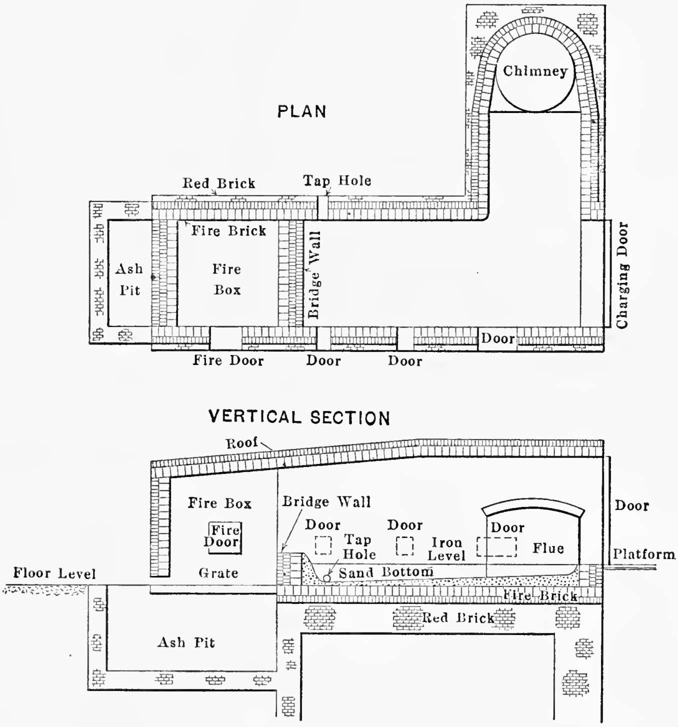


Fig. 38.—Air furnace for iron foundry.

Fig. 38 illustrates an air furnace used in the iron foundry. The melting chamber, fire-box and flue to chimney are really a continuous room the roof and sides of which provide excellent radiating surfaces. The fire built on the grate (to the left of the illustration) receives the necessary air from beneath. The chimney draws the air through the fire over the bridge wall sweeping forward to the main charging door closing the entire end of the melting chamber. Then the flame sweeps around into the large flue to the base of the chimney, up which it ascends. The fire is cleaned with the slice bar at the open end of the grates, clinkers and ashes dropping into the pit.

Natural draft is used almost universally in the iron-foundry air-furnace melting operation. In malleable air-furnace practice, forced draft is nearly always employed, usually with the addition of a top-blast, as will be mentioned later. For natural draft the chimney must be fairly high, 60 to 85 ft. being the usual range, and 75 ft. a good average. A good draft is necessary to insure proper combustion of the coal used and carry the hot gases quickly to the farther end of the melting chamber. Too much draft is objectionable as it raises the temperature of the flue and chimney walls too high, thereby exposing the rather thin layer of molten metal at these points to oxidizing influences with consequent damage to the iron. Hence, while 60 ft. may be considered too low a chimney, 85 ft., on the other hand, is somewhat high.

The American arrangement of placing the chimney at one side of the end of the melting chamber—this itself arranged as an "L"—is a rather good one. When the interior lining of the furnace has become incandescent, it will be noticed that there is heat radiation upon the bath from every angle. The roof radiates downward, the sides toward each other, the charging door toward the bridge wall, the end wall of the fire-box toward and over ths bridge wall. Similarly, the rear chimney wall toward the front wall of the furnace, and the flue walls and roof upon the bath beneath. If the interior surfaces of the furnace are kept in first-class condition, the doors are lined and tight, and the firing is done so that the excess air over that necessary for combustion is held down to a minimum, excellent results are obtained.

The English (Staffordshire) air furnaces are straight—the chimney at the end—and thereby lose the advantage of the bend. Doubtless the bend in question was an after-thought as the size of the furnaces increased. The arrangement in question allowed the charging of heavy pieces, impossible in Staffordshire furnaces as ordinarily constructed, and also made the length of the furnace better adapted to the buildings used. In American malleable practice the air furnace used is also straight but simpler in its lines than the European types. In all these furnaces the lowest point of the bath—the location of the breast and tap-hole—is near the bridge wall. That is, the heaviest stock is placed close to the hottest part of the flame, and the pool of metal collects there first, becomes deepest and receives the greatest heat.

In German air-furnace practice, this is reversed. The furnace is straight as in the English and the American malleable furnace, with the chimney at the end. The deepest point of the bath, however, will be found not at the bridge wall but right under the chimney. In fact, the metal is tapped from the rear wall of the chimney. The faultiness of this arrangement lies in the exposure of the thinnest part of the bath to the most intense heat, with the corresponding disadvantage of placing the deepest part of the bath at the point of lowest temperature. This must make for cold iron at the tap, and burnt iron at the end of the heat in far greater measure than in American and English practice.

There are, however, a number of oddities in furnace construction—just as in the case of the cupola—which have given the metallurgical world the "camel-back" furnace, a development of the Staffordshire furnace intended to have the lines of the roof and bottom follow the supposed sweep of the flame. Then also, the German idea of the sump (deepest part of bath) under the chimney may be seen in some English furnaces. All these phases of the air-furnace problem will not be discussed here, as, while still to be seen in service, they are unnecessarily complicated and obsolescent.

The story is quickly told when the cost of repairs and the melting ratio is considered. The simpler the furnace, the straighter the lines, the cheaper to keep it in repair. The coal bill for the tonnage produced shows remarkable variations for different furnaces of the same tonnage. Ideally, 4 lb. of iron should be melted per pound of coal. Practically 2½ may be considered fair, and oftentimes 1 to 1 is the best that can be obtained. That this should be the case with the oldest melting furnace in existence (the shaft furnace, though older, was originally used for ore reduction rather than melting) shows how sadly the scientific development of this furnace has been neglected. This has been due to two facts: First, the secrecy of the founder operating such a furnace. He did not show his own furnace and consequently could not see that of his competitor. He, himself, knew nothing of the technology of combustion, and hence changed the lines of his furnace and his firing practice until he got what he thought was good action. Second, the scientific effort that was brought to bear upon the problem resulted in caring for the waste heat and developed the Siemens-Martin (or open-hearth) furnace without improving the air furnace itself. Those who have operated the open-hearth furnace do not willingly go back to the air furnace again.

The fact, however, that a better grade of iron is produced in the air furnace than in the cupola, when both are run properly, has allowed the former to compete with the latter in spite of the waste in fuel through poor design and the unavoidable heat losses in the escaping gases. Again, the skill required in operating the open-hearth furnace, and its high first cost, have kept this highly efficient melting furnace out of the gray iron foundry, though it has found its way into malleable practice sufficiently extensive to show unquestioned superiority in every way.

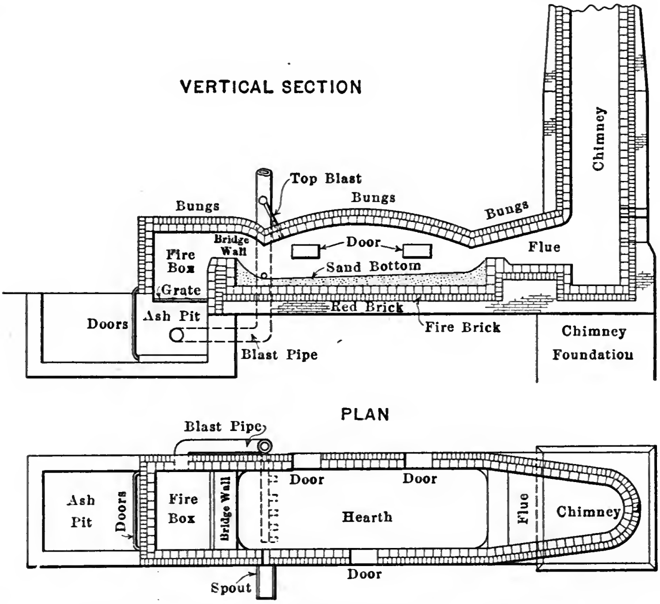


Fig. 39.—Air furnace for malleable iron foundry.

Reference to Fig. 38 shows that the iron-foundry air furnace is roomy, wide, easily charged and on the whole not costly to build. Hence the natural tendency to use it where a better grade than cupola iron is required. The furnace is found in all roll foundries, the larger works making gas and steam engines of great power, for locomotive cylinders using highly superheated steam, pistons and piston rings and castings that require specially fine iron. The great cast-iron guns of former days were all made of charcoal iron melted in the air furnace, and today there is a revival of this melting process because of the demand for quality castings. It is a case of retaining the advantages of the peculiar physical structure of cast iron, if this can be gotten of greater general strength, rather than turning to the steel casting.

Fig. 39 shows the general idea of the air furnace used in the malleable iron foundry. It is of very simple design, long, narrow, with a low roof and this conforming somewhat to the sweep of the flame. The ash pit is closed and a forced draft applied. In addition some of the air is introduced just beyond the bridge wall and inclined forward, the idea being to furnish extra air for more intense combustion and at the same time deflecting the flame upon the stock to be melted. The hearth is arranged just as in the iron-foundry air furnace. Particular care must be taken with the top-blast, as too much free air introduced at this point may do more damage than good. The position of the top-blast must be tested out until a proper location is found consistent with the draft conditions.

The roof of this furnace is usually arranged to be entirely removable in sections, called "bungs." This allows easy repairing of the furnace as well as cooling it down quickly. Further, in case a bung drops another can be readily put in its place during the heat without much interruption of the melting. A few bungs are always kept in reserve. The roof, or crown, of the larger type iron-foundry air furnace as also that of the open-hearth, is a more difficult problem and any serious accident to these means a partial if not complete shutdown for repairs. In charging the malleable air furnace, the required number of bungs are lifted off, put to one side, and after charging are replaced again, the joints between the bungs and with the side walls of the furnace being "mudded up" with fire-sand containing a little clay.

In discussing air-furnace details, the first thing to be considered is the relation of grate surface to that of the hearth. This is generally taken at 1 to 3 for furnaces of about 20-ton capacity. The range is 1 to 2.5 for small furnaces down to 1 to 4 for the very large ones. Strictly speaking, the relation should be calculated between grate surface and hearth volume, instead of hearth area, for the volume travel of the gases is a very important item.

To understand the action of the hearth furnace in general it is necessary to distinguish between the transfer of heat by conductivity and heat radiation. As previously stated, only a small portion of the heating effect in the air furnace is due to direct contact of the flame with the metal. The real work is done by the radiation of the furnace walls. This will be better understood when comparing the relative conductivity of iron and fire-brick. As the flame impinges on the metal charge in passing over and through the upper part of it, the heat is conducted away quite rapidly by the colder iron at the bottom and eventually reaches the hearth. In the meantime, the fire-brick of the roof and sides receive heat, and as the conductivity of this material is very poor, it accumulates rapidly at the surfaces and these become incandescent before the iron shows any inclination to start melting. This accumulation of heat within the brick increases proportionally with the temperature rise, for at about the melting point of cast iron the conductivity of the brickwork is more than five times as high as at ordinary temperatures. Yet even this would be taken as poor conductivity, particularly when compared with iron. As the fire-brick lining cannot pass much of the heat received outward, it begins to give it off inward in the form of radiated heat. The more heat received, the more given off, and a point is reached eventually when the process becomes stationary. It is the object of the furnace builder to so proportion his design that the hot gases remain in the furnace just long enough to attain this result.

This figure is a matter of practice and must be obtained from furnaces which have given specially good results. The simplest basis to calculate upon is to find out how many cubic feet of gas comes from the fuel burned per second, and divide this into the total cubic feet of space in the melting chamber. This will give the number of seconds the gases remain in the furnace for effective work.

In connection with the above basis for calculation, the following data have been developed: The amount of coal supposed to be fired in the air furnace per hour, per square foot of grate surface, will usually run from 40 to 55 lb. The latter figure is really forcing the fires very much, and unless the stack is high enough to give a sufficient supply of air, there will be incomplete combustion and a considerable waste of fuel. As a case in point, the performances of two American air furnaces may be given. One of them was fired strong enough to burn 53.5 lb. of coal per sq. ft. of grate surface, and melted a heat with a ratio of 3.65 lb. of iron to 1 lb. of coal. The other furnace used 51.3 lb. of coal per sq. ft. of grate surface and got only 2.30 lb. of iron per lb. of coal. The same furnaces, when running 22-ton heats each, and fired with 44 lb. of coal per sq. ft. of grate surface, had ratios of 4.00 and 2.75 lb. of iron to 1 lb. of coal respectively.

While 40 lb. of coal per sq. ft. per hr. has been given as the usual lower limit, it may be stated that it is far better to fire only 30 lb. of coal per sq. ft. of grate surface. This allows the pushing of the fires when the heats charged are larger than usual. As a matter of fact, this point has been examined by the author in connection with a number of American air furnaces, and the firing rate in the majority of cases varied from 31 to 35 lb., and incidentally the melting ratios for this range of firing ran from 3.5 to 4 lb. of iron per lb. of iron, or far better than the usual results obtained with the air furnace—which is often as low as 1 to 1. Indeed, the firing rate of 31 to 35 lb. per sq. ft. of grate surface per hr. in vogue can be considered as rapid firing, for in boiler practice 25 lb. is considered a good figure and 40 lb. is extreme, the latter figure requiring air passed over the bed in addition to that drawn through the grates.

The general conclusion that would be drawn from the above figures, the grate area of a furnace being fixed, while the capacity can be materially increased by deepening the bath of metal, is that the tonnage should be limited to the amount it is possible to melt reasonably fast without increasing the firing rate over 35 lb. of coal per sq. ft. of grate surface per hr. Long heats are not good for metallurgical reasons (excessive oxidation and reduction in silicon and manganese), and hence, if possible, the grate area should be made more nearly two-fifths of the hearth area than one-third at the time the furnace is originally built. This will enable easy firing and give greater satisfaction.

The volume of the gases coming from a given quantity of fuel would be the next consideration. It has been stated that the percentage of air in excess of that required should be a minimum—to keep the flame temperature as the highest point possible. Therefore, the usual 100 per cent. given in boiler firing should be reduced to possibly 25 per cent. This figure will, of course, vary with the coal used, the skill of the melter or stoker doing the firing, atmospheric conditions, etc.

The calculation of the gas volume obtained by the combustion of 1 lb. of coal, with an air excess over the theoretical of 25, 50 and 100 per cent., would give the following figures:

Temperature, degrees F	Volume of gas per pound fuel in cubic feet			
	No excess air	25 per cent. excess	50 per cent. excess	100 per cent. excess
32	150	187.5	225	300
212	205	256.0	307	409
1112	479	598.0	718	957
1832	697	872.0	1,046	1,395
2500	906	1,128.0	1,359	1,812
2800	992	1,240.0	1,481	1,985

This would indicate that for every pound of coal burned in the air furnace under what might be called normal conditions—that is with easy firing and only 25 per cent. excess air—the volume of the gases produced, at the prevailing average temperature over the hearth of 2,800°F., is about 1,240 cu. ft.

The table above given has been taken partially from Rankine, the data for the column of 25 per cent. excess air, as well as all the figures for the temperature of 2800°F. having been worked out by the author. The supply of air to burn a pound of coal under theoretical conditions is taken at 12 lb. With a 25 per cent. air excess, it becomes 15 lb., with 50 per cent. excess air, 18 lb., and with 100 per cent. excess air, 24 lb. At 32°F. the volume of a pound of air can be taken at 12.5 cu. ft., and the volume of the gases for the several degrees of dilution with excess volumes at the temperatures given are worked out by the formula: Volume wanted equals volume at 32°F. times temperature plus 461.2, divided by 493.2.

Where, as in malleable practice, the ash-pit doors are sealed tight and a forced draft is depended upon, the figures just given will enable a calculation of the size and speed of the fan to be used —the fan serving the purpose perfectly here as there little back pressure and no change in this during the operation. Taking 12.5 cu. ft. to the pound of air, and 15 lb. air as required for burning a pound of coal with 25 per cent. excess air, we have 187.5 cu. ft. air at 32° F.—or better 200 cu. ft. at ordinary temperatures—for each pound of coal to be burned. With the area of the grate known and the rate of 50 lb. coal per sq. ft. per hour used, the cu. ft. per minute to be delivered by the fan can be easily calculated. In malleable practice, with forced draft, it is best to use the high figure for coal consumption in order to have enough air to care for the "top-blast" in addition to the volume sent under the grates.

The author has calculated out the volume travel of the gases in a number of American air furnaces, and then compared these with the published results of Osann, for German air-furnace practice. First, the pounds of coal burned per second were figured out for each furnace, and the range was from 0.24 to 0.59, the latter for a 35-ton heat. These results multiplied by 1,240 —the cubic feet of gases at 2800°F., coming from each pound of fuel—gave the total cubic feet of gases per second traveling through the furnaces. Dividing these figures into the cubic feet of melting chamber space for each furnace, gave the number of seconds the gases remained in the furnaces while giving off their heat to the brickwork and the metal. These figures varied from 0.83 up to 1.48 sec. It was interesting to note that in two cases giving 1.48 sec. as the rate of volume travel, the melting ratios were 4 lb. of metal to 1 lb. of coal each. The case with 0.83 sec. was as low as 2.3 lb. of metal to 1 lb. of coal. The same furnace when fired easier, or with a rate of 1.00 sec. gas travel, improved the melting rate from 2.3 to 2.75 lb. of metal per lb. of coal. Other furnaces showing this rate at from 1.20 to 1.26 had melting ratios of 3.5 to 3.75 to one. All of which shows the importance of giving the gases a chance to deliver their heat to the brickwork before passing out of the melting chamber.

Referring to the German furnace results published by Osann, which he quotes as inferior to American practice, a recalculation of his figures to bring them on the same basis as the author's, namely, changing his assumption of a 100 per cent. air excess to only 25, and giving the gas volume at 2800°F. instead of at 32, result in multiplying his figures by 4.5. As a consequence the volume travel rate of the gases is very high, running from 0.38 to 0.66 sec., or more than twice as rapid as in American practice. In fact, an American furnace quoted by the German authority in question shows 0.80 sec., or very close to the fastest rate given by the author. These remarkable speeds, only realized when figuring the gases at their proper temperature, will probably account for the particularly slow melting rate shown by the German air furnaces. Fourteen-ton heats are given as taking 12 hr. to carry through the melting process, American practice doing this in 7 hr., and in the case of the malleable air furnace in less than 5. An 8-ton heat is given as taking 8 hr. whereas it should be less than 5. Finally, a 27-ton heat is quoted as taking 20 hr., while American practice can get a 35-ton heat in 9 hrs.

A further investigation of the German figures reveals the fact that while the relation of grate area to that of the hearth in American furnaces is 1.0 to 3.0 down to 1.0 to 4.4—being probably similar in the German furnaces—the relation of grate area to the volume of the melting chamber must be quite different. Unfortunately the actual dimensions of the German air-furnace grates are not given, but as the space contained in the melting chamber above the bath, and the tonnage is given for each furnace, this relation will serve for comparison. This varies from 9.60 cu. ft. of melting chamber space per ton of iron melted to 18.48. The American furnace quoted has it 18.85 cu. ft. per ton of iron melted. The American furnaces investigated by the author, on the other hand, run from 22.5 cu. ft. (in the furnace with a poor melting ratio) up to 45.5 cu. ft. of melting chamber space per ton of iron melted. The German furnaces are evidently too low for effective combustion, and this is further borne out by the very bad melting ratios given—all but one being 2.5 lb. of iron melted per lb. of coal, and lower. These figures again emphasize the desirability of plenty of melting room and time for the hot gases to unload their heat units upon the brickwork.

While the velocity of the gases in the air furnace, as shown by the foregoing figures, must be very high, this must be understood as occurring only when the furnace is up to full heat (2,800°F.). Until that period is reached the volume of gases is much smaller, as can be seen from the table quoted previously. That the velocity is high, however, can be readily imagined when watching the minute particles of incandescent ash carried along with the flame.

Hearth.—The dimensions of the hearth of an air furnace will depend upon the tonnage to be melted, the nature of the coal to be fired (length) and the allowable width. The latter should not exceed 6 ft. 6 in. for ready firing, though American examples show up to 7 ft. A minimum would be found in 4 ft., naturally for very small air furnaces. American examples show an average of about 6 ft. whether the tonnage is large or small. Furthermore, there is a pretty fair agreement on the length of American air furnaces, this being an average of 18 ft. In many cases, however, but 14 ft. is allowed for the melting chamber proper, and the other 4 are credited to the short arm of the "L"—that is, the large flue leading to the chimney, the bottom of which serves as part of the metal bath. With these dimensions pretty nearly fixed as the result of experience, the proper proportioning of the melting chamber volume is arranged by fixing the height to give the desired gas travel. Hence, for small tonnages the furnace would have a comparatively low roof, whereas for large tonnages the roof would be high for almost the same hearth area. This, however, can be overdone to some extent and it were better to keep the roof high, have a good length and narrow the furnace for light tonnages.

The selection of 18 ft., as the average length of American furnaces is probably due to the use of the very fine Westmoreland gas coal as fuel. The flame from this is remarkably long and gives the best melting results known. Where it is necessary to use a poorer grade of fuel—it should be as non-caking as possible —the flame will be shorter, and here the length of the furnace can be cut down to advantage and the width increased correspondingly. Such a condition often exists in large cities where the smoke problem is acute. Probably this also accounts for the lengths quoted for European furnaces, the coal there being different in its properties from the American. Nine feet 6 in. to 12 ft. 6 in. are the lengths in question. In designing for American conditions, it would be desirable, therefore, to fix the length of the furnace at 16 to 18 ft., the width from 5 ft. to 6 ft. 6 in., and make the roof high enough to give 35 to 40 cu. ft. per ton of normal charge.

It may be mentioned in passing that the former method of sloping the roof down toward the stack, and thus reducing the furnace cross-section toward the rear, has given way to the opposite procedure. The cross-section of the chamber is made larger just before reaching the flue to the chimney, it having been found desirable to provide combustion space to utilize the otherwise imperfectly burned gases and hydrocarbon vapors from the fuel. In some furnaces the roof of the rear half of the melting chamber is made to rise abruptly, making an easier construction problem as well as furnishing a convenient charging chamber right at the end charging door. It is probably better, however, to have a straight roof sloping a little upward from front to rear of the furnace. It is just as desirable to have a good combustion chamber over the.grates as over the bath.

The designer of a furnace usually likes to have some figures on the square feet of hearth surface per ton of metal charged on it. The limits are usually taken at 10 sq. ft. per ton for small furnaces and 4.5 sq. ft. for very large ones. If the above-mentioned limits for width and length of hearth are adhered to the areas in question will work out 8.0 sq. ft. per ton for furnaces of about 10-ton capacity, down to 4.7 sq. ft. per ton where the capacity is about 25 tons. For very large tonnages the length of the furnace will have to exceed the 18 ft. given, and the width cannot be less than 7 ft. American furnaces do run about 4.3 sq. ft. per ton for very large units and are perhaps unnecessarily generous for the smaller units, these going as high as 10.5 sq. ft. per ton. This is probably, however, in order to overstep the normal capacity of the furnace when necessary.

The *grate area* has been given as preferably two-fifths of the hearth for small tonnage furnaces down to one-third the hearth area for the larger ones. Since the depth (length) of the grate should be the same as the width of the hearth for easy furnace construction, this would bring the width of the grates two-fifths to one-third of the length of the hearth. In actual American example the lower limit is stretched to one-fourth the hearth length, and this accounts for the forcing of the fires to make good time.

The *chimney area* can be taken as one-fourth that of the grate surface. With a proportionally large grate area it is possible to reduce this figure, and in fact one American furnace it goes as low as 14 per cent.; all the others varying from 20 to 40 per cent. The chimney in question is, however, very high and in this way makes up for the small cross-section. It is better to have the chimney larger and higher than actually necessary, for if the rear wall near the base is provided with an arched opening which can be partially or completely closed off with a grid of loose brick, it is possible to check the draft as desired by admitting cold air. The best height of the furnace chimney has been found to be about 75 ft.

The *flue* connecting the chimney with the melting chamber is supposed to approximate about 10 per cent. of the grate area in cross-section, in fact two of the American furnaces studied show 10 and 16 per cent. respectively. The conditions existing at this point are, however, so severe upon the brickwork that repairs are somewhat costly, and hence American practice has leaned toward large flues. Most furnaces, therefore, have the flue and chimney cross-section about equal; or in other words, the chimney, as a flue, really begins at the melting chamber—the shape being rectangular and the position horizontal, so that the bottom may serve as the continuation of the hearth. Considering the circumstances this arrangement is probably better than the severe reduction in area mentioned, and hence a flue cross-section of 25 per cent. the grate area, just as for the chimney, is recommended.

The height of the *fire-bridge* or bridge walls above the grates ordinarily varies between 22 and 24 in. For very small furnaces it may go as low as 18 in. and for very large ones up to 26 in. In general it is better to keep this distance low to get the flame into the furnace quickly, as also to compel the fireman to hold the fuel bed as thin as may be. The mistake is often made of putting layers of loose fire-brick upon the bridge wall and thus retaining the heat which should go to the melting chamber promptly in the fire-box. The consequences are sometimes disastrous to the roof at that point. Moreover, if the roof is low, the free passage of the flame is choked considerably by such a procedure and there is little chance of heat radiation from the fire-box walls over the bridge into the melting chamber. The situation at this point in the iron-foundry air furnace is better than in that for the malleable industry as the cross-section of the furnace above the bridge wall in the former is at least 40 per cent. of the grate area if not actually equal to it; whereas in the latter it may be as low as 20 per cent. No attempt should therefore be made to retard the flame and products of combustion in the fire-box by an extra-high bridge-wall, or very low roof, but a good roomy space should be provided to aid the perfect burning of the fuel.

The bridge wall is usually allowed to overtop the level of the molten iron by 6 to 12 in., the sand-bottom being made accordingly. This should slope but slightly—say 1/4 in. to the foot—and be arranged so that the iron may not feather out to a thin end at the rear of the hearth, but be at least 2 in. deep at the edges. This prevents undue oxidation of the metal and consequent damage to the heat. The thickness of the layer of molten metal should not ordinarily exceed 12 in. at the deepest point. In very heavy heats it may go to 18 in. and for small heats about 8 in. is the deepest point of the bath.

The sides and roof of the air furnace should have a thickness of at least 9 in. of first-grade fire-brick, and this reinforced outside at the side walls with either second-grade or red brick to make 13 or 18 in. Usually, however, an inner lining of 4 in. is used in connection with the regular 9-in. wall. The material at the slag-line is particularly liable to be cut away and hence must be watched carefully to prevent eventual collapse of the interior lining. The doors are best made as small as may be convenient to work through. The one for the fire-box can be 18 by 24 in. Those in the side walls may be 12 by 18 in. and even smaller. The furnace must be well tied in with beams and rods.

Recapitulating the air furnace data just given, for the purpose of planning as well as judging existing constructions, the following summary will serve:

1. *Hearth Area.*—For a required tonnage, if small, 8.0 sq. ft. per ton; if large, 4.7 sq. ft. (5 tons would be considered small, 35 tons large. Twenty tons is a good medium and would require 6.7 sq. ft. of hearth area per ton charged normally).
2. *Width of Hearth* (also depth of fire-box).—For 10-ton furnace 5 ft. For 25-ton furnace 6 ft. 6 in. For 35-ton furnace 7 ft. and for 5-ton, 4 ft. Other tonnages in proportion.
3. *Length of Hearth.*—Sixteen feet for tonnages up to 15; 18 ft. to 25 tons; 20 ft. above this.
4. *Capacity of Melting Chamber.*—Forty cubic feet per ton up to about 15 tons; 35 cu. ft. above this.
5. *Grate Area.*—Two-fifths of the hearth area up to about 15 tons; one-third the hearth area above this.
6. *Bridge Wall.*—Height above grate 26 in. for large tonnage, and 18 in. for small. Range of tonnages in proportion.
7. *Bridge Wall.*—Height above top level of bath 12 in. for heavy tonnage, and 6 in. for light. Other tonnages in proportion.
8. *Depth of Bath.*—Not over 8 in. for light tonnage, and not over 18 in. for heavy tonnages.
9. *Flue to Chimney.*—Preferably equal to chimney area, but rectangular and bottom a continuation of hearth, if necessary.
10. *Chimney Area.*—Twenty-five per cent. of grate area.
11. *Chimney Height.*—Preferably 75 ft.
12. *Firing Rate.*—Preferably 35 lb. of coal per sq. ft. of grate surface. per hr. The grate to be as near 50 per cent. "effective" as can be had without loss of coal.

The furnace construction should include proper platform arrangement, crane service for charging large pieces of scrap, bars for rabbling, skimming and patching bottom. Also a "peel" or heavy spade-like bar on which pigs can be placed, run into the furnace and tilted off. A large water-tank for cooling the tools as they come from the heat after straightening, and storage facility for coal, sand, etc.

As the operating of an air furnace is far more difficult than the cupola the foundryman who wishes to add this melting method to his equipment should visit existing plants and study the situation first. He can then build his air furnace with the aid of a good melter to remain in charge of it, and begin with small heats working until thoroughly familiar with the situation.

AIR-FURNACE MELTING PROCESS

The first thing that is necessary is the preparation of the sand-bottom of the furnace. When the furnace has been built and is ready to be dried out and bottom made, fire-sand, mixed with a very little clay, is thrown on the hearth bottom a few inches in depth at a time, and a slow fire kept up to bake it together. At the same time the heat will dry out the brickwork thoroughly. Gradually, the sand is thrown in at the doors and spread—also smoothed down from an opening in the end charging door—until the bottom slope has been approximately attained. The firing is then intensified for a while to thoroughly harden the bottom but not fuse it, the tie rods of the furnace being watched for any adjustment that may be necessary. The furnace is now ready for final preparation for charging.

Charging.—The end charging door being removed and the furnace sufficiently cool to work in it, fire-sand is first spread over the bottom to give the final pitch of the hearth from end and sides to the tap-hole in the breast. The breast and tap-hole in it is also made at this time, as it must be ready before firing commences—the lining of the spout being attended to later on during the heat. The sand used for the finish of the hearth can contain a little fluxing material, and hence sea-sand, which contains many minerals, is often used. However, perfectly pure silica sand will also answer, for the oxide of iron formed during the melting operation unites with the silica and makes it adhere together as a solid crust.

The amount of sand put on the bottom depends upon the tonnage to be charged at the time. A heat smaller than the normal capacity of the furnace requires more sand, to bring the level of the bath up to working doors. Extra large tonnages may even require blocking up part of the doors to prevent the metal from coming out. In any case, the sand should be banked around the edges to give a few inches depth of metal at the shallowest points, to prevent oxidation. Melters become quite expert in arranging their bottoms for required tonnages. Furnaces should not be overloaded if at all possible—better to run another heat to care for surplus molds.

As the sand is loose until the heat is well under way, it is necessary to protect the bottom while charging. Hence, scrap boards are laid over the bottom which burn away later on. Any heavy pieces to be used go in first, being placed right against the bridge wall. Where the air furnace can be served by a Gantry-crane in the metal yard, a counterweighted beam can be used to advantage—this reaching into the furnace and depositing the heavy piece where wanted. Scrap rolls can be gotten in readily, but salamanders give no end of trouble if moved by hand. Hence the protection of the bottom is necessary. The heavy special pieces being in, the lighter scrap and sprues are charged next, either being wheeled in and dumped next to the large pieces or carried and placed to advantage. Finally, the pig iron is charged in specially built up grid-like rows piled crosswise upon each other. This arrangement gives a high pile of metal perfectly open to the passage of the flame and gases. In fact, the hot gases must pass through the piles to get into the chimney. The big charging door is then closed and luted up.

The fire is now lit up, the necessary shavings and split wood having been laid previously. Some oil-soaked waste put in the bottom of the stack through the door at the base, when lit up starts a good draft and keeps the smoke out of the foundry. The fireman now begins to get his fire agoing, throwing in his coal a little at a time and spreading the burning and coking fuel over the entire grate surface. In this way he builds up his fire until the bed is just thick enough for proper combustion. The firing problem now becomes extremely important, as it is necessary to attain the highest temperature possible and maintain an even generation and flow of the gases over the bath. Perhaps there is more ignorance exhibited in this part of the melting process than in the rest of the operation. Few firemen give the necessary attention to the niceties of the work that they should. The consequence is long and poor heats.

The proper method of firing is the following: The general principle is to open the firing door, pile up the coal to be charged as close to the front as possible, and close the door again. At the proper interval, the door is opened, the burning and coking coal is pushed forward over the fire and spread evenly about it, the new supply of coal put in as stated and the door closed again. This should be done as regularly as clockwork. Between the firing periods the fire must be sliced to break up clinkers that may have formed, let the ash drop through the grates, and generally keep the bed clean and the air inlets open.

It will be seen that with a given consumption of coal—say 35 lb. to the sq. ft. per hr., if the smelter or fireman has to care for a grate area of 30 sq. ft., or about 12 ton per hr., he can divide this into charging periods of so many minutes each and introduce the proper number of shovel-fulls each time. The fire-door must be kept closed as much as possible to prevent air currents coming in and thus interfering with the regular combustion by that entering through the grates. If sufficient air comes through the grates to give proper results, any excess passing in over the fire can only cool the gases. Special devices have been gotten out to compel the shutting off of this extra air, the coal going into a hopper and falling in position to be pushed inward on turning a gate. The pushing bar passes through a movable plate which allows perfect freedom and yet prevents the entrance of the air. This method does away with the fire-door altogether and is very successful if the furnace is properly designed for ample grate area. Where, on the other hand, furnaces are overcharged, the fuel used is usually so excessive that the door must remain open practically all the time, as coal is passing in almost continuously, no special device of the kind mentioned will be of any use. The melting operation starts with a handicap under any firing conditions.

The fire should be in fair shape within the first ½ hr., and gradually the interior of the furnace will begin to brighten up. It will still be possible to see the joints of the brickwork and the pieces composing the metal charge for some time, but gradually the light becomes too strong for the naked eye and glasses have to be used to distinguish the individual pigs, etc. About 1½ hr. after lighting up melting should be well under way, the molten metal dripping from the pigs in the sweep of the flame, and the lighter scrap collecting into a pool as it melts. Next, the tops of the heavy scrap pieces right at the bridge wall begin to waste away, and as the heat progresses the melter should introduce his heavy rabbling bar and break up the metal pile as much as he can, throwing the pieces into the bath of molten metal already formed. This saves time, for if the mass of metal settles down in a heap of half-melted and tightly adhering pigs and scrap pieces these will keep the bottom they cover cold for a long time.

In the long and comparatively narrow malleable air furnaces, a good melter piles up his pig carefully at both ends of the hearth and charges the light sprues in the center. These melt first and as the heat progresses, he skillfully loosens pig after pig from the melting piles and directs them into the molten bath. In this way ½ hr. may be saved of the usual melting time, and this means coal saved, less oxidation, and therefore better iron.

In the large iron-foundry air furnaces, this method of hastening the heat can hardly be applied. Nevertheless, the melter should industriously poke the melting charge about as much as he can, push the partly melted material lying on the bottom and under the surface of the bath to new places, and in every way try to communicate the superheat of the molten metal to the pieces not yet fully melted. In this way the entire heat becomes liquefied, the heavy chunks probably going last. The heat is now well rabbled, the melter pushing the current of the top metal toward the rear and urging the bottom metal to the bridge wall. The metal is thus well mixed and the temperature made more uniform. The heat is now ready to test.

One of the advantages of air-furnace melting is the ability the foundryman has to correct his analysis before tapping out the heat, to some extent at least. This, of course, refers particularly to the relation of the carbons as wanted in the final castings—which, in turn, depends upon the section and the silicon percentage in greatest measure. Hence the universal use of a "chill test" in air-furnace practice. This is a rapid method of determining the chilling quality of the metal and judging the silicon content therefrom. A box of molding sand is kept at the furnace for the purpose. The sand is properly tempered and rammed about a block of wood set against a thick plate of cast iron to serve as a "chiller." The block of wood serving as the pattern being removed, an open-sand mold remains, one side of which is of metal. The molten iron poured into this mold is chilled at the point in question. As soon as set the casting is taken out, dipped into the water-tank to cool sufficiently, and then broken across the chilled end. The fracture gives the depth of the chill and from this it is possible, with regular daily practice, to estimate the silicon content pretty accurately. In roll-work, where the depth of the chill required of the product is one of the principal requirements, it is necessary to make allowances in judging from the test piece. The roll will always come out with a lighter chill than the test, and hence an allowance of about ¼ in. is made; a test showing ¾ in. chill would mean probably one ½-in. chill in the roll. Again, for flat work, or lighter section pieces than rolls, other experiences may be had. Hence the foundryman using the air furnace must work to a code of his own in this regard, so that he may know whether his heats are ready to pour—from the composition end.

After the test has been made, the heat is allowed to remain under full fire until superheated enough to pour. It may be necessary to remove the slag which has collected on top of the bath in order to allow a better penetration of the radiated heat. This also gives a chance for vigorous oxidation, which is not good for the iron, but cannot be avoided under the circumstances. The metal gradually becomes hotter, the silicon and manganese, as also the carbon, going down. If carried on too long, there is a possibility of the chemical reaction becoming so intense that the heat actually "Bessemerizes," or starts to burn up, a phenomenon not good to see. Throwing in cold pig is the only way to stop this action.

A second test is now made to see if the chill has increased as expected, the first test always showing less chill than the final result. If the second test lacks slightly in depth of chill, the heat is held a little longer to allow more oxidation of the silicon, etc.—formerly called "refining." In the meantime, the heat is rabbled again and again to keep the temperature and composition as uniform as it can be made. Should the test show a serious lack of chill, low-silicon pig is charged in sufficient quantity to give the desired effect, due allowance being made for the time necessary to get the temperature up again. If, on making the first test, there is too much chill in evidence, or at least such a depth of chill that in heating up the bath the end result will be beyond the requirements, high-silicon pig is charged at once, and the bath allowed to heat up the usual way. The practice of adding iron ore to the bath to cut down the silicon and some of the carbon is to be condemned, as the addition of low-silicon pig is safer, and the use of steel takes care of the carbon question.

When the heat is ready to tap, so far as composition and temperature are concerned, it should go out at once. Every minute the metal is kept under the oxidizing influences of the furnace is detrimental to the quality of the product. The mistake is often made of letting the bath simmer a little longer, usually because the cranes are not available at the time, or the ladles not quite ready. This should be closely watched and taken in hand rigidly. An air-furnace heat is a sensitive thing which can turn out good or bad accordingly as attention has been given it. The general rule is to bring the temperature of the heat to where it is wanted and then out with it. Hence also the quicker the heat, the better. The following illustrates the time taken in making a typical roll heat of 11 tons, in a 12-ton capacity furnace:

Time of lighting-up	8:00 a.m.
Pig starts to melt	9:30 a.m.
Heavy scrap starts to melt	9:40 a.m.
Pig all melted	11:40 a.m.
Heavy scrap all melted	12:20 p.m.
First test	12:25 p.m.
Iron tapped, on second test	2:00 p.m.
Heat poured into castings	2:20 p.m.

The heat, therefore, took 6 hr., which is considered not much over normal for an iron-foundry air furnace, but would be 2 hr. too long in the malleable foundry. It must be remembered, however, that the malleable shop has not to deal with broken rolls as scrap, nor are the sprues as heavy in section.

Attention is again called to the necessity of avoiding feather edges of molten metal in the furnace, as the iron at the end of the bath if allowed to thin out to nothing is certain to be badly oxidized. When put into castings these are liable to severe internal strains which may cause them to fail. This is particularly noticeable in roll castings, the author having repeatedly traced the metal coming from the bath last—or the very end of the bath right under the chimney—as having gone into rolls which split lengthways, whereas the metal from the first and middle portions of the heat going into the identical sized molds came out all right. It is the close attention that must be given the air-furnace metal that makes the roll-casting industry the most difficult of the entire foundry line, for not only does the foundryman have his air furnace to watch but he deals with very low-silicon irons which are peculiarly liable to oxidation and consequent damage.

In general, it may be stated that the air-furnace product is lower in silicon than that of the cupola for the same classes of castings, because the avoidance of contact between fuel and metal allows this. The sulphur is much lower, the chances of oxidation —as compared with the way the cupola is usually run—much less. Hence, no special difficulty is experienced in getting good machinable castings with the silicon down to 1.25, a thing very unlikely with cupola melted stock.

The advantages of the air furnace may be summed up as follows:

1. A stronger, better iron than that from the cupola, if both are run properly.

2. Lower sulphur and less oxidation as a general rule. The coal must be good, of course, otherwise the sulphur may climb very high. As to oxidation, it may be stated that compared with the best of cupola practice, the air furnace has no advantage in this regard, for the silicon drop in the cupola then is 0.20, whereas it is 0.30 in the air furnace. The cupola is, however, not usually run as careful as the air furnace has to be.

3. The opportunity to change the composition before tapping—a thing impossible in the cupola, except to a small extent in the ladle.

4. The ability to reduce the total carbon definitely by steel addition in the charge (up to 30 per cent. steel can be used in the air furnace). This is not the case with the cupola, for even with 50 per cent. steel, or more, one does not know how the total carbon will come out on account of the absorption of this element from the fuel.

5. The getting of a large tonnage available in one tap if desired. This is not possible with the cupola unless there are several of them running at a time.

6. The ability to dispose of large and heavy pieces of scrap—impossible of handling and melting in the cupola.

The disadvantages of the air-furnace melting process are the following:

1. The great skill required, as compared with the cupola.

2. The inability to take off small amounts of iron at a time, as required in the ordinary foundry for gray iron. A cupola can

be banked for a while, an air furnace can be handled that way if necessary by putting on a slag cover and throwing over this a lot of slack coal—to hold the silicon unchanged—but this would rarely be done or even thought of. Even in the case of the malleable air furnace, where the metal is usually taken off in small amounts, it must be taken when ready and all of it must be used or pigged.

3. It is not possible to make several mixtures during the same heat in the air furnace, as can be done in the cupola. When this situation becomes obligatory, the custom is to add high-silicon cupola metal from the spout to a ladle partially filled with the harder air-furnace metal. While this gives a softer and better metal than cupola iron alone, it is not strictly air-furnace product.

4. The comparatively high cost of the air-furnace product, as compared with that of the cupola.

5. The necessity of making a fairly large heat even if only a small amount of metal is required. Similarly, the inability of overloading the furnace beyond a given tonnage. The cupola has a much wider range in this respect.

6. The comparatively high first cost of the furnace, and the larger cost of repairs, when compared with the cupola.

On studying the pros and cons of the situation, the deciding factor will after all be the quality required. Unless this is high enough to warrant the extra cost, the use of the air furnace is out of question. Many foundrymen hold that they can do just as good work with the cupola as the air furnace, and indeed many castings are made today from furnace iron which could just as well come from the cupola. The fact remains, however, that an air-furnace roll is ahead of one mdae from the cupola for certain mill uses, and there is no getting round the situation. It would seem, therefore, that cupola iron should be made under the best operating conditions possible, before the air furnace is taken up. After it has been taken up, however, the air furnace should be run under the best possible conditions also. The world is striving for the best in every line of activity. Hence, the eye of the foundryman should be turned toward the air furnace if running the cupola only, the foundryman who runs an air-furnace department should keep the open-hearth furnace in view, and all of them should keep the electric furnace in their minds.

But little need be added as to the operation of the air furnace. The breast must receive special attention, for the pressure of the metal behind it may be no larger than in the case of the cupola, but the chance of an accident, with consequent loss of the entire heat on the foundry floor, means special care. Where more than one heat is run per pay, as in the malleable foundry, a special graphite cylinder with finished tap-hole is built into the breast. The front of this shape is rounded carefully so that another graphite "stopper" held against it closes the orifice sufficiently to check the stream of metal. The melter can thus regulate the outflow of metal from full force down to almost nothing. With an arrangement of this kind, it is also easy to stop up and open up again with the usual body of clay, and the danger of driving at the tap-hole with the sledge so often necessary with the second heat for the same day is obviated.

THE OPEN-HEARTH-FURNACE MELTING PROCESS

It is not the purpose of this book to go into the details of the open-hearth furnace and process so far as the iron foundry is concerned, for the industry is not yet ready to take it up seriously, clinging to the air furnace for many good and sufficient reasons. Hence the reader is referred back to Chapter V for a general description of the furnace and the process. There need only be said that gas is the only fuel to be used, or oil sprayed in with air under pressure, amounting to gas for all practical purposes. If coal is the only fuel available, it must be converted into producer gas before it can be used.

The burning of the gas in the melting chamber of the furnace, the passing of the products of combustion into special rooms filled with checker-brick to absorb as much of the heat as is economical, the introduction of the cold air drawn in by the chimney into these chambers (after reversing the operation and sending the products of combustion the other way, into a second set of checker-chambers) and burning the gas with preheated air—all this means a far higher temperature than is available in the air furnaces. Whereas the maximum average temperature attainable in the air furnace is 2800°F., that of the open-hearth can be brought to and held at 2950°F. and be pushed if necessary to 3100. (Burgess.)

The consequence of the high-temperature situation is that the heats can be made much shorter, and the iron tapped out hotter. Comparing the time of the same tonnage heat of the different furnaces with each other, we have, for instance the 11-ton heat previously mentioned. This took 8 hr. in the iron-foundry air furnace. It could be made in the malleable-foundry air furnace in 4 hr. (in an 11- to 12-ton furnace, not in a 10-ton construction). In the open-hearth furnace, however, it should be taken out in 2½ hr. Hence also the efficiency of the fuel, the ratio being more nearly 6 of molten metal to 1 of fuel—or less effective only when compared with cupola melting. Where, therefore, a foundryman using a series of air furnaces at the present time, is reasonably certain to keep one or more of the furnaces in constant operation, the installation of the first open-hearth furnace seems the logical course.

The degree of skill required is necessarily higher than with the air furnace, the first cost is larger. The surprising feature, however, is that with big tonnages running perfectly steady, the cost of the molten metal in the ladle is hardly ½ ct. per lb. higher than where the cupola is used. The cost of iron under the same conditions in the air furnace is quite another story.

The tendency of the present day is to keep gray iron and steel jobbing foundries separate. This does not always work out well, and difficulties are constantly arising where the foundryman gets his contract for both classes of castings and has to sublet the steel, or *vice versa.* Hence, it is only a question of time when such shops may have to equip for both iron and steel castings—a thing quite prevalent in manufacturing concerns that consume their own product. It is under such conditions that the gray iron shop can use a small open-hearth furnace for making the steel castings wanted, and at the same time run gray iron heats for high-quality work otherwise made in the air furnace. The author ran gray, malleable and steel heats in the same furnaces day after day in his own foundry without any difficulty.

With the growth of the country advanced melting methods are bound to find their place, and it will be only a question of whether it is the open-hearth or the electric furnace which becomes the survival of the fittest.

THE ELECTRIC-FURNACE MELTING PROCESS

If but little has been said of the open-hearth melting process for the iron foundry, even less need be said for the electric-furnace melting method. The method in question has but just gotton a foothold in the steel-casting industry and has yet to prove its superiority over the open-hearth process. That is to say, it is well known that the electric furnace can do readily what is almost impossible in any other furnace—namely melt and superheat without the slightest oxidation. To do this regularly day after day, and without operating features which are disturbing to easy routine, has yet to be worked out satisfactorily, for electric steel castings show the same occasional blowholes as the best of open-hearth steel. This will, of course, not be so noticeable in gray iron work, but the problem will naturally have to be worked out for steel first.

The use of the electric furnace in the foundry generally is closely connected with the problem of cheap commercial electric current from central stations. The conversion of coal to current in enormous quantity under the most economical operating conditions may eventually be possible—with equally economical transmission factors—so that the foundryman can get his electric energy for melting during the periods of low load. With but little beyond the furnace proper, as an investment, he can melt his metal and pour the required molds. To do this economically, however, the charge for current must be very low indeed, but as the public service corporations, and the owners of coal mines are at work on this problem, it is quite possible that the not so far distant future may see something practical developed of benefit to the foundryman. He will then be all the more able to hold his own for quality as against the crowding of the steel casting which at one time threatened cast iron as well as malleable castings very seriously.

CHAPTER XII

MIXTURE-MAKING

In working out his daily and special mixtures, the foundryman has the following things to consider: First, the metal produced must be suited for the castings wanted; second, the metal must be the cheapest possible consistent with the quality desired. These considerations are based upon the supposition that the metal yard of the foundry contains the necessary selection of stock. As this is seldom the case, a further consideration would be the fitting of what is on hand to the purpose in view.

Taking up the first item: Chapter VII contains a list of practically all the commercial classes of castings, with the recommended analyses. It is not always possible to follow the recommendations, for—as above stated—a foundry metal yard rarely contains a sufficient variety of pig and scrap to do this. In selecting the metal for a given line of castings for which the mixture is to be made, the analysis is studied first to see whether the ordinary foundry irons will do, or if it is necessary to use Bessemer pig iron (phosphorus below 0.100), high-phosphorus iron (phosphorus over 1.00), high-manganese pig, or any other line of pig iron not classified as foundry stock. Again, the situation is examined to see whether extra-quality metal is necessary, as for instance cold-blast charcoal, the ordinary Lake Superior warm-blast charcoal pig irons, nickel and chrome pig, etc. Finally, the proportion of scrap and the kind of scrap that may safely be allowed. There are cases in which no scrap may be used, as for instance for ingot molds, where these, when worn out, go into the acid open-hearth furnace for making steel and must not exceed a given phosphorus and sulphur limit. Here pig iron together with the previous day's comparatively small percentage of sprues only may be used, to the exclusion of any foreign scrap.

The foundry business dividing itself into practically the jobbing shop, in which a general line of machinery and similar castings are made; and the specialty foundry, such as for car wheels, rolls, stoves, automobile cylinders, etc., the foundryman will have a general knowledge of the proportioning of his pig and scrap and hence no great detail is required here. It should be mentioned, however, that many foundrymen are apt to be too economical with their mixture, using poor pig irons, too much scrap, and badly selected scrap at that. The result is that they pay for this at the other end, and the losses are excessive. In times of high pig-iron prices the temptation to use 60 to 75 per cent. scrap instead of not more than 40 is strong. And yet it may prove good economy to use no more than 25 per cent. of shop and bought scrap combined, the latter being carefully selected at that.

Where therefore the foundryman is not limited to certain classes of iron or pig and scrap proportions at the outset, he must make up his mind as to the pig and scrap relation to be certain that his work will stand inspection and test. In ordinary jobbing work, the latitude is fairly wide, and perhaps a few instances can be cited to prove this. The author, as already stated in chapter VIII, in the absence of all pig iron ran 3 days on all scrap. Three per cent. silico-spiegel was charged with this scrap to keep the metal soft enough to machine. When pig iron came in, the old 60-pig and 40-scrap proportion began again, and probably not too soon as the sulphur in the mixture must have been climbing steadily from the sprues returned every day. This situation is not always realized in shops where very small castings are made and the proportion of sprues and gates to castings is consequently very large. The first day's heat may start with 0.06 sulphur in the mixture, and yield castings with 0.08. If the sprues amount to 75 per cent., meaning that but 25 per cent. pig goes into the mixture, the next day's heat will have possibly 0.07 sulphur and yield castings with 0.09. The sulphur content of the mixture will therefore climb one point a day, or thereabouts, and eventually there will be a lot of trouble.

A pig and scrap relation which will hold the sulphur down to normal by a proper amount of pig iron in the mixture should be ordinarily sought in all foundries where the work can stand heavy scrap percentages.

Another instance, showing the opposite scrap situation, may be found in foundries of those countries which can get the very cheap Middlesbrough, Luxemburg, or Birmingham pig irons by water. Here these irons are actually used as scrap, for the analysis rarely goes with the metal and, if originally known, is soon lost with the shifting of ballast from boat to boat by the time it gets to India, for instance. Foundrymen in such a position have but to add a lot of steel to the pig irons to get perfectly sound castings of quality.

The next question to consider is the behavior of the elements in pig iron and scrap during the remelting process, so far as this affects the mixture to be made to produce the required work. The elements to be considered are—in the order of importance—silicon, sulphur, manganese, phosphorus and total carbon.

Silicon is partially oxidized in the cupola and furnace melting processes. It is slightly increased in crucible melting if this is of long duration, as silicon is reduced from the clay of the crucible itself and enters the metal (as in steel-making). It can be kept unaltered in the electric furnace if desired. The only two phases of interest to the foundryman at the present day are the loss in cupola and in air or open-hearth furnace melting. This has been previously discussed and given at 10 per cent. for the cupola and 15 per cent. for the air furnace and open-hearth, roughly, with the best of melting practice. With poor practice the loss may be much higher, particularly in the furnace, when the heats are longer than they should be. For mixture-making purposes the foundryman may use 0.25 as the loss in silicon for the cupola, and 0.35 for the furnace. If he finds the first too high, or the last too low, he may use what he finds for his subsequent calculations—at the same time investigating the cause of the excess loss.

Sulphur is next in importance to silicon in mixture calculations. Every time a piece of iron is remelted, whether in cupola or furnace, the sulphur content is increased. Hence the previously mentioned attention to the scrap content of the mixture, so that this together with the sprues and gates may not eventually send the sulphur up to the danger point. The ordinary sulphur content of foundry pig iron is 0.05, that of bought scrap—the best machinery—must now be taken at 0.12. There was a time when it was but little higher than pig iron is now. Machinery scrap, after all, at one time meant good castings, for the metal was cast, machined up and used under good foundry conditions. Hence, it can be no worse than the material found in foundry sprues. Present-day specifications for cast iron and finished castings find it necessary to limit the sulphur content to 0.12, which tells the story. If the machinery scrap—meaning thereby that every piece must show evidence of being tooled in some way

—as bought is not carefully inspected, a variety of metal grades will be found accompanying the serviceable iron which seriously affect the results. Broken car wheels, for instance, mean low silicon and high sulphur. Grate bars—likely partially burnt—intensify the sulphur effect by the introduction of oxygen into the molten metal, etc.

The sulphur increase due to melting is the result of a direct absorption of this element from the fuel—by way of the products of combustion and the sulphur they carry. In good cupola practice this increase should not exceed 0.02 unless the coke is very high in this element. With poor practice and especially if complicated with bad coke, this increase may go up to 0.06. In the air furnace the situation is not so serious unless very bad coal has been used and the heat is long drawn out. With first-class conditions the sulphur rise should not be over 0.01. In the open-hearth furnace, with natural gas as the fuel, the rise may not be over 0.005.

Unfortunately, however, good practice has become more of an exception than the rule with the advent of the steel melter in the foundry using furnaces. This man will not put in the hard work required to shorten a heat, the moving of carefully laid pig into the bath one by one, the mixing and rabbling to promote uniformity of composition and temperature throughout the bath. He will wait for the mass to melt as it chooses and get his superheat through internal combustion of silicon, etc. The result is a long heat and unsatisfactory results when compared with the proper method. Incidentally a high sulphur increase—0.03 not being unusual.

Manganese begins to oxidize before the silicon, and in doing so partially protects the latter. The difficulty in making high-manganese irons in the blast furnace indicates how easy manganese returns to its oxide again if given the opportunity. Hence an unusual reduction in the manganese of a mixture on remelting is a sign of poor practice. With ordinary foundry pig irons used in a mixture it is generally recognized that if the manganese falls below 0.50 in the melt, this means trouble with the castings. In justice to those pig irons made of ores low in manganese and hence carrying less than 0.50 of this element, it should be stated that with good melting practice no difficulty is experienced.

For cupola work, if the manganese is figured with at all, the drop is supposed to be about 15 per cent. In the furnace, the reduction is much greater and may be taken at 35 per cent. This figure presupposes that no attempt at long drawn out refining is made but only simple melting and superheating. Otherwise the manganese loss may rise to 65 per cent., and that of the silicon up to 50 per cent. It is much easier and better to add steel to the furnace mixture to cut down silicon and carbon than to do any so-called refining.

Phosphorus.—The action of any remelting process of the acid type is simply that of concentration. That is to say, this element remains in the metal whatever else is oxidized away. If, for instance, 100 lb. of cast or pig iron contain 1 lb. of phosphorus, or 1.00 per cent., and on remelting in cupola or furnace but 99 lb. are recovered, then the phosphorus content will have risen to 1.01 per cent. From which it will be seen that provided the proper phosphorus content is had in the pig irons and scrap used, the mixture calculations need not include this element. Probably the only place where high phosphorus is essential is in the art-castings foundry, and here the purchase of pig iron with phosphorus specified over 1.00 will cover the case as the sprues and gates are usually so abundant that no outside scrap need be bought.

In the analyses recommended for the different groups of castings in Chapter VII, the phosphorus may vary quite materially from that given. The limits are fairly wide and under the ordinary conditions of operation the foundryman seldom bothers with this element in his mixture calculations.

Carbon.—The behavior of this element on remelting iron depends upon the process used and on the conditions existing at the time. In the air furnace and open-hearth melting processes there is a considerable reduction in the total carbon of the heat, this varying from 5 to 15 per cent. depending upon the silicon content, time of running and temperatures attained. In the cupola the change is not so marked, the influences being of an opposing nature. As cupola melting is an oxidizing process the natural tendency would be to cut down the carbon. On the other hand, however, the presence of incandescent carbon from the fuel in immediate contact with the molten iron tends to an absorption. Further, the silicon content determines—in connection with the temperature—the amount of carbon the iron may hold. Finally, with much steel used in the mixture, the metal is greedy for carbon absorption, as it were, and the content goes up. In general, therefore, with the higher-silicon mixtures and the absence of steel, the total carbon is apt to drop somewhat. With very low-silicon mixtures, as in malleable castings, the result of the cupola melt may show a higher total carbon, as the author has often found, particularly if the bed was high and the temperatures higher than the average. With steel in the mixture the absorption of carbon is so uncertain in amount though unquestioned in fact, that any attempt to base a new division of cast iron on the use of this material (semi-steel—*mirabile dictu*) must seem unjustified in the eyes of men trained in scientific reasoning.

The fact that irons may lose carbon in cupola remelting occasionally makes it necessary to specify that element (total carbon, not graphite or combined carbon) in the pig irons bought. This is, however, only where a peculiar softness is wanted in the higher-silicon ranges, or, *per contra,* where a maximum of total carbon is required in low-silicon chilled work to give exceeding hardness.

Ordinarily, however, the question of carbon does not enter into the mixture calculation beyond judging the percentage of steel scrap to be used in cutting down the total carbon content in the castings.

The question of nickel, chromium, vanadium, titanium and other additions in the mixture or in the ladle is a special one and need not be considered here.

From what has been stated so far it will be seen that mixture-making is a rather simple procedure if the following precautions are observed. First, to have the analysis of the pig bought, the specification of the elements being made to suit the requirements of the foundry. Next, to have frequent, if not daily determinations of the silicon and sulpur of the heats. Further, watching the sulphur in the fuel, and the scrap and pig proportions possible as shown by the sulphur analyses. The making of the mixture then sifts down to the calculation of the silicon only, and this is comparatively simple.

The question of pig iron specifications has been discussed in Chapter VIII, hence only one typical example of the proper method of buying this material, as required in the jobbing foundry, need be given, as follows:

Silicon to be stated exactly as wanted (see below).
Sulphur to be under 0.05.
Manganese to be under 0.80.
Phosphorus to be under 0.700.

The silicon preferably specified as 1.50, 1.75, 2.00, 2.25, 2.50, 2.75, etc. The Standard Specifications of the American Society for Testing Materials, which should be part of the contract, provide for the variations allowable on the part of the furnace filling the order. Iron bought this way and found by verifying the analysis that the specifications have been met, leaves the foundryman safe to calculate his mixtures on the silicon only.

To illustrate the method of calculation, let it be assumed that castings with 2.15 per cent. silicon are wanted, and that the melting will be done in the cupola. This means an addition of 0.25 silicon, or a total of 2.40 silicon in the mixture. The mixture is assumed to contain 60 per cent. pig and 40 per cent. sprues and scrap, each one, let us say 20 per cent. Every 1,000 lb. of the mixture will then contain the following:

Pig irons	600 lb.
Sprues	200 lb.
Scrap	200 lb.

If the castings made the previous days also contained 2.15 silicon, the sprues in question will have this amount. The scrap used, if good machinery quality, can be counted to contain 2.00 silicon. The simplest method to figure the silicon is in pounds. Thus the 1,000 lb. of the mixture must contain 2.40 per cent. silicon, or 24 lb. So far the following items are settled: Sprues, 200 lb. with 2.15 silicon, or 4.3 lb.; and scrap, 200 lb. of 2.00 per cent. content, or 4.0 lb. Of the 24 lb. required, the 400 lb. sprues and scrap will furnish 8.3 lb. This means that the 600 lb. pig iron has to bring the difference (24.0 less 8.3, or 15.7 lb.). Assume that the yard is well stocked and that the following pig irons are available: "A" with 3.00, "B" with 2.45, "C" with 2.20 silicon, etc. Since 600 lb. pig iron has to carry 15.7 lb. silicon into the mixture, the average composition of the irons used must be 15.7 divided by 600, or 2.61 per cent., which indicates that "A" may be mixed with "B," or preferably with "B" and "C" to get the proper quota of silicon to fill in with. Finally, it is not good to mix extremes in silicon (or any other element for that matter) in the cupola, for the product is apt to be irregular. It is bad enough to have pig and scrap come down separately and be caught in ladles and taken away for pouring in this divided condition, but if the pig is thus caught separately, the irregularity in the work is accentuated. The wisest course is therefore to purchase pig iron of the desired silicons and get but little of the higher- and lower-silicon extra irons for mixing purposes. Mixing 3.00 and 2.20

Si irons is not so serious, but when a 4.25 is mixed with a 1.00 silicon metal the results are not very trustworthy.

The division of the quantities of pig iron making up the 600 lb. under discussion is somewhat at the option of the foundryman as regards using up the metal he wants to have go first. Assuming in this instance that no preference exists, the division becomes a matter of cut and try. If equal parts of "A," "B," and "C" are taken, then the average of the 3.00, 2.45 and 2.20 silicons will be 2.55, or not far below the requirement. Again, if half of the iron were taken from the "A" pile, and the other half be divided between "B" and "C," the result would be as follows:

"A," 300 lb. pig iron with 3.00 silicon, contains	9.00 lb. silicon.
"B," 150 lb. pig iron with 2.45 silicon, contains	3.68 lb. silicon.
"C," 150 lb. pig iron with 2.20 silicon, contains	3.30 lb. silicon.
Total 600 lb. pig iron.................... with	15.98 lb. silicon.

The average would then be 2.66, or a little too high. For practical purposes either of these trials would not be far enough off to affect results seriously. To get the mixture more exact it will be necessary to reduce the item "A" and increase either "B" or "C" correspondingly. Thus, with 50 lb. taken from "A" and put on "B," the following showing will be made:

"A," 250 lb. with 3.00 silicon, gives.....	7.5 lb. silicon.
"B," 200 lb. with 2.45 silicon, gives.....	4.9 lb. silicon.
"C," 150 lb. with 2.20 silicon, gives.....	3.3 lb. silicon.
Total 600 lb. pig iron............ with	15.7 lb. silicon.

The average would be 3.61, or exactly the proportion desired. The mixture now stands as follows:

"A"..	250 lb.
"B"..	200 lb.
"C"..	150 lb.
Spruces....................................	200 lb.
Scrap......................................	200 lb.
Total......................................	1,000 lb.

If the charge of metal for the cupola is 2,000 lb. the above amounts are simply multiplied by 2. If it were intended to make an air-furnace heat, the castings from which would run as high as 2.15 silicon, the mixture would be 2.50 instead of 2.40 in this element, and the same method of calculation used. If the heat were one of 20 tons, the quantities would be 1,000 lb. times 40.

Take another example—using steel this time, for cylinders of heavy section. The analysis desired has been given as the following:

Silicon	1.00
Manganese	0.90
Sulphur	0.10
Phosphorus	0.30
Total carbon	3.00

A study of this analysis shows several things rather plainly. The total carbon is low because of a 35 to 40 per cent. steel content necessary in the mixture. The phosphorus can be gotten as desired with but little Bessemer pig iron as the steel content is so high and this carries practically no phosphorus. The sulphur will practically take care of itself as there is no objection to having this element below 0.10, though this point is not too high for cylinder castings. The manganese is somewhat higher than the ordinary but can be gotten by using one brand of pig iron with perhaps 4.00 manganese. The mixture calculation therefore could come down to a silicon basis finally. Since so large an amount of steel is used, it will not be safe to take any scrap other than the regular sprues of the previous melt, or if there are none, then no sprues at all. For purposes of calculation let it be assumed that the pig irons available, excepting some Bessemer iron, run about 0.700 in phosphorus; that the steel used shall be 35 per cent.; that the sprues used will be 10 per cent., and that one of the pig irons contains 4.00 per cent. manganese, the others running about 0.80 on an average. To settle the question of phosphorus, every 1,000 lb. of the mixture must contain not over 0.300 per cent. of this element. This would mean 3.0 lb. or less. Since there are 350 lb. steel in the mixture, and this material carries about 0.06 phosphorus only, this would mean 0.21 lb. Again, with 10 per cent. sprues, or 100 lb. and these carrying 0.300 phosphorus (the gates, etc., of previous days' work), a further 0.3 lb. phosphorus would be accounted for. This leaves the total pig, or 550 lb. of the 1,000 calculated for, to carry no more than the remainder of the phosphorus (3.0 lb. less 0.51, or 2.49 lb.) or an average of 0.45 per cent. phosphorus. Now with the exception of the Bessemer pig iron, which will not run over 0.100, the rest of the pig irons carry 0.700 phosphorus. Hence, there is at once an opportunity to fix upon the percentage of Bessemer pig in the mixture. This will work out as follows:

	325 lb. foundry pig irons, with 0.700 P contain	2.275 lb. P.
	225 lb. Bessemer pig iron, with 0.100 P carries	0.225 lb. P.
Total	550 lb.	2.500 lb. P.

Since the 550 lb. of pig were expected to contain 2.49 lb. of phosphorus, the above division between Bessemer and foundry metal is excellent.

The mixture so far contains the following:

Steel	350 lb.
Sprues	100 lb.
Bessemer pig	225 lb.
Foundry pig	325 lb.
	1,000 lb.

The foundry pig iron has still to be divided into one brand to carry the necessary amount of manganese, and the rest must supply the required silicon. The high-manganese brand in the yard has 4.00 per cent. Mn, and the rest of the pig irons run only 0.80, the sprues run 0.90 and the steel can be figured at 0.30. This would give the following: 1,000 lb. mixture to contain 0.90 manganese, plus the amount oxidized in the melting (or 15 per cent.). This means 1.06 manganese in the mixture (85 per cent. of this being 0.90), or 10.6 lb. Of this the 350 lb. steel furnishes (0.30 Mn) 1.05 lb., the 100 lb. sprues (0.90), or 0.90 lb. Mn, or a total of 1.95, leaving the remaining 550 lb. pig iron—of which 225 lb. is Bessemer carrying the 0.80 Mn presumed—to care for the total of 10.6 lb. minus the 1.95 in the steel and sprues, or 8.65 lb. manganese. Since the special manganese pig has 4.00 Mn., and the others 0.80, it becomes a matter of trial to see how much high-manganese pig must go into the mixture. This works out as follows:

	130 lb. high-manganese pig, with 4.0 per cent.	Mn—5.20 lb.
	420 lb. ordinary pig and Bessemer with 0.80	Mn—3.36 lb.
Total	550 lb. pig iron carrying	Mn—8.56 lb.

which will be near enough to the requirements.

The mixture now stands as follows:

Steel	350 lb.
Sprues	100 lb.
Bessemer pig	225 lb.
High-manganese pig	130 lb.
Foundry pig	195 lb.
	1,000 lb.

The silicon has now to be regulated. This will not be easy, as only 195 lb. of the whole mixture can be shifted. The conditions, so far as the silicon are concerned, are obviously the following: The steel can be taken as having no available silicon; the sprues carry 1.00 from the previous days' heats. The Bessemer iron will probably run 1.50 Si. The high-manganese pig will have perhaps 2.50. In addition, while the mixture should run 0.25 over the silicon of the castings, when so much steel is used it is wise to add an extra 10 per cent. Thus, with the castings at 1.00, the mixture would ordinarily run 1.25 (or with very good practice, 1.20). With so much steel, however, it is safer to try for 1.35 Si. This, for 1,000 lb. would mean 13.5 lb. silicon. Taking the silicons as estimated above, the known conditions would make the following showing:

350 lb. steel, with no silicon to use	lb. Si.
100 lb. sprues, with 1.00 silicon	1.00 lb. Si.
225 lb. Bessemer pig, with 1.50 silicon	3.38 lb. Si.
130 lb. high-manganese pig, with 2.50 silicon	3.25 lb. Si.
805 lb. metal carrying	7.63 lb. Si.

The remaining 195 lb. of foundry pig would therefore have to contain 5.87 lb. of silicon, or run 3.00 per cent. in silicon. This is a perfectly possible situation, and would complete the calculation, or 1,000 lb. mixture would contain 13.48 lb. of silicon, the required amount being 13.5 lb. to give the 1.35 silicon and yield castings with 1.00, under the charging conditions existing.

Attention is called to the fact that very good cylinders are made with higher phosphorus, lower manganese, and a total carbon obtained with smaller steel percentages; hence while the calculations just worked out seem very elaborate and few foundries will have all the pig irons with the estimated compositions on hand, the foundryman must do the best he can with what is available. If, therefore, he finds that he cannot get over 0.70 manganese, not less than 0.600 phosphorus, and the sulphur runs up to 0.12, he need not be discouraged at all. Where this class of work is put up every day it is quite possible to come near the ideal requirements. Even in such a case changes can be made in what has been suggested. For instance, instead of purchasing expensive Bessemer pig iron, the comparatively cheaper Bessemer malleables can be taken, these running over the 0.100 phosphorus limit, but remaining under 0.200, etc.

It is not the purpose of this book to give detailed mixtures for all classes of castings made in the foundry. Every foundryman should know enough from practical experience and from rubbing elbows with his foundry friends at the foundrymen's conventions, regarding the scrap and pig proportioning, the grades of metal, the steel scrap percentages, and other kinks incident to his line of work. The purpose of this chapter is to show the method of working out mixtures from analyses and general experience with scrap compositions, in order to reach the desired ideal castings' analyses. A simple and a complicated condition has been studied to show the line of thought necessary. Once the foundryman has tried this method out, he will find it exceedingly simple. After all, however, in addition to the simple figures which insure actual melting results, a lot of judgment must be exercised if castings are to be made without having the yard a curiosity shop in irons.

CHAPTER XIII

TESTING CAST IRON

It is not the purpose of the author to go into the science of testing materials in general, or the investigation methods applicable to cast iron in particular. Enough of the characteristics of the metal at issue have been presented in Chapter VI. It is desirable, however, that the foundryman should know the scope of such a laboratory as he may find desirable to install when his daily tonnage increase or the acquirement of special lines of work warrant it. Moreover, the specifications requirements of today make it highly desirable to have laboratory help, either on the ground or from commercial testing bureaus, as a matter of insurance.

The work of the laboratory divides itself into two general lines, a proper valuation of which will determine the caliber of the men selected to operate it. First, routine analyses and physical tests, for which young men with ordinary schooling can be trained, if available, and who would probably stay attached to this work for at least a few years. Second, research work of a pretty high character. Here good men are necessary, and as every establishment will have a different line of problems to solve, no institution of learning can equip its graduates to exactly fill the bill from the start. Graduate metallurgists, engineers or chemists must be taken and allowed to train themselves—which is always possible when the right stamp of a man can be secured. Only very large interests can afford to branch out into scientific foundry investigation, for a considerable expenditure of time, money and patience is necessary before direct returns are realized.

The large majority of foundries will therefore try to combine the two general lines and have one good man in charge, and as the work piles up let him have functionaries to care for the routine. Probably no foundry, as such, can afford to have a metallurgist unless the daily production is over 25 tons of castings. With a smaller output, unless very special, it is cheaper to obtain the analyses and tests from commercial chemists of good repute for accuracy and speed. What is really wanted in a smaller foundry is the silicon of the sprues every third day, as an example, so that the mixture can be kept in shape. Then also, the sulphur about once a week, to check the scrap-pig relationship. If the foundryman knows his business, he will make physical tests of his product as well—that is, cast test bars for transverse breaking strength and deflection—and he can put the broken pieces in the lathe and turn off his samples for analysis. With a sufficient number of such tests it will pay to get a small testing machine for cross-breaking purposes, and later on the establishment of a laboratory becomes a matter of course.

In addition to the daily, semi-weekly or weekly tests of the product, it is necessary to have the analysis of the pig iron bought, as well as that of the coke. Eventually, the molding sand will come in for such an examination, and then will follow the specification of the miscellaneous supplies. Once it pays a foundryman to put in his own laboratory, there will be no lack of work for it. On the score of the pig-iron analyses, it may be stated that the blast furnaces are now so alive to the use of their metal on a metallurgical basis in even the smallest foundry, that the analyses furnished to foundryman are usually quite reliable. The discrepancies found are almost always those due to defective sampling and poor methods of analysis. Careless and indifferent chemists (or rather analysts) at the blast furnaces are promptly weeded out in short order. They become too expensive to keep. Hence the furnace card, if it represents the actual analysis of the car shipped, is on the whole quite reliable. Unfortunately, however, there is a variation of the elements contained in pig iron from one end of the furnace cast to the other, and hence there exists quite a chance for differences in the silicon and sulphur in the several cars from that cast shipped. The foundryman should therefore get at least the silicon and sulphur of every car of iron bought. The manganese, phosphorus, and very rarely the total carbon (the graphite or combined carbon, or both, should never be asked for, as these show nothing of value in view of the fact that the iron will be remelted) need not be determined very frequently for a given brand of iron, as these elements run very uniformly for the regular burdening of the furnace. The usual card, therefore, is amply sufficient for the purpose unless there are special reasons for the extra precaution of an analysis for these elements.

The coke should be examined for the sulphur and ash content, as these are vital in cupola practice. The moisture and volatile matter are important also, but would only be gone into where the foundry has its own laboratory.

The experience of both furnace and foundrymen in regard to chemical laboratory work was somewhat discouraging in the early days of the foundry advance. The results indicated that some system of standard methods of analysis, and particularly sampling, was essential if satisfaction was to be had, disputes avoided and progress made in the art. Hence the foundry metallurgists of America got together, under the auspices of the American Foundrymen's Association at first, and later merged with the American Society for Testing Materials, and methods of sampling and analysis were investigated and standards suggested. Finally, with the coöperation of the U. S. Bureau of Standards, the present accepted "Standard Methods" of the American Society for Testing Materials were brought about and are today used officially in America as well as proposed for international use. These methods will be found in the Appendix. Similarly the study of coke has received attention from the Foundrymen's, the Testing Materials', and the U. S. Bureau of Mines' experts, and the official "Standard Methods" will also be found in the Appendix. Foundrymen having chemical work done either in their own laboratories or those of commercial chemists, should see that these standards are followed very strictly, for in this way the work becomes more reliable and comparable.

The establishment of a laboratory is not expensive. Any little room with a floor free from vibration and a chimney connection will do. The delicate balance is the most costly item of the outfit necessary, the total of which should not exceed $500—including the arrangement of the room for heat, gas, electricity and water. Physical testing of bars will probably be done in the foundry machine shop at first, and unless it is necessary to purchase a drill press for the pig-iron samples and a lathe for the chemical samples (in the absence of a machine shop), the testing machinery will be covered by another $250.

The advance in testing cast iron, which in America has led to standard specifications for the purchase of pig iron, general castings, water pipe, car wheels, malleable castings, locomotive cylinders, soil pipe, etc., has also spread to Europe, Germany in particular having standard specifications in operation for columns, general castings, pig iron, etc. Great Britain is following slowly and the other iron-producing nations have the situation under advisement. All this makes for progress, the eliminating of the unfit from the industry, the economy of material by raising the quality and hence reducing weight, finding new applications in the arts, and compelling the foundryman to know what he is doing.

The testing of cast iron for physical qualities may be looked at from the following standpoint: In view of the discussion on the "shrinkage" situation, and the belief of the author (and all others with whom he has discussed this situation) that there is no such thing in existence as an absolutely sound casting, the only exact test is to actually break a casting to learn of its resistance to the destructive forces it has to meet in service. Manifestly it will not do to break every casting made, and hence wherever possible, a given number, say 3 of each 103 castings from the same heat, are taken for testing to destruction. This is done in the case of car wheels under regular specification. It is common for malleable castings, and every foundryman making a specialty does this for his own information.

For the ordinary line of work in machinery, pipe and in fact nearly everything except specialty castings of identical dimensions for enormous output, it is not possible to make selections for destructive tests. Hence, another measure for the value of the casting must be found, and this is by testing the metal under the best possible conditions to show up its quality, neither aided nor impaired by disturbing influences. The tangible shape of such a casting has been worked out as the standard "Arbitration" bar, so named by Walter Wood, chairman of the commission having the matter in hand at the time (July, 1903). This bar is round (1¼ in. in diameter), cast 15 in. long in order to allow breaking transversely on supports 12 in. apart, is cast vertical (top pour), in dry sand, is neither rumbled nor machined, and is fully described in the Appendix under the standard specifications for general castings.

It will be noted that the round section eliminates errors from four hard corners; the vertical position in the mold eliminates differences in strength found in flat poured castings when tested cope-side up or cope-side down. Pouring from the top means giving every inch of the vertical casting molten metal of the same temperature and is the only way of getting this casting as sound as such a casting can be made, the casting practically feeding itself as it is poured. Dry sand for the mold means the elimination of a hardening (strengthening) influence from the dampness of the ordinary green sand.

Through the efforts of Walter Wood and the author, the two American members of the Commission on Cast Iron, of the International Association for Testing Materials, the subject of an "International Cast-iron Test Bar" has been brought to a point warranting belief of favorable action when the industrial world's attention can be directed that way again. The matter has been previously discussed in Chapter VI, and it need merely be mentioned that the American Bar seems acceptable to everyone except that the length shall be sufficient to allow 18 in. as the distance between supports on test.

Coming now to the tests as actually carried out in the shop, there will be found the following situation: The cardinal test for cast iron in use the world over is the transverse-breaking one. The Arbitration Bar was especially devised for this test. It is so named as it is used more particularly in cases of dispute between buyer and seller—many foundries having other shaped bars for their daily shop tests to which they cling in order not to lose the value of previous records. Such bars are the 1-in. square, the 2 by 1-in., the ½-in. square, etc. Fortunately, with the advent of scientifically trained men into the foundry management these bars are gradually disappearing and the standard bar is supplanting them on the basis of its merit and the demand of the purchaser.

The test bar should always be cast separate, and not as a "coupon" of the casting it is to represent. At first glance it would appear wise to attach the bar to the casting, so that it can be identified. It happens, however, that this very attachment—the idea being that the iron flows into both casting and coupon at the same time—introduces the shrinkage problem, and the coupon may get iron not at all representative of every part of a big casting. The chances, further, are great so far as the mold is concerned. This may be damp, the sand may be close to a heavy iron flask-side. The position of the coupon is another matter, three coupons, one at the top, another in the middle and the third at the bottom will give three different results for the same casting. On the whole, therefore, it is wisest to cast the bars separately—of the same ladle as the casting if desired, or a given number of bars for the whole heat, all of them to pass a given standard.

The testing machine for the transverse, or cross-breaking test is usually of 5,000 lb. capacity, and costing less than $150, should be in every foundry. These machines all have attachments to measure the deflection of the bar, and as catalogues are available to the foundryman for the asking, need not be described specially. The Standard Specifications, drawn up by men of experience, divide all castings into three classes: the light, medium and heavy (up to ½ in. section, light; between ½ and 2 in., medium; beyond 2 in., heavy). The transverse breaking strength of these classes should be not less than respectively 2,500, 2,900 and 3,300 lb.; and the deflection in no case less than 0.10 in. This gives the foundryman an excellent guide as to his own work.

Only the cross-breaking strength and deflection of the transverse test are used in daily practice. For scientific work the "modulus of rupture" is often calculated out from the results. It should not be forgotten, however, that this "modulus" is not constant for cast iron—being higher for the same bar when tested on supports near together than when these are farther apart. Hence conclusions must not be drawn unless this situation is reckoned with.

The test used next in frequence is that for tensile strength. That is, the test piece is pulled apart. Here the bars are put into the machine and the load applied until rupture takes place. There being no appreciable elongation in, nor reduction in the area of the bar, the tensile strength only is measured. Since cast iron is highly sensitive to an oblique pull, it is necessary to machine the ends of the test specimen to provide true screw threads which fit into corresponding sockets in the jaws of the testing machine. Unless this is done, a slight slip of one of the double "V" jaws ordinarily used for other ductile metals will mean a considerable reduction in the showing of the bar. This uncertainty and the cost of preparing the specimen has militated against the tensile test to such an extent that it has been cut out of the German specifications, has been made optional in the American ones, and has not been recommended at all for the proposed International Standard Specifications.

The author does not recommend it either, and feels that the only reason it is still quoted in text-books, etc., is the fact that all the other metals and alloys useful for construction work are more ductile than cast iron, and hence can be put under tensile strain for testing purposes probably better than any other way.

The mere fact that the smaller the specimen the higher the results of the tensile test, should warn those interested to look closely upon the dimensions of the test specimen before forming their final judgment on the quality of the material.

Where the tensile test is still used and the specimens are prepared from the broken halves of the Arbitration Bar, as explained in the Specifications given in the Appendix, the figures obtained for light, medium and heavy classes of work should be not less than 18,000, 21,000 and 24,000 lb. per sq. in. respectively.

This actually ends the tests for cast iron in general use. For specific lines of work, as for car wheels, there is the so-called "drop test" which at one time consisted of dropping a weight of considerable size upon the wheels, but has now been standardized to 200 lb. dropped upon the hub, from varying heights a given number of times. The car-wheel specifications contain further information, and those who may be interested can obtain them from the American Society for Testing Materials. Punching, shearing, torsional, impact tests with the heavy pendulum which in swinging breaks the bar, all have their value but have no evident applicability for shop-testing and use in working under specifications. The only further test that seems to show signs of increased application is the Brinell test for hardness. This, as described briefly in Chapter VI, refers to pressing a steel ball into the surface of the casting under standard conditions. Unfortunately this excellent test is used only to obtain soft castings, and hence is dreaded more than used in the foundry. Moreover, those who specify under this method are usually engineers well versed in the principles of machine design, but knowing little of the physical constitution of cast iron. The foundryman, therefore, while fully alive to the value of the transverse test, and welcoming this as a measure of the quality his work should exhibit, will oppose the introduction of other tests—and justly so—until these have demonstrated their value as reliable tests in themselves, and further, as applicable to the very unhomogeneous material he deals with daily.

There remains, finally, to discuss the possible value of investigation in the foundry. Those who are familiar with the methods of the research laboratory know that the work ahead has no limit. One would not think that men could devote their entire lives to patiently digging out new explanations for old phenomena, and yet this is the case. Castings were made just as good as now hundreds of years ago. Then, however, they were accidents, now they are the result of deliberate preparation based on some knowledge of the principles involved. And so the laboratory will dig on and unearth new facts, using the new developments in apparatus, new methods, new avenues of thought, and thereby fill out an hiatus here and another one there in the chain of our achievements.

One of the best of these added methods of investigation is the microscope. This has done wonders in tracing the relation of the elements in cast iron to each other. Yet no one pretends to go into the foundry with this instrument and bring about a practical result. In steel this is different, as the whole science of heat treatment is based upon the teachings of the microscope. In cast iron, the casting is shipped before the microscope could be used for any purpose. It would come in "after the fact." Nevertheless, a high-class foundry laboratory should contain a good outfit of this kind, for it will be useful on many an occasion.

The same can be said of the pyrometer—meaning thereby such a one as the "Le Chatelier" of the best type. This finds no immediate use in the foundry either—for a thermometer will usually do for the core room, or at least a cheaper type of the high-temperature registers. And yet, no investigator in the foundry laboratory would be without his "Le Chatelier."

The *x*-ray apparatus, the spectroscope, the electric furnace, gas apparatus, and other developments which amount to trying out the patient—cast iron—a new way, will possibly tell us something of value. More likely, however, in the laboratory of the university rather than in the foundry, for life is too short and the results required are too immediate to allow even the best of foundry laboratory investigators much time for what might be called unproductive work, no matter how much it adds to the sum of our knowledge. The ornamental must yield to the essential as the hard rule of life, but a little of the speculative, the treading of the "bypaths" in foundry metallurgy, is to be recommended to the foundry investigator. It keeps him in love with his work, and spurs him on to a keen observation of the minutiæ appearing now and then in the development of new phases of old processes. He will not then regret the day that brought him in touch with that most servicable, curious and still little understood conglomeration of elements called cast iron.

GLOSSARY OF THE FOUNDRY TERMS

Air Furnace.—A common form for the "hearth," or "reverberatory" furnace (see "Reverberatory Furnace").

Two forms in general use. One, with high roof, for making gun iron. Other one, long and with low roof, for production of malleable castings.

Air-furnace Melting Process.—Melting pig iron and scrap in the air furnace under conditions giving unoxidized and superheated molten metal suitable for the castings to be made.

Anneal (for malleable castings).—Subjecting the proper kind of white iron castings to heat treatment at sufficient high temperatures, long enough continued, to effect a change from combined carbon to "temper-carbon" (amorphous graphite).

Bath.—Molten metal held in hearth of furnace during melting process.

Bed.—Initial charge of fuel in cupola upon which the melting is carried on.

The height of the bed is kept constant by the descent of subsequent fuel charges to replace what has been consumed.

Blast.—Air driven into the cupola through the tuyères for the combustion of fuel.

Blast Pipe.—The conductor through which air under pressure is carried from the blower to the air chamber (wind box) of the cupola.

Bod.—A cone-shaped lump of clay attached to the end of an iron or wooden "bod-stick" and to close the tap-hole of the cupola.

Bottom (sand).—The layer of sand with clay rammed upon the "bottom doors" of the cupola to form the sloping hearth or crucible bottom.

Breast.—Part of cupola lining connecting spout with bottom and made up with tap-hole for every heat.

Bung.—Individual sections of removable roof of air furnace as used in malleable castings practice.

Cast Iron.—An iron containing so much carbon that it is not usefully malleable at any temperature.

The dividing line between steel and cast iron is taken at 2.00 per cent. total carbon. The practical range of total carbon in cast iron is from 2.50 to 4.00 per cent.

Charge.—A given weight of metal or fuel introduced into the cupola or furnace.

Charging Door.—Opening in cupola or furnace through which the charges are introduced.

Cheek.—The middle portion of a three-part mold.

Chill.—A properly shaped casting, forming part or the entire interior mold-surface, intended to withdraw heat from the molten metal so rapidly that it solidifies faster at that point and becomes sound. Also, the hard white iron portion of the casting resulting from the contact of the molten metal (of proper composition) with the iron "chill" (or chiller) above mentioned.

As an example of the second use of the word, the "chill" of the car wheel, chilled roll and crushing of jaw may be mentioned.

Chipping-out.—The process of removing slag and refuse attached to the lining of the cupola or furnace after a heat has been run.

Accomplished with a tool, pointed at one end, called the "hand-pick" or "chipping-hammer."

Clay-wash.—A thin emulsion of clay and water.

Of a consistency like "grout." The fire-brick are dipped into clay-wash when to be laid with a very close joint.

Cold-shut.—An imperfect junction line between two flows of metal in a mold.

Cope.—The upper part of a mold.

Core.—A body of green or dry sand placed in the mold to form a corresponding cavity in the casting.

Cupola.—A variety of the shaft furnace. Vertical and usually circular in shape. Blast admitted near the bottom. Metal and fuel charged into the upper part and molten metal drawn from the bottom. Metal and fuel in intimate contact.

Cupola Melting Process.—This consists of melting pig iron and scrap in the cupola under conditions which will result in unoxidized and highly superheated molten metal suitable for the purposes of the foundry.

Daubing Up.—The process of applying a mixture of clay and sand to the defective parts of the cupola lining after a heat, to restore the original lines as nearly as may be.

The word "daubing" implies a wet, stiff and sticky paste.

Drag.—The lower part of the mold.

Dry Sand.—Green sand dried in an oven to remove moisture and strengthen it.

The dry-sand mold is a mold made of green sand which is treated as above.

Dump (Cupola).—This is the fuel bed and slag falling out of the cupola when bottom is dropped after the heat has been run.

Feeding.—Pouring additional molten metal into a freshly poured mold to care for volume shrinkage during progressive setting.

Ferro-alloy.—An iron so rich in some element other than carbon, that it serves to introduce this element into molten iron or steel when added to the bath or ladle.

Fire-brick.—Brick made of highly refractory clays.

Fire-clay.—Highly refractory clays used in the preparation of heat-resisting materials and structures.

Fire-sand.—A sand so free from fluxes that it is highly refractory.

Flask.—Containers of wood or iron into which green sand is rammed about a pattern to make a mold.

Flux.—Basic material added to the cupola charges to unite with sand, ash and dirt during the melting, to form a slag.

Fore-hearth.—A stationary covered container directly attached to the cupola, into which the metal flows as fast as melted, and from which it is tapped for distribution.

Foundry.—An establishment in which molds are made and metal melted to pour them, for the production of castings.

Gate.—An opening cut into the cope through which the molten metal is poured into the mold.

Gray Iron.—A cast iron the combined carbon of which is under two-fifths of the total carbon contained.

For a maximum total carbon of 4.00 per cent., the combined carbon would be below 1.60. For a minimum total carbon of 2.75, the combined carbon would be below 1.10—or just machinable with difficulty in each case (see "Machinability)."

Green Sand.—Molding sand tempered up with water.

The "green-sand mold" is rammed up with properly tempered molding sand.

Hand Molding.—The art of making molds by manual operation.

Hearth.—The floor or sole of a furnace.

Heat.—A stated tonnage of metal obtained from a period of continuous melting in cupola or furnace.

Lining (Cupola).—This is the refractory material, of uniform and ample thickness built up within the cupola shell to form the container of the fuel and metal charged for melting purposes.

Loam.—A molding sand rich in clay substance.

The "loam-mold" is a mold built up of brick-work, coated with loam to conform to the dimensions of the casting required, and subsequently baked.

Machinability.—The property of permitting tooling or finishing by machinery.

Ordinarily good when the combined carbon at the point to be cut is under 0.75; difficult when between 0.75 and 1.50; bad if over 1.50. With abnormal compositions of cast iron the combined carbon must be held even lower.

Machine-cast Pig Iron.—Pig iron by running the blast-furnace metal directly into open iron molds.

Machine-molding.—The art of making molds by mechanical operation.

Malleable Cast Iron.—Originally white cast iron of proper composition subsequently rendered malleable by annealing without remelting.

Melting Loss.—This is the reduction in weight on the part of the metal charged incident to the melting operation.

Melting Rate.—In the cupola operation this is the tonnage of iron melted per hour.

That is, from "blast on" to "drop bottom" means the melting of the total metal charged, less any unmelted material recovered from the drop. This weight, divided by the hours, gives the "melting rate" per hour. For immediate use in judging the action of the cupola, however, it is customary to estimate the weight of the metal tapped into ladles as so many tons per hour, any time during the heat.

Melting Ratio.—The proportion of metal weight charged to fuel weight in cupola melting.

In America, the weight of the fuel bed is included in the relation. In Europe, the ratio is strictly the metal charge weight to that of the intermediate fuel charge, the bed being excluded.

Metallurgy.—This is the art of extracting metals from their ores and refining them up to the point required by the metal industry.

Mold.—A body of molding sand or other heat resistant material containing a cavity which when filled with molten metal yields a casting of the desired shape.

Molding.—The art of making molds.

Molding Sand.—Sand containing sufficient refractory clay substance to bond strongly without destroying the permeability to air and gasses when rammed to the degree required.

Mottled Iron.—A cast iron the fracture of which is white mottled with more or less gray.

It is intermediate between gray and white iron, and may shade from almost white to almost gray in fracture appearance.

Over-iron.—The metal melted in addition to the amount estimated to cover the day's requirement on the molding floor.

This "over-iron" should not amount to more than 5 per cent. of the heat, and is cast into a pig bed at the cupola. If possible, the cupola bottom should be dropped the moment the last metal for molds has been poured, and the extra metal recovered in an unmolten state in the drop.

Parting Sand.—A fine, bondless sand dusted on the joint of a mold to prevent the cope and drag from adhering to each other.

Pattern.—A wooden or metal counterpart of a casting to be made.

Pig Bed.—Small excavations or regularly made open-sand molds in the floor of the foundry, near the cupola, to hold the "over-iron" and other waste metal.

This over-iron and molten metal too cold to pour into molds is best cared for in a group of reversible iron molds, placed at the cupola, or scattered through the shop, rather than being poured into the sand.

Pig Iron.—A cast iron which has been run into pigs direct from the blast furnace or its equivalent.

Pouring Basin.—A basin cut into the cope of a mold to hold a pool of molten metal while discharging it clean into the gate.

Prop.—The iron post used to rigidly support the hinged bottom doors of the cupola. (Also called "spud.")

Pumping.—The act of churning molten metal in the risers of a mold to retard setting as long as possible and thus facilitate the feeding of the casting.

Reverberatory Furnace.—A hearth furnace with fire-box and melting chamber separate. The flame is drawn over the fire-bridge and sweeps through the chamber to the chimney. Burning gases heat the stock, roof and side walls of the furnace. Radiation of heat melts and superheats the metal.

Riddle.—A sieve for removing the coarse material while sifting sand on the pattern.

Riser.—An enlarged gate to act as a feeder for the casting. Also an outlet over a high part of the mold to indicate the level of the molten metal.

Runner.—An enlarged pouring basin, or deep channel, connecting with the gates to bring metal to them.

Sand-cast Pig Iron.—Pig iron made by running blast-furnace metal directly into open-sand molds.

Scab.—Imperfection in the surface of a casting due to the breaking away of portions of the mold by the stream of molten metal.

Shell.—The shell of the cupola is the riveted steel-plate structure forming the cylindrical container for refractory material used as the furnace lining.

Shot.—Globules of metal scattered by the falling stream in a mold. These globules solidify and are carried along by the rush of metal without re-incorporation in the mass.

Shrink-head.—A very large riser intended to feed the casting as well as collect impurities. It is subsequently machined off the casting.

Silica-brick.—Highly refractory brick made of nearly pure silica.

Skim-gate.—A gate so arranged that it skims off dirt from the iron passing through it and keeps it out of the casting.

Skin-drying.—The drying of the mold surface by direct application of heat. This drying should extend inward at least an inch.

Slag.—The molten substances other than the metal which separate out from it on standing.

Slag consists of sand, clay, ash, etc., fluxed with lime or iron oxide during melting.

Slag-hole.—An aperture in the cupola slightly above the top level of the molten metal to be held in it, through which the slag is drawn off.

Slag-spout.—The channel casting bolted to the cupola serving for the convenient removal of slag coming through the slag-hole.

Spout.—A channel casting bolted to the cupola or furnace. When lined with refractory material it forms the continuation of the "bottom" and carries the metal from the tap-hole to the ladles.

Sprue.—Channels from the gate into the mold.

Sprues.—The metal setting in the gates, risers, runners and pouring basins of a mold, and forming the scrap of a foundry other than defective castings and "over-iron."

Steel.—This is iron cast from the molten state which is malleable at least in some one range of temperatures.

Ordinarily a steel is expected to contain enough carbon (over 0.30) to harden usefully when cooled rapidly from above the critical range. Custom has, however, included materials made by the same processes with carbon as low as 0.06, which will not harden.

Tap-hole.—The opening in the cupola and furnace breast through which the molten metal is allowed to run out over the spout.

Tuyère.—An opening in the body of the cupola through which the blast is forced into the fuel bed.

Vent.—A small hole in the mold (made with a wire) to facilitate the escape of gases.

White Iron.—A cast iron the total carbon of which is practically all in the combined form.

Wind box.—A chamber surrounding the cupola at the tuyère level, to equalize the volume and pressure of the air delivered to the tuyères.

Wrought Iron.—A malleable iron which is aggregated from pasty particles without subsequent fusion. It contains so little carbon that it does not harden usefully when cooled rapidly.

APPENDIX

STANDARD SPECIFICATIONS FOR GRAY IRON CASTINGS.

(American Society for Testing Materials)

Process of Manufacture.—Unless furnace iron is specified, all gray castings are understood to be made by the cupola process.

Chemical Properties.—The sulphur content to be as follows:

Light and medium castings	not over 0.10 per cent.
Heavy castings	not over 0.12 per cent.

Classification.—In dividing castings into light, medium and heavy classes, the following standards have been adopted:

Castings having any section less than 12 in. thick shall be known as "light castings."

Castings in which no section is less than 2 in. thick shall be known as "heavy castings."

"Medium castings" are those not included in the above classification.

4. Physical Properties.—*Transverse Test.*—The minimum breaking strength of the "Arbitration Bar" under transverse load shall be not under:

Light castings	2,500 lb.
Medium castings	2,900 lb.
Heavy castings	3,300 lb.

In no case shall the deflection be under 0.10 in.

Tensile Test.—Where specified, this shall not run less than:

Light castings	18,000 lb. per sq. in.
Medium castings	21,000 lb. per sq. in.
Heavy castings	24,000 lb. per sq. in.

5. Arbitration Bar.—The quality of iron going into castings under specification shall be determined by means of the "Arbitration Bar." This is a bar 1¼ in. in diameter and 15 in. long. It shall be prepared as stated further on and tested transversely. The tensile test is not recommended, but in case it is called for, the bar as shown in Fig. 40, and turned up from any of the broken pieces of the transverse test shall be used. The expense of the tensile test shall fall on the purchaser.

6. Number of Test Bars.—Two sets of two bars shall be cast from each heat, one set from the first and the other set from the last iron going into the castings. Where the heat exceeds 20 tons, an additional set of two bars shall be cast for each 20 tons or fraction thereof above this amount. In case of a change of mixture during the heat, one set of two bars shall also be cast for every mixture other than the regular one. Each set of two bars is to go into a single mold. The bars shall not be rumbled or otherwise treated, being simply brushed off before testing.

7. Method of Testing.—The transverse test shall be made on all the bars cast, with supports 12 in. apart, load applied at the middle, and the deflection at rupture noted. One bar of every two of each set made must fulfil the requirements to permit acceptance of the castings represented.

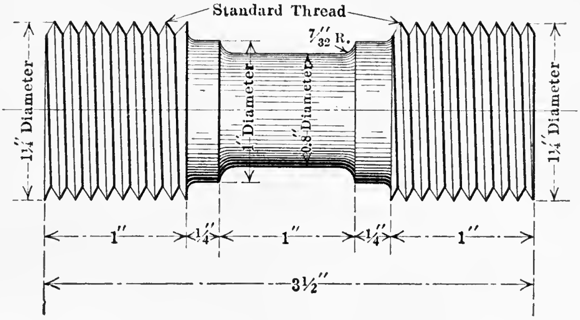


Fig. 40.—Arbitration test bar. Tensile test piece.

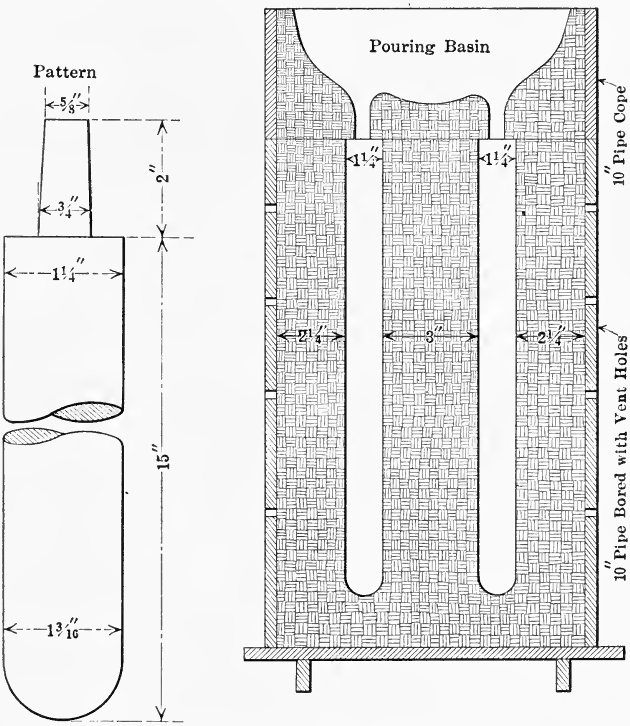


Fig. 41.—Mold for arbitration test bar.

8. Mold for Test Bar.—The mold for the bars is shown in Fig. 41. The bottom of the bar is $\frac{1}{16}$ in. smaller in diameter than the top, to allow for draft and for the strain of pouring. The pattern shall not be rapped before withdrawing. The flask is to be rammed up with green molding sand, a little damper than usual, well mixed and put through a No. 8 sieve, with a mixture of 1 to 12 bituminous facing. The mold shall be rammed evenly and fairly hard, thoroughly dried and not cast until it is cold. The test bar shall not be removed from the mold until cold enough to be handled.

Speed of Testing.—The rate of application of the load shall be from 20 to 40 sec. for a deflection of 0.10 in.

Samples for Analysis.—Borings[1] from the broken pieces of the "Arbitration Bar" shall be used for the sulphur determinations. One determination for each mold made shall be required. In case of dispute, the standards of the U. S. Bureau of Standards shall be used for comparison.

Finish.—Castings shall be true to pattern, free from cracks, flaws and excessive shrinkage. In other respects they shall conform to whatever points may be specially agreed upon.

12. Inspection.—The inspector shall have reasonable facilities afforded him by the manufacturer to satisfy him that the finished material is furnished in accordance with these specifications. All tests and inspections shall, as far as possible, be made at the place of manufacture prior to shipment.

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[1] For the preparation of the borings, see the "Standard Methods for Sampling and Analysis of Pig and Cast Iron," under general head of "Sampling," and subhead "Castings," second paragraph.

STANDARD METHODS FOR SAMPLING AND ANALYSIS OF PIG AND CAST IRON

(American Society for Testing Materials)

Sampling

Pig Iron.—One pig shall be selected at random from each 4 tons of iron and 10 such pigs (representing 40 tons of iron) shall constitute a unit for sampling. The surface of each pig shall be cleansed with a stiff wire brush or in any manner that will remove all loose sand without introducing deleterious matter.

The skin, down to clean metal, shall then be removed with an emery wheel at the center of the upper face of each pig and the surface carefully brushed off.

Drillings shall be taken with a ¼-in. twist drill, from top to bottom of each pig, starting from the center of the cleared space and stopping when the point of the drill appears below. One hole only shall be bored in each pig.

Suitable precautions shall be taken to prevent the escape of fine particles during the drilling. To this end a disk of clean sheet metal shall be clamped upon the pig after the skin has been removed. This disk shall have a hole in its center just large enough to receive the drill. Most of the drillings will then accumulate on top of the disk and can be brushed off after the drill is withdrawn. The pig shall then be turned bottom side up over any suitable receptacle for collecting what may have remained in the drill hole.

Castings.—In accordance with the Standard Specifications for Gray Iron Castings of the American Society for Testing Materials, three test bars, 1.2 in.[1] in diameter, shall be cast in sand from each heat at the beginning and again at the end of the pouring.

One bar from each set having been broken, one end of each next the fracture shall be thoroughly cleaned and the outer skin removed for a sufficient distance from the fracture and down to clean metal. Chips shall then be taken by means of a lathe or milling machine across the whole face of the bar and until not less than 100 grams weight has been collected. The same amount shall be taken from each bar. The bar shall be so clamped as to permit the attachment or use of any suitable device for collecting every part of the sample and the machine shall be run slowly enough to reduce to a minimum the danger of loss of fine particles.

Subsequent Treatment of Sample from both Pig and Castings.—In the determination of total and graphitic carbon, and in the case of check analyses on the other constituents, the following precautions shall be taken:

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[1] The diameter is really 1.25 in. but 1.2 in. is given in these standard methods because they are also proposed for "international" use, and 1.2 in. corresponds to 30 millimeters used in European standard bars.

The entire unit shall be weighed and then sifted on tight-fitting sieves (with cover) having 80 (and if need be 120) meshes to the linear inch (approximately 900 and 2,500 per sq. cm.). The finer sieve need be used only in case the particles passing the coarser sieve are not sufficiently uniform in size and shape to meet the requirements of the treatment that follows.

The two (or three) portions so obtained shall be separately weighed. Each one shall then be thoroughly mixed without any loss of material and divided by weight into two (or three) exactly equal portions, each of which shall be placed in a clean, glass-stoppered bottle or other receptacle of suitable material and appropriately labeled. Of the three sets of the subdivided samples, one shall be retained by the works, one sent to the purchaser's chemist and the third reserved.

Before weighing out for analysis, the contents of each bottle shall be thoroughly mixed and each portion used for analysis shall be made up of the two (or three) partial samples in the same proportion which they bear to the gross sample. Thus, if the gross sample, weighing, say, 500 grams has been separated into portions weighing 400, 80, and 20 grams, the amounts of each that must be weighed to yield a 2-gram portion for analysis are 1.6, 0.32, and 0.08 gram respectively.

METHODS OF ANALYSIS

DETERMINATION OF SILICON

BY THE

NITRO-SULPHURIC (DROWN) METHOD

Solutions Required

Nitro-sulphuric Acid.—Mix 1,000 c.c. of sulphuric acid, sp. gr. 1.84, 1,500 c.c. of nitric acid, sp. gr. 1.42, and 5,500 c.c. of distilled water.

Dilute Hydrochloric Acid.—Mix 100 c.c. of hydrochloric acid, sp. gr. 1.20, and 900 c.c. of distilled water.

Method

Add cautiously 30 c.c. of the nitro-sulphuric acid to 1 gram of iron in a platinum or porcelain dish of 300-c.c. capacity, cover with a clock glass, heat until the metal is dissolved, and evaporate slowly until copious fumes of sulphuric acid are evolved. Cool, add 125 c.c. of distilled water, heat with frequent stirring until all salts are dissolved, add 5 c.c. of hydrochloric acid, sp. gr. 1.20, heat for 2 min. and filter on a 9-cm. paper. Wash the precipitate several times with hot water, then with hot hydrochloric acid and hot water alternately to complete the removal of iron salts, and finally with hot water until free from acid. Transfer the filter to a platinum crucible, burn off the paper carefully with the crucible covered, finally igniting over a blast lamp or in a muffle furnace at 1000°C. for at least 20 min.; cool in a desiccator and weigh. Add sufficient sulphuric acid, sp. gr. 1.84, to moisten the silica and then a small amount of hydrofluoric acid. Evaporate to dryness, ignite and weigh. The difference in weights represents silica from which the percentage of silicon may be calculated.

Run a blank determination on all reagents.

DETERMINATION OF SILICON

BY THE

HYDROCHLORIC-ACID METHOD

SOLUTIONS REQUIRED

Hydrochloric Acid.—Mix equal volumes of hydrochloric acid, sp. gr. 1.20, and distilled water.

METHOD

Place 1 or 2 grams of the metal in a casserole or 400-c.c. beaker and add 30 to 40 c.c. of the hydrochloric acid. When action has ceased, evaporate to dryness and bake in an air bath or on a hot plate until all acid is removed. Cool, add 15 c.c. of concentrated hydrochloric acid and heat until all iron salts are in solution. Dilute with four or five times the volume of water, filter, wash, ignite and treat the precipitate as described under the "Nitro-Sulphuric Method."

DETERMINATION OF SULPHUR

SOLUTIONS REQUIRED

Barium Chloride.—Dissolve 100 grams of barium chloride ($BaCl_2 \cdot 2H_2O$) in 1,000 c.c. of distilled water.

METHOD

Dissolve 5 grams of iron in a 400-c.c. beaker, using a mixture of 40 c.c. of nitric acid, sp. gr. 1.42, and 5 c.c. of hydrochloric acid, sp. gr. 1.20. Add 0.5 gram of sodium carbonate, evaporate the solution to dryness and bake the residue on the hot plate until fumes are no longer given off. Treat the residue in 30 c.c. of strong hydrochloric acid, dilute and filter. (See subsequent paragraph in this section for treatment of this residue for extraction of its possible sulphur content.) Cool the filtrate and add ammonia until a permanent cloudiness appears, then add 5 c.c. of strong hydrochloric acid so as to obtain a perfectly clear liquid. Precipitate the sulphur in the cold filtrate (about 100 c.c.) with 10 c.c. of the barium-chloride solution. After 24 to 48 hr. collect the precipitate on a filter paper, wash first with hot water (containing 10 c.c. of concentrated hydrochloric acid and 1 gram of barium chloride to the liter) until free from iron, and then with hot water till free from chloride; or, first with cold water, then with 25 c.c. of water containing 2 c.c. of concentrated hydrochloric acid to the liter. Keep the washings separate from the main filtrate and evaporate them to recover any dissolved barium sulphate.

Place the insoluble residue, containing silica, graphite, etc., in a platinum crucible, cover with sodium carbonate (free from sulphur) and char the paper (use an alcohol lamp for this and subsequent heating operations) without allowing the carbonate to melt; the crucible should be covered during this operation. Then thoroughly mix in 0.2 gram of sodium nitrate and fuse the mass with the cover removed. Dissolve the contents of the crucible in water, filter and evaporate the filtrate with hydrochloric acid in excess, using a porcelain container; repeat the evaporation with water and hydrochloric acid to insure removal of nitrates. Extract the residue with a few drops of hydrochloric acid and water, filter off the insoluble matter and add barium chloride to the filtrate. Add the barium sulphate obtained to the main portion.

Run a blank with all reagents.

DETERMINATION OF PHOSPHORUS

Solutions Required

Nitric Acid for Dissolving.—Mix 1,000 c.c. of nitric acid, sp. gr. 1.42, and 1,200 c.c. of distilled water.

Nitric Acid for Washing.—Mix 20 c.c. of nitric acid, sp. gr. 1.42, and 1,000 c.c. of distilled water.

Ammonium-molybdate Solution for Precipitating.

Solution No. 1.—Place in a beaker 100 grams of 85 per cent. molybdic acid, mix it thoroughly with 240 c.c. of distilled water, add 140 c.c. of ammonium hydroxide, sp. gr. 0.90, filter and add 60 c.c. of nitric acid, sp. gr. 1.42.

Solution No. 2.—Mix 400 c.c. of nitric acid, sp. gr. 1.42, and 960 c.c. of distilled water.

When the solutions are cold, add solution No. 1 to solution No. 2, stirring constantly; then add 0.1 gram of ammonium phosphate dissolved in 10 c.c. of distilled water; agitate thoroughly, let stand at least 24 hr. and filter before using.

Ammonium-molybdate Solution for Washing.—Mix equal volumes of the above compounded molybdate solution and of water.

Potassium-nitrate Solution.—Dissolve 10 grams of potassium-nitrate in 1,000 c.c. of distilled water.

Phenolphthalein Solution.—Dissolve 0.2 gram of phenolphthalein in 50 c.c. of 95 per cent. ethyl alcohol and 50 c.c. of distilled water.

Standard Sodium-hydroxide Solution.—To 100 grams of pure sodium hydroxide add an amount of distilled water just insufficient to completely dissolve it. Pour into a tall cylinder, close the cylinder and allow the insoluble matter to settle. Dilute in the proportion of 30 c.c. to 2,000 c.c. of distilled water.

Standard Nitric Acid.—Measure 2,000 c.c. of distilled water into a glass-stoppered bottle, add 20 c.c. of nitric acid, sp. gr. 1.42, and mix thoroughly. Measure accurately 10 c.c. of the "standard sodium-hydroxide solution." Place this in a small flask, add 40 c.c. of distilled water and 3 drops of "phenolphthalein solution." Drop "standard nitric acid" from a carefully calibrated burette into the flask until the pink color just disappears. If the solutions are not of the same strength, dilute the stronger with water until they agree.

The solutions being of equal strength, standardize them as follows: Titrate the ammonium phosphomolybdate from an iron in which the phosphorus has been accurately determined, and divide the percentage of phosphorus by the number of cubic centimeters of the "standard sodium-hydroxide solution" required to neutralize it. The result is the value of the "standard sodium-hydroxide solution." The solution should preferably be of such strength that 1 c.c. = 0.0002 gram of phosphorus. Protect the solution from carbon dioxide by a soda-lime tube.

Magnesia Mixture.—Dissolve 110 grams of crystallized magnesium chloride ($MgCl_2.6H_2O$) or 50 grams of the anhydrous salt in distilled water, and filter. Dissolve 28 grams of ammonium chloride in distilled water, add a little bromine water and a slight excess of ammonia and filter. Add this solution to the solution of magnesium chloride, add enough ammonia to make the solution smell decidedly of ammonia, dilute to about 2 liters, transfer to a bottle, shake vigorously from time to time, allow it to stand for several days, and filter into a small bottle as required for use. Ten cubic centimeters of this solution will precipitate about 0.15 gram of P_2O_5.

Ammonia Wash Water, Approximately 10 Per Cent.—Mix 1,000 c.c. of ammonia water, sp. gr. 0.90, and 2,000 c.c. of distilled water in which has been dissolved 25 grams of ammonium nitrate.

Methods

A. Molybdate Method for Non-titaniferous Irons

Procedure for Obtaining Phosphomolybdate.—In a 400-c.c. beaker dissolve 1 gram of metal (2 grams for irons low in phosphorus), using 25 (or 50) c.c. of "nitric acid for dissolving." Evaporate to dryness and heat on the hot plate or in the air bath at approximately 200°C. for about an hour. Allow the beaker to cool, dissolve the residue in 15 c.c. of concentrated hydrochloric acid and evaporate to dryness to render the silica insoluble. Redissolve in 15 c.c. of concentrated hydrochloric acid, dilute with water, filter off insoluble and wash. (Burn off the filter paper and graphite; expel silica with a few drops of hydrofluoric acid and a drop or two of sulphuric acid, taking care not to drive off all of the last-named acid. Take up the residue with concentrated hydrochloric acid, dilute, and filter if need be into the main solution.) Evaporate to a small volume until salts just begin to separate. Add 10 c.c. of concentrated nitric acid and evaporate until salts again begin to separate; add 15 c.c. more of concentrated nitric acid and evaporate to a small volume. The solution being in an Erlenmeyer flask and the initial volume not over 25 c.c. and its temperature that of the room, add 25 to 100 c.c. of the molybdate reagent, according to the phosphorus content of the iron, shake for 4 or 5 min. and let stand for 30 min. to 3 or 4 hr. at room temperature.

Then (*a*): Filter on a Gooch crucible, wash with the solution of "ammonium-molybdate solution for washing" and then with water containing 1 per cent. of nitric acid, dry at 120°C. and weigh as ammonium phosphomolybdate containing 1.63 per cent. of phosphorus.

Or, (*b*): Filter on a 9-cm. paper and wash, first with the "nitric acid for washing," and then with "potassium-nitrate solution," until the washings are no longer acid. Place filter and precipitate in the precipitating vessel and run in from a pipette 10 c.c. of the "standard sodium-hydroxide solution." If, after agitation, this is insufficient to dissolve the precipitate, add 10 c.c. more, and if necessary continue the additions until the precipitate is dissolved. Dilute to 50 c.c., add 3 drops of "phenolphthalein solution," and add from a burette "standard nitric acid" until the pink color disappears; subtract the number of cubic centimeters of "standard nitric acid" used from the number of cubic centimeters of "standard sodium-hydroxide solution" taken to dissolve the precipitate, and the remainder will be the number of cubic centimeters of the "standard sodium-hydroxide solution" required to neutralize the ammonium phosphomolybdate. From this calculate the amount of phosphorus.

Or, (*c*): Filter on a small filter and wash with the "ammonium-molybdate solution for washing" until a drop of the filtrate gives no reaction for iron with potassium ferrocyanide. Dissolve the precipitate in 2 or 3 c.c. of strong ammonia and filter through the paper that held the precipitate into a small beaker of about 100-c.c. capacity, washing with ammoniacal water. With large precipitates more ammonia may be needed, but always the amounts of ammonia and wash water used should be as small as is consistent with perfect solution of the precipitate and thorough washing. When the precipitate is small the filtrate and washings should amount to about 25 c.c. Neutralize the solution with strong hydrochloric acid; if the yellow precipitate forms, add ammonia until it redissolves.[1]

To the cold alkaline liquid add very slowly 10 c.c. of "magnesia mixture," stirring constantly, add a little more ammonia and again stir vigorously. It is well to stand the beaker in cold water and stir the solution several times after the precipitate has begun to form. After 4 hr., filter on a small filter and wash with the "ammonia wash water." Dry, ignite in a crucible very carefully to burn off the carbonaceous matter, and finally heat for 10 min. over the blast lamp. (The heat should not be so high as to cause partial fusion of the pyrophosphate.) Fill the crucible half full of hot water, add from 5 to 20 drops of hydrochloric acid, and heat for a few minutes to dissolve the magnesium pyrophosphate. If a residue remains, filter, wash, ignite in the crucible used for the pyrophosphate, weigh it, and deduct its weight from that of the unpurified salt. Calculate the phosphorus on the basis of 27.84 per cent. in $Mg_2P_2O_7$.

B. MOLYBDATE METHOD FOR IRONS CONTAINING TITANIUM

Proceed as under method A until the solution resulting from treatment of the insoluble residue has been combined with the main solution. Then proceed according to Blair[2] up to a certain point, as follows:

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[1] If a flocculent white precipitate now shows, filter it off, dry and ignite it in a platinum crucible, fuse the residue with a very little sodium carbonate, extract the melt with hot water, filter, acidify the filtrate with nitric acid, add some ammonium nitrate and molybdate reagent and if phosphorus is indicated by the formation of a yellow precipitate, filter, wash and dissolve this in ammonia and add to the main solution.

[2] "The Chemical Analysis of Iron," 7th ed., p. 81.

Heat the solution nearly to boiling, remove from the flame and add gradually from a small beaker a mixture of 2 c.c. of acid ammonium sulphite[1] and 10 c.c. of ammonia, stirring constantly. The precipitate, which forms at first, redissolves, and when all but a little of the reagent has been added, replace the beaker over the flame. If, at any time while adding the sulphite solution, the precipitate formed will not redissolve, even after vigorous stirring, add a few drops of hydrochloric acid, and when the solution clears, continue the addition, very slowly, of the acid ammonium sulphite. After replacing the beaker over the flame, add to the solution (which should smell quite strongly of sulphurous anhydride) ammonia, drop by drop, until the solution is quite decolorized, and finally until a slight greenish precipitate remains undissolved even after vigorous stirring. Now add the remainder of the sulphite solution, which should throw down a white precipitate, which usually redissolves, leaving the solution quite clear and almost perfectly decolorized. Should any precipitate remain undissolved, however, add hydrochloric acid, drop by drop, until the solution clears, when it should smell perceptibly of sulphurous anhydride. If the reagents are used exactly in the proportions indicated, the reactions will take place as described, and the operations will be readily and quickly carried out. If the solution of acid ammonium sulphite is weaker than it should be, of course the ferric chloride will not be reduced, and the solution, at the end of the operation described above, will not be decolorized and will not smell of sulphurous anhydride. In this case add more acid ammonium sulphite (without the addition of ammonia) until the solution smells strongly of sulphurous anhydride, then add ammonia until the slight permanent precipitate appears, and redissolve it in as few drops of hydrochloric acid as possible. The solution being now very nearly neutral, the iron in the ferrous condition, and an excess of sulphurous acid present, add to the solution 5 c.c. of hydrochloric acid to make it decidedly acid and to insure the complete decomposition of any excess of the acid ammonium sulphite that may be present. Boil the solution while a stream of carbon dioxide passes through it, until every trace of sulphurous anhydride is expelled.[2] Add a few drops of bromine water or of a solution of ferric chloride, and cool the solution by placing the beaker in cold water. To the cold solution add ammonia from a small beaker very slowly, and finally, drop by drop, with constant stirring. The green precipitate of ferrous hydroxide which forms at first is dissolved by stirring, leaving the solution perfectly clear, but subsequently, although the green precipitate dissolves, a whitish one remains, and the next drop of ammonia increases the whitish precipitate or gives it a reddish tint, and finally the greenish precipitate remains undissolved even after vigorous stirring, and another drop of ammonia makes the whole precipitate appear green. If before this occurs the precipitate does not appear decidedly red in color, dissolve the green precipitate, by a drop or two of hydrochloric acid, and add a little bromine water or ferric-chloride solution (1 or 2 c.c.), then add ammonia as before, and repeat this until the reddish precipitate is obtained, and then the green coloration as described above. Dissolve

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[1] Made by saturating strong ammonia water with sulphur-dioxide gas. Eighteen cubic centimeters of such a solution will deoxidize a solution of 10 grams of iron.

[2] If arsenic is present pass a current of hydrogen-sulphide gas through the solution for 15 min., filter, and expel excess of the precipitant by a current of carbon dioxide.

the green precipitate in a very few drops of acetic acid (sp. gr. 1.04), when the precipitate remaining will be quite red in color, then add about 1 c.c. of acetic acid, and dilute the solution with boiling water, so that the beaker may be about four-fifths full. Heat to boiling, and when the solution has boiled 1 min., lower the flame, filter as rapidly as possible through a 14-cm. filter, and wash once with hot water. The filtrate should run through clear, but in a few minutes it will appear cloudy by the precipitation of ferric hydroxide. The points to be observed are the red color of the precipitate and the clearness of the solution when it first runs through.

Dry the filter and precipitate without scorching the paper. Remove with filter paper any precipitate adhering to the beaker and dry the paper. Transfer the main portion of the precipitate (all that can be removed) to a small porcelain mortar. Burn carefully the filter and the wipings of the beaker and transfer the ash to the mortar. Grind the contents of the mortar with 3 grams of sodium carbonate and a little nitrate and transfer the mixture to a platinum crucible, cleaning pestle and mortar with a little sodium carbonate. Fuse the whole for half an hour or more, cool, dissolve the fused mass in hot water, filter,[1] and wash with hot water.

Acidify the alkaline solution with nitric acid, evaporate in a small casserole nearly to dryness, transfer to a small Erlenmeyer flask, so that the final volume shall not exceed 25 c.c., add at room temperature 25 to 100 c.c. of the molybdate reagent and shake for 4 or 5 min. Let stand for 30 min. to 3 or 4 hr. From this point the procedure is exactly as described for non-titaniferous irons under method A.

DETERMINATION OF MANGANESE

BY THE

BISMUTHATE METHOD

SOLUTIONS REQUIRED

Nitric Acid for Solution.—Mix 500 c.c. of nitric acid, sp. gr. 1.42, and 1,500 c.c. of distilled water.

Nitric Acid for Washing.—Mix 30 c.c. of nitric acid, sp. gr. 1.42, and 970 c.c. of distilled water.

Stock Sodium Arsenite.—To 15 grams of arsenious oxide (As_2O_3) in a 300-c.c. Erlenmeyer flask, add 45 grams of sodium carbonate and 150 c.c. of distilled water. Heat the flask and contents in a water bath until the oxide is dissolved, cool the solution and make up to 1,000 c.c. with distilled water.

Standard Sodium Arsenite.—Dilute 300 c.c. of "stock sodium arsenite" solution to 1,000 c.c. with distilled water and titrate against potassium-permanganate solution (about N/10), which has been standardized by using Bureau of Standards Sodium Oxalate.[2]

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[1] The residue on the filter contains the whole of the titanium.

[2] *Circular* No. 40, Bureau of Standards, Oct. 1, 1912.

Adjust the solution so that 1 c.c. is equivalent to 0.10 per cent. of manganese, when a 1 gram sample is taken.

The factor $Na_2C_2O_4 \longrightarrow Mn = 0.16397$ (using the 1913 atomic weights).

METHOD

In a 300-c.c. Erlenmeyer flask dissolve 1 gram of iron in 50 c.c. of the "nitric acid for solution" and boil to expel the oxides of nitrogen, cool, filter,[1] add about 0.5 gram of sodium bismuthate, and heat for a few minutes or until the pink color has disappeared, with or without precipitation of manganese dioxide. Add small portions of ferrous sulphate (or any suitable reducing agent) in sufficient quantity to clear the solution and boil to expel the oxides of nitrogen. Cool to about 15°C., add an excess of sodium bismuthate and agitate for a few minutes. Add 50 c.c. of the "nitric acid for washing" and filter through an alundum filter or asbestos pad,[2] washing with the same nitric acid. Titrate immediately with "standard sodium arsenite" solution to the disappearance of the pink color, each cubic centimeter required representing 0.10 per cent. manganese.

DETERMINATION OF MANGANESE

BY THE

FORD-WILLIAMS METHOD

SOLUTIONS REQUIRED

Nitric Acid for Solution.—Mix equal volumes of nitric acid, sp. gr. 1.42, and distilled water.

Standard Ferrous-sulphate Solution.—Dissolve 10 grams of pure crystallized $Fe_2SO_4 \cdot 7H_2O$ in 900 c.c. of distilled water and 100 c.c. of sulphuric acid, sp. gr. 1.84.

Standard Permanganate Solution, about N/10.—Dissolve 3.735 grams of potassium permanganate in 1,000 c.c. of distilled water. After aging, standardize this solution by means of sodium oxalate of ascertained purity (Sörensen's as furnished by the Bureau of Standards for a fee of $2 for 120 grams or $3 for 200 grams.

METHOD

Dissolve 3 grams of iron in 40 c.c. of "nitric acid for solution," dilute, filter,[3] and evaporate almost to a syrupy consistency. Add 40 c.c. of nitric acid, sp. gr. 1.42, and 3 grams of potassium chlorate. Boil the solution for 15 min. Remove from the source of heat and add 15 c.c. of nitric acid, sp. gr. 1.42, and 3 grams of potassium chlorate. Boil again until yellow fumes

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[1] The insoluble residue should be examined for manganese.

[2] In making the asbestos pad it is advisable to have a thin bed and as much surface as possible. This insures rapid filtration, and the filter may be used until it becomes clogged with bismuthate. The filtrate must be perfectly clear, since the least particle of bismuthate carried through the filter will vitiate the results.

[3] The insoluble residue should be examined for manganese.

cease to come off. Cool quickly and filter on an asbestos pad in a carbon funnel. Wash with cold nitric acid, sp. gr. 1.42 (free from oxides of nitrogen[1] until the iron is removed and then with water until the nitric acid is removed. Transfer the filter to the beaker in which precipitation was made, add a measured amount of the "standard ferrous-sulphate solution," so that there shall be an excess, and titrate the excess with the "standard permanganate solution."

In another operation titrate the same amount of "standard ferrous-sulphate solution" directly against the permanganate. The difference between the two amounts of permanganate used gives the measure of the manganese present in the iron. The comparison of the ferrous sulphate and permanganate solutions should be made each day they are used.

DETERMINATION OF CARBON

BY THE

DIRECT-COMBUSTION METHOD

The method of direct combustion of the metal in oxygen is recommended, the carbon dioxide obtained being absorbed in barium-hydroxide solution, the precipitated barium carbonate filtered off, washed, dissolved in a measured excess of hydrochloric acid and the excess titrated against standard alkali.

The use of potassium-hydroxide solution or soda lime for the absorption of carbon dioxide, with suitable purifying train between absorption tube and furnace, is recognized as being capable of very satisfactory refinement and as possessing merit where the time element is of prime significance.

Owing to the diversity of apparatus by which correct results may be obtained in the determination of carbon, the recommendations are intended more to indicate what is acceptable than to prescribe definitely what shall be used.

Apparatus

Purifying Train.—The method employed eliminates the necessity of a purifying train following the furnace, in asmuch as no precautions are necessary to prevent access of water vapor, or sulphur trioxide—the impurities usually guarded against—from the absorbing apparatus. All that is needed is a calcium-chloride tower filled with stick sodium hydroxide placed before the furnace, or between the furnace and catalyzer, if, as recommended, the latter is used for the purpose of oxidizing organic matter in the oxygen.

Material for Lining Boats.—Alundum, "R Alundum, alkali-free, espcially prepared for carbon determination," as supplied by dealers is suitable, and is recommended. The 90-mesh or finer grades are used. Chromite, properly sized and freed from materials causing a blank, may also be employed. No substance containing alkali or alkaline earth metals, or carbon as carbonates or in other form, should be used as a lining material. Quartz

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[1] It is very important to use nitric acid free from oxides of nitrogen, since these dissolve the precipitated manganese dioxide.

sand, owing to its liability to fuse or to slag with the oxides of iron, causing bubbles of gas to be enclosed, is objectionable. Aluminum oxide, made by calcining alum or otherwise, often contains sulphate not easily destroyed, or may contain objectionable substances of an alkaline nature.

Catalyzers.—Suitable catalyzers are copper oxide, platinized quartz or asbestos, or platinum gauze. One of these should be used in the forward part of the combustion apparatus, as well as in the purifying train preceding the combustion tube (see above). Platinized materials sometimes give off volatile substances on heating, and whatever material is used should not be subject to this defect.

Combustion Apparatus.—Any apparatus heated by gas or electricity which will bring the sample to a temperature of 950 to 1100°C. may be used. Combustion tubes may be porcelain, glazed on one or both sides, quartz or platinum. Quartz is liable to devitrification when used continuously at temperatures above 1000°C., and may then become porous. Combustion crucibles of platinum may be heated by blast or by Meker burners.

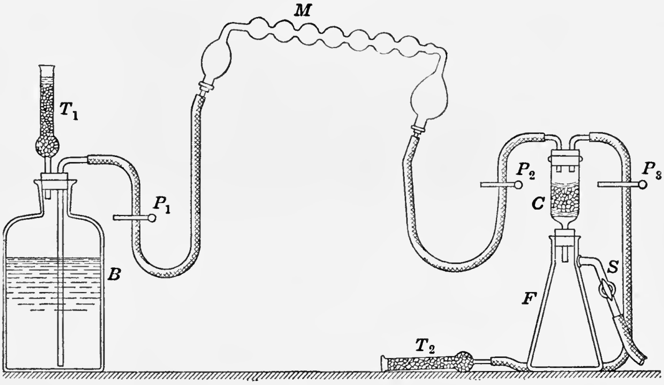

Fig. 42.—Apparatus for filtering barium carbonate.

Boats or Other Containers of Samples being Burned.—These may be of porcelain, quartz, alundum, clay, platinum, or nickel, and should always receive a lining of granular alundum.

Purifying Train before Combustion Apparatus.—This consists of a tower filled with stick sodium hydroxide, preceded by a catalyzer.

The Train after the Combustion Apparatus.—This consists merely of the Meyer tube for absorption of the carbon dioxide, protected by a soda-lime tube at the far end. Meyer tubes with 7 to 10 bulbs of 10 to 15-c.c. capacity each, and large bulbs at the ends, having volumes equal to the combined capacity of the small bulbs, have been used and found satisfactory.

Filtering Apparatus.—In filtration for accurate work, care should be taken to protect the solution from access of extraneous carbon dioxide. This is accomplished in the apparatus shown in Fig. 42. For work requiring less accuracy, the barium carbonate may be filtered off on a filter made by fitting a carbon funnel with a perforated procelain disk and filtering by suction. The precipitate is then washed with distilled water from which the carbon dioxide has been removed by boiling.

REAGENTS

Oxygen.—Oxygen of not less than 97 per cent. purity is recommended. Endeavor should be made to obtain oxygen which gives no blank, since the correction for or elimination of this is troublesome and uncertain. For the most accurate work the blank should be completely eliminated by the use of a catalyzer before the furnace, with a carbon-dioxide absorbent interposed between furnace and catalyzer.

Tenth-normal Hydrochloric Acid.—This may be standardized by any of the accepted methods, or as follows: Twenty cubic centimeters of the approximately N/10 acid is measured out with a pipette, and the silver chloride precipitated by an excess of silver-nitrate solution in a volume of 50 to 60 c.c. After digesting at 70 to 80°C., until the supernatant liquid is clear, the chloride is filtered off on a tared Gooch filter and washed with water containing 2 c.c. of nitric acid per 100 c.c. of water, until freed from silver nitrate. After drying to constant weight at 130°C., the increase of weight over the original tare is noted, and from this weight, corresponding to the silver chloride, the strength of the hydrochloric acid is calculated, after which it is adjusted to the strength prescribed. The standardization should be based upon several concordant determinations, using varying amounts of acid.

$$1 \text{ c.c. } N/10 \text{ HCl} = 0.0006 \text{ gram carbon.}$$

Methyl Orange.—Dissolve 0.02 gram in 100 c.c. of hot distilled water and filter.

Tenth-normal Sodium-hydroxide Solution.—This is standardized against the hydrochloric acid. Methyl orange is used as the indicator. The sodium-hydroxide solution should be stored in a large bottle from which it may be driven out by air pressure, protecting against carbon dioxide by soda-lime tubes.

Barium-hydroxide Solution.—A saturated solution is filtered and stored in a large reservoir from which it is delivered by air pressure, protecting from carbon dioxide by a soda-lime tube. Use enough of this solution to fill all the small bulbs of the Meyer tube when the latter is properly set up for absorption.

FACTORS INFLUENCING RAPID COMBUSTION

Manner of Distributing Sample in Boat.—This is of considerable importance. With all samples, close packing in a small space is conductive to rapid combustion. In the case of samples which burn too vigorously, a satisfactory regulation may sometimes be attained by spreading the sample loosely over the lining in the boat.

Rate of Admitting Oxygen.—The rate at which oxygen is admitted is also a factor in the velocity of combustion; a moderate rate of burning is to be sought. This is desirable from the standpoint of the complete absorption of the carbon dioxide by the barium-hydroxide solution. The above-mentioned factors can be governed so as to burn successfully irons of a very wide range of compositions, in either fine or coarse particles.

METHOD

After having properly set up and tested the apparatus, place 1 gram of iron in a moderately packed condition on the bed material and introduce the boat into the combustion apparatus, already heated to the proper temperature. After about a minute (to allow the sample and container to reach the temperature of the furnace), admit oxygen somewhat more rapidly than it is consumed, as shown by the rate of bubbling in the Meyer tube.[1] The sample burns completely in 1 or 2 min., and all that is now necessary is to sweep all the carbon dioxide into the absorption apparatus. This can be accomplished in 6 to 8 min. by passing about 1 or 2 liters of oxygen. Detach the Meyer tube and filter and wash the barium carbonate, using the special filtering apparatus shown. After solution in a measured excess of hydrochloric acid (the Meyer tube being washed out with a portion of the acid, to remove adhering barium carbonate), titrate the excess of acid against alkali and from the data thus obtained calculate the percentage of carbon.

APPARATUS AND PROCEDURE FOR FILTRATION

The apparatus is shown to approximately one-tenth size in Fig. 42, which is self-explanatory. The stop-cock is a three-way cock connected to the suction pipe. The rubber tubing connected to the Meyer tube should be of best-grade black rubber and the lengths should be so chosen as to permit of easy manipulation of the tube.[2] The Meyer tube is connected or disconnected by the rubber stoppers which are left always attached to the rubber tubes. The carbon tube *C* is fitted with a perforated porcelain plate sliding easily.

The funnel is prepared for filtration by making on the porcelain disk a felt of asbestos about 1/16 to 1/8 in. in thickness, using amphibole (not serpentine) asbestos which has been carefully digested with strong hydrochloric acid for several hours and washed with water until it gives no acid reaction. On top of the asbestos pad is placed a layer of similarly treated quartz mixed with asbestos, of the height shown. A mixture of quartz grains of various sizes (approximately 50 per cent. passing a 20-mesh sieve and 50 per cent. passing a 10-mesh and remaining on a 20-mesh sieve) is suitable. The mixture of quartz and asbestos may be obtained by filling the funnel from a beaker (directing against it a stream from a wash-bottle) while maintaining a gentle suction. In this way the asbestos is properly mixed with the quartz. A little experience and attention to these details will enable one to prepare the quartz-bed in a manner that will greatly expedite filtra-

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[1] As a precaution against error resulting from too rapid passage of the gases, it is well to attach a second barium-hydroxide tube to retain any carbon dioxide that may pass the first.

For the most accurate work the Meyer tubes should be washed with dilute acid before beginning work each day. After a determination is finished the tube should be completely filled two or three times with tap water, then rinsed with distilled water, in order to remove the carbon dioxide liberated when dissolving the carbonate from the previous determination.

The flask containing the carbonate should be thoroughly agitated after adding the acid, since the carbonate sometimes dissolves rather slowly if this is not done; this is particularly the case if it has packed much during filtration.

[2] It is well to wash out the rubber tubes connected to the Meyer tube with a little water each day before beginning work.

tion.[1] The stopper is now inserted in the funnel, the Meyer tube connected as shown and the liquid and precipitate sucked into the funnel. Only a gentle suction should be used. When necessary P_2 is opened to admit air back of the column of liquid in the Meyer tube. When the contents of the Meyer tube have been transferred, the large bulb nearest B is half filled with water by opening P_1; the stop-cock S is operated during this and subsequent operations so as to maintain a gentle suction all the time. M is now manipulated so as to bring the wash water in contact with all parts of the interior, after which the water is sucked through C; P_2 is left open during this and subsequent washings.[2] After eight washings as directed, allowing the wash water to drain off thoroughly each time before adding more, M may be detached, the stopper removed from the funnel and the washing completed by filling C to the top with CO_2-free water, sucking off completely and repeating the operation once. With care the washing may be done with 150 c.c. of water. Air is now admitted through the side opening of S, C is removed and the porcelain disk carrying the asbestos, quartz and barium carbonate is thrust, by means of a long glass rod, into a flask, removing any adhering particles from the sides of C, by a stream of water from a wash-bottle. An excess of the standard acid is now added from a burette or pipette, using a portion to wash out M, and after the contents of the flask have been thoroughly agitated by shaking, the excess of acid is titrated against the standard alkali, using 3 drops of the methyl-orange indicator.

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[1] Glass wool should on no account be used as a substitute for the quartz, on account of the probability of errors arising from its attack by the alkali or acid.

[2] The operation of filtering can be carried out very rapidly after a little practeic.

STANDARD METHODS FOR LABORATORY SAMPLING AND ANALYSIS OF COKE[1]

(American Society for Testing Materials)

DETERMINATION OF TOTAL MOISTURE AND PREPARATION OF LABORATORY SAMPLES

Apparatus

Galvanized-iron Pans 24 by 24 by 4 in. Deep.—For total moisture determination.

Balance or Solution Scale.—For weighing the galvanized-iron pans with samples. It should have a capacity of 10 kg. and be sensitive to 1 gram.

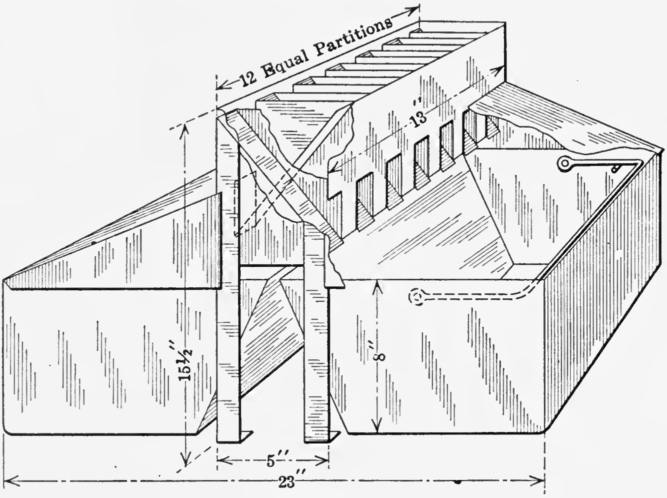

Fig. 43.—Riffle sampler.

Jaw Crusher.—For crushing coarse samples to pass a 4-mesh sieve.

Roll Crusher.—For reducing the 4-mesh product to 10-mesh.

Abbé Ball Mill or Hard-steel Diamond Mortar.—For reducing the 10-mesh product to 60-mesh. The porcelain jars for the ball mill should be approximately 9 in. in diameter and 10 in. high. The flint pebbles should be smooth, hard and well rounded.

A Large Riffle Sampler, with ⅝ or ¾-in. Divisions.—For reducing the 4-mesh sample to 5 lb. (Fig. 43).

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[1] These methods were still "tentative" at the time of going to press, but will become standard in due season, as provided by the statues of the Society. They are now in use and no objections have been brought to the attention of the committee of representative American chemists in charge of the work.

A Small Riffle Sampler, with ¼ or ⅜-in. Divisions.—For dividing down the 10 and 60-mesh material to a laboratory sample.

An 8-in. 60-mesh Sieve with Cover and Receiver.

Containers for Shipment to Laboratory.—Samples in which the moisture content is important should always be shipped in moisture-tight containers. A galvanized-iron or tin can with air-tight friction top or a screw top which is sealed with a rubber gasket and adhesive tape is best adapted to this purpose. Glass fruit jars sealed with rubber gaskets may be used, but require very careful packing to avoid breakage in transit. Samples in which the moisture content is of no importance need no special protection from loss of moisture.

Oven, Stove or Hot Plate.—For drying coke samples in the determination of total moisture. If an oven is used it should have openings provided for natural ventilation and should be capable of being regulated between 104 and 200°C. If the coke is dried on a stove or hot plate a thermometer should be placed in it, and care exercised that the temperature does not exceed 200°C. at any point in the pan of coke.

Method

Total Moisture Determination.—Dry the entire sample received at the laboratory without any preliminary crushing to constant weight at a temperature of not less than 104° nor more than 200°C.

Calculate the loss in weight to percentage of moisture, which shall constitute the total moisture in the coke as received at the laboratory.

The allowable difference in duplicate determinations by the same analyst is 0.5 per cent.

Reduction of Sample.—Crush the dried sample mechanically with a jaw or roll crusher, or by hand on a chilled iron or hard-steel plate by impact of a hard bar or sledge, avoiding all rubbing action, as otherwise the ash content will be materially increased by the addition of iron from the sampling apparatus, even though hardened iron or steel is used. Continue the crushing until all the sample passes through a 4-mesh screen, mix and quarter this to not less than 5 lb.; again crush the 5-lb. sample to a fineness of 10-mesh; mix and quarter to 400 grams. Transfer this 400-gram portion to the porcelain jar of an Abbé ball mill and pulverize to 60-mesh. When pulverization is complete, pour the contents of the jar on a ½-in. screen and separate the sample from the pebbles by shaking the screen. Reduce the quantity of sample by quartering or riffling to about 50 grams. Pass the entire 50-gram portion through a 60-mesh sieve, pulverizing any coarse particles in a diamond mortar, and mix with remainder of sample, preserving the sample for analysis in a rubber-stoppered glass bottle.

In case a ball mill is not available for fine grinding, quarter the 5-lb. 10-mesh sample to 200 gram and pulverize to 60-mesh, by impact in a hard-steel diamond mortar. The use of rubbing surfaces such as a disk pulverizer or a bucking board is never permissible for grinding coke.

Note

The accuracy of the method of preparing laboratory samples should be checked frequently by resampling the rejected portions and preparing a duplicate sample. The ash in the two samples should not differ more than 0.4 per cent.

DETERMINATION OF MOISTURE

Apparatus

Moisture Oven.—An ordinary drying oven with openings for natural air circulation and capable of temperature regulation between limits of 104° and 110°C. may be used.

Capsules with Covers.—A convenient form, which allows the ash determination to be made on the same sample, is the Royal Meissen porcelain capsule No. 2, 7/8 in. deep and 1 3/4 in. in diameter. This is to be used with a well-fitting flat aluminum cover, illustrated in Fig. 44.

Platinum crucibles or glass capsules with ground-glass caps may also be used. They should be as shallow as possible, consistent with convenient handling.

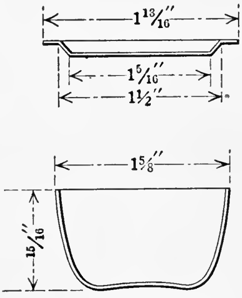

Fig. 44.—Porcelain capsule with flat aluminum cover.

Method

Heat the empty capsules under the conditions at which the coke is to be dried, stopper or cover, cool over concentrated sulphuric acid, sp. gr. 1.84, for 30 min., and weigh. Transfer to the capsule an amount slightly in excess of 1 gram and bring to exactly 1 gram in weight (± 0.5 mg.) by quickly removing the excess weight of coke with a spatula.

Place the capsules, uncovered, in a preheated oven (at 104° to 110°C.). Close the oven at once and heat for 1 hr. Then open the oven, cover the capsules quickly and place them in a desiccator over concentrated sulphuric acid. When cool, weigh.

The percentage moisture in the 60-mesh sample shall be used to calculate the other results to a dry basis.

The allowable differences in duplicate determinations are as follows:

	Per cent.
Same analyst	0.2
Different analysts	0.3

DETERMINATION OF ASH

Apparatus

Gas or Electric Muffle Furnace or Meker Burner.—The muffle should have good air circulation and be capable of having its temperature regulated to not exceed 950°C.

Porcelain Capsules.—Royal Meissen Porcelain Capsules No. 2, 7/8 in. deep and 1 3/4 in. in diameter, or similar shallow dishes or platinum crucibles.

Method

Place the capsules containing the dried coke from the moisture determination in a muffle furnace or over a burner, and heat to redness at such a rate as to avoid mechanical loss. Finish the ignition to constant weight (± 0.001 gram) at a temperature not exceeding 950°C. Cool in a desiccator and weigh.

The allowable differences in duplicate determinations are as follows:

	Per cent.
Same analyst	0.2
Different analysts	0.3

Notes

Before replacing the capsules in the muffle for ignition to constant weight, the ash should be stirred with a platinum or nichrome wire. Stirring once or twice before the first weighing hastens complete ignition.

Test the ash for unburned carbon, by moistening it with alcohol; any carbon remaining will show as black particles.

DETERMINATION OF VOLATILE MATTER

Apparatus

Platinum Crucible with Tightly Fitting Cover.—The crucible should be of 10-c.c. capacity, with capsule cover having thin flexible sides fitting down into crucible. Or the double-crucible method may be used, in which the sample is placed in a 10 or 20-c.c. platinum crucible, which is then covered with another crucible of such a size that it will fit closely to the sides of the outer crucible, and its bottom will rest ⅓ to ½ in. above the bottom of the outer crucible.

Vertical Electric Tube Furnace, or a Gas or Electrically Heated Muffle Furnace.—The furnace may be of the form shown in Fig. 45. It is to be regulated to maintain a temperature of 950°C. (± 20°C.) in the crucible, as shown by a thermocouple kept in the furnace. A Meker burner may be used, if satisfactory to both parties to the contract.

Method

Weigh 1 gram of the coke in a weighed 10-c.c. platinum crucible, close with capsule cover and place on platinum or nichrome-wire supports in the furnace chamber, which must be at a temperature of 950°C. (± 20°C.). After the crucible has been heated 2 or 3 min. tap the cover lightly or more perfectly seal the crucible and thus guard against the admission of air. After heating exactly 7 min., remove the crucible from the furnace and, without disturbing the cover, allow it to cool in a desiccator. Weigh as soon as cold. The loss of weight minus moisture equals the volatile matter.

The allowable differences in duplicate determinations are as follows:

	Per cent.
Same analyst	0.2
Different analysts	0.4

Alternate Method, Using Meker Burner

Weigh 1 gram of the coke in a weighed 10 or 20-c.c. platinum crucible, close with capsule cover or another crucible as described above under "Apparatus," and place in the flame of a No. 4 Meker burner, having approximately an outside diameter at the top of 25 mm. and giving a flame not less than 15 cm. high. The temperature should be 950°C. (± 20°C.), as determined by placing a thermocouple through the perforated cover, which for this purpose may be of nickel or asbestos. The junction of the couple should be placed in contact with the center of the bottom of the crucible; or the temperature may be indicated by the fusion of pure potassium chromate in the covered crucible (fusion of K_2CrO_4, 940°C.). The crucible is placed in the flame about 1 cm. above the top of the burner and the heating is continued 7 min. Where the gas pressure is variable it is well to use a U-tube attachment to the burner.

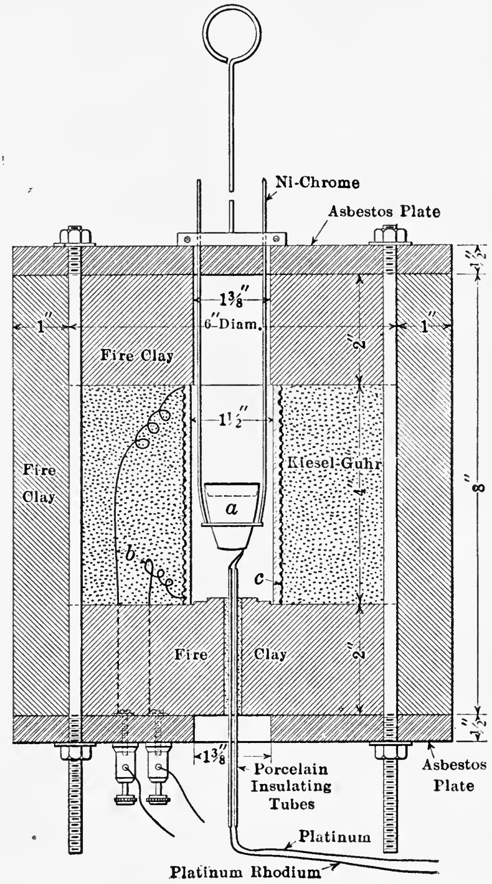

Fig. 45.—Electric tube furnace for determining volatile matter.

DETERMINATION OF FIXED CARBON

Compute fixed carbon as follows:
100 − (moisture + ash + volatile matter) = fixed carbon (expressed in percentages).

DETERMINATION OF SULPHUR BY THE ESCHKA METHOD

Apparatus

Gas or Electric Muffle Furnace, or Burners.—For igniting coke with the Eschka mixture and for igniting the barium sulphate.

Porcelain, Silica, or Platinum Crucibles or Capsules.—For igniting coke with the Eschka mixture.

No. 1 Royal Meissen porcelain capsule, 1 in. deep and 2 in. in diameter. This capsule, because of its shallow form, presents more surface for oxidation and is more convenient to handle than the ordinary form of crucible.

No. 1 Royal Berlin porcelain crucibles, shallow form, and platinum crucibles of similar size may be used. Somewhat more time is required to burn out the coke owing to the deeper form, than with the shallow capsules described above.

No. 0 or 00 porcelain crucibles, or platinum, alundum or silica crucibles of similar size are to be used for igniting the barium sulphate.

Solutions and Reagents

Barium Chloride.—Dissolve 100 grams of barium chloride in 1,000 c.c. of distilled water.

Saturated Bromine Water.—Add an excess of bromine to 1,000 c.c. of distilled water.

Eschka Mixture.—Thoroughly mix 2 parts (by weight) of light calcined magnesium oxide and 1 part of anhydrous sodium carbonate. Both materials should be free as possible from sulphur.

Methyl Orange.—Dissolve 0.02 gram in 100 c.c. of hot distilled water and filter.

Hydrochloric Acid.—Mix 500 c.c. of hydrochloric acid, sp. gr. 1.20, and 500 c.c. of distilled water.

Normal Hydrochloric Acid.—Dilute 80 c.c. of hydrochloric acid, sp. gr. 1.20, to 1 liter with distilled water.

Sodium Carbonate.—A saturated solution, approximately 60 grams of crystallized or 22 grams of anhydrous sodium carbonate in 100 c.c. of distilled water.

Sodium-hydroxide Solution.—Dissolve 100 grams in 1 liter of distilled water. This solution may be used in place of the sodium-carbonate solution.

Method

Preparation of Sample and Mixture.—Thoroughly mix on glazed paper, 1 gram of 60-mesh coke and 3 grams of Eschka mixture. Transfer to a No. 1 Royal Meissen porcelain capsule, 1 in. deep and 2 in. in diameter, or a

No. 1 Royal Berlin crucible or platinum crucible of similar size, and cover with about 1 gram of Eschka mixture.

Ignition.—On account of the amount of sulphur contained in artificial gas, the crucible shall be heated over an alcohol, gasoline or natural gas flame, as in procedure (*a*) below, or in a gas or electrically heated muffle, as in procedure (*b*) below. The use of artificial gas for heating the coke and Eschka mixture is permissible only when crucibles are heated in a muffle.

(*a*) Heat the crucible, placed in a slanting position on a triangle, over a low flame at first, then gradually increase the temperature and stir occasionally until all the black particles disappear, which is an indication of the completeness of the procedure.

(*b*) Place the crucible in a warm muffle and gradually raise the temperature to 870° to 925°C. (cherry-red heat) in about 12 hr. Maintain this maximum temperature until on stirring all black particles have disappeared.

Subsequent Treatment.—Remove and empty the contents into a 200-c.c. beaker and digest with 100 c.c. of hot water for ½ to ¾ hr., with occasional stirring. Filter and wash the insoluble matter by decantation. After several washings in this manner, transfer the insoluble matter to the filter and wash five times, keeping the mixture well agitated. Treat the filtrate, amounting to about 250 c.c., with 10 to 20 c.c. of saturated bromine water, make slightly acid with hydrochloric acid and boil to expel the liberated bromine. Make just neutral to methyl orange with sodium-hydroxide or sodium-carbonate solution, then add 1 c.c. of normal HCl. Boil again and add slowly from a pipette with constant stirring 10 c.c. of a 10 per cent. solution of barium chloride ($BaCl_2.2H_2O$). Continue boiling for 15 min. and allow to stand for at least 2 hr., or preferably over night, at a temperature just below boiling. Filter through an ashless filter paper and wash with hot distilled water until a silver-nitrate solution shows no precipitate with a drop of the filtrate. Place the wet filter containing the precipitate of barium sulphate in a weighed platinum, porcelain, silica or alundum crucible, allowing a free access of air by folding the paper over the precipitate loosely to prevent spattering. Smoke the paper off gradually and at no time allow it to burn with flame. After the paper is practically consumed raise the temperature to approximately 925°C. and heat to constant weight.

The residue of magnesia, etc., after leaching, should be dissolved in hydrochloric acid and tested with great care for sulphur. When an appreciable amount is found this should be determined quantitatively. The amount of sulphur retained is by no means a negligible quantity.

Blanks and Corrections.—In all cases a correction must be applied either: (1) by running a blank exactly as described above, using the same amounts of all reagents that were employed in the regular determination; or, more surely, (2) by determining a known amount of sulphate added to a solution of the reagents after these have been put through the prescribed series of operations. If this latter procedure is adopted and carried out, say, once a week or whenever a new supply of a reagent must be used, and for a series of solutions covering the range of sulphur content likely to be met with in coke, it is only necessary to add or to subtract from the weight of barium sulphate obtained from a coke whatever deficiency or excess may have been found in the appropriate "check" in order to obtain a result that is more certain to be correct than if a "blank" correction as determined by the former procedure is applied. This is due to the fact that the solubility error for barium sulphate is, for the amounts of sulphur in question and the conditions of precipitation prescribed, probably the largest one to be considered. Barium sulphate is soluble in acids and even in pure water, and the solubility limit is reached almost immediately on contact with the solvent. Hence, in the event of using reagents of very superior quality or of exercising more than ordinary precautions, there may be no apparent "blank," because the solubility limit of the solution for barium sulphate has not been reached, or at any rate not exceeded.

$$(\text{Weight of } BaSO_4 - \text{blank}) \times 13.73 = \text{percentage of sulphur.}$$

The allowable differences in duplicate determinations are as follows:

	Per cent.
Same analyst	0.03
Different analysts	0.05

DETERMINATION OF PHOSPHORUS IN ASH

Method No. 1. To Cover all Cases.—To the ash from 5 grams of coke in a platinum capsule is added 10 c.c. of nitric acid and 3 to 5 c.c. of hydrofluoric acid. The liquid is evaporated and the residue fused with 3 grams of sodium carbonate. If unburned carbon is present 0.2 gram of sodium nitrate is mixed with carbonate. The melt is leached with water and the solution filtered. The residue is ignited, fused with sodium carbonate alone, the melt leached and the solution filtered. The combined filtrates, held in a flask, are just acidified with nitric acid and concentrated to a volume of 100 c.c. To the solution, brought to a temperature of 85°C., is added 50 c.c. of molybdate solution and the flask is shaken for 10 min. The precipitate is washed six times, or until free from acid, with a 2 per cent. solution of potassium nitrate, then returned to the flask and titrated with standard sodium-hydroxide solution. The alkali solution may well be made equal to 0.00025 gram of phosphorus per c.c., or 0.005 per cent., for a 5-gram sample of coke, and is 0.995 of one-fifth normal. Or the phosphorus in the precipitate is determined by reduction and titration of the molybdenum with permanganate.

Note on Method No. 1.—The advantage of the use of hydrofluoric acid in the initial attack of the ash lies in the resulting removal of silica. Fusion with alkali carbonate is necessary for the elimination of titanium, which if present and not removed will contaminate the phospho-molybdate and is said to sometimes retard its precipitation.

Method No. 2.—When titanium is so low as to offer no objection, the ash is decomposed as under method No. 1, but evaporation is carried only to a volume of about 5 c.c. The solution is diluted with water to 30 c.c., boiled and filtered. If the washings are turbid they are passed again through the filter. The residue is ignited in a platinum crucible, fused with a little sodium carbonate, the melt dissolved in nitric acid and its solution, if clear, added to the main one. If not clear it is filtered. The subsequent procedure is as under method No. 1. The fusion of the residue may be dispensed with in routine work on a given coke if it is certain that it is free from phosphorus.

TENTATIVE METHODS FOR ULTIMATE ANALYSIS OF REFRACTORY MATERIALS[1]

(American Society for Testing Materials)

I. GENERAL CONSIDERATIONS

1. The sample shall be crushed in a hardened tool-steel mortar, using a pestle of the same sort. Fine grinding shall be done in an agate mortar, either by hand, or by a mechanical sample grinder of the McKenna, Carling or similar type, so constructed as to prevent the introduction of impurity.

2. Moisture shall be determined in the sample in its ordinary air-dried condition, and all other percentage compositions shall be calculated to a moisture-free basis. Whenever a sample is weighed out for any determination, a moisture determination shall also be made.

3. In all cases, check determinations shall be made, and the results shall be redetermined if satisfactory checks are not obtained. It shall be considered satisfactory if the differences between check determinations do not exceed the following limits:

For silica or other constituent amounting to 30 per cent. or over	0.3 per cent.
For alumina or other constituent amounting to 10–30 per cent	0.2 per cent.
For any other constituent amounting to under 10 per cent.	0.1 per cent.

These figures are stated in terms of the whole sample as 100 per cent.

II. SOLUTIONS REQUIRED

4. The acids referred to as concentrated shall be of approximately the following specific gravities:

Hydrochloric Acid	1.20
Sulphuric Acid	1.84
Nitric Acid	1.42

5. Dissolve 1.5 g. of ammonium carbonate in 50 cc. of cold water.

6. Dissolve 107 g. of ammonium chloride in 1000 cc. of warm water.

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[1] These methods were just issued as "tentative" by the Society at the time of going to press. They are subject to possible amendment for a year, and will become "standard" as provided by the statutes of the Society. The methods are, however, the outcome of a thorough investigation of the subject by a committee of experts in this line of work, and hence can be recommended as the best in use.

7. Neutralize 20 cc. of concentrated nitric acid with ammonium hydroxide and dilute to 1000 cc. Test with litmus; the solution shall not be acid.

8. Dissolve 1 g. of ammonium oxalate in 50 cc. of water, heating gently.

9. The strength of the final standard titania solution shall be 1 cc. = 0.0001 g. TiO_2. To prepare the solution weigh out in a platinum crucible an amount of potassium titanium fluoride (K_2TiF_6) sufficient to make from ½ to 1 liter of "stock solution" in which 1 cc. = 0.001 g. TiO_2. Evaporate several times with sulphuric acid without taking to dryness, thus driving out all fluorine. Take up the residue with water containing enough sulphuric acid to make at least 5 per cent. of the solution, when finally diluted to the standard solution strength. To standardize the stock solution take out two 50-cc. portions, dilute, boil and precipitate with ammonia. Filter, wash with hot water until free from alkali, ignite, blast and weigh. The duplicate should check very closely. From the weight of titania thus determined calculate the strength of the stock solution. The standard solution to be used is obtained from the stock solution by diluting until 1 cc. = 0.0001 g. titania (TiO_2).

10. Dissolve about 0.4 g. (a little less) of potassium permanganate in 1 liter of water and check against an iron solution of known purity and strength. Dilute the solution until 1 cc. = 0.001 g. Fe_2O_3.

III. METHODS

11. To determine moisture, heat approximately 1 g. of the sample at a temperature not under 105 nor over 110° C., to constant weight.

12. To determine loss on ignition, heat about 1 g. of the sample over a blast lamp or in an electric furnace at 900 to 1000° C., to constant weight. Ignition loss may be determined in the sample from which the moisture has been removed. The percentage of ignition loss is calculated to a moisture-free basis.

13. To determine silica, weigh out approximately 0.5 g. of the sample and mix with 5 g. of sodium carbonate. Put a little sodium carbonate in the bottom of the crucible before introducing the mixture, and then cover the mixture with a little more sodium carbonate. Fuse over a Meker burner or blast lamp until complete solution is obtained. Cool the fusion and as it solidifies, rotate the crucible to spread the mass up the side walls. Dissolve the fusion in about 100 cc. of water in a platinum or porcelain evaporating dish. Add about 20 cc. of concentrated hydrochloric acid, introducing it slowly by means of a pipette, keeping the dish covered with a watch glass. Evaporate to dryness and heat until the fumes of hydrochloric acid are gone. Add about 5 cc. of concentrated hydrochloric acid and 30 to 40 cc. of water. Warm on a water bath for 10 to 15 minutes and break up the lumps. Decant the clear liquid onto a filter paper and collect the filtrate in a 400-cc. beaker. Add more hydrochloric acid and water to the evaporating dish, warm again and decant. Repeat this a third time.

Finally transfer the contents of the dish to the filter paper. Wash with cold water until silver nitrate shows no chlorides to be left. Transfer the filtrate to the original evaporating dish, evaporate again to dryness and wash as before. Transfer to a platinum crucible. Ignite carefully over a Bunsen flame until the filter paper is burned off, then blast for about 30 minutes; cool and weigh. Repeat blasting for 5 minutes, weigh again and repeat until constant weight is obtained.

To the residue in the crucible, add about 5 cc. of water and 5 drops of sulphuric acid (the latter to prevent the formation of titanium fluoride). Evaporate to dryness. Again moisten with about 5 cc. of water and 5 drops of sulfuric acid. Add hydrofluoric acid drop by drop at first, and then slowly until the crucible is almost one-half filled. Warm on a hot plate until almost dry, add 2 or 3 cc. more of hydrofluoric acid and evaporate to dryness. Heat the crucible to bright redness and then blast for 5 minutes. Cool and weigh and repeat blasting to constant weight. The loss in weight from the original silica residue represents the actual silica content (SiO_2), except for that part of silica which is later recovered from alumina, etc. The residue from the hydrochloric-acid evaporation is left in the crucible and the total precipitate of alumina, etc., is added to this same crucible in which it is ignited and weighed.

14. To determine alumina, to the filtrate from the silica determination, add about 10 cc. of ammonium chloride and heat to boiling. Then add ammonium hydroxide very slowly and with constant stirring until there is a slight excess. Filter hot and rapidly, and wash four times by decantation with hot solution of ammonium nitrate. Carefully wash the precipitate from the filter paper into a beaker, using hot water. Dissolve the precipitate in hot dilute hydrochloric acid. Repeat the precipitation with ammonium chloride and ammonium hydroxide. Decant four times as before, using hot ammonium nitrate. Transfer to the filter paper and wash with hot ammonium nitrate until the washings are free from chlorides when tested by silver nitrate. Evaporate the filtrate nearly to dryness, add a little ammonium hydroxide and continue the evaporation. Keep the solution alkaline to coagulate any iron and aluminum hydroxides. Transfer the precipitate to a filter paper and wash thoroughly. Transfer the moist filter paper to the platinum crucible containing the residue from the silica. Burn off the filter paper and blast the precipitate. Cool in a desiccator and then moisten with one drop of nitric acid and heat gently until all fumes are gone. Blast again and weigh. Repeat blasting and weighing to a constant weight.

15. To determine iron oxide, fuse the ignited alumina precipitate with about six times its weight of potassium pyrosulphate or potassium bisulphate. Avoid sputtering. Heat carefully to redness and continue heating until the residue is all dissolved. Cool. Dissolve in warm water, add about 10 cc. of dilute sulphuric acid (1:5). Evaporate to a small volume. Then heat to a higher temperature until copious fumes of sulphuric acid are evolved. Sufficient sulphuric acid should be present to form a pasty mass when cooled. Take up with water, filter off, wash, ignite and weigh the silica as before and evaporate with hydrofluoric acid as before. The loss in weight is extra silica to be added to the original silica determination and subtracted from the alumina. Fuse the residue with a little potassium pyrosulphate or potassium bisulphate, and add the solution of this cake to the main solution. Transfer the total filtrate to a 250-cc. graduated flask and dilute to 250 cc. mixing thoroughly. Draw off 50 cc. of this solution and reserve for titania

determination. Pass the remaining 200 cc. through a Jones reductor, or otherwise reduce the solution with pure zinc and sulphuric acid. To the solution add 3 cc. of 10-per-cent. copper-sulphate solution and titrate with standard potassium-permanganate solution (1 cc. equivalent to 0.001 g. Fe_2O_3), until a faint pink tinge is seen. If Jones reductor or similar apparatus is used, subtract the potassium permanganate equivalent, which has previously been determined on blank samples run through the apparatus. From the result, calculate the iron as iron oxide (Fe_2O_3).

16. To determine titania, place in a small Nessler tube the 50 cc. of filtrate previously set aside for titania determination, and fill the tube up to the graduation mark. Add 1 cc. of hydrogen peroxide and shake well. The color of this solution is now compared in any standard color comparator with the color of a known standard solution, preferably of such strength that 1 cc. equals 0.0001 g. of titanium dioxide (TiO_2). To make the comparison, put 10 cc. of this standard solution into a second small Nessler tube and dilute with water from a burette until the color is matched. Note the amount of water added and calculate the percentage of titanium dioxide in the sample.

17. To determine lime, evaporate the filtrate from the alumina precipitation to about 250 cc. While still boiling add about 5 cc. of acetic acid. Meanwhile, dissolve about 1 g. of oxalic acid in a little hot water and add to the solution. In about 5 minutes add a slight excess of ammonium hydroxide and boil until precipitation is complete. Cool thoroughly and filter. Wash three times by decantation with dilute ammonium hydroxide (1:10) or a 1-per-cent. solution of ammonium oxalate. Dissolve the precipitate by adding about 50 cc. of dilute nitric acid (1:5). Again add a slight excess of ammonium hydroxide and a few drops of oxalic-acid solution. Boil well and let stand a couple of hours to cool. Filter and wash as before. Transfer the precipitate to a platinum crucible, carefully burn off the paper and ignite over a blast lamp for about 10 minutes. Cool and weigh quickly. Repeat the blasting to constant weight. The increase in weight of crucible is calcium oxide.

18. To determine magnesia, add to the filtrate from lime precipitation about 2 g. of sodium-ammonium-phosphate dissolved in 15 cc. of water. Stir vigorously and while stirring add drop by drop about one-third of the volume of the solution of ammonium hydroxide. Let stand 12 to 24 hours. Filter and wash the precipitate with dilute ammonium hydroxide (1:10). The filtrate is discarded. Wash the precipitate until the washings show no discoloration when tested with silver nitrate. Redissolve the precipitate in warm dilute nitric acid (1:5), using about 50 cc., and collect in a beaker. Precipitate and wash as before. Collect the precipitate on a Gooch asbestos crucible. Dry slowly and then heat over a Meker burner for about 10 minutes; cool and weigh. Re-ignite to constant weight.

19. To determine alkalies, the J. Lawrence Smith method shall be used. Weigh out about 0.5 g. of the sample and mix well with 0.5 g. ammonium chloride and 3 g. calcium carbonate. Transfer to a platinum crucible, placing about 0.5 g. calcium carbonate in the bottom of the crucible and a similar amount over the top of the mixture. Heat gently over a low flame for about 15 minutes to volatilize ammonium chloride. Then raise the

temperature until the lower three-quarters of the crucible is dull red. Hold this temperature for about one hour. Cool, take up with about 50 cc. of water and heat over a water bath, adding water to replace that lost by evaporation. Break up any lumps with a small pestle. Decant the clear liquid through a filter paper and wash four times by decantation. Then transfer the residue to the filter. Wash until silver nitrate shows only a very faint turbidity. To the filtrate add ammonium hydroxide and ammonium carbonate and heat to boiling. Filter and again digest the precipitate with ammonium hydroxide and ammonium carbonate. Filter and allow the filtrate to collect with the previous filtrate, then evaporate to dryness in a platinum or porcelain dish. Remove ammonium salts by gentle ignition in a moving flame. Treat with water and remove the last trace of lime by adding ammonium oxalate to the boiling solution and let stand over night. Filter, evaporate to dryness, ignite gently and allow to cool. Then moisten the residue with hydrochloric acid, evaporate again to dryness, ignite gently and weigh. The increase in weight is potassium chloride plus sodium chloride. Dissolve in water. Ignite and weigh any insoluble residue, deducting this from the mixed chlorides.

Dilute the solution of the mixed chlorides and add hydrochloroplatinic acid in amount equal to 0.3 cc. more than would be necessary if all chlorides were present as potassium chloride. Evaporate to a syrupy consistency. Cool and treat with a few cubic centimeters of 80-per-cent. ethyl alcohol. Stir and decant through a weighed Gooch crucible. Treat again with 80-per-cent. alcohol and decant. Repeat washing and decantation until the alcohol leaving the Gooch crucible is colorless and the precipitate appears golden yellow, not orange. Transfer the precipitate to the Gooch crucible, wash with 80-per-cent alcohol about six times and dry at 130° C. to constant weight. This residue is potassium chloroplatinate.

The oxides are calculated as follows:

Weight of potassium chloroplatinate × 0.3068 = potassium chloride.
Weight of potassium chloroplatinate × 0.1941 = potassium oxide (K_2O).
Total chlorides – potassium chloride = sodium chloride.
Sodium chloride × 0.5303 = sodium oxide (Na_2O).

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