METALLURGY
OF
CAST IRON

THOMAS D. WEST

METALLURGY OF CAST IRON

A COMPLETE

EXPOSITION OF THE PROCESSES INVOLVED IN ITS
TREATMENT, CHEMICALLY AND PHYSICALLY, FROM THE BLAST FURNACE
THROUGH THE FOUNDRY
TO THE TESTING
MACHINE.

A Practical Compilation of Original Research.

BY

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SELECTED TABLES OF UTILITY FOR FURNACE AND FOUNDRY WORK.

PREFACE TO FIRST AND SECOND EDITIONS.*

This work is written with a view to its value not only to the founder, the moulder, the blast furnace-man, the chemist, and the engineer, but also to the designer, the draftsman, the pattern-maker, the college specialist, and all that may in any manner be desirous of obtaining a practical knowledge of cast iron in its application to founding or any allied interests.*

In compiling this volume, the author has been guided by a broad experience as a moulder and founder in loam, dry, and green sand work, in the various specialties of founding, all of which require a knowledge of the subject as a whole in order to arrive at correct conclusions on questions pertaining to cast iron.

A factor which has also aided the author in presenting this volume is that of being since 1892 surrounded, in his present foundry location, by blast furnaces, thus affording him every opportunity of making a close study of modern furnace methods and the principles involved in making iron. This has also enabled the author, as a foundryman, to determine wherein many principles involved in furnace practice can often be well utilized in constructing and operating cupolas, as well as in mixing iron.

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* Preface to Third Edition is found on page xiii.

In many respects this work will be found to be in advance of general practice, presenting many new subjects, principles, and ideas calculated to greatly broaden practical literature upon the metallurgy of cast iron, but the author does not advocate any measures that have not been thoroughly tested by experience or a close study of the subjects presented. While this work will be found largely the product of the author's own experience and research, he has also drawn upon the work of others wherever, in his judgment, this could in any way prove of practical value in giving a completeness to the various subjects treated.

This work contains illustrations of valuable appliances which the author has originated and upon which he could have secured patents, but believing the advancement of founding best aided by their being given freely to any that desire to use them, all are at liberty to freely utilize the various improvements shown.

About a dozen of the chapters are revised extracts of papers which were presented by the author before the British Iron and Steel Institute, the American Society of Mechanical Engineers, the American Institute of Mining Engineers, and the Eastern and Western Foundrymen's Associations. The leading trade papers of America and Europe are also to be credited with having given first publicity to some of the author's writings herein presented. Among those to be mentioned are the *American Machinist*, the *Iron Age*, the *Iron Trade Review*, and the *Foundry*—American publications; and *Engineering*, of London, *The Engineer*, of Glasgow, and other leading trade papers of Europe. To all these associations and trade papers the author tenders his thanks. The encouragement thus rendered has served to stimulate the completion of this work, which has taken about four years to compile, due to the experiments, research, etc., found necessary in order to advance the original information presented. The result has been to bring all the author's writings on the various subjects treated under one cover, giving to the reader an advantage that could not be otherwise obtained.

The first and second editions are divided into four parts (the third edition is divided into three parts, as explained in the foot-note), the first illustrating the principles involved in a general way in the making of iron, commencing with a very complete chapter on coke and its kin, iron ore, followed by a description of furnace methods and principles which can often be well applied to cupola practice.

The second part of the first and second editions treats of cupola practice, showing the latest improvements. It illustrates all the known methods for the application of "center blast," accompanied with information on cupola practice necessary to be used with the author's first two volumes to give a complete presentation of the subject up to date.*

The third part in the first and second editions (now the second part in the third edition) is devoted to instructions of chemistry in founding, and clearly illustrates the requirements of a wholly different practice

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* The chapters on cupolas in the second part were all transferred to "Moulder's Text Book" after the publication of the second edition. This caused the third edition to be divided into three parts, as shown by Table of Contents, also Preface to Third Edition, page xiii.

than has been followed to about the year 1895 by most founders, namely, of judging pig iron for mixture by its fracture, a quality which chemistry has proven to be wholly impractical. It shows the founder following such methods, why he cannot expect to meet with other than bad, undesirable results as well as heavy losses. It teaches how the greatest possible economy and desired ends in making mixtures are best achieved. It also defines, for practical application in the various specialties, the affinity which one chemical property or metalloid has for another in changing the character or grade of iron, and discloses valuable information on the science of mixing and melting cast iron.

The fourth part of the first and second editions (now the third part of the third edition) is devoted to the subject of testing, and discloses new discoveries made by the author which explain causes for erratic results heretofore obtained for the most part from transverse and tensile tests, contraction chill, etc., recorded from bars of like area poured from the same ladle and gate, and presents methods best calculated to reduce erratic results to the least possible minimum.

Following the seventieth chapter (seventy-first chapter, third edition), the work is closed with a few tables and an index. The first table gives the net weight of pig iron in gross tons of 2,268 pounds, ranging from one to one hundred tons. (The third edition gives a table of 2,240 pounds for figuring chilled pig.) The second table presents the full names of chemical properties in metal, accompanied with their abbreviations or symbols as generally written by chemists. The tables following are copied from Messrs. Cremer and

Bicknell's "Handbook for Chemical and Metallurgical Practice."

It is not intended that this preface shall convey a complete statement concerning the importance of all the subjects treated. In order to obtain further conception of the important subjects discussed in the various parts of the work, the reader is kindly referred to a close study of the table of contents.

THOS. D. WEST.

SHARPSVILLE, PA., Jan. 5, 1897.

PREFACE TO THIRD EDITION.

A comparison of this third edition with the two previous ones shows that this work has been extensively revised and enriched by the addition of much new matter on making, mixing, melting and testing of cast iron, part of which constitutes twenty new chapters embodying researches, experiences, experiments, discoveries, and illustrations that have been secured by the author since the publication of the first edition in 1897. To provide space for this large addition of new matter thirteen chapters treating of cupola practice, published in the first two editions, have been transferred to the "Moulder's Text Book," leaving this work to the treatment of subjects more appropriate to its title, dividing the third edition into three parts instead of four, as in the first and second editions. For information on the special subjects treated in this work, readers are referred to the preface of first and second editions which precedes this, and also retained as originally written to assist in illustrating the changes made in the third edition.

The author's original researches, experiments, and discoveries described in this work involved an outlay of much time and money, and he is indebted to a number of individuals for their valuable assistance in making chemical analyses, etc., and who have received proper credit throughout the work. The melting and physical testing was chiefly done by the author, or under his supervision, as he advocates that all investigators should do their own experimenting or other work as far as possible.

There are a few works, in almost all epochs, that are so original and in advance of the times in their treatment and advocacy of new methods and suggested improvements, that it requires a lapse of several years to test their utility. The sales of some never exceed their first edition, while others, by force of merit, live and are recognized as standards, receiving much credit for their utility and praise for the benefits they render. This work belongs to the latter class and has met with a success that is very gratifying, as the reforms and new-school practices of mixing metals, by utilizing chemistry, testing, etc., advanced by the author in the first two editions are to-day, 1901, adopted and highly praised by a large number of those interested in the making and use of cast iron. About 25 per cent. of our present founders still follow the old-school practices, and to further influence some toward an adoption of the methods advanced in this work the author is pleased to present the following extracts seen on the next two pages from a few of many testimonials tendered him during the year 1901.

THOS. D. WEST.

SHARPSVILLE, PA., October, 1901.

ISSUE OF FOURTH EDITION.

Preannouncement of the issue of the third edition so rapidly exhausted it, that this fourth edition was found necessary before trade papers, etc., could announce and review the third edition.

THOS. D. WEST.

SHARPSVILLE, PA., January, 1902.

PREFACE TO FIFTH EDITION.

The first edition of this work, which can, in its present form, be justly called a practical compilation of original research, was issued sooner than it would have been, had not the author been anxious to combat and thwart impractical theories and practices that some inexperienced in general founding were laboring to establish, and which can be found in past records of trade papers and engineering societies, etc., and are now proven to be incorrect. The original information and reforms advanced in this work were too far in advance of the times to escape severe criticism or insure the popular support they were entitled to, but are now receiving in such measure as to be very gratifying to the author. The impractical theories and practices that were advanced are not yet all set aside or acknowledged to be wrong and injurious as they should be by their advocates. However, the exhaustion of the third and fourth editions of this work in the short period of two months is a strong endorsement of the original practices, reforms, etc., advanced, and its practical utility. Time will demonstrate to all those not yet convinced of the impracticability of past teachings what is correct.

Not only does the large sale of this work demonstrate its growing popularity, but also forcibly illustrates the advancement of founders to accept its advocacy of chemical analyses, etc., in mixing metal instead of judging pig iron by the appearance of its fracture. One class of castings (ingot moulds) made by the firm of which the author is the manager, is subjected to the most rigid tests, when in use, that castings can be put to. In making these castings, an excellent opportunity is afforded to test the utility of working by chemical analyses. There are about half a dozen ingot mould makers in the United States and all of them will agree with the author when he asserts that being guided by chemical analyses instead of pig iron fractures has increased the efficiency of ingot mould service over fifty per cent. Manufacturers of other lines of castings can find similar and other benefits by the adoption of chemistry and following the teachings of this work. We have other works and writings showing effects of the carbons, silicon, sulphur, manganese, phosphorus, etc., in changing the character of iron, but they fail in not setting forth essentials that must be followed in order to make chemistry a success in founding or insure the greatest certainty and economy in obtaining desired mixtures of iron. The work has been said to be too large; but not until certain impractical theories and practices have been entirely set aside can it be abridged or parts cut out.

About one month after the issue of the third edition of this work Mr. W. J. Keep brought out a book entitled "Cast Iron," published by John Wiley & Sons, New York. On page 129 of this work he refers to a report made by a committee of the Western Foundrymen's Association, in which preference was given to square bars cast flat instead of round bars cast on end, which had fluidity strips and chill attached to them. This was due to the lack of skill on the part of the molders and their inexperience in making such round bars on end. Why does Mr. Keep refer to the Chicago foundrymen's local Association report and not to that of the national body (American Foundrymen's Association), accepted at Buffalo, June 1901, in which they recommend the use of round bars cast on end, and that bars should not be smaller than 1½ inches diameter, as recorded on pages 574 to 584 of this work, and also still persist in advocating the use of ½-inch square bars with the evidence obtainable to prove their unfitness for testing cast iron. Good evidence of the unfitness of ½-inch square bars is presented by Mr. Keep in his book, "Cast Iron," pages 173 and 174. Here we find that a slight difference in the fluidity of the same metal gave a difference of a hundred pounds in the body of two ½-inch square bars — a quality exactly in keeping with the evidence presented in this work — showing how easily such small bars are made unreliable by slight variations in the temper or dampness of molding sand and temperature of pouring metal.

Mr. Keep has presented tests in his work that were obtained by the American Foundrymen's Association committee, but in so doing endeavors to carry along tests of the ½-inch bar also. The A. F. A. committee found that a bar as small as ½-inch square or round was wholly unsuited to test any kind of iron, and hence totally ignored it in their recommendation, which was unanimously accepted by this national body, as stated above. It is to be regretted that men of inexperience in the actual work of broad molding or founding may be led to adopt incorrect practices, and that the general adoption of correct methods for testing cast iron is to be retarded by the advocacy of such an unreliable and impractical test bar as the ½-inch square.

The author would not have embodied these remarks in a preface, did he not feel that events warranted them and he trusts it may be the means of doing some good in assisting to abolish an impractical and injurious practice.

THOS. D. WEST.

SHARPSVILLE, PA., February, 1902.

PREFACE TO SEVENTH EDITION.

During the period intervening the publication of the revised third and the sixth editions, the demand has been such as to allow no time to make changes in the plates. Thus, a few errors remained in the revised work until the seventh edition went to press. The few errors found, however, were, I am pleased to say, of such a character as not to injure the practical value of the work.

The appreciation expressed by reviewers who have recommended this work to the public through the press, and by individuals, has done much to increase its popularity. I am not disregardful of these compliments tendered my work, and wish here to thank all those who have interested themselves in its behalf.

THOS. D. WEST.

SHARPSVILLE, PA., June, 1902.

COMMENTS.

Mr. W. G. Scott, Metallurgist and Chemist for J. I. Case T. M. Company, Racine, Wis., and laboratories at Philadelphia, Chicago, and Milwaukee, says of "Metallurgy of Cast Iron": "Nearly every foundryman has this work, and I believe that it has done more to advance the science of founding than any work ever published. Since the appearance of this book there has been a notable change in foundry practice. The number of firms now mixing by analyses is astonishing, and I think that its author is entitled to the credit of starting the greater part of them on the modern plan, i.e., chemical metallurgy. I cannot say too much in praise of this book."

Mr. Frank L. Crobaugh, Proprietor and Expert, The Foundrymen's Laboratory, Cleveland, O., and author "Methods of Chemical Analyses and Foundry Chemistry" says: "'The Metallurgy of Cast Iron' has caused many advances in foundry practice, including the application of chemistry."

Mr. Edgar S. Cook, President and General Manager of The Warwick Iron & Steel Co., Pottstown, Pa., says: "I frequently hear the most complimentary remarks in regard to the beneficial influence of Mr. West's papers, and especially with reference to his 'Metallurgy of Cast Iron.' There is evidently a strong desire on the part of all interested in the subject, blast furnace managers as well as progressive foundrymen, to arrive at some formula whereby guesswork may be replaced by certain well determined facts, and thus afford a safe foundation for scientific methods in foundry practice. Mr. West's efforts in this direction are deserving of the widest recognition."

Mr. E. H. Putnam, Foundry Superintendent, Moline, Ill., and editor of the foundry department of *The Tradesman*, Chattanooga, Tenn., in writing of "Metallurgy of Cast Iron" says: "I am glad to attest my appreciation of its great practical value. It is unsurpassed in foundry literature, and is an invaluable adjunct to the foundryman's library."

Mr. Francis Schumann, the first president of the American Foundrymen's Association, says: "The foundry industry owes a lasting tribute to Thomas D. West for his efforts towards more comprehensive and rational methods in its processes. Mr. West holds the singular position of a foundryman engaged in the actual practice of his art, who, with ability, enthusiasm, and zeal in original research imparts the knowledge so obtained freely and without reward. Much information is contained in his work of 'Metallurgy of Cast Iron' which cannot fail to interest foundrymen and engineers, touching, as it does, upon every stage from melting to the test bar. The work is of a kind that can come only from the practical founder about matters seldom found in print, because practical foundrymen of Mr. West's attainments are, as yet, a rarity."

PART I.

CHAPTER I.

THE MANUFACTURE AND PROPERTIES OF COKE.

The chemical and physical properties of fuel, having much to do with the physical and chemical properties of cast iron, when made or remelted, the author has thought that a general article on this subject would be very fitting in this work. Coke was first successfully used in this country at the Clinton Furnace, in Pittsburg, in 1860. Prior to this anthracite and bituminous coal, also charcoal, had been almost wholly used for smelting in furnaces; while anthracite coal was the chief fuel used by founders. In changing from the use of anthracite coal to coke for making and remelting iron, Pennsylvania and Ohio took the lead. It was not long until its use increased to such a degree that few are now found in this country depending on coal entirely as a fuel for making and remelting iron. Coke has forced its adoption for making iron mainly because it is a cheaper fuel, and for remelting iron because, aside from cheapness, it requires less blast and melts more quickly than coal. Coal, however, has still some advantages for remelting iron.

The process of making coke consists of taking soft or bituminous coal and letting it burn for a number of hours in what are called coke ovens, generally of the form seen in Fig. 1. Other forms and methods are used, and some of them are covered by patents. Some of the advantages claimed for patent ovens are in the recovery of by-products and in saving labor and obtaining a greater yield of coke from the same amount of coal.

The main principle in coking lies in admitting the air to support combustion at or over the surface, instead of causing it to pass through the coal as in burning fuel for firing boilers, etc., thus being an action of distillation more than of combustion. This prevents destruction of the coal while burning, and causes it to "cake" and become the coke of industrial commerce.

The kind of ovens generally used in America is the bee-hive oven, as illustrated in Fig. 1, page 8. Ovens are generally built from ten and one-half to twelve feet in diameter and from five to eight feet in height. The standard size is twelve feet in diameter and from six to eight feet high. Some are built on the plan seen in Fig. 1. The interior of the oven is fire-brick, and the space between the ovens is packed with clay or loam. Pillars, as at K, are used for the support of the larries on the track B, so as to take their weight from the arch of the ovens. The outside of the ovens, as at S, are built of stone and made very strong. The filling is clay or loam, and the floor X is composed of tile fire-brick.

Coal is sometimes coked in mounds, heaps, or piles similar to the method used for making charcoal of wood. It was by such method that coke was first made. By such methods of coking the coal must be chiefly in lumps, and piled in such a manner as to leave all the air space that is practical through the body of the mounds, and also piled so as to have as little of it touch the ground as possible. The mounds or piles are generally built around a brick chimney laid with loose bricks, left as full of holes in every other course of bricks as is practical, so as to provide openings for draft from the outside of the mounds at various heights. These piles range from fifteen to thirty feet in diameter, and from four to seven feet in height. They are set on fire by means of openings left in their bodies where wood and light brush can be inserted. Some piles are built in an oblong form, often running two hundred feet or more in length, with a base of twelve to fifteen feet in width. The plan of building such long piles is to lay a body of coal about sixteen inches high, then commence the formation of flues as seen in C, Fig. 2, page 10. These flues are filled with wood, brush, or any light kindling, and then set on fire at every opening, the aim being that no one part of the pile burn faster than another. If the fire should be too strong at any one point, the outside surface is banked with wet coke dust or earth, and applied to the whole surface of the structure as soon as the volatile matter has stopped burning so as to smother the fire and complete the coking of the coal. The last operation in this method of coking is to pour a little water down the vertical flues so as to diffuse steam throughout the entire body of the coke, which it is claimed is beneficial, resulting in the least moisture in the coke. It takes from five to eight days, according to the state of the weather, to perfect coking by this plan. The coke produced is said to be of very good quality, but as a general thing there is a considerable loss in the yield where coal is coked in mounds or heaps, and the method has the disadvantage of requiring the coal to be in lump form. It is only where it is costly to secure building material, or where the coking qualities of coal are to be tested before expensive ovens are erected that mounds are used to coke coal at the present time.

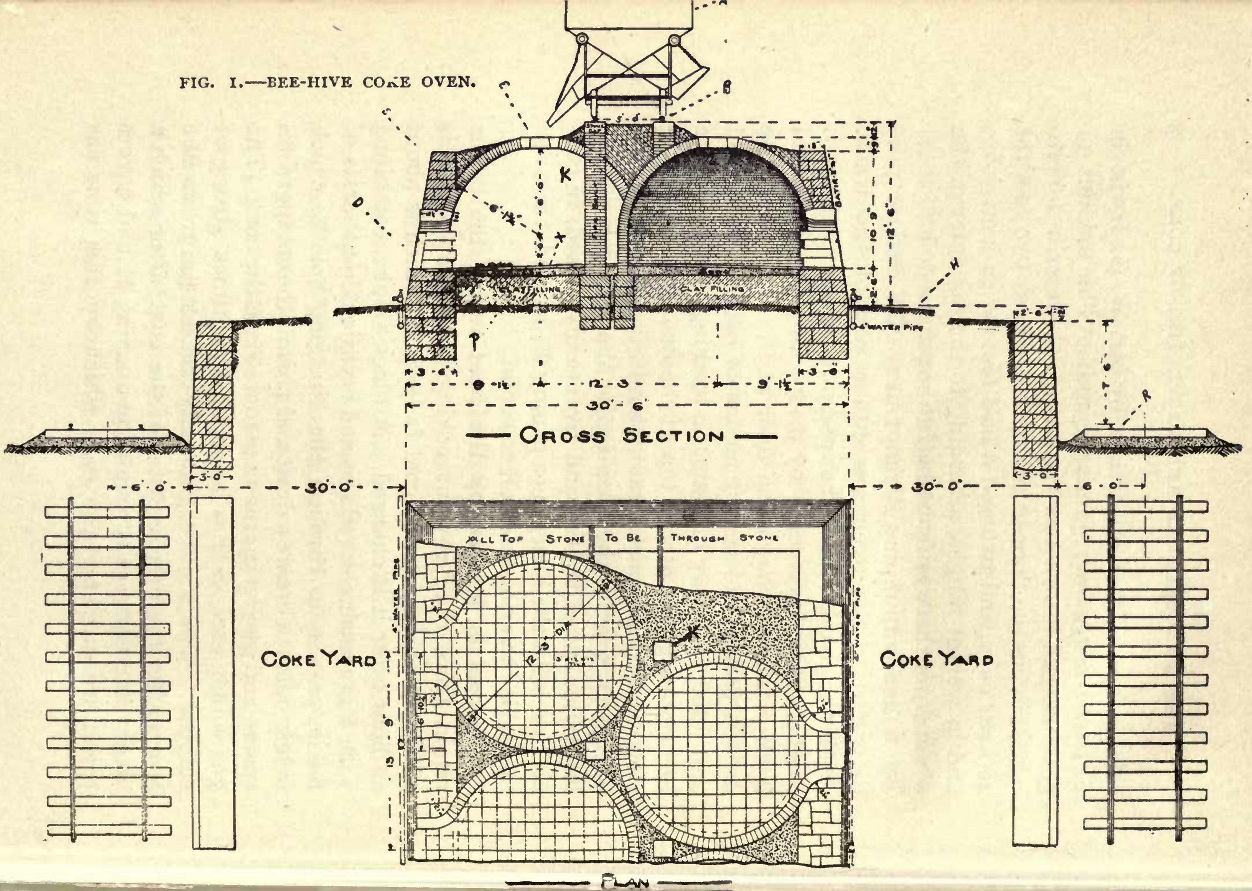
Coke has been found in a natural state. Appleton's Encyclopedia cites a bed existing on both sides of the James River and near Richmond, Va. It is said to be hard, very uniform, and dark in color, but rather porous. It is claimed to be serviceable for melting purposes.

By-product coke ovens have been erected by some firms owning steel plants, etc., whereby they can make their own coke at their works or at the mines. By this process, in connection with the by-products, such as gas, tar, and other substances produced, it is claimed they can make a good profit on money invested and also be independent of the regular coke manufacturers. It is said that out of one ton of coal ten thousand feet of gas can be produced, and out of fifteen hundred pounds of coke ninety to one hundred pounds of tar, with other by-products, can be produced. The gas from such ovens could prove of much value to some founders in drying moulds, cores, etc., and running boilers. What coke the author has seen and used coming from by-product ovens is not as solid as the regular Connellsville coke, and it required a greater percentage of it to melt iron.

In charging the bee-hive ovens enough coal is generally carried by one larrie, A, to fill an oven at one charge. This larrie runs on a track over the top of the oven, as shown at B, Figs. 1, 3, and 4. The latter two cuts are from an article by Mr. W. G. Irwin in *Cassier's Magazine*, January, 1901. The amount of coal charged into a bee-hive oven, as described herewith, covers the floor to a depth of about two feet for 48-hour coke, and two and a half feet for 72-hour coke, and in weight ranges, according to the diameter of the oven, from three and one-half to six and one-half tons. By a handy dumping arrangement, the coal may be delivered to the ovens on either side of the track. After the coal has been dumped into the ovens through the hole E, it is leveled by means of a long-handled hook worked through the door at D. This done, the door is partially closed by means of bricks loosely laid and luted with clay or loam, an opening of about three inches being left at the top of the door for the admission of air to support combustion in the oven. As the coking progresses the opening for the admission of air is gradually made less and eventually closed, in connection with the charging opening E, should the oven be carried over or burn off too soon.

The coal is ignited by the heat which the ovens retain from the previous coking. A sharp draft is admitted as soon as the coal is ignited, which is about an hour after it is charged. A black smoke, combined with a greenish colored gas and occasional outbursts of flame, passes up through the charging hole E, which is left open to create a draft and permit the escape of all smoke and gases that may emanate from the coal. The gas which escapes has an odor sometimes strong of sulphur. The smoke generally ceases ten to twelve hours after the first ignition of the coal, after which a bright flame passes through the opening E and covers the entire surface of the coal, which by this time has

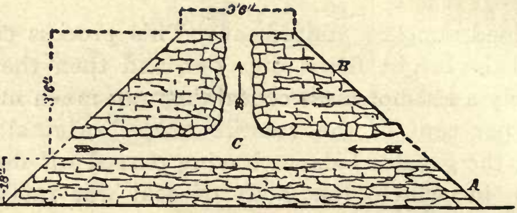
FIG. I.—BEE-HIVE COKE OVEN.



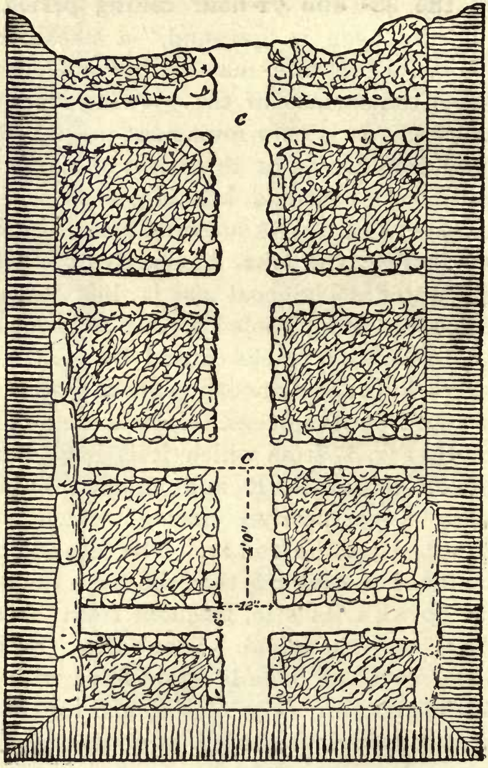
attained almost a white heat. This process continues until the bright flame dies out, and then the coke is simply a red-hot mass containing not much more than one per cent of the volatile matter originally in the coal, the greater balance having passed off during the time in which the body of coal was raised to its highest temperature.

When the 48- and 72-hour coking period is completed, or the oven is "around," a stream of water from a hose (or the water may be thrown from buckets) is sent over the surface of the glowing mass to extinguish the fire. It is very important to cool off or stop all further combustion at this point of the coking, as, if permitted to continue burning, carbon would be consumed, thus causing a material loss of coke.

Before drawing the coke, it is partly or wholly cooled off with water. The coal as it lies "caked," or "coked," after being cooled in one solid mass, is full of vertical seams or cracks caused by the contraction. The cokers insert their hooks in these seams in drawing the coke from the ovens. It is landed on the coke wharves H, Fig. 1, from which it is loaded into cars standing on the track R and shipped broadcast to consumers, a perspective view of which is seen in Figs. 3 and 4, pages 12 and 21. The care exercised and the time taken in drawing the coke from the ovens has much to do with its size, freedom from "braize," or small coke, and the yield. Soon after the coke has been withdrawn, the oven is again filled with a charge of coal, the drawing door closed, and the heat of the oven from the previous coking, as above stated, ignites the fresh coal and the coking process is again started. Some manufacturers have followed the practice of



Cross Section



Ground Plan.

FIG. 2.—COKING IN MOUNDS.

drawing the coke from the ovens before cooling it off with water. The method of cooling the coke on the inside is hard on the brick composing the interior, but it makes a brighter coke and more comfortable work for the cokers. In so far as it relates to the question of moisture in coke, the product absorbs less moisture when cooled off in the inside than outside of the ovens.

Some coke holds water to the extent of fifteen to twenty per cent of its own weight. Good fresh coke should not possess much over one per cent of moisture when protected from rain and snow. As it takes about fifteen pounds of coke in a cupola to evaporate one pound of water, it is evident that the less moisture a coke contains the less fuel required in melting, etc. Some firms recognize this factor and build stock houses so as to keep coke under cover. It is claimed that exposing coke to outdoor weather will reduce sulphur. To what extent this is true has never been demonstrated.

Coal is sometimes of such poor quality, or full of slate or iron pyrites, that it must undergo a process of washing before it can be charged into the oven to be coked. The method of treatment consists in crushing the coal, if it is in lump form, so as to make it as fine as slack. It is then carried by means of buckets attached to an endless chain from boat, car, or crushers to tubs of water, so arranged with "jiggers" that a constant agitation and flow of water causes the different bodies in the coal to take their place in the water according to their several specific gravities. The pyrites and slate, being heaviest, sink to the bottom, and by a series of jogging tubs through which the coal is passed, the floating bodies — the coal partially freed

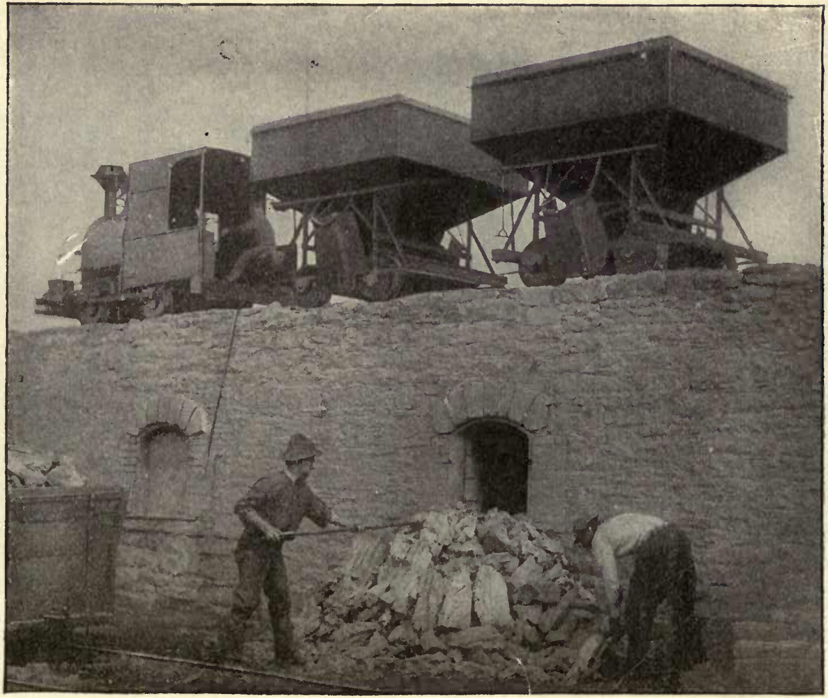


FIG. 3.—DRAWING COKE FROM AN OVEN.

from its pyrites and slate — are caught by perforated iron buckets on an endless chain and carried to a stock pile or to the larries, then to the ovens to be charged for coking. The impurities in the form of slate and iron pyrites which have sunk to the bottom, are passed along through the shutes with outflowing water to the refuse bed. The washing process often removes bitumen with the slate to such a degree as to rob the coal greatly of its coking qualities.

The yield of coke obtained from ovens generally ranges from sixty to seventy per cent of the coal charged, whereas the yield from heaps or mounds does not exceed fifty to fifty-five per cent. The long mounds are said to be productive of better coke and furnish a larger yield than round or small oblong piles having one center draft provision. The following table No. 1 shows the yield of a few grades of Connellsville coke in ovens prepared by Mr. John Fulton, and published in the *American Manufacturer* of February 10, 1893:

TABLE I.—YIELD OF COKE FROM COAL.

No. of test.	Time in oven.	Coal charged.	Ash made.	Fine coke made.	Market coke made.	Total coke made.	Per cent. of yield.				Per cent. lost
							Ash.	Fine coke.	Market coke.	Total coke.	
	h. m.	lb.	lb.	lb.	lb.	lb.					
1	67 00	12,420	99	385	7,518	7,903	00.80	3.10	60.53	63.63	35.57
2	68 00	11,090	90	359	6,580	6,939	00.81	3.24	59.33	62.57	36.62
3	45 00	9,120	77	272	5.418	5,690	00.84	2.98	59.41	62.39	36.77
4	45 00	9,020	74	349	5.334	5,683	00.82	3.87	59.13	63.00	36.18
		41,650	340	1,365	24,850	26,215	00.82	3.28	59.66	62.94	36.24

The question of density in coke is largely one of cell space, which can vary greatly in hard as well as in soft grades of coke. Oven coke is generally considered to have a cell structure of about fifty per cent greater than exists in coal. The quality of hardness is one of much importance, especially in blast furnace practice, as the coke should possess a certain strength to sustain the weight of the stock which is charged on top of it. If it is not strong enough to resist the load, it can be crushed into a mass so compact as to prevent the free passage of blast through its body, which is necessary to create proper combustion and make the furnace work well. To a degree it has the same effect on passage of blast in cupolas. Then again a soft coke can crush so as to lower a bed, cause dull iron, and make a cupola bung up much more readily than hard coke. (See close of chapter.) Oven coke can be light and porous as well as heavy and dense, and is often spoken of as hard or soft. The terms hard and dense do not mean the same thing. Coke can be dense but soft. The following table, No. 2, of physical tests, by Mr. John Fulton, will illustrate the crushing strength of coke with other properties. A chemical analysis of the same coke by Mr. A. S. McCreath and Mr. T. T. Morrel is seen in Table 3, and which is taken from an article by the late Joseph D. Weeks of Pittsburg, which appeared in the Pennsylvania Annual Report of the Secretary of Internal Affairs, 1893. In referring to the coke tested, Mr. Fulton says: "These tests show a compact, hard-bodied coke, harder than the average Connellsville standard. This coke has been carefully prepared and cannot be distinguished from Connellsville coke. The cells are a little less than the Connellsville, but the difference is not large enough to induce any marked change in blast furnace. It has proved an excellent fuel for this and kindred uses."

Table 4 is an average of several analyses of coke from the Connellsville region. The author has used this coke extensively at his foundry and has found it to be a fair grade of coke.

TABLE 2.—PHYSICAL TESTS OF SEVENTY-TWO HOUR COKE.

Locality.	Grams in one cubic inch.		Pounds in one cubic foot.		Percentage.		Compressive strength per cubic inch ¼ ultimate strength.	Height of furnace charge supported without crushing.	Order in cellular space.	Hardness.	Specific gravity.
	Dry.	Wet.	Dry.	Wet.	Coke.	Cells.					
Standard coke, Connellsv'le	12.46	20.25	47.47	77.15	61.53	38.47	284	114	1	3.5	1500
Walston	16.63	23.4	63.36	89.15	71.07	28.93	270	109	1	3.7	1900

TABLE 3.—CHEMICAL ANALYSES.

Locality.	Fixed Carb.	Mois.	Ash.	Sulph.	Phos.	Volatile matter.
Standard coke, Connellsville	87.46	0.49	11.32	0.69	0.029	0.011
Walston coke, (A. S. McCreath 72-hour coke)	88.476	.148	9.731	.951	.008	.692

TABLE 4.

Moisture	.058
Volatile matter	.634
Fixed carbon	89.960
Sulphur	.790
Phosphorus	.014
Ash	8.554

Forty-eight-hour and 72-hour coke refers to the time the coal is subjected to the coking process in the oven. Table 1, page 13, shows that 48-hour and 72-hour coke varies in the length of time it is in an oven, and that the actual time coal is coked is largely regulated by local conditions best suiting the working convenience of the coke workers in going the rounds of their ovens; and we might say we have instead of 48-hour and 72-hour coke, two- and three-day coke. Where machinery is used instead of mules and hand labor in charging ovens, the coal is insured a longer coking than forty-eight and seventy-two hours, as by the means of machinery the ovens can be charged earlier in the day and the coking resumed. Seventy-two hour coke, which is used chiefly by foundrymen, is generally due to coke remaining in the ovens over Sunday, which day the cokers do not work. Seventy-two hour coke is not always up to the high standard that many claim for it. The author has melted with furnace, or 48-hour coke, for six months at a time, and he cannot say that the fact of its being 48-hour coke caused it to be unsatisfactory, when the difference in price was considered. Nevertheless, as a rule, 48-hour coke is of less value as a melter than 72-hour coke, as the latter is generally a harder, larger, and cleaner fuel. As large a coke may be produced from a 48-hour as a 72-hour burning, but owing to the conditions which permit furnacemen to use smaller and more dusty coke with less evil results than are apt to follow its use in cupola work, 48-hour coke is not selected nor handled with the same care as 72-hour coke, and hence the former will give a greater yield from the same amount of coal. The method used for obtaining the best "selected" coke is that of cooling off the coke inside the ovens and in picking out the black ends and fine as well as poorly burned coke. There are times when coke is burned from ninety-six to one hundred and twenty hours, and then again only coked twenty-four hours in bee-hive ovens; but this latter product is generally not suited for making or melting iron. It is said that if coke makers take the precaution, they can make 24-hour coke nearly as good as the 48-hour article, with the exception of its not being quite as long in its body.

Gas house coke is obtained from the retorts used in gas works to produce illuminating gas, or from the retorts used in manufacturing coal-tar or other by-products. Some kinds of coal will produce gas coke by the use of which iron can be melted. Coal of the quality found in the Connellsville region is suitable for making this coke. When gas, or soft coke, is used for melting it is often necessary to use double the quantity or number of bushels than of hard oven coke, and at its best it is an undesirable fuel for this purpose. It will often give good satisfaction in drying cores or moulds, and work even better than hard coke, but much more of it must generally be used than of the oven, or hard coke.

Comparison of Connellsville coke with others has shown that the opinion held by many that Connellsville coke could not be equalled, was an error. The localities shown in Table 5, by Mr. John R. Proctor, published in the Kentucky Geological Survey Report, are furnishing considerable good coke to furnacemen and founders.

TABLE 5.—ANALYSES OF COKE FROM DIFFERENT LOCALITIES.

Where Made.	Fixed carbon.	Ash.	Sulphur.
Connellsville, Pa. (Average of 3 samples.)	88.96	9.74	0.810
Chattanooga, Tenn. " " 4 "	80.61	16.34	1.595
Birmingham, Ala. " " 4 "	87.29	10.54	1.195
Pocahontas, Va. " " 3 "	92.53	5.74	0.597
New River, W. Va. " " 8 "	92.38	7.21	0.562
Big Stone Gap, Ky. " " 7 "	93.23	5.69	0.749

Coke of a silvery metallic lustre and possessing a solid, hard body, with cells well connected and of uniform structure, can generally be called "good coke." The hidden element that might do serious harm in such coke is sulphur or phosphorus, for these can be high or low in any grade of coke. This can only be properly determined by analysis. The coke generally condemned by the consumer, especially the founder, is small sized coke, mixed with ash cinder or coke dust; then again coke that is dark in its general appearance, having black ends, and soft in quality. Even when the coke has all other commendable qualities but is in small pieces, such is often sufficient to produce bad results in melting iron. Then again coke may not possess the much desired "silvery or bright metallic lustre" and still be good, if it is only large and hard in character, possessing a good cellular structure. The harder or more dense the coke, the stronger blast is required in melting iron.

Black ends are of two kinds. One is called black tops and the other black butts, the latter coming from the bottom of the charge of coal as it lays in an oven, and the former from the top. Black tops are rarely injurious, while black butts can be. These latter may often be caused by reason of an inch or more of the coal lying on the bottom of a cold or hot oven being uncoked or fused. The coking process proceeds from the top of a charge. There are times when the heat of the crown of a very hot oven may fuse the top surface of the coal and form a thin crust or film which will prevent the usual freedom in the escape of gases. These being held back for a time, will deposit a soot or lampblack in the cells of the forming coke so as to result in giving black tops, or a black coke. As soon as the gases gain sufficient pressure to burst through the top crust or film, then the deposit of sooty matter ceases.

Stock coke is generally of a smaller size than that conveyed directly from ovens to cars for shipment, for the reason that it is broken up by extra handling. It is called stock coke for the reason that it is coke that, for want of orders or cars to make shipment, has to be stored in large piles at the coke works — sometimes months and sometimes years. Lying thus it is subjected to rain, snow, dust, and smoke, collects excessive moisture, and becomes dirty. Sometimes, in order to keep the ovens going and save stocking, heavy charges are resorted to and the coal coked from ninety-six to one hundred and twenty hours. This process causes a loss of coke in the ovens.

The fixed carbon in coke used for furnace and foundry work generally ranges from eighty to ninety per cent. Sometimes it is considerably under this, and occasionally it may exceed the highest limits by two to five per cent. Some of the carbon is lost by the process of coking. If cooled by water at the proper time the percentage lost is rarely very large. When more than from two to four per cent of carbon is lost, either the coal is inferior to Connellsville coal or it has not been treated properly, and the coke has been allowed to waste. The amount of loss is due to several factors. One may be the indisposition of the coal to coke, and again it may be the fault of the ovens and their treatment.

The ash in coke is an impurity which, like phosphorus and sulphur, lessens the commercial value of the coke as the percentages increase. The ash in furnace and foundry coke generally ranges from nine to fourteen per cent. It may exceed this two to four per cent, or be as low as five per cent. The ash of coke generally includes the impurities found in Table 6, obtained by Mr. E. C. Pechin. The less ash coke contains the greater is its value, generally speaking, although very low ash is not desirable in all cases. It is often beneficial in assisting the formation of a good slag. The coke made from washed coal contains less ash and sulphur than that made from unwashed coal.

TABLE 6.—ANALYSES OF ASH IN CONNELLSVILLE COKE.

Silica	5.413
Alumina	3.262
Sesquioxide of iron	0.479
Lime	0.243
Magnesia	0.007
Phosphoric acid	0.012
Potash and soda	Traces.
	9.416

The chemical properties desirable in coke are, first, low sulphur and often low phosphorus, and second, high carbon. As a rule when adopting a new brand of coke, and often in the use of old ones, it will pay a founder to assure himself as to the chemical properties of the coke before using it. This is a practice which furnacemen generally follow. In sampling coke for analysis much more should be selected than is actually

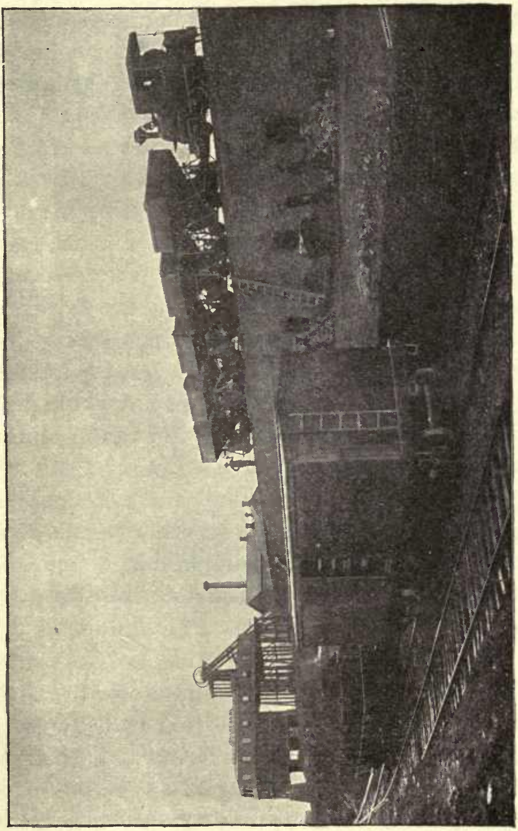


FIG. 4.—ENGINE AND CARS FOR CHARGING TO OVENS AND LOADING COKE FOR SHIPMENT.

required, and the sample obtained should be carefully picked from different parts of a pile or car.

High sulphur in coke may lead to very serious results in founding as well as in furnace work. It is generally very essential in making coke that plenty of pure water be had. A drought can make water so scarce as to compel the use of mine water. Such usually contains enough sulphur to seriously affect the coke when quenching the fire. The process of coking has much to do in controlling the amount of sulphur in coke. Coke from the same mine and oven can and often does vary greatly in the percentage of sulphur. If sulphur is above .90 per cent it can often be told by the odor of escaping gases and the stifling fumes a furnace or cupola will emit, as compared with coke below .80 per cent. High sulphur can often be detected by the eye, due to its causing yellow spots or stains to appear on the surface of the coke. A quick test is made by heating pieces red-hot and dropping them into a pail of water. This drives off the sulphur to such a degree that, with a little practice, one can detect differences in the amount of sulphur coke may hold. The best way, of course, to determine the sulphur or other properties, is by chemical analysis.

Phosphorus in coke may be injurious and then again beneficial to both furnacemen and founders. This depends upon the percentage of phosphorus desired in any special brand or mixture of iron, as whatever phosphorus coke contains is generally taken up by the iron when being made or remelted. If, for example, regular Bessemer iron or castings calling for phosphorus not exceeding .10 is desired, the high phosphorus coke would certainly be injurious; but if it is foundry iron that is desired to make thin castings, then higher phosphorus coke is essential, as increasing phosphorus increases fluidity, see page 216. It always requires chemical analysis to detect the phosphorus while the eye may at times detect the sulphur.

The best brand or grade of coke to use in smelting or melting iron is often regulated by its cost. Certain localities in the Connellsville region are generally conceded to give the best grades of coke to be found in this country, but the great distance of many consumers from this point makes the cost so great that they use other brands. However, almost every locality can furnish different grades, and it is often surprising how much less of the best grade is required than of poorer ones in doing the same work in melting. It is rare that there is any economy in using poor grades of coke if the difference in price is at all reasonable.

In the first use of coke in cupolas it was bought and charged by the bushel, instead of by weight as at present. Coke weighs from thirty to seventy pounds per bushel, the more dense and hard, the heavier it is. In using coke in cupolas it is very important to note its hardness and be governed by the same, as with the same weight of coke in good soft and hard grades one can readily conceive that the bed and charges of coke would vary in height and could often cause trouble, as for example the same weight in a soft coke that would bring it up to eighteen inches or so above the top of the tuyeres, could, in hard coke, bring it only to a level of the tuyeres or a little above, which all experienced founders know would soon bung up or prevent a cupola from melting. Where one is called upon to use a soft coke — and which will not permit cupolas to run as clean or as long as hard coke, although soft coke may give good hot iron—he should, as a rule, use less weight of the soft coke than of the hard in the bed and between charges, and at the same time reduce the weight of the iron in both the bed and charges, as, if the same weight of soft as of hard coke found best is used, the bed of fuel would be raised above that point best for rapid and economical melting. It is to be understood that this does not mean that a less weight of soft coke will be required throughout the whole heat. Reducing the weight of iron on the bed of coke and between the charges calls for a greater number of charges of coke, as well as of iron, and thus may cause as much or a greater weight of soft coke to run off a heat than if hard coke had been used. When using soft grades of coke and following the above suggestions, the rule of charging three pounds of iron to one of coke on the bed and ten to one between the charges will often serve as a guide in decreasing the weight of iron to approximately correspond with the decrease in the weight of fuel that may be found best to adopt. This is assuming the height of tuyeres to be about eighteen inches above the bottom plate; with lower tuyeres three to five pounds of iron to one pound of coke may often be charged on a bed of coke. Where, by reason of coke being soft, dull iron is obtained, or the cupola bungs up badly, such trouble may not only be decreased by making smaller charges of iron, but a milder blast is also generally desirable. A strong blast often blows all the life out of soft coke, facing the tuyeres, and often leaves a space that can fill up with chilled slag or iron droppings which can soon bung up or stop a cupola from melting. For further information on charging, etc., of cupolas, see American "Foundry Practice" and "Moulder's Text Book."

CHAPTER II.

PROPERTIES OF ORES USED IN MAKING CAST IRON.

A brief description of elements in ores will point out varying qualities in the material from which cast iron is made, and also help impress one with the great difference ores can and do make in the different brands of iron. The ores from which cast iron is made are largely oxides of iron, containing other elements and impurities, among which generally exist more or less manganese, sulphur, phosphorus, alumina, and silica. It is called "rich ore" when high in iron, and "lean ore," when low. The oxides of iron are known as "ferric oxide" and "ferrous oxide." The former, theoretically, contains 70 per cent of iron and 30 per cent of oxygen, the latter 77.78 per cent of iron and 22.22 per cent oxygen. Percentages of iron and oxygen vary in the ores, but the above percentages constitute distinct chemical compositions.

Many soils and rocks contain more or less oxide of iron, but such material is not generally considered suitable to make cast iron unless it contains more than 30 per cent of iron. Ores are now very rarely used for making cast iron or pig metal unless they contain more than 40 per cent of iron. The ore used in the manufacture of cast iron and worked to an economical advantage generally contains from 50 to 65 per cent of iron, and it is rare that ore of sufficient quantity to keep a furnace going steadily on a fair uniform product can be obtained containing more than 70 per cent of iron.

The pig iron which the founder uses (barring ferro-silicon, etc.) generally contains from 92 to 96 per cent of metallic iron, with 4 to 8 per cent of impurities, chiefly carbon, silicon, manganese, sulphur, and phosphorus. These impurities, while called such, are really the elements which make iron of any practical value in the various industries. According to changes in the proportions of these so-called impurities, we are given the different grades of pig iron so essential to meet varying conditions called for in our widely diversified use of iron.

Silica ranges in ores from a trace to 20 per cent, and often higher. The ores generally used for ordinary pig metals contain from 3 to 8 per cent of silica. Next to the iron in the ore, silica is the largest constituent in nearly all ores used. The combined silica in the ores, fuel, and flux gives the silicon to the iron. Where high or ferro-silicon iron is desired, high silicious ores are used in connection with a greater amount of fuel and higher temperature in the furnace. With like fuels, ores, and fluxes the higher the temperature in a furnace, the higher silicon will be found in the iron. The higher the temperature desired, the more fuel it is necessary to use. Furnaces may work so cold by reduction of fuel, or bad working, as to cause the greater part of the silica to be carried off with the slag, instead of its making silicon in the iron.

Manganese is found in nearly all iron ores. It readily alloys with iron, and all the manganese contained in pig iron is obtained from the ores. Manganese occurs in ores in the form of manganese dioxide and manganese oxide. Some ores are so high in manganese that they are called manganiferous ores, and of late years their reduction has been achieved in blast furnaces about as readily as iron ore is reduced, although at one time it was thought impossible to obtain high manganese pig from a blast furnace.

Ferro-manganese is obtained by smelting manganiferous ores in a blast furnace, and is placed on the market as a commercial product containing from 40 per cent to 90 per cent of manganese. The standard contains from 79 to 81 per cent.

Spiegeleisen or "spiegel" is a product of manganiferous ores, but lower in manganese than ferro-manganese. It ranges from 7 per cent to 40 per cent of metallic manganese. The standard contains from 19 to 21 per cent. In this form it generally presents a silvery white fracture with a crystalline structure. By some this metal is called "looking-glass iron," the English translation of spiegeleisen. Spiegeleisen is readily produced, whenever sufficient manganese is present in the ore. Both these manganese metals are chiefly used in the manufacture of steel in its many and various grades.

Phosphorus exists in most iron ores. Almost all the phosphorus contained in the ore, fuel and flux is reduced and absorbed by the metallic iron when smelting or remelting it. Low phosphorus ores are generally of greater value than high phosphorus ores. For Bessemer iron, in which phosphorus must not exceed .10, lower phosphorus ores must be used than in making foundry irons. It is often found beneficial to have pig iron contain as high as 1.50 phosphorus, owing to the fact that phosphorus possesses the quality of giving life and fluidity to molten metal, which is most desirable in running thin castings.

For de-phosphorizing magnetic ores, different kinds of devices have been used. Fig. 5 will convey an idea of the principles involved in the separation of "tailings" and "concentrates" by the employment of magnetic power. By the use of separators or magnets from 50 per cent to 80 per cent of the phosphorus originally contained in ore is said to be removed. Magnetic ores which contain pyrites (which is a combination of 53.3 per cent of sulphur with 46.7 per cent of iron) can have, it is also said, a larger per cent of their sulphur contents removed by magnetic concentration with a separator than by roasting, as referred to below. Sometimes the sulphur is present in pyrrhotite (which is 39.5 per cent of sulphur combined with 60.5 per cent of iron) in which state experiments have shown that there would be as much sulphur in the con-

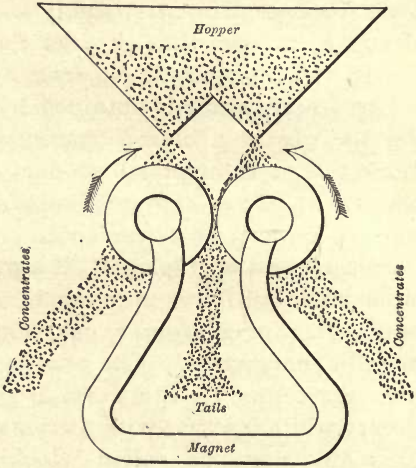


FIG. 5.—BUCHANAN SEPARATOR.

centrates as existed in the crude ores, and hence, separators to eliminate sulphur from this class of ore have proved a failure.

High sulphur ores are sometimes subjected to a process called "roasting" or "calcination" which generally drives off a greater part of the sulphur.

Varieties of iron ores are very numerous. In order to classify them they are chiefly placed under one or the other of the following heads: hematites, magnetites, and carbonates. Of the first there are two kinds, known as the brown and red hematites. There is more red hematite used than all the other ores combined. Red hematite is generally quite free from sulphur, and it is found in almost every shape in which ore is found and exists in large quantities. Messaba ore, a soft ore now largely used to make both Bessemer and foundry iron, is a red hematite which, it was thought, a few years ago, by experts, to be unsuited for the blast furnace on account of its being such a dusty, fine soil material.

Magnetic ore is the next variety generally recognized in the order of classification. This ore is found in veins and is generally classed with the hard and refractory ores. It is generally a dense black material, which must be crushed or broken to suit the varying conditions of smelting. In Canada and New Zealand magnetic ore is found in the form of coarse gravel or sand, which, as a rule, furnacemen prefer not to use if it can be avoided. Magnetic ores are often discovered by the attraction they exert upon the compass needle. They are often very free of phosphorus and sulphur, but if they are too high in phosphorus and sulphur they will not be used as long as sufficient ore of suitable grade can be obtained without the cost necessary to prepare objectionably high sulphur and phosphorus ore for smelting.

Brown hematites include bog ores, which are found in shallow rivers, etc., and are now very little used; they are largely the result of the oxidation of the carbonates of iron. No ore is more irregular in its characteristic qualities. It may be of a yellow as well as a brown color. It is generally porous and easy to reduce and smelt in a blast furnace. It is found mixed in undue proportion with earthy and gangue matter and often rich in carbonate of lime, and is also generally high in phosphorus. It is found in beds and veins and often forms the cover of copper ores.

Carbonate and spathic ores are generally of a whitish color, but they are often found mixed with manganese, which turns them brown. They are largely found in massive veins of great thickness and in combination with other carbonates and may be of a greenish gray color. Brown hematites are also found existing in sands or soils of a coarse character. There is some dispute as to their value. Some claim that they excel red hematites for making high grade iron. A variety of carbonate of iron ores is known as clay iron stone by reason of its being found in the clay bands of the coal fields. This class of ore is largely used in Scotland as well as in England. "Black band" is one variety of this class of ores, and is of a glossy black color.

Black band ores give strong irons, and when mixed with soft hematite ores make a soft, or good grade of Scotch iron; but of late years they have become so scarce that they cannot compete with the more plentiful ores, which can be made to produce an iron that will be accepted in some cases as equally satisfactory. An ore approaching black band, and called "band iron stone," is now often used. This is of a bluish gray color, and exists in coal formations similar to black bands. Some of these ores are smelted in their raw state, while others are roasted and converted into higher oxides before being smelted.

Titaniferous ores, free of sulphur and phosphorus, containing 10 to 16 per cent of titanium and 50 to 60 per cent iron, found in the Adirondack mountains, are now being used to make ferro-titanium by the Ferro-Titanium Co., Niagara Falls, N. Y., Mr. A. J. Rossi being the inventor of the process. Nearly half the ores found on this continent contain more or less titanium, but furnacemen have always found it most difficult to use titaniferous ores on account of the titanic acid making an infusible slag. Since Mr. Rossi has lately succeeded (January, 1901) in overcoming this difficulty, it is rather early to predict to what extent this ferro-titanium may prove of value to steel manufacturers and founders, as titanium is known to strengthen or chill iron by holding the carbon more in a combined form, similar as with manganese and sulphur.

Mill cinder iron is a grade of metal derived from the smelting of rolling mill cinder exclusively, or in admixture with iron ores. Rolling mill cinder can be classed under the heads of puddle, tap cinder, heating furnace, flue cinder, roll cinder, and bosh cinder; the latter being collected in a trough or bosh of water in which the puddlers cool their tools. Roll scale is generally supposed to contain the most iron, followed in order by bosh, tap, and flue cinder. Mill cinder is generally used first because it can often be purchased for about one-half the price of iron ore and because it often contains a large percentage of iron.

Tap cinder is of two varieties, one is "boilings" that flow over the floor plate of a puddling furnace when making the iron, and the other is "tappings" that runs out of a furnace at the end of the heat. As a general thing boilings are very much higher in phosphorus and silica than tappings. Mill cinder, as above outlined, is composed largely of protoxide of iron and silica. It contains, at times, ferric and magnetic oxides and is generally high in phosphorus. Table 9 is an analysis of four samples of mill cinder which the author secured to give an idea of the chemical composition of the same. As it would take about two tons of such cinder to make one ton of iron, there would be about twice the amount of phosphorus in the iron produced than is contained in the cinder ore where all cinder was used.

TABLE 9.—ANALYSIS OF MILL CINDER.

	1.	2.	3.	4.
Iron	52.48	52.20	52.91	53.70
Phosphorus	1.32	.34	.47	.37
Silica	24.65	25.06	23.43	23.39
Manganese	.34	.45	.57	.35

Iron mill cinder is only used for making foundry or mill iron. It is not used for making Bessemer for the reason that it would raise the phosphorus too high, which for foundry iron is not so objectionable; in fact, foundry iron often requires high phosphorus. It can be said that a few are now using steel cinder in making

Bessemer iron, owing to such being very low in phosphorus. Aside from the iron being low (see Chapter XXXIV.), it is mainly the phosphorus that is to be feared in mill cinder iron, as this cannot well be eliminated. If the "iron" is lower and the phosphorus higher than is beneficial in pig metal there are grounds for rejecting it, but otherwise the foundryman is rarely justified in condemning mill cinder mixed pig iron on the ground that it contains slag because cinder was used in making the iron, until he has tested it to have a knowledge of its chemical constituents and physical properties. Founders have used mill cinder mixed pig iron when they thought there had not been an ounce of cinder mixed with the ore. Not only is mill cinder mixed with ores, but a furnace has been kept going steadily making pig metal with simply all mill cinder. Mr. C. I. Rader has done this at the Sheridan Furnace, Sheridan, Pa., in making forge or mill iron.

CHAPTER III.

CONSTRUCTION OF BLAST FURNACES.

In the first days of furnace practice the necessity for good deep foundations was not realized as at the present day. If deep excavations were now to be made under many of the old furnaces tons of iron might be found. Past experience, dearly bought, has taught the furnaceman to provide reliable foundations. In some localities the depth required is greater than in others, and in some cases piles have to be driven before the foundation is started. In the furnace shown, Fig. 6, the stone-work illustrated is about five feet deep, on top of which a bed of fire-brick about five feet deep is laid before the bottom or bed of the furnace is reached. Such foundations are costly, but it has been found wiser to have capital lying idle in them than in lost iron.

Generally no boiler casing is now used to support that portion of the hearth and bosh which incloses the tuyeres and water coolers V. This portion of the furnace has its fire-brick work supported by means of wrought iron bands, six inches wide by one inch thick, which encircle this portion at the height of every two feet, as seen at S. One idea of not encasing this part with solid boiler plates riveted together, as is done with the upper part of the furnace as shown, is so as to make the placing and attachment of coolers convenient and permit this portion of the furnace brick-work to be exposed to the cooling influence of the atmosphere as much as possible. It is at this part of the bosh and hearth that the lining is subjected to the greatest heat. Furnaces are contracted at the hearth—which constitutes all that portion below the tuyere at B, mainly to aid the blast in reaching the center more strongly and causing a more even distribution of its pressure throughout the fuel, as well as to save the lining. Such a form not only assists the blast to reach the center, but the "batter" or bevel of such a bosh as shown assists in supporting the weight of stock charged, thus lessening pressure at the tap hole, permitting the metal to be under better control, with less liability to cut the breast as the metal flows out to the

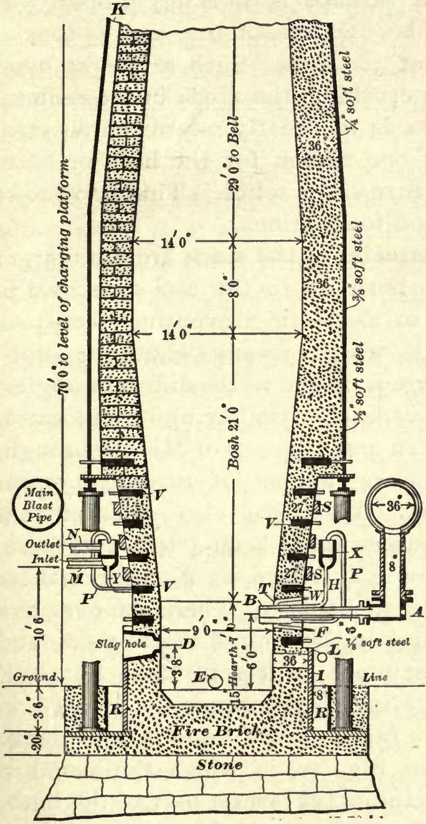


FIG. 6.

runner. When a furnace of the size shown is full of stock (coke, ore, and lime) the weight bearing down on the hearth (when a furnace is working properly) is about 100 tons of coke, 160 tons of ore, and 35 tons of lime, a total of about 300 tons. Such a weight must be very effective in crushing the stock in the reduced body of the bosh, so as to greatly retard the penetration of blast, and is one reason for the high pressure found necessary in furnace practice. This also shows the necessity for good foundations.

Decreasing the diameter of the stack from its larger portion joining the bosh up to the top, as shown in Fig. 10, is mainly to assist in preventing the stock from "scaffolding," which means "hanging up." (See page 55.) There is no end to the different angles, etc., given to furnaces, each style having its advocates. We now have Hawden and Howson of Middlesbrough, England, who are using a plan of turning present forms upside down. We might also mention that strictly straight furnaces have been tried, but these, it is said, have proved a failure, as a study of these pages would lead us to believe. There are over five hundred blast furnaces in the United States today and many of them differ more or less in their "lines," etc. The shape or "lines" now generally adopted in this country for coke furnaces are more in accordance with those shown in Fig. 10, in which the hearth is about half the diameter of the largest part of the bosh, and the throat or top of the stack about two-thirds of the bosh's largest diameter, in a height of about eighty feet.

The construction and principle of furnace tuyeres is shown at B, Fig. 6. For the size of furnace shown, eight tuyeres are evenly divided around the circumference and project from 6 to 10 inches beyond the lining. These are for the purpose of aiding the blast to reach the center, and also protecting the lining. A tuyere protruding no farther than the face of the lining would rapidly cut out the brick-work at that point. These furnace tuyeres are made of an alloy chiefly composed of copper, so as to approach a bronze metal. This class of metal has been found good to prevent the melted iron, as it drops down, from adhering to or clogging around the tuyeres, which, if it should occur, would be very troublesome and liable to cause much damage.

To prevent these tuyeres from melting or burning away from exposure to the heat of the fuel and hot blast, a constant stream of cold water flows through them, going in at H and coming out at P. Often through irregular workings, tuyeres may become bunged up as in cupola practice, and the method generally followed to open them is to shut off the blast and endeavor to knock a hole through the chilled material, after which the hot blast (of about 1,000 degrees heat) with its high pressure, which ranges from 6 to 24 pounds, instead of 6 to 20 ounces, as in cupola practice, will assist to cut or burn away the chilled material fronting the tuyeres. Should this fail, the blast is shut off and the tuyeres are pulled out, thereby leaving a big hole to work through, and by means of sledges and steel bars an opening is cut into the furnace and the cold, chilled debris pulled backward out of it. In replacing such a tuyere, a large lump of clay is pushed forward into the face of the hole to prevent the heat melting the tuyere, and then the tuyere is pressed or knocked inward against the pressure of the stock in the furnace until it is in its right place. After this is done, any clay that might block up the hole in the tuyere to prevent blast to the furnace is broken away by means of a bar, and after the water pipes are attached, the blast is again put on. The removal or insertion of furnace tuyeres is an operation very readily performed, owing to the taper seen in the stationary sleeve at T, Fig. 6. This stationary tuyere support is cast hollow, of the same metal as the tuyere proper, and is kept cool by a flow of water going in at W and coming out at F. It is very rare that one of these sleeves has to be removed, as they do not project into the furnace, as is the case with the tuyere proper.

Coolers are very important in furnace construction to provide means to assist in lengthening the life of a lining. Some furnaces are better provided with cooling appliances than others. In the furnace shown, water is admitted to a suspended cast-iron receiver (as seen at X), which encircles the furnace, excepting an opening of about two feet at the front or breast side of the furnace. The cold water is admitted to this receiver in its lower division at M, and after having done its work it flows into the upper division and is carried off through the waste pipe N. The pipes Y are those which admit the cold water to the coolers, and P those returning the heated water to the waste receiver. At V V V are seen some of the many coolers which are built in the furnace lining to preserve its life. In the furnace shown these are placed in layers about thirty inches apart in height, and has about two feet of space between them. Some furnaces have them built much closer than this, both in height and circumference. There are various plans of coolers used with furnaces. The coolers here illustrated are made of cast-iron about three inches thick by two feet square, and each has three independent coils of one and one-half inch pipe cast in it, so arranged that should the front coil be attacked by the heat as it burns out the lining, it can be shut off, and the inner coils be made operative independently or as a whole. Some furnaces have these coolers made of bronze, cast hollow. It is very seldom trouble is experienced with the coolers shown, and if any should occur arrangements permit their being taken out and replaced. At L is seen a two-inch pipe, perforated with one-eighth inch holes about two inches apart, which encircles the furnace and keeps a constant stream of cool water running down the plate I which supports the hearth portion of the furnace. This water runs down on the outer surface of the plate to a reservoir at R, and which can be filled up with water to a height of about three feet, to protect the lower portion of the hearth with a heavy body of water. A valve is so arranged in the reservoir R that any height of water can be maintained in it. It is no unusual occurrence for the metal to break out at this portion of a furnace, resulting in much injury to life and property. The furnaceman's lot is by no means one any need envy, for he shares very fairly the troubles and dangers he has who "meddles with hot iron."

CHAPTER IV.

LINING AND DRYING OF FURNACES.

Methods of lining a furnace and the shape of the bricks have as much to do with the life of the lining as other qualities defined in this chapter. It is very expensive to line a modern furnace, and when completed it should give, at least, a continuous service of two years with hard ores and three years with soft ores, and this length of service may often be doubled. When it is stated that 450 tons of fire-brick and 60 of fire-clay, or a heavily laden train of about twenty-five cars of material, are necessary to line such a furnace as seen in Fig. 10, the magnitude of such a job, as compared with lining even our largest cupolas, can be readily perceived. Bricks for a furnace are largely made to order, so as to neatly fit its curves, slant, or circle which the form of the shell or inside of the lining, etc., may exact. This is done so as to have all joints fit as closely as possible without cutting bricks or filling in the clay. Bricks of a softer quality than those used for the stack portion of the furnace are desired for the hearth and bosh, as the former are exposed to greater destruction from friction, while those in the hearth and bosh portion are chiefly subjected to the action of heat. Such a quality, if used in the stack portion, though its composition is best able to withstand the heat, would soon wear away by the constant friction of the stock, so that better service is found by sacrificing the heat qualities to those best calculated to withstand friction for stack linings.

In laying bricks, a thin grouting of the best fire-clay, without mixture of sand, is used. The clay is mixed of such consistency that a brick, if dipped into it, would, upon being lifted out, have a coating of about one-eighth of an inch adhere to it. To make a bed of clay for the brick to be laid in, a dipper is used to pour the clay upon the surface of the last course, laid to a thickness of about one-fourth of an inch. The bricks are then slid on soft clay up to each other so as to imbed themselves firmly, and closely force the clay between all joints, after which a hammer is used to crowd the joints still more closely together or bed the bricks more firmly. In order to obtain a true circle when lining the hearth, bosh, and stack of a furnace, a plumb bob-line is dropped from the top to obtain a center for a "spindle" with a "sweep" attached, which is to be carried up as the work progresses, just as a loam moulder would build a large cylinder mould. The time usually occupied in lining such a furnace as shown in Fig. 10, employing four masons and twelve helpers, is about thirty days. The work of lining a furnace is considered a specialty, and the leading men in such work are carefully selected from those having the greatest experience in this line, as any faulty construction can easily result in a very short run of a furnace, thus causing a great expense in "blowing out" to remedy the evil.

Space for expansion of fire-brick, as illustrated at K, Fig. 6, and both sides of Fig. 10, page 49, is a practice now followed in lining furnaces. This space ranges from three to four inches in width, and in length from the bosh portion up to the top of the stack, as shown, the hearth being built solid, as seen in the sketch. A material now extensively used for filling this expansion space, K, is the slag of a furnace, after being granulated by the action of water. A loamy sand was at one time used, but it packs too firmly. Then, again, a coarse class of sharp sand has been used, but the slag as above prepared has been found the best. Experience has proven the necessity of such a system, as several furnaces have had their shells ruptured by the expansive force of fire-bricks when not permitted room to swell from the effects of the heat. Not only have furnaces provided for this lateral expansion, but also for longitudinal strains as well, as such action has been known to press the brick-work, bell, hopper, and charging platform upward from three to four inches above the top of the shell, or its original level. All the iron work at the top of a furnace is constructed independent of the shell, so as to liberate it from all strain when longitudinal expansion takes place.

Drying a furnace becomes necessary before it is charged for "blowing in." There are several methods of doing this. One is by building a fire inside the furnace; another by constructing a fire-place outside, at the breast portion, and letting the heat from the same pass into the furnace; still another by the admission of natural gas, or the gas from the ovens of another furnace, should two or more furnaces be near each other. The objection to building a fire inside a furnace is that the dirt and ash which it creates requires considerable labor to clean out, and requires more fuel than by any other plan, but is quicker in its action of drying. After a fire has been well started, all holes around the furnace and the top, with the exception of a "bleeder" H, Fig. 13, page 57, of about twelve inches diameter, are closed, the "bleeder" being left open to create draft. The time taken to dry a furnace ranges from one to four weeks.

The life of a furnace lining not only depends upon qualities described in preceding paragraphs, but also upon the manner in which a furnace is worked. Those that are driven hard by high blast pressures, to get the greatest possible output of iron, have not nearly the life of those driven more mildly. America is noted for fast driving to attain greatest output. For this reason if furnaces run steadily for five years in our country they are doing very excellent work, whereas in Europe furnaces have run steadily for ten to fifteen years; although they are commencing to drive them faster than formerly.

One factor of great protection to linings exists in the formation of a kind of graphite or carbonaceous concrete which accumulates on the face of the lining; this comes from the kish, slag, and carbon refuse generated in the furnace, which may be found two to twelve inches thick on the lining, the greatest thickness being found in the hearth or lower body of a furnace.

The factors which destroy the life of furnace linings are defined under four heads by Fritz W. Lurmann in the Journal of the Iron and Steel Institute, 1878, Vol. I., page 200, as follows:

"1. The actual wear due to contact with the descending charge. This is relatively unimportant. 2. The actions of the alkaline cyanides and other substances present in the furnace gases which, though probably important, produce an effect the amount of which is at present not accurately determined. 3. The action of sodium chloride or other alkaline substances contained in coke; this is probably one of the most important causes of wear, as at a high temperature salt is decomposed by silica, and a fusible silicate is obtained. 4. The flaking of the bricks due to decomposition of carbon from carbon monoxide around any iron particles reduced from impurities in the original bricks."

The best grades of fire-brick are necessary in lining furnaces. Absolute fire-proof bricks, it may be said, are not obtainable. Several kinds of material have been tried in an effort to secure a lining for furnaces that would exceed the life of the general character of fire-bricks used. We have what are called silica, carbon, ganister, coke, magnesia, and asbestos bricks, all of which have been experimented with, and, to some degree, all have advocates of their utility in certain lines of work. Carbon bricks, it is claimed, have worn well, made of fine coke (poor in ash), or charcoal mixed with clay with tar as a binder. If such bricks contain more than 70 per cent of silica, as used for high temperatures, they are generally very friable and disintegrate with the least friction, so that bricks of this character would be suitable only for the lower body of a furnace. As clay is chiefly silicate of alumina, which is also a good substance to resist high temperatures, it works well as a binder with silica in making fire-bricks. The other substances in clay are iron oxide, lime, magnesia, potash and soda, which, to some degree, decrease the durability of fire-bricks. As fire-bricks come to the furnace or foundry they are often composed of about equal parts of silica and alumina. Bricks should contain silica or alumina in proportion to the amount of heat or friction they are required to withstand. The life of fire-brick depends upon the purity of these ingredients. The silica should be pure quartz or anhydrous silica, and not uncalcined or raw rock for a substitute as is often practiced by some. It can be readily seen that one kind of fire-brick may give excellent service with one character of work and very poor for others.

CHAPTER V.

OPERATING BLAST FURNACES AND REDUCTION OF ORES.

The amount of stock that passes through a furnace the size of that seen in Fig. 10, page 49, every twenty-four hours is about 280 tons of ore, 190 tons of coke, and 60 tons of limestone, a total of 530 tons. In filling a furnace by hand labor, two gangs of men are always employed, one at the top, and the other on the ground floor load the buggies and wheel them to the elevator, which ascends a distance of 70 to 100 feet in about twenty seconds. There being two cages to the elevator, an empty one is returned as the loaded one

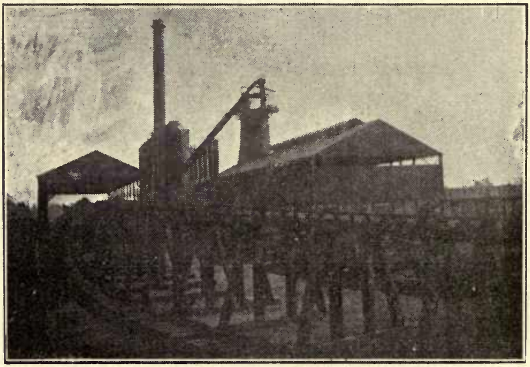


FIG. 7.— MODERN BLAST FURNACE WHERE HAND LABOR IS MINIMIZED.

ascends. The buggies used hold about 800 pounds of ore and of coke 450 pounds. The men charging the furnace are called "top fillers" and those loading the buggies "bottom fillers." The work is thoroughly systematized, each man knowing his part. Top fillers hold a somewhat hazardous position, as it is not uncommon for men to be "gased" by the fumes escaping at the bell and hopper of a furnace. Some furnaces suspend a sheet iron stack about ten feet over the top

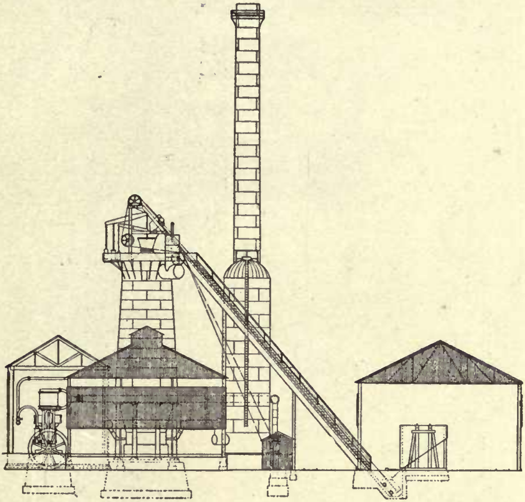


FIG. 8.—HOISTING APPARATUS OF A MODERN FURNACE—LABOR ALL ACCOMPLISHED BY MACHINERY.

of the bell, on the charging platform, for creating a draught to carry off the escaping gases. Improvements have been made whereby all stock is carried up and dumped by machinery into the hopper, so that there is no need for men working on a furnace as "top

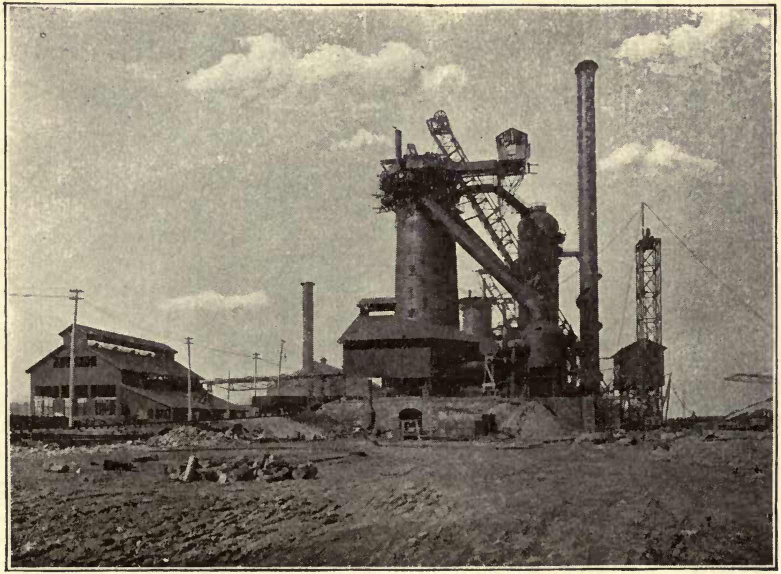


FIG. 9.—ENLARGED VIEW OF MODERN BLAST FURNACE.

fillers." A view of this more modern plan of charging a furnace is shown in Figs. 7 and 8, and which are illustrations used by Mr. Walter Kennedy in the *American Manufacturer*, January 3, 1901. We also present cut Fig. 9, which was originally shown in the Journal of the Association of Engineering Societies, January, 1901.

In charging a furnace, the coke, limestone, and ore are generally dumped in the order mentioned and dropped independently of each other in the hopper H, Fig. 10. After the completion of each charge, the bell B is then lowered as indicated, and the material falls into the furnace shown, about as illustrated at the mound M M. After the delivery of the charge, the bell returns to its position, ready to receive the next supply of stock. There are several ways of oper-

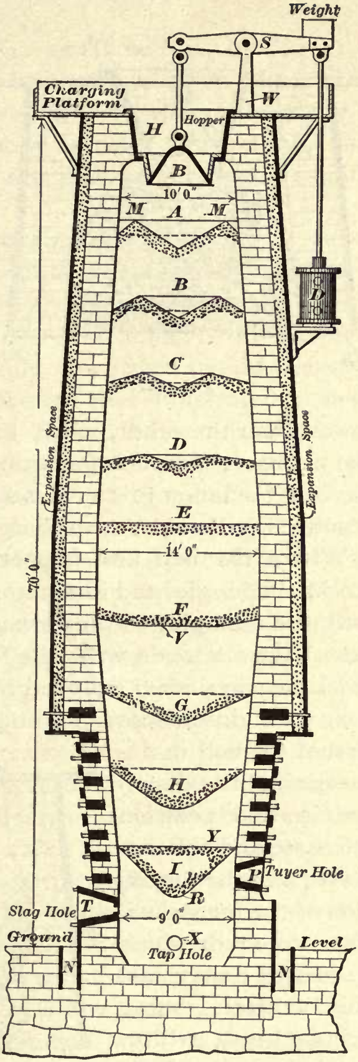


FIG. 10.—ACTION OF STOCK DESCENDING A FURNACE.

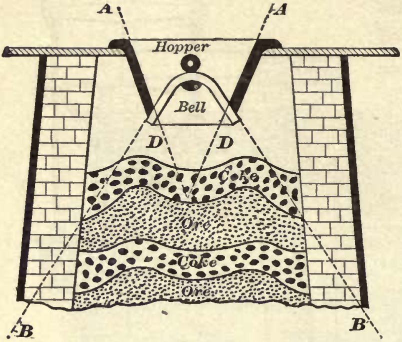


FIG. 11.

ating the bell, but the method used with the furnace shown is that of moving the beam S up and down by means of a piston D, which can be operated by steam or the blast pressure. The bell must be hung true, since, if one side should swing lower than the other, when the stock is admitted to the furnace, the charge would lodge unevenly and have a tendency to cause scaffolding and other evil results, similar to uneven charging of stock in a cupola.

Where the bell and hopper are used for charging stock, the angle and diameter of each, as compared with the diameter of the furnace at its throat or stock line, have all to do with the form and position which stock assumes when dropped into it. The angle of the hopper influences that of the bell in determining the distribution and position of coarse and fine material, also the formation of the irregularities in mounds which a charge may assume, after being dropped by a bell into a furnace. It is

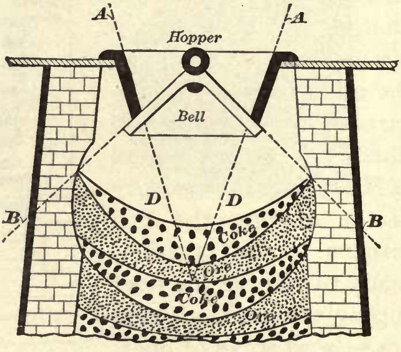


FIG. 12.

generally conceded that the small bell, as in Fig. 11, sends the coarse material to the outside circle, while the larger bell, Fig. 12, sends it to the inner circle, and the coarse material may descend faster than the fine stock. Furnacemen are now largely using small bells.

The action of stock in passing down through a furnace should attain, if possible, an occasional shifting movement, so as to retard the formation of any solid mass of the stock. This is best achieved in a taper stack, as the stock in passing downward should assume an action somewhat similar to that illustrated in the various levels, A, B, C, D, E, and F, seen in Fig. 10, page 49. When stock is dropped by a bell, such as in the size of the furnace shown, it is generally, if all is working well, distributed in a form somewhat like that in the mounds M M, seen at the level A, which is called the "stock line," and is generally ten feet below the level of the bell. The stock in settling down to fill the increasing diameter of a tapering stack must have a spreading out or leveling action taking place, or in other words, the outside would descend faster than the inside stock. It seems reasonable that the tendency of the stock in settling would be to have the angles constantly leveling themselves somewhat after the idea illustrated at the various strata B, C, D, and E, Fig. 10, until it has reached the bosh at F, when reaction would take place and the stock in descending would be retarded by the walls of decreasing diameter and cause the center portion to travel faster than the side, until at the last stratum, I, the center stock would have traveled ahead of the side stock as shown at R. Before this point is reached, however, the reaction (which changes the oxide of iron in the ore to metallic iron, and carbonizes it to form cast iron) has taken place and all the stock is liquefied, gases have escaped, and what passes to the point Y is some remaining fuel which replenishes the bed over the melted iron and slag. The total length of line at the different levels, B, C, D, and E, is the same. In cupola practice, foundrymen have the advantage over furnacemen in being able to observe the action of the stock until it has reached the "melting point." In observing stock settle at the last charge in a straight cupola, when all is working well, little or no change is noticed in the position of the material, and this is generally so true that the founder knows that whatever way stock is delivered into a cupola it will generally be found so situated when it reaches the "melting point." For this reason founders often have experience with "bunged-up" cupolas or iron dumped at "bottom-drop," which could not be melted owing to fuel or iron not having been charged evenly. Often stock reaches the melting point with fuel mostly on one side and iron on the other through carelessness in charging in that manner.

In the descent of the stock, coke, limestone, and ore, all moisture is driven off, the thoroughly dry and heated ore now comes in the zone of reduction, where the oxygen is taken from it, and changed from oxide of iron to metallic iron, during which process the iron takes up carbon from the fuel, and, melting in the zone of fusion, finally arrives at the bottom in form to be tapped out. The non-metallic or earthy matter, in separating from the reduced iron, unites with the lime or flux and, being lighter than iron, floats on its surface and is tapped off as slag through the slag hole T, Fig. 10, page 49, while the iron is delivered at the tap hole X. The amount of fuel and limestone necessary, depends upon the nature of the ore charged and the grade of iron desired. All material charged into a furnace passes off either as a liquid or as a gas. The gas which comes off at the top is made to pass through the down comer into the ovens and burned there. There the blast is heated while passing to the furnace. The liquid products which pass off are iron and slag, both formed at a point ranging from a level with the tuyeres to a height of about four feet above them, a portion generally called the "melting zone," or bosh, the hottest part of a furnace.

If ore is not properly reduced a percentage of its iron may pass off with the slag, the reason for this being that it is not thoroughly extracted from the ore and non-metallic matter. This is generally due to an insufficient amount of fuel, or decrease in temperature from other causes. Moreover, too small an amount of silicon is reduced at the same time from the fuel and ore, and consequently the iron obtained is smaller in amount and silicon contents and richer in sulphur. The furnace is working cold, or "off," and a greater per cent of fuel may make it work better.

Sulphur in iron is generally largely obtained from the fuel in a furnace. Iron from the ore, as well as the lime in the flux absorbs sulphur. Which of these two elements, in the process of reducing the ore, will absorb the greater percentage of sulphur from the fuel depends upon the degree of heat obtained. Lime has a great affinity for sulphur, and if the slag is made thin and hot it can counteract the absorbing power of the iron and take much of the sulphur itself. If the furnace is working cold so as not to properly fuse the limestone, then the iron will absorb and retain higher sulphur; and hence the greater sulphur found in the iron coming from a coldworking furnace, which often results in giving a hard or "white iron." The way high silicon and low sulphur iron, or No. 1 pig iron, is generally obtained is by having a hot furnace, well but not excessively fluxed with lime. To make high silicon and high sulphur iron, as is often obtained, it is necessary to have a hot furnace poorly fluxed with lime. A cold furnace gives a thick, bad slag, the same as a cold cupola retards good fluxing or slagging out. A good working furnace sends the most silicon into the pig and sulphur into the slag; a poor working furnace reverses these conditions.

CHAPTER VI.

CAUSE AND EVILS OF SCAFFOLDING AND SLIPS IN A FURNACE.

The factors causing the greatest irregularity in the working of a furnace are scaffolding and slips. This means that a portion of the stock will hang at one point for a period and then suddenly becoming loosened, will slip for a distance and reach material filling the bottom or hearth of a furnace. There are four factors effecting the hanging of stocks and slips, which are evils all furnacemen aim to overcome. The first of these is the lines of the furnaces, the second the manner in which the stock is delivered to the furnace, the third the quality or nature of the ore and fuel used, and the fourth the state of the temperature of the blast and atmosphere causing a furnace to work cold or hot. A few years ago experts said that the Messabi ores could not be smelted in a furnace, owing to their being so fine and loamy. But the large percentage of iron which they contain, their low phosphorus, (which makes it a good ore for Bessemer,) and low sulphur, three very desirable elements, combined with low cost, caused furnacemen to try it and persevere in its use, until to-day it is a large percentage of the ores charged into many furnaces. Nevertheless, furnacemen find much trouble from slips and wastage of this ore in the form of fine dust being carried out with the gases through the "down-comers." There is much study being given in hopes to devise methods to overcome these difficulties. To help matters, a few have taken out their old bells and replaced them with smaller ones, and they report a very commendable improvement in preventing slips when using Messabi ores.

The reason for stock scaffolding in a furnace is often found in the irregularity of the lining. The constant friction of the stock in working downward cuts cavities into the lining, often forming regular shelves upon which the stock can easily hang up. The longer a furnace runs, the more favorable conditions become to scaffolding, and when it is stated that ore is a substance which becomes gummy and swollen before it is reduced to a fluid state, one can readily perceive why such trouble may be expected in a furnace, causing an irregularity in the product, and at times disarranging all calculations of the furnaceman by producing an undesired character of iron. When furnacemen experience trouble with scaffolding, etc., not due to a hot furnace, as described in Chapter X., page 75, they often resort to the use of more fuel than when all is working well. The additional percentage of fuel causes a greater heat, making the stock more plastic, and causing it to give way more easily from the walls of a furnace. It generally takes from five to ten hours for stock to work down from the top to be tapped out as iron.

A slip in a furnace often means the falling of from twenty-five to two hundred tons of stock from a height of one to fifteen feet. The contemplation of this taking place within a furnace filled with combustible gases, heated stock, and liquid metal should enable any one to form some conception of the damage that could be done, and the reason all hands around a furnace have good cause to fear a slip. The scaffolding of a furnace can prove so disastrous as to disable or make unsafe its working parts. The author has seen a slip cause such an explosion as to lift the bell and hopper F. and K, Fig. 13, throwing them out almost on top of the furnace platform, and straining it to such an extent that it was a question whether it was safe to rely on the furnace shell; and he has heard of a bell and hopper being thrown about twenty feet from a furnace. Plans have been adopted to relieve sudden gas pressure, some of which are working very satisfactorily, especially the system used at the Alice Furnace, Sharpsville, Pa., designed and patented by Mr. P. C. Reed, the furnace superintendent, and shown in Fig. 13. The idea is to build four large openings equally divided around the circumference within a few feet of the

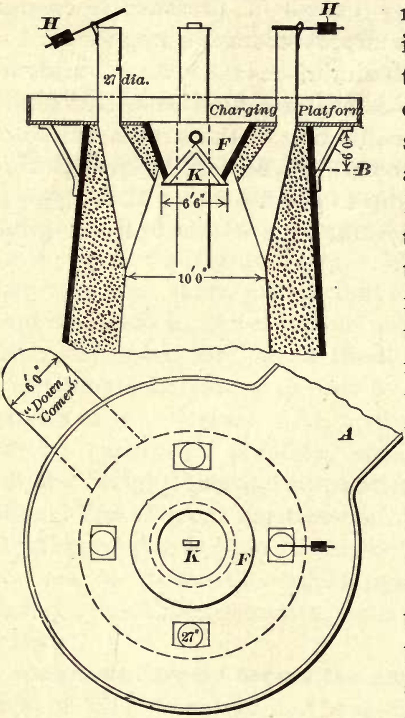


FIG. 13.

top of the stack. These are connected with flues branching upward about eight feet high, and closed by means of valves hung on pivots, as seen at H H, and so regulated by weight that they will open of themselves when any excess of pressure is created in the furnace. This improvement is a step forward in furnace practice which diminishes the risks of accidents and loss of life, but it still remains to better guard against the evils of scaffolding or the slipping of stock so detrimental to successful furnacing, often requiring several days after a slip to get a furnace back again to working satisfactorily and give a fair uniform grade of iron.

CHAPTER VII.

COMPOSITION AND UTILITY OF FLUXES.

The object of fluxing furnaces and cupolas is to give fluidity to the non-metallic residuum of the iron ore and the ash of the fuel, to carry it out of the furnace or cupola in the form of slag. While this is an important function, there are certain chemical compositions that can exist in fluxes which best assist in obtaining desired results, similar as there are certain chemical constituents necessary in ores to obtain the brands or grades of iron desired. All fluxes should be as free of earthy matter as possible, since such retards their action. High silica and sulphur are likewise objectionable. The element most essential in a flux to aid the creation of slag is lime. This is found in various substances, as in marble, spalls, oyster and clam shells, limestone, chalk, dolomite, calc-spar, fluor-spar, and felspar.

Magnesia largely serves the same end as lime, but less of it is required. About two of the former is sufficient, where three of the latter would be required. Dolomite contains more magnesia than any other class of limestone, and is often called magnesia limestone and generally contains about 55 per cent of calcium carbonate and 40 per cent of magnesium carbonate, with the rest largely silica, oxide of iron, and alumina.

Dolomite is now being used in the making of high silicon and other irons, but it is said it is not as effective in lowering sulphur in iron as limestone where sulphur is troublesome.

The more silica a flux contains the greater fuel or higher temperature required to fuse it and the less its value as a flux, for the reason that more lime is required to unite with the silica to make a good slag, and the more silicious the ore the more lime generally required to flux it. It has been known to require more lime than there was ore charged in order to flux the high silica which the ore contained. Silica as found in slag is not only derived from the fuel and ore, but also from the scale and sand of any iron which may be charged into a furnace or cupola, and from the oxidation of the silicon in iron during the heat. It is to be remembered that the more lime a flux contains, the better it serves the end of creating slag to affiliate with the earthy matter and debris formed in a furnace or cupola, and also the more silica or lime there is in a furnace or cupola, the more fuel required to smelt or melt the iron. Alumina is also pronounced in its effects upon the decrease or increase of the fluidity of the slag. As a general thing, the more alumina the higher the temperature required to fuse the flux in order to make a good liquid slag.

The following Table 10 is a compilation of fluxes which the author has used with good results, and will serve to illustrate the physical as well as the chemical properties, and will also show that a flux which might work well in a furnace can often be well utilized in cupola practice:

TABLE 10.

	No. 1.	No. 2.	No. 3.
Silica	3.00	1.98	.54
Iron Oxide	.92	.60	.12
Alumina	1.25	.90	.36
Phosphorus	.020	.037	....
Sulphur	.020	....	....
Carbonate of Lime	92.10	82.85	98.78
Carbonate of Magnesia	1.26	13.04	....
Lime Oxide	51.57	46.41	55.32
Magnesium Oxide	1.63	17.23	....

The physical character of No. 1 is very hard and of a dark color, and is a grade of limestone largely used for blast furnaces. It is obtained near New Castle, Pa. No. 2 is of a much softer quality than No. 1 and also more white and clear in its color. It is known as Kelly Island limestone and is mined at Marblehead and Lakeside, O. No. 3 is softer and purer in color than either Nos. 1 or 2 and has something of a checked marble cast. It is obtained from the Benson Mines, New York, and instead of being called limestone as are the first two shown, it is defined as calcite by the shippers. It will be noticed that Nos. 2 and 3 have no sulphur. For many classes of work this is preferable to No. 1 As sulphur in limestone is similar in its effect to sulphur in fuel, it largely passes into the iron and raises its sulphur contents. For cupola work preference, as far as labor is concerned, would be given to Nos. 2 and 3 owing to these being more friable than No. 1, but the furnace limestone No. 1 is less expensive. All the above fluxes are used just as they are mined, being in no way burned or roasted — a treatment necessary to some grades of limestone — and will benefit, it is claimed, almost any flux of a rock character. When this is done with limestone it gives us quicklime, a form that requires less weight when charged than limestone. The action of burning or roasting causes the limestone to become friable, so as to largely eliminate its carbonic acid and other volatile matter and generally make a limestone more ready to unite with the impurities. While such treatment of limestone would naturally be expected to be economical, it has not proven so in all cases. When the fuel required to roast it is taken into consideration with that which may be saved in converting it into slag in the smelting of iron, there is considerable difference of opinion in regard to the question of economy for furnace practice.

CHAPTER VIII.

FLUXING AND SLAGGING OUT FURNACES

The percentage of ore and fuel which must be carried off by the slag in making iron consists of ten to thirty per cent of the former and ten to fifteen per cent of the latter. A portion of this extraneous matter is basic, the rest acid. The chemical affinity thus existing is such that, when this material is subjected to high heat, union is effected, the whole passing into a fluid state. Generally the percentage of basic in the refuse is not sufficient in its action on the acid matter to reduce it to such a fluid state that it will flow freely, or properly extract all extraneous matter from the ore. To remedy this defect, limestone or other flux is generally added to all charges of ore going to a furnace. While the lime, etc., assists in fluxing the refuse to the state of fluidity required, it also affects the quality of the iron produced as described in pages 53 and 54.

The grade of iron which is to come from a furnace can generally be foretold by the nature of the slag tapped or flushed before the iron is tapped. If a lump of solid slag, when broken, presents a black color, very dense in its composition, it is generally supposed to denote the production of iron very low in silicon and high in sulphur, with high iron in the slag. If slag is of a light or gray color and its fracture presents a porous composition, it is generally an indication of a production of iron which will be well up in silicon and low in sulphur, with low iron in the slag. Degrees in color and solidity of the slag between the two extremes may vary according to the difference found in the grade of the iron. Foundry irons generally produce a slag more silicious or "stony" than Bessemer irons. The use of high manganese or manganiferous ores generally produces either a green or brown slag. A green, glassy slag, from such ores, indicates that the furnace is working well, but a brown slag denotes the reverse. These grades of slag are generally produced in the making of spiegeleisen and high manganese iron.

The slag called "scouring cinder" is generally the worst slag which comes from a furnace. It is of a reddish brown color and is chiefly caused by a slip or some bad working of a furnace, causing ore to pass down to the fusion zone in an unreduced state. This class of slag is very cutting to the lower lining of a furnace, owing to its containing so much oxide of iron and being very basic, a combination most effective in dissolving the silica in the bricks forming the lining. Some furnacemen are having their slags analyzed at every cast, as a guide in regulating their furnace. This proves very satisfactory in assuring a furnaceman as to the character of the iron he may expect, or whether any changes are taking place which might call for prompt attention in making alterations in the manner of charging or working of his furnace. Some expert furnacemen can greatly vary the grain of an iron by methods of fluxing or, in other words, cause like percentages of silicon, sulphur, and carbon to make some casts open-grained and others close-grained iron. This shows still further why the appearance of fractures in pig iron is so often deceptive.

To afford some knowledge of the chemical relation which slags bear to the iron produced, the analyses in Tables 11, 12, and 13, obtained by the author, are presented:

TABLE 11—ANALYSIS OF FOUNDRY IRON.

Silicon.	Sulphur.	Manganese.	Phosphorus.
2.09	.013	.25	.769

TABLE 12—ANALYSIS OF SLAG.

Silica.	Alumina.	Lime.	Manganese.	Magnesia.	Iron.	Total.
33.08	19.74	44.74	.11	1.44	.40	99.51

Table 13 is slag selected from the compilations of different authors to present a knowledge of the character of slag produced from different ores and classes of fuel. The first and second columns are slags produced from raw coal smelting at Dowlais, Wales, presented by Riley. The first column is a slag from gray iron and the second from white iron. The third column is a slag from coke with Cleveland ores making gray iron, by Bell. The fourth is from anthracite, making gray forge iron, at Bloomington, N. J., and the fifth is from charcoal iron made at Josberg, Sweden, by Sjogren:

TABLE 13—ANALYSES OF BLAST FURNACE SLAGS FROM DIFFERENT ORES AND FUELS.

	1	2	3	4	5
Silica	38.48	43.07	27.68	42.17	61.06
Alumina	15.13	14.85	22.28	13.59	5.38
Lime	32.82	28.92	40 12	33.02	19.81
Protoxide of Iron	0.76	2 53	0.80	1.28	3.29
Manganese	1.62	1.37	0.20	0.27	2.63
Magnesia	7.44	5.87	7.27	8.31	7.12
Sulphide of Calcium	2.22	1.90	2.00	0.64	....
Alkalis	1.92	1.84	....	....	....
Phosphoric Acid	0.15	....	....	....	....
	100.54	100.35	100.35	99.23	99.29

The percentage of silica slag contains, sometimes as high as 60.00, as seen in Table 13, shows us ways in which silicon can be carried off or reduced in smelting or remelting iron. The weight of slag produced is dependent upon the character of the ore, fuel, and flux used. The furnace can produce a greater weight of slag than iron, but, as a rule, 600 to 1,000 pounds of slag are made to the ton of iron. The richer the ore, the less slag in the normal working of a furnace. The slag created at a furnace must be disposed of. We find machinery utilized in this work, as in other manipulations of furnace practice. Some have it conveyed in large receptacles, which are hauled by power to cars or dumping ground. When overturned, they release the slag in a molten form, or solidified state. Another plan is to let it run from the spout Y, Fig. 18, page 90, to furrows in the ground, which may be run for a length of two or three hundred feet, often covering an acre of ground. This slag is pulled out of its furrows by hooks in the hands of men before it has thoroughly solidified. In removing the slag from the ground it is shoveled into carts and teamed to the dump, or thrown on cars to be transported and used for railroad ballast, or for making roadways. Then again, the slag is run into a deep pit, after being granulated by a stream of water issuing from a pipe in the trough, which strikes the slag as it leaves the trough to drop into the pit. This granulated slag is hoisted by a steam shovel and dumped into cars, doing away with much hand labor. This plan is used at the Alice Furnace, Sharpsville, Pa., and Ella Furnace at West Middlesex, Pa., after plans designed by Mr. E. H. Williams, the general manager. The pit used is about twenty feet square by twenty feet deep, and all the slag made by the furnace is dumped by the steam shovel into cars and used by some railroads as ballast, and filling up dumps.

Mineral wool is made from slag by remelting furnace slag in a cupola, under patents obtained by Wood Brothers, of Wheatland, Pa. The process consists of charging the slag in connection with coke after the plan of melting iron. As the slag flows out it is met at the outlet of the slag-hole by three flat streams of steam, which divide its particles into threads of mineral wool and blow the same into a large building about one hundred feet long and thirty feet wide, prepared for its reception. Variations in the character of slags create different grades of wool, which is sorted and packed according to its commercial value. The wool may often be of such a coarse, poor quality as to be unfit for commercial purposes. There is always a difference in the density of the wool at every cast. The lightest is deposited or blown farthest from the cupola and the heaviest grade nearest to the cupola. The wool is chiefly used as a non-conductor of fire, packed between the walls and floor spaces of fire-proof buildings, etc. This mineral wool resembles in character that which the founder finds coming from cupolas which are slagged out.

For every tap of iron made from a furnace, there are generally two taps for slag. This is termed "flushing a furnace." In the furnace shown, Fig. 6, page 34, the number of taps for iron during twenty-four hours generally ranges from four to five. In about the middle of every tap the furnace is "flushed" and then again about twenty minutes before tapping for iron. The old way of tapping to flush a furnace is simply by having a hole in the lining through to the inside of the furnace, and after the same is tapped to plug it with clay, on the same principle generally followed in tapping a slag-hole in cupola work. The modern plan for making and operating a flushing-hole is that shown in Figs. 18 and 19, pages 90 and 93. At N is a bronze casting into which is inserted what is termed a "monkey tuyere," P, both of which are kept cool by a flow of water passing through them. In tapping a slag-hole to flush a furnace the projection H is slightly jarred by means of a sledge which loosens the stopper R. After this has been removed, as shown by A, Fig. 18, a steel pointed bar is then used to cut through the inch or two of chilled slag, which has generally been formed in front of the plug F. This chilled slag is generally removed with ease, permitting the cinder to flow out. The time generally taken for the slag to be all flushed out ranges from five to seven minutes. It is not long after the slag has commenced to run before the blast makes its appearance, blowing gas and sparks of cinder for from twenty to thirty feet from the flushing-hole. As soon as the flushing is completed, the iron plug stopper R is quickly thrust into the hole, which at once chills the slag around it, and stops the leakage of blast. The stopper R is a wrought iron bar with a cast iron cone cast on the rod which forms the plug as shown. The difference between this method of tapping a flushing-hole and the old plan used is simply in the convenience, and the use of clay is avoided. The iron and slag-holes of a furnace are sometimes lowered or raised from their original positions by reason of a furnace filling up with chilled iron, but if this can be avoided by tapping the iron, as well as the cinders, out of the slag-holes, as described in the middle of the chapter, it is often done in preference to changing the position of the iron and slag-hole, as above described. Any one desiring further information on fluxing or slagging in its relation to cupola work is referred to "American Foundry Practice," page 331, and the "Moulder's Text-Book," page 310.

CHAPTER IX.

COLD AND HOT BLAST VS. COMBUSTION.

There are four kinds of blast. The first is called "cold blast," the second "warm blast," the third "hot blast," and the fourth "superheated blast." Cold blast is generally employed by founders in remelting metals in a cupola, air, or crucible furnace; also by charcoal blast furnace operators. Warm, hot, and superheated blasts are generally used for smelting ores to produce iron or other metals. Warm blast is air heated from 250 to 400 degrees F. Blast heated above 1,100 degrees F. is generally termed superheated blast, and if the temperature ranges from 700 to 1,100 degrees F. it is generally known as hot blast. There are two properties in the blast, the first being physical and the second chemical. With a temperature of 60 degrees F. and the barometer at 30 inches, air weighs about one-eight-hundred-fifteenth part as much as water.* The weight of blast passing through a furnace in smelting ore to produce iron is greater than the combined weight of the fuels, ore, and flux charged. Blast or air contains chiefly a mixture of two gases, nitrogen and oxygen, which is recorded by volume and weight in the following Table 14:

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*Table 131, page 591, at the close of this work, gives the difference in value of degrees between Fahrenheit and Centigrade methods.

TABLE 14.

	Volume.	Weight.
Nitrogen	79.19	76.99
Oxygen	20.81	23.01
	100.00	100.00

As the blast is forced into a furnace or cupola, the oxygen combines with the carbon of the fuel and produces carbonic acid gas, which is two atoms of oxygen to one of carbon. This gas, in passing upward, takes up more carbon and is gradually converted into carbonic oxide, a gas which soon gains supremacy in lowering the high temperature necessary to liquidize ores or metals. By considering that a state of carbonic acid is necessary to liquidize, and that carbon-oxide alone will not heat metals to a red hot color, we are in a position to fairly comprehend the difference in degrees of temperature which ascending gases must have in reducing ores in a furnace or melting iron in a cupola. It is said that one unit of carbon passing to the state of carbonic oxide only yields 2400 heat units centigrade, but when it becomes carbonic acid, 5,600 additional heat units are evolved, further illustrating the difference in temperature which the two states of carbon can create.

The existence of carbonic oxide is essential in the blast furnace for the reduction of ores to produce iron, but not in remelting iron. In the cupola the less carbonic oxide gas, the greater the economy, and, to decrease this gas, upper tuyeres are sometimes utilized. These supply additional oxygen to the escaping carbon and convert it back more to carbonic acid gas and give greater heat in the cupola. This is so effective that where upper tuyeres are not used, the escape of carbonic oxide gas may often be so great that when it reaches the charging door and obtains oxygen from the air, it often creates such a combustion as to send a flame many feet above the top of the stack, causing much loss of heat.

The following Tables 15, 16, and 17 show the amount of heat absorbed in smelting and that lost by radiation and in gases, according to Sir Lowthian Bell's estimate, expressed in hundredth-weight heat units per ton of iron produced:

TABLE 15.—HEAT PRODUCTION.

Oxidation of carbon	81,536	units	
Contributed by blast	11,919	"	
			93,455

TABLE 16.—HEAT ABSORPTION.

Evaporation of water in coke	312	units	
Reduction of iron	33,108	"	
Carbon impregnation	1,440	"	
Expulsion of CO_2 from limestone	5,054	"	
Decomposition of CO_2	5,248	"	
Decomposition of water in blast	2,720	"	
Phosphorus, silicon and sulphur reduced	4,174	"	
Fusion of pig iron	6,600	"	
Fusion of slag	16,720	"	
			75,376

TABLE 17.—HEAT LOSS.

Transmission through walls of furnace	3,658	units	
Carried off in tuyere water	1,818	"	
Carried off in gases	8,860	"	
Expansion of blast, loss of hearth, etc	3,743	"	
			18,079
			93,455

By increasing the height of furnaces from seventy to one hundred feet, as practiced at the present day, much more heat is utilized than formerly when furnaces were about forty to fifty feet high. This practice has greatly assisted furnaces in achieving their present large output and economy in making iron. This experience is one which the founder has also found advisable to follow in the construction of cupolas, as they are made to-day from four to twenty feet higher than they were fifteen years ago. The height now generally followed is about ten to sixteen feet from the bottom plate to the lower level of the charging door, whereas it used to be only from six to nine feet. The Carnegie Steel Co. has cupolas as high as thirty feet to the charging ring.

CHAPTER X.

EFFECTS OF BLAST TEMPERATURES IN DRIVING FURNACES.

Hot blast is claimed to have been first introduced by Mr. James Beaumont in Scotland in 1825. Up to this time cold blast only had been used. The use of hot blast has increased in temperatures from 100 to 1,500 degrees and higher. Every increase in temperature in blast was found to effect more or less of a saving in fuel and improve the working of a furnace up to 1,700 degrees; over this it has not proved economical. When only 100 degrees was used it proved to be an advantage over the cold blast. Then 200 degrees was used, showing better results than 100 degrees, followed by 300 and 400 degrees, and upward until a temperature of 1,000 degrees was obtained, which was as high as iron stoves or pipes would stand the heat without being rapidly burned away. The knowledge that every increase in temperature had proved beneficial gave confidence that a higher temperature than 1,000 degrees would prove still more economical, but in order to utilize a higher heat than 1,000 degrees, some other plan than " iron stoves " had to be devised. This improvement was not long in making its appearance. Different designs of stoves having all-brick flues which could not be damaged to any radical degree were introduced with great success, and the temperature of the blast was soon raised by degrees until 1,500 to 1,600 degrees were often utilized with benefit where a furnace had "chilled" or "got off"; but the general practice of high temperature of blast in the normal working of a furnace is not to exceed 1,300 degrees, being kept at 1,100 to 1,200 degrees with brick stoves and 900 to 1,000 degrees with iron stoves. When a furnace is working well, any increase over 1,200 degrees in the temperature of the blast is claimed by many to be more injurious in its results on the stock than beneficial in assisting a furnace to produce a good yield of iron, or "drive well." The reason that high degrees of heat in the blast will not cause the desirable and economical reduction of ore in the furnace, that high heat derived from the fuel will, is a phenomenon which all seem at a loss to understand. Experience has demonstrated that a temperature between 1,000 and 1,200 degrees is the most desirable to maintain. The temperature of the blast may be raised from 600 to 800 degrees with but little improvement, but let this 200 degrees increase be added to 1,000 degrees and the benefit derived is extraordinarily greater than any increase of 200 degrees on a lower temperature. In the normal working of a furnace the best results are obtained with a temperature of blast ranging between 1,000 and 1,200 degrees F.

By reason of utilizing the waste gases of a furnace to heat cold blast, blast furnace practice excels all other industries in obtaining the greatest efficiency from fuel, as about 75 per cent of the heat generated from the solid fuel is utilized. This is attained where one ton of coke will produce one ton of iron; and Sir

Lowthian Bell claims that where this is done all the economy is achieved that is practical to be expected in making iron, as long as the present fuel is used. To note the manner in which heat is produced, absorbed and lost, see Tables 15, 16 and 17, page 72.

Pyrometers. Various methods are employed for measuring degrees of heat. Those of a crude nature consist, for example, in using dry sticks of wood, which when inserted in hot air take fire, indicating a temperature of about 650 degrees F. Again, sticks of zinc, if melted, indicate about 750 degrees. To obtain a record of higher temperatures in a more accurate manner, many different kinds of instruments have been devised and in recent years have been largely adopted. A pyrometer recently designed and patented by Mr. E. A. Uehling, of Birmingham, Ala., in which the expansion and contraction of air between two small apertures is the principle used to denote temperature, is claimed to be giving excellent satisfaction. It is being largely adopted by blast furnacemen to record for them any variations in the temperatures of the hot blast or escaping gases, and enables them to regulate the workings of a furnace so as to give a greater output and produce a more uniform product than heretofore.

The question of temperatures in driving a furnace fast or slow is one of interest. It will appear strange to the founder, as well as to others, that a furnace can be got so "hot" as to retard the speed of making iron, and also may result in "scaffolding;" nevertheless there is a limit to attaining temperatures best calculated to drive a furnace to its utmost, which means obtaining the largest tonnage possible in making iron.

After this limit is reached, it would seem that too great a body of the ore was suddenly brought to such a swollen, gummy state, as to retard the proper ascent of the blast and gases. The first factor to give notice that a furnace is getting "hot" is an increase in the temperature of the gases and the refusal of the stock to descend as rapidly as when the furnace is working in a normal condition. To retard the increase of heat or lower the temperatures to the best point, it has been found that increasing the blast pressure would often bring a "hot furnace" back to its normal working. By this method a greater volume of blast is admitted, which having a lower temperature than the incandescent stock in the furnace, naturally cools it down. Then, again, a plan is now largely adopted in having arrangements made so that cold blast can be turned on at a moment's notice. This "brings a furnace 'round" more quickly and in a much better manner than by increasing the pressure of the regular blast which, it should be understood, will have its temperatures lowered as much as is practical before being admitted.

It is chiefly with brick hot-blast stoves that arrangements are provided for admitting cold blast to cool off a furnace, as these carry higher temperatures of blast than iron hot-blast stoves, as can be seen by referring to Chapter XI. The causes leading to "hot" furnaces can be traced to excess of fuel, often brought about by using larger percentages than ordinary, which may be called for by reason of having to use small, or what is thought to be inferior coke or fuel, and again in burdening a furnace with fuel in order to raise the silicon in the iron or guard against "scaffolding" or "slips" from the use of fine ores, etc. It may also be caused by a furnace perfecting combustion of its own accord to such a point as to overreach the best temperature for driving well. It may be said that brick stoves have many advantages over iron stoves in permitting a furnaceman to regulate the temperature of his furnace so as to drive it well and increase or diminish the silicon or sulphur in the iron, and that a radical change is generally noticed in this direction when cooling down a "hot furnace," as by such procedure the silicon is often materially decreased and sulphur increased.

Humidity of blast. It is generally conceded by experienced furnacemen that a furnace will work better and produce more iron in cold than in hot weather. It is said that in June, July, and August a furnace never produces tonnage to equal other months in the year. The air is generally dryer in cool than in warm weather, and it is now an accepted fact that the extra humidity in the summer air over that in cold weather is the cause of the less tonnage in the summer months. Some will think the heat imparted to the blast would drive out all the moisture, but this is claimed to be simply transformed into a vapor which passes into the furnace as steam. It has been estimated that twenty tons of water are often transferred, by the blast, to the interior of a furnace per day by reason of the high humidity of air in summer months. Further comments on this subject can be found in Chapters IX. and XXXIX.

CHAPTER XI.

PLANS AND METHODS OF WORKING BRICK AND IRON STOVES IN THE CREATION OF HOT BLAST.

A knowledge of methods used in creating hot blast at the blast furnace is valuable to the founder and moulder, as it presents good ideas for the benefit of those desiring to design appliances for the purpose of creating warm or hot blast for any purposes.

The terms "iron stoves" and "brick stoves" are understood to mean, in the case of the former, that the cold air passes through iron pipes, while with the latter, in being heated to make hot blast, it passes through flues or checkered work composed wholly of fire brick.

The iron stove is fast disappearing and being replaced by the brick stove, owing to the ability of the latter to create the highest temperatures in blast, which allows iron to be made more cheaply than where a temperature no higher than 1,100 degrees F. can be created, as with iron stoves. A further reason for this displacement is that the brick stove is less expensive, in matters pertaining to repairs and "shut-downs," to keep a furnace running steadily, also in giving more gas for use under boilers, etc. than iron stoves.

The operations of brick and iron stoves differ in their methods of being "in blast." The brick stoves generally go out of blast every hour, whereas the iron stoves generally run steadily for six weeks at a stretch, and have been known to run without interruption for several months. This difference in their operation is due to this principle. Brick stoves now in use require the cold air to abstract heat from the bricks comprising the flues in the ovens, after the combustible or heating gases have all been shut off, and in the "iron stoves" by reason of the iron pipes or flues through which the cold air passes, being separated from union with the gases; hence the iron stove can run steadily, whereas the brick stove runs only at intervals.

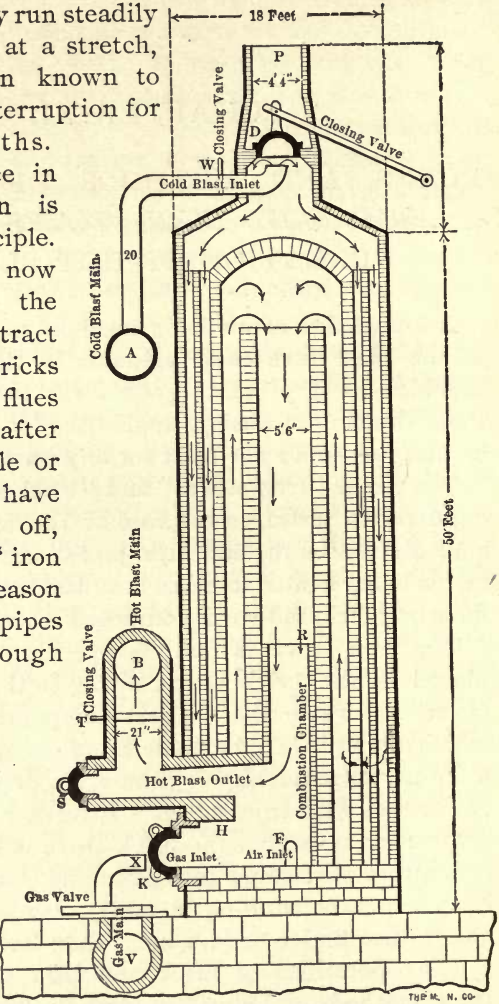

FIG. 14.—MASSICK & CROOKE PATENT BRICK HOT BLAST STOVE.

The short duration of the brick stove being "in blast" is due to the rapidity with which the introduction of cold air abstracts heat from the brick work. The temperature of a brick stove decreases from 100 to 300 degrees F. in one hour's time. With the plan

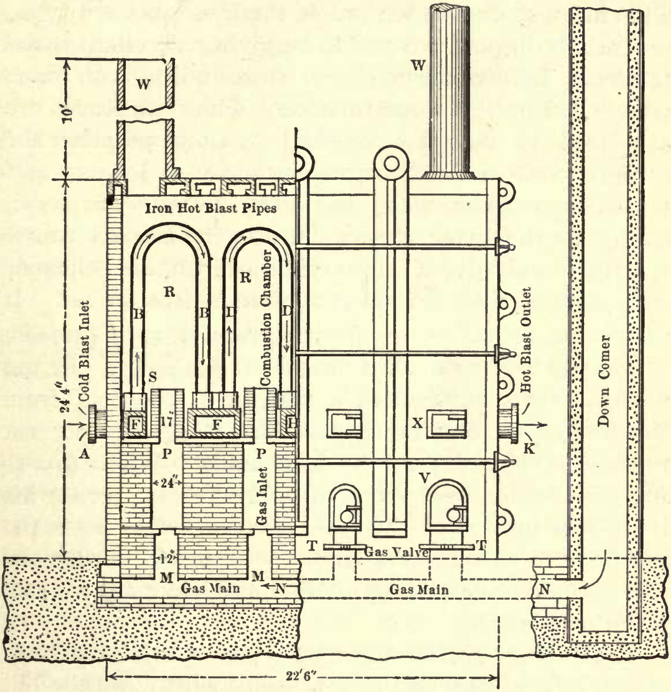

FIG. 15.—IRON HOT BLAST STOVE.

of stove shown at Fig. 14 four stoves are required to keep a furnace steadily in blast. Of the four stoves, only one is generally in blast, although two may run together for the whole of one turn of the stoves. The plan generally followed is to "put on" the stove going in blast a few minutes before the one going out of blast is shut off.

The sectional views of iron and brick hot blast stoves shown in Figs. 14 and 15, respectively, are of stoves in use within a "stone's throw" of the author's foundry. The brick stoves shown are of the most modern type, recently built, and are said to be giving excellent satisfaction. Before these stoves were built, iron ones were used by the same furnace. The four stoves are said to have cost $40,000, and by their adoption the owners were enabled to produce pig iron 30 cents per ton cheaper than when the iron stoves were used, owing to the brick stoves causing the furnace to use less fuel and give a larger yield of iron, also cheaper cost of repairs than those required in iron stoves. It may seem a small saving for the investment of $40,000. When pig iron was selling for from $30 to $50 per ton and the furnaceman had a margin of profit of from $15 to $30, no one thought of investing $40,000 just to save 30 cents per ton on iron made. When $10 to $14 per ton is about all a furnaceman can get for his iron, as is now often the case, a saving of 30 cents per ton is quite an item, especially so if it will permit one furnaceman underselling another and leave a few cents profit on his sales.

There are several different types of brick hot blast stoves now in use, and it now seems as if it will be but a few years before iron stoves will be almost wholly abandoned, mainly because the brick stove can make iron more cheaply than the iron stove. A large number of furnaces are still using iron stoves, but as soon as they are worn out, or competition gets too keen, they will no doubt be largely replaced by the brick stoves.

However, a description of some of the main features and principles involved in "iron stoves" cannot but be of value to many.

The plans and workings of an iron stove should first be considered. There are several different methods used in piping an iron stove. Those commonly employed have the inverted U and straight pipes, as shown in Figs. 16 and 17. The inverted U pipe in Fig. 16 is the same as those used in the iron stove illustrated in Fig. 15. This oven contains forty-four of such pipes, there being eleven in a row and four rows in the length of the oven. The length and height of the oven are shown. The width is twelve feet. As the pipes stand up in the oven there is about three inches space between them. The knobs seen at T, Fig. 16, form the space of division between them. The section seen in Fig. 17, page 84, is what is called "straight pipe." The division bar X answers the same purpose as making the pipes of a U form, owing to the rib X running up within about six inches of the top end of the pipe, when erected in the oven. A similar partition as at X is also in the bed pipe; this causes the blast to pass up one side and come down the other, thus serving the same purpose as the pipe at Fig. 16.

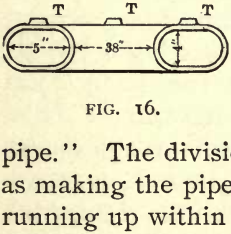

FIG. 16.

The straight pipes have the advantage of being more easily handled in taking them out of an oven when they burn out or crack, as they often do. The top of the oven is so constructed that the plate can be removed to permit bad pipes being hoisted out by means of an erected pole on the outside of the oven. It is far from being an easy or pleasant job to replace burnt or worn-out pipes. For this reason much care is exercised to prevent the temperature rising above 1,100 degrees in the oven.

There is a plan used in iron stoves of suspending the iron pipes from the top of the oven instead of letting them rest with their weight on the "bed pipe," as shown in Fig. 15. This plan prevents the iron pipes from "buckling" or bending from their own weight when they get red hot.

The usual plan adopted for heating cold air to make "hot blast" in the iron stove will be readily understood by a study of the design illustrated in Fig. 15. The arrow seen at A, Fig. 15, is the point at which the cold air enters the iron pipes in the hot blast oven. As soon as the cold air enters the first "bed pipe" E, it takes the direction shown by the arrow in the pipe B; passing from this to the "bed pipe" F, then traveling up the pipe D and down into the bed pipe H, continuing such a line of travel through four to six more pipes, according to the length of an oven, until the blast reaches the outlet at K on the right, from which it then enters the blast furnace as "hot blast."

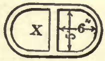

FIG. 17.

The action of gases is next to be considered. A point to be understood is that of the means employed for heating the oven or iron pipes to create "hot blast." This is accomplished through the use of waste gases, which escape at the top of a furnace, and are passed down through the "down-comer," seen on the right, to a flue N N, and then rising into the ovens through the openings M and P, until they reach the combustion chamber R, where they ignite as soon as they reach the point S, by reason of the gas being met by a fresh supply of oxygen or air and the heat of the oven. The chimney seen on top of the ovens at W creates a draft and permits the smoke or dead gas to escape. All the space about the pipes B and D is called the "combustion chamber," and when the gas is burning in the oven this space area is filled with a flaming gas fire.

Should the furnace go out of blast for any reason to exceed two hours, the oven will generally cool down to such a degree as to be very liable to cause an explosion when the gas begins to enter. Again, the oven being cold, could not heat the blast at the start to any effective degree, and hence less iron would be produced, with a chance of also promoting "chilling" in the furnace. To prevent or guard against such ill results, a wood or coal fire is generally built in flues P by opening the doors V. By such a plan the heat of the oven can be maintained to 700 to 800 degrees. It is not infrequent that items are noticed in the trade and daily papers speaking of some furnace having had a gas explosion. A cold oven is often the cause, and furnacemen watch this point very closely. Not only is it necessary that the ovens be hot when the gas from the ovens first enters them, but it is also desirable that a flame be burning in the oven to insure the gas igniting. Some furnacemen will take no chances in this respect. If they shut down but for half an hour they will either have some dry wood or a few lumps of soft coal placed in the oven so as to insure a flame therein when the furnace begins to send its gas down the "downcomer." A gas explosion can cause great damage, and the wise take no chances or risk with it.

The color of the gases escaping from the chimney

W, and also of the flame in the ovens, affords an experienced furnaceman much knowledge of the condition of a furnace or what results may be expected in its workings. In this respect, also in regard to explosions, the same is to be said of a brick stove as of the iron one, and a close watch is generally kept of the color and action of the gases. The gas, as it escapes from the top of a furnace in its passage downward to the iron or brick oven, is chiefly in the form of carbonic oxide and may often not have a temperature of 300 degrees of heat, although it generally ranges from 400 to 500 degrees as it passes through the "down-comer" to the ovens. This form of gas is an explosive, requiring air to make it combustible. This element it receives after it has entered the ovens, the air being drawn from outer channels or flues in the brick work of the iron stoves, as at H and F in the brick stove; this action creates the flame in the ovens just cited, which then raises the temperature to the degrees above noted. If the gas were allowed to pass into the oven in the state in which it comes from the top of a furnace through the "down-comer" without receiving a sufficient supply of air, the gas would be of little value in raising the temperature of the blast confined in the pipes on its passage to the furnace.

The plans and working of a brick stove are as follows: The line of the arrows seen in Fig. 14 displays the various channels through which the cold blast travels after entering the brick stove at E, seen at the end of the cold blast inlet pipe. The direction of the cold blast in being heated is directly opposite to that taken by the gas coming from the furnace to heat up the walls and various channels and checkered brick work in the stove. This is the plan followed in all modern brick stoves. The gas in leaving the "down-comer" is carried through gas mains to V, where it passes the gas valve at X and enters the furnace at H. Before the gas is turned on, the cap K, which closes the gas inlet while the blast is passing through the stove to be heated, is removed and the gas valve slid up so that the end of the pipe at X is about even with the face of the gas inlet. The pipe X, being smaller in diameter than the hole of the gas inlet at H, permits air to unite with the gas as it enters the stove, thereby causing combustion or ignition of the gas at the entrance before it passes to the combustion chamber, where it receives more air by means of the air inlet T, which is opened when the gas is turned on. At T, W and D are seen points at which valves are arranged for opening or closing the passage of air or gas, as the case may be. When the gas is being turned on, the valve D is opened. As now shown, it is closed so as to prevent any gas escaping up the chimney P. Before the gas is turned on, the valve D is opened so as to create draft and permit the dead gas and flames to escape through the chimney. The valves T and W are closed when the gas is on, as will be evident to any making a study of the plans shown. In a general way the blast is on a stove for one hour and the gas for three. Three stoves are generally on gas while one is in blast, unless one is being cleaned of the caked flue dust which rapidly gathers on the combustion chambers for a distance of about twenty feet in height, and on the bottom of the stoves, which have openings as at K and S for getting at or cleaning out the stove, or, if shut off, for repairs.

The valve at T is arranged with piping, through which water runs in order to protect the exposed parts of the valve from burning out. The valves W and D do not require the presence of water, for the reason that when the gas is on, the brick work of the stove absorbs the greatest heat at its bottom, which prevents the highest temperature being confined to the upper part of the stove. One stove, when a furnace is working well, is all that is generally "in blast;" but if there should be a "slip" to chill a furnace or make it work cold, two or three stoves are often put on at one time for a short duration to assist in raising the temperature in the furnace so as to restore it to its normal condition, after which the additional stoves are taken off and the work continued with but one, as in ordinary practice.

The four stoves are placed together as closely as is convenient to leave room for working around them. They cover an area of ground about 40x50 feet. The four stoves are connected by band pipes and separate valves, so that the cold blast coming from the "blowing tubes" and the hot blast leading to the four stoves come from and lead into one main pipe. The pipes which convey the hot blast to the furnace are either coated with an asbestos covering or have their interior lined with fire brick, the same as is done with the "down-comer" which carries the dead gas from the top of the furnace down to the combustion chamber of the hot blast stoves to protect them and prevent loss of heat.

CHAPTER XII.

TAPPING-OUT AND STOPPING-UP FURNACES AND CUPOLAS.

It has taken much time, study, and experience to attain the present perfection in controlling the output of a modern furnace. The history of blast furnaces shows many disasters in "breakouts," "boils," and explosions. When all is working well about a furnace everything seems very simple and as if taking care of itself, but it is when all does not go well that one is impressed with the fact that furnacing is often more like hades let loose than a paradise of comfort, ease, and pleasure. An observing founder standing at a distance watching a furnace being tapped might often be at a loss to understand why a cupola cannot have its "breast" stopped the same as the "notch" of a furnace. The founder often has trouble with cupola tap-holes, which when once started to work badly will often continue to do so throughout the balance of the heat. The secret of the furnaceman being able to stop a notch by hand in the way it is generally done, is that the metal, when all is working well, is left lower than the notch-hole, about as illustrated at the level O, Fig. 18, page 90. How the metal goes down to such a low level as shown is a puzzle to the founder who has

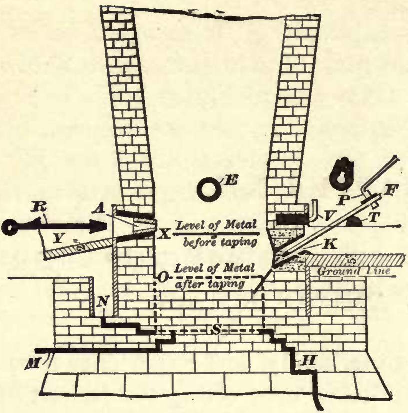

FIG. 18.

never seen a furnace. The tapping-hole K is generally made at an angle somewhat as shown. After the metal has run out all it will by force of gravity, the blast pressure is increased above the ordinary to drive or siphon it out, as called by some, to about the level shown at the dotted line O. With the weight of stock bearing down on the molten mass in a crucible and blast pressure of 10 pounds or more to the square inch, it seems reasonable to expect the results described. We know the weight of stock and pressure of blast exerts such a driving-out influence, from the fact that when about two-thirds of the pig beds are poured, the metal will often almost stop running, at which point the blast pressure being increased a fourth more metal will often be forced out, and the more acute the angle of the notch, so as to carry its opening lower into the crucible, the more metal to a depth of about 15 inches below the level of the bottom of the iron trough can be siphoned out in tapping a furnace. A question which suggests itself here is the reason for having such a body of metal below the level of a notch-hole. The great depth sometimes attained is not really desired, but is caused by the liquid mass burning out the bottom brick-work.

When "blowing-in" a new furnace, the bottom bed of the hearth or crucible is not much over four inches below the level of the notch, but continual running and "fast driving" of a furnace soon cut out the bottom lining, so that it is no uncommon result for metal to burn the bottom down two to three feet below the level of a notch, as indicated by the dotted line S in Fig. 18. Furnacemen claim it is not until a bottom is cut down for a foot or two that the best output and quality of product can be obtained, and also that a deep bed is very desirable to help maintain a uniform product. Often has a furnace cut the bottom out to such a depth as to force an opening for metal to pass downward through the ground or outward through the sides, about as is indicated by the lines N, M, and H, Fig. 18. The havoc such an escaping body of metal can make, if bursting out, as it often does, into a reservoir of water, which is always more or less deep around the hearth of a furnace at N, can be but partly conceived.

The mass of liquid metal in the bed of a furnace often weighs 50 to 100 tons. This often solidifies and lies in a furnace until it is torn down, or the hearth portion removed to permit its being broken by dynamite. It has happened that, through a furnace "getting off" or working badly, the bed of metal has solidified above the level of the notch, so that to tap the metal out of the furnace it would have to be drawn off at the flushing or slag-hole at A, Fig. 18. Some furnaces have run for a week or two in this manner before they were able to get the solidified mass melted down, so as to again draw metal from the notch-hole. A furnace in this condition must be tapped much oftener than when it can be tapped at the regular notch. It is often surprising how rapidly, through a furnace getting cold, the bed of metal in the hearth will solidify, and then again how, when a furnace is working hot, it will often cut out such a solid mass of iron; but generally, like all workings of mechanical affairs, the evil is prolonged more than the good is hastened, when trouble once begins.

Fig. 19 shows the effect of a chill in a furnace causing metal to solidify around and above the notch. This is one form, and another form, instead of having a chill all around the sides with liquid metal in the middle, may have one side solidified while its opposite is in a fluid state. Solidification of such masses generally occurs by reason of scaffolding, cooling off the furnace, and then letting a mass of chilled stock slip down to the tuyeres or lower into the hearth. There are two forms of such evils resulting from a slip, the first being the solidification of metal as above described, and the other what is called a "lime-set," which is generally caused by reason of a furnace carrying a heavy burden of limestone, and the furnace, becoming cold from "scaffolding" or any other bad working, chills the lime so that it becomes too thick to flush out, and "sets" in a solid state in the crucible or at the tuyeres.

Furnacemen generally fear a "lime set" more than that of molten metal solidifying, for the latter can be melted away much more readily than the former. Lime-sets have been so serious that furnaces have had to "blow-out" to remove them. A method sometimes employed to gain access through solidified iron, which had closed up tuyeres, or a "notch," so as to prevent its being tapped, is that illustrated by the hydrogen blow-pipe at A, Fig. 19, page 93. As used in this case,

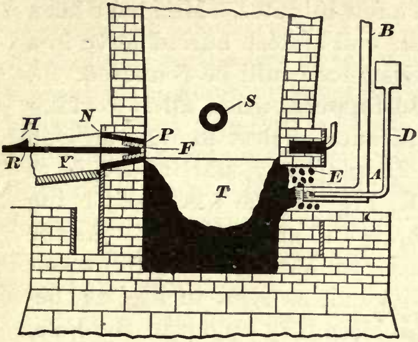

FIG. 19.

it is simply a 2-inch gas pipe leading from the hot blast pipe (cold blast can also be used), into which a ¼-inch pipe D carries a stream of coal oil. This is contained in a can sufficiently high to force the oil out and overcome the blast pressure at the outlet; there it ignites by combination of the air and oil. Sufficient heat is thus generated to melt the iron or enable it to be knocked away. Space is made, in this manner, which admits the blast and metal blowing out to further cut away the solid iron to a point warranting the replacing of the notch for regular working. In some cases a coke or coal fire may be encased in front of the blow pipe, and the stock is to be cut away as illustrated by the small lumps of fuel seen at E, Fig. 19. The principle involved in this process is one which may often be practically applied by the founder in preparing a casting to be burned, by bringing the point of fracture to almost a molten state, thereby saving labor of melting and handling a large quantity of molten metal. It may at times also be found of value in assisting to cut away heavy bodies of iron that may be found almost impossible to be otherwise manipulated. In using this device to cut out a notch of a furnace, great care is exercised, as it may cut through the chilled material and, without warning, the molten contents may burst out with such force as to empty the furnace in a few minutes. Men have been struck by such outbursts and almost buried alive in a pool of metal before assistance could be rendered.

The process for hand-tapping, when all is working well with a notch of a furnace, is first to take an iron bar and prick into the stopping clay, starting a hole as seen at the entrance K, Fig. 18, the "keeper" being careful to give it the shape and angle desired. As the clay is loosened, a ⅜-inch rod, having a flat lifter about 1½ inches square on its end, as seen in Fig. 21, below, is used to pull the loose clay up out of the hole, which is generally made about 4 inches in diameter at the top, tapering down to 2½ inches at the bottom. Picking by hand bars and lifting out the loosened clay is continued until the solid clay shows by its red heat that its thickness preventing the metal bursting out is not over 3 inches; then a steel bar of about 1¼ inches diameter having a sharp point is placed as shown in Fig. 18, the upper end resting on a piece of pig metal thrown across the top of the iron trough, as seen at T. A sledge is now used at the end F, the bar in the meantime having its point guided by hand so as to cut around the edge of the hole. This is continued until metal commences to ooze out slightly, when the bar is driven through the started body of the clay into the metal seeking to force itself out. The bar is then

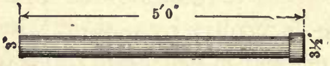

FIG. 20.

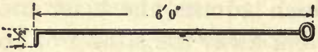

FIG. 21.

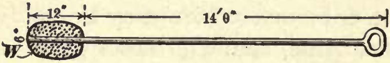

FIG. 22.

pulled out, in which movement, should any difficulty be experienced, a device as seen at P, Fig. 18, is used, which by sledging on the end of the wedge shown, backs the bar out of the notch. Sometimes, instead of the device shown, a stout ring will be used, and by inserting the wedge as shown a similar result is insured. This device is a simple affair, and should suggest to many founders a remedy for difficulty often experienced in pulling back bars driven into the breast, tuyeres or slag-holes of a cupola.

After a bar has been removed from the notch, the metal generally flows out with a fair speed, but should lumps of dross or fuel impede its passage, a smaller bar than the one used to tap it is generally inserted in the notch-hole, and by working it up and down the passage is eventually cleared so as to permit the flow desired. It is not infrequent that the metal rushes out with too great speed, often coming with an unexpected burst, so as to strike the "keeper" with a spreading sheet of rushing metal if he is not continually on his guard. After a furnace has been tapped and the iron commences to flow well, a cover composed of fire brick held in an arch shape by a cast iron bracket casting is swung by means of an iron arm close up to the furnace front at the cooler V, Fig. 18, and let rest on the edge of the trough shown. Any space between this cover and the furnace shell is closed by means of sand being thrown around this section. This cover prevents the metal and slag from blowing up against the shell of the furnace and burning it out.

An arrangement which is generally used at every hand-tap to assist in lessening the force of the stream is a stopper, as seen in Fig. 22. The end W, being held at the mouth of the notch, can, if there is not too great a force, often almost stop the escape of metal. This stopper is made by rolling a 1¼-inch rod in a stream of slag as the furnace is being flushed out. Should the metal force itself out too fast at any time during a tap, the blast is slackened or stopped, until the metal has flowed off all it will of its own gravity, when the blast is again put on, and the increased pressure then drives out the metal and slag as above described. This end achieved, the blast is then completely shut off and the notch stopped.

The process of stopping the notch by hand is proceeded with as rapidly as possible, in order to prevent loss of time in making iron. The first thing done is to throw a sheet-iron plate across the top of the iron trough; which, covered over with sand, protects the men from the heat of the trough, and permits them to come directly over their work. The notch at this stage greatly resembles a crater that has died down after vomiting its lava. Lumps of dross and fuel will be found sticking to its sides, which have been greatly increased in area from the effects of the "blow." A bar is used to loosen this *débris*, and then an iron scoop pulls it out of the notch-hole. After this *débris* has been removed as well as the inflowing slag will permit, the bar is again used to push down into the crucible any lumps which may be sticking to the sides of the notch, and a bar of the same shape as Fig. 21, only made of round iron, is now used to press down into the crucible the dross and slag which endeavor to rise to fill the notch-hole. This done, the bar is hastily removed, and men standing with two shovelfuls of clay toss it into the notch-hole, the clay is then quickly rammed down as far as it is possible with the rammer rod just described. After as much clay is pressed downward with these rammers as is found possible, then a round stick about 3 inches in diameter at the small end and 3½ inches at the top, having a ring to prevent the sledging splitting the timber as seen at Fig. 20, is inserted into the notch and driven with two sledges down to the bottom, thus driving the dross and clay back into the crucible, as far as possible, to make a solid filling of clay in the notch at its bottom. This method of packing having been performed half way up the notch, the packing stick is removed, the blast started, and the balance of the notch is then filled with clay packed with hand rammers. A stream of hot blast is now turned on the top of the notch and the clay grouting used to coat the iron trough, so that at the next tap there will be no dampness to start a "boil."

The above description is one plan of hand-stopping a furnace, but lately a machine has been designed to be worked by steam forcing out a stopper,* by which a furnace can be stopped at any part of a tap without shutting off the blast.

Many furnaces are now using stopping machines. They prove valuable in many ways, especially in permitting a more steady blast, and which gives a greater output and more uniform grade of metal and greatly lessens the chances for scaffolding due to a more steady heat being maintained in the furnace. It is said that all users of these stopping machines praise them very highly, and it now looks as if it would not be long before all furnaces would adopt them in their practice,

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* Patented by S. W. Vaughn, Johnstown, Pa.

especially those using fine grades of ores, as any stoppage of blast is apt to cause a temporary chill and to retard good working of the furnace.

Not all grades or kinds of clay are suitable for stopping notches. It must be of a quality to withstand fire to the best possible degree. Some use a good grade of fire clay and others grind up old crucibles to mix with the fire clay in an effort to improve its heat-resisting qualities. The clay is mixed to a consistency about like that found good for cupola stopping clay, and in some places is prepared in pans crushed by heavy rollers.

The success of stopping a notch by hand being due to the fact of having the metal lower than the level of the notch, affords the furnace an advantage not permitted to the cupola. Conditions in the latter calling for a "bottom drop," every heat makes it most desirable that no metal should remain in the bottom of a cupola when a heat is finished. For this reason the bed of a cupola as seen at Y, Fig. 23, is generally made on a slant, and the tap-hole placed at its lowest level, as seen at R. With such an arrangement, when difficulty in tapping and stopping once commences, it often causes the cupola tender much harassing labor, and the founder loss in casting. Any one desiring further information on tapping out and stopping up cupolas is referred to "American Foundry Practice," page 331.

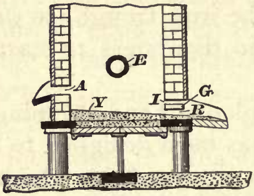

FIG. 23.

CHAPTER XIII.

MOULDING SAND, CASTING SAND, SANDLESS PIG IRON AND "OPEN SAND" WORK.

The many devices which are employed by furnacemen in controlling the distribution of 20 to 100 tons of molten metal, when tapped, display experience and knowledge which the foundry manager and moulder can often well utilize in founding. Every branch of handling molten metal has its own little "tricks" in practice, which have often taken years to perfect, and I propose now to illustrate some of those involved in controlling metal and making "open sand" moulds and casts at a blast furnace, as the information and ideas such study imparts, even though furnaces should abandon casting pigs in sand beds, as referred to on pages 113 to 116, will prove of value in many ways to general founding.

A moulder, however well experienced, who has never seen a blast furnace, would be very liable to make bad work of things at the start, should he attempt, without any instruction, to direct the making and casting off of a floor of pigs. In preparing a moulding bed for making pigs, the floor is dug out from 2 to 3 feet deep, and then filled up with a medium grade of bank sand, of a very open, sandy nature. The reasons for going down to such a depth to simply mold pigs that are not more than four inches deep, also for using such a coarse grade of sand having very little binding qualities about it, are found in the desirability of having conditions as favorable as possible for permitting the escape of steam from any excess of moisture or water, which the sand may contain, or for draining downward, and hence lessening the chances of a "boil." The moulder must bear in mind that when once a stream of iron is started, the furnaceman cannot plug up a "run-out" or dampen the ardor of a little "kick," the same as when pouring a mould, and hence the precaution of not being dependent upon one's judgment to get sand just the right "temper," etc. Where sand is as open as is generally used for pig beds, and as deep in the floor as above described, water, after having been absorbed to a certain point, will, to a large degree, filter through coarse sand towards the bottom of its depth, so that should an excess of water have been used, the chances are it will not cause the "boil" it would certainly do if the sand was of such a character as that generally used for green sand molding in a foundry. Another point which makes it desirable to use such open-grained sand is that of saving labor in mixing sands. About all the mixing that furnace sand generally gets is what the force of water from a two-inch nozzle gives it. I have seen such a stream play steadily on one spot for two or three minutes and no attention paid to it. If moulding sand in a foundry received such abuse, the iron would mostly go to the roof the moment it struck

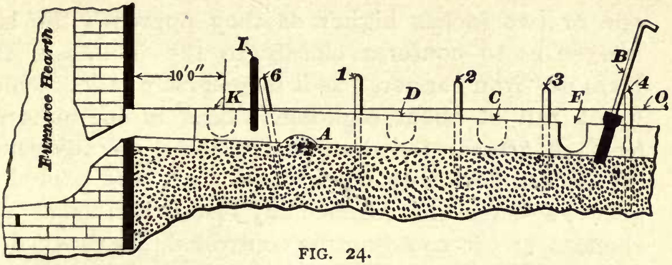

FIG. 24.

the sand. But like all else in mechanics, there is a limit to abuse, and too much carelessness in wetting down the floor of a casting house can result in disastrous "boils."

Moulding pig beds is generally done by three men, who will mould up fifteen to twenty beds in about one hour. The main runner leading to the pigs Nos. 1, 2, 3, 4, 5, 6 and 7, Fig. 29, page 103, is called the "sow runner." There are generally from 24 to 28 pigs to a sow. Each sow is leveled, likewise the pigs connected to it, but each bed is, in commencing from the lower end, made

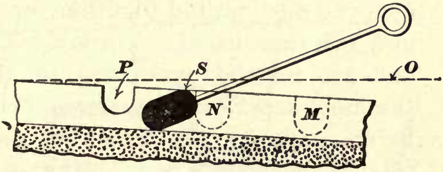

FIG. 25.

FIG. 26.

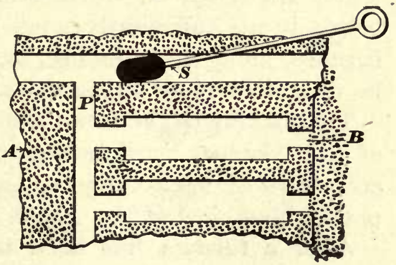

FIG. 27.

one or two inches higher as they approach the last bed, so as to conform closely to the incline of the main or "iron runner," as it is generally called, which has a fall of about eighteen inches in one hundred feet. A greater fall than this would generally cause the iron to flow with too great a rush, and should it get away from the furnace any faster than usual, the chances are it could not be controlled, and instead of its being distributed as desired throughout all the pig beds, the lower two or three beds would be overflowed, and a "boil" easily started by reason of a large area of floor space being all covered with a plate of fluid metal, permitting no escape of gas and steam from the sand cores between the pigs. The founder often receives pigs united together, and often much thicker in depth than usual. These are called "jump cores," and are formed by reason of the body of sand in the mold separating the pigs, being raised or pressed to one side by the action of too quick a flow, poor sand, or a little "boil." It has been no uncommon occurrence for metal to come so fast down the iron runner that it could not be controlled, and by reason of covering over a large area, cause a whole tap to go under the drop, or, worse still, require dynamite to break it up sufficiently small to be charged into the furnace, along with the ore, or sold for scrap metal to be re-melted in air furnaces or big cupolas.

The making of the iron runner is generally the work of the "keeper." Figs. 24, 25, 26 and 27 show different views of such runners, and Fig. 34, page 104, a perspective view of the whole.

After a furnace has been tapped, the metal often comes slowly, to prevent it from chilling until its

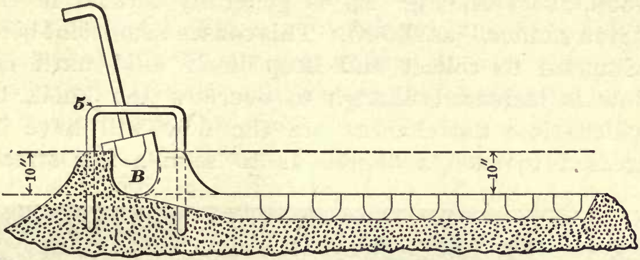

FIG. 28.

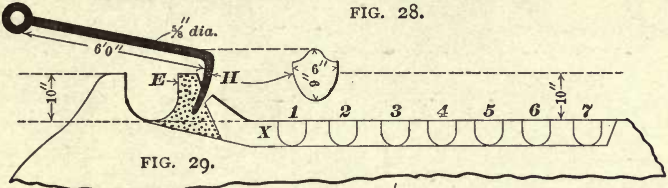

FIG. 29.

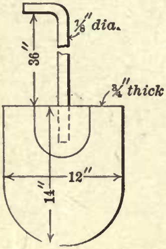

FIG. 30.

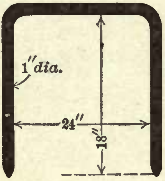

FIG. 31.

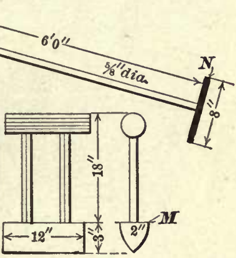

FIG. 32.

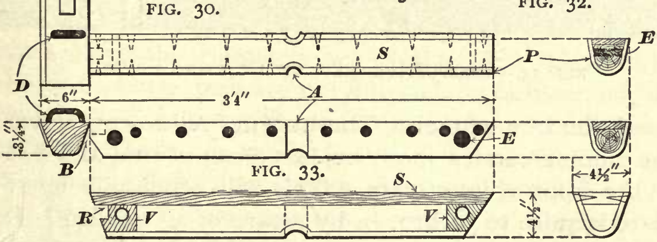

FIG. 33.

speed is sufficient to fill the runner as desirable, a little knoll, as at A, Fig. 24, is generally formed in the "iron runner," as shown. This causes a sufficient body of metal to collect and keep itself fluid until the flow is increased enough to overflow the knoll, by which time the chances are the flow will have increased to such a degree as to send a fair stream

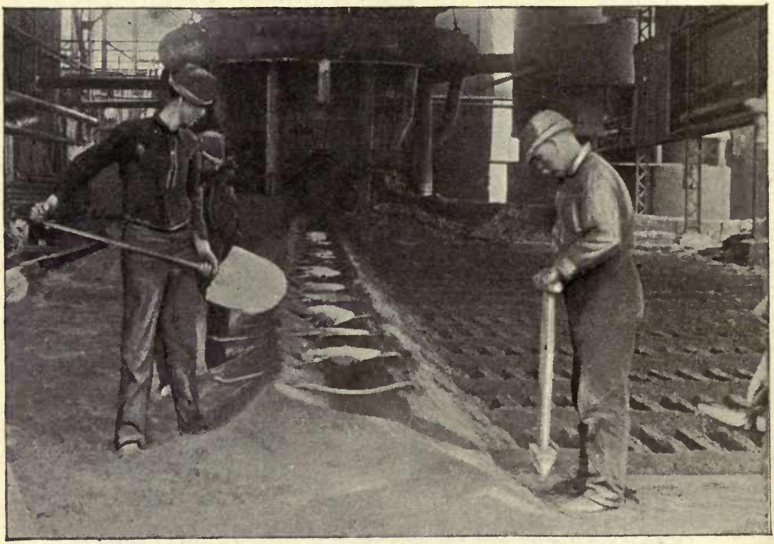

FIG. 34.—PERSPECTIVE VIEW OF A CASTING HOUSE.

down the iron runner. The iron in first flowing down the runner carries more or less slush of iron and dirt in the front of its stream. This will often pile up so as to require to be broken by means of a wooden pole in the hands of a man, as seen in Fig. 34. As soon as the metal has reached and filled the lower bed, a "cutter," as shown at Fig. 30, and in the hands of the man at the left in Fig. 34, is then quickly placed with pressure so as to be bedded into the main runner, as seen at B, Fig. 24. A few moments before this is done a man with a ravel, as seen at Fig. 34, pulls away the mound of sand, closing the connection from the "iron runner" to the "sow," as seen at C and D, Fig. 24, also at E, Fig. 29, to make an opening, as seen at F, Fig. 24. The top level of the pig beds should be below the level of the bottom of the main runner in order that all the metal may be drained from the main runner; and, again, the pig beds should not be too far below the level of the bottom of the main runner, as this would cause the metal to rush from the main runner to the sow with a force very liable to cut up the sand where the metal would strike the bottom level, or wash away the cores between the pigs. The distance sought for is about that shown in the cuts, Figs. 28 and 29. If the moulder would consider trying to make a mould with what is generally termed a medium grade of bank sand, having the life pretty well burned out of it, he would then be in a position to understand how easily a rush of metal could cut up a pig bed of moulds, and the necessity for having certain conditions prevail, even if it is only "pigs" that are being moulded and cast. As the metal flows down the runner, much of the sand floats with the iron; but as pigs are not finished, or condemned, if they are a little rough on their surface from dross or sand, there are no serious objections as long as it is not sufficient to impede its passage to the pigs. At H, Fig. 29, is seen the "ravel" as it is placed in the sand ready to make an opening to admit the molten metal from the main runner to the sow.

At Fig. 31 are shown what are called "runner staples," which are used to support the "cutters," as seen at Nos. 1, 2, 3, 4, 5, and 6, Figs. 24 and 28, also in the perspective view of the main runner seen in Fig. 34. As each pig bed fills up, the cutters stop the flow of metal, permitting it to flow into the adjoining bed as above described. When half of the beds are about poured off, slag then commences to come out with the iron at the notch-hole. To prevent the slag from passing down the runner to the pig beds, a "skimmer plate," seen at I, Fig. 24, is knocked down to about the depth shown and then some sand is thrown against it on the side at K. By ramming this sand, the opening below the lower edge of the skimmer plate I and the bottom of the runner can be decreased at will, so that only iron may pass beyond the skimmer plate and its flow may be regulated. The slag is let run out at the "slag runner" shown at the dotted lines K, Fig. 24. The slag running out of the tap-hole at every cast is considerable; often for every ten tons of iron there may be two tons of slag.

After the pigs are cast they must be broken. This constitutes the most laborious work about a furnace. Before starting to break the pigs, which is not done until they have solidified sufficiently to not "bleed," sand to a depth of about ¼ inch is thrown over their surface. Two or three men wearing wooden soles about 1½ inches thick attached to their shoes, now start at the first poured bed with pointed 1¼-inch bars about six feet long. By inserting the point of the bar between the pigs at the end furthest from the "sow," they are readily broken loose from the sow. After the pigs are all separated, the sow is then broken by taking the ends of the pigs of the next row as a rest to pry the sow up; if not broken by being lifted, a sledge is then used. When two to three men will separate about five hundred pigs and break about eighteen sows in several pieces in about a half-hour's time and not seem in any hurry, it is safe to conclude that the work is done by a very commendable system.

After the pigs and sows are broken as above described, a stream of water is turned on to cool them off so that they can be handled and removed from the casting house in time to permit the bed being re-moulded for its next turn in casting. This, in a furnace of the size as seen on page 49, making five taps every 24 hours, leaves but about three hours for the " iron carriers " to break up and load on buggies, for removal from casting house, about 40 tons of pig metal. To permit a buggy being brought close to the iron to be loaded, a wooden track fastened together in sections of about 10 feet is laid down on the casting floor to any length or turn desired. There are always two floors to a casting house, so as to permit one being molded and got ready for a cast while the other is being relieved of its pig metal and wet down ready for molding. A casting house, as it generally appears about one-half hour before casting time, is seen in Fig. 34. The keeper seen standing by the notch of the furnace has his runner made with the runner staples and cutters in position. The man on the right, at the lower end of the runner, is shown just finishing the ramming of the last bed of pigs. To afford an idea of casting, the first man on the left of the main runner is shown standing ready to drive the cutter into the runner to stop the metal from flowing to the first bed. The second man seen on the left stands ready to ravel out the branch runner to the pig bed. The third man having a pole in his hand is supposed to be breaking up the crust of slush formed in the front of the metal as it first comes down the main runner. These last three men are simply placed in position shown to illustrate their work, as if metal had been actually running down the runner as above described. To those never having seen a casting house, Fig. 34 should give a general idea of the methods employed for moulding and casting pig metal.

Moulders are often employed at a furnace to make moulds, open and closed, to be poured with metal as it comes down the runner. How to regulate the flow so as to stop it as soon as the mould is filled is a trick often worth knowing for application even in a foundry. At Fig. 26 is seen a section, through A B of Fig. 27. The moulds shown are supposed to be "open sand" plates, which should be as uniform in thickness as possible. By the plan shown, if the metal is as "hot" as is generally obtained, the plates can be made not to vary over ⅛ inch in thickness, which is as close as a founder can generally run them where he has metal in a ladle supposed to be under perfect control. To explain this principle, attention is first called to Fig. 25, which is a section of the main runner. At the dotted lines N and M is seen the depth to which the branch runners connecting the sow and main runner are generally made and which are supposed to drain all the metal from the main runner until "cut off" by the "cutters" B, as seen in Figs. 24 and

28. By making a comparison in the depth of the opening P with M and N, Fig. 25, it will be seen that the opening at P could not deliver any metal unless the iron was raised in the runner to its level, and the chances are, in the general working, that the iron in the main runner might never reach the bottom of the opening at P. But to compel it to do so, a stopper composed of slag, chilled on the end of a one-inch iron rod, as seen at S, Figs. 25 and 27, is placed in the main runner to impede the flow of the metal. This action raises the height of the metal in the runner so as to make it flow out at P, and the moment the stopper S is lifted, the metal is lowered below the level of this outlet, and hence instantly ceases to flow into any mould which may be run by such a plan. This last method governs well the actions of the main runner in filling moulds; but there is still another point to guard against where two or more castings are poured from such a branch runner, and this is the tendency of one mould to fill before another, and hence produce castings thicker or thinner than might be desired. To regulate this point, a portion of the edge of the mould is cut away to the thickness desired, as seen at B in the plan view, Fig. 27, and also in the section A B, Fig. 26. Such moulds being generally raised above the level of the floor, it can be readily conceived that any overflow at the points B will be received at a lower level than that of the castings, hence the difficulty, with good metal, of obtaining such castings thicker than they might be desired. It may be well to state that outlets, such as at P, should be made well up towards the upper end of the main runner, so that when the stopper S is lifted the metal will have a good chance to

run down the runner and fill the pig beds through lower outlets, as at N and M. The dotted lines O O, in Figs. 24 and 25, are supposed to be level, and the angle of the main runner shows the incline from this level line.

A plan of the pattern is seen at T, Fig. 33. The recess at A is to assist the pigs being broken in two pieces when cold, and the formation as seen at B where the pig and sow join to make their separation at this point easy when breaking the iron after a cast. The same number of patterns are used as there are pigs to be moulded in a bed. A good method of forming these patterns is by a combination of sheet steel and wood. The steel which forms the outside, as shown by the heavy black line at P, is about $\frac{3}{32}$ inch thick, and formed to shape over an iron block before the wood is secured, as shown at V V and at S, the latter being a 1¼-inch piece of hard wood, secured by wood screws passing through the steel at the upper edge of every 4 inches into the wood board. To secure the pattern at its end, a ¼-inch rod passes clear through each end and is riveted. This method makes a very light pattern, and one which will last for years, and discounts a dozen times over the old plan of making all-wooden patterns, which are still used by some. The principle involved in the construction of these patterns is one the founder and patternmaker might often well utilize. The sow pattern is made of a continuous stick of timber, having one side at T faced with a sheet of ⅛-inch steel, so as to prevent warping of the pattern. There is also a piece of iron ½ x 2 inches set in and screwed down on the top surface of the sow pattern, as seen at K, for the purpose of leveling; as constant friction of a level on the surface of wood would cause it to splinter and be uneven for leveling purposes.

In using these patterns and bedding them in the floor, there is no heavy sledge hammer used to settle them, as a moulder generally does with his patterns. In fact, no sledge or hammer is used on them, the only thing leveled is the sow; if one end is high, the pattern may be lifted and sand scraped away from under it, or the low end may be raised and sand tucked under it by means of the handle end of the shovel or a push of the foot. The sow having been leveled, the pig patterns are then laid down on the floor, which has previously been leveled off with a shovel as near as the eye can judge, and which is generally done truer than many of our moulders are capable of doing. When the patterns are all in place, sand "riddled through the shovel" fills up the space between them, and a man with a rammer 12 inches long, as seen at the right, in Figs. 32 and 34, rams the sand between the patterns. After going over with this rammer once, sand is then shoveled over the bed, and a flat scraper 18 inches long scrapes the sand off level with the top surface of the patterns, which is all the packing or sleeking the surface or joint of the bed receives. Sand having been pushed with the back of the scraper to raise a mound of sand between the pig beds to prevent metal flowing over, the sow pattern is now drawn out by means of the lifting iron seen at D, Fig. 33. The sow having been removed, the pig patterns are then drawn out by first raising one end with the hand in the recess at the end R until they can be lifted by the center, when they are tossed on to the next bed ready to be set up for another filling of sand. Some moulders might feel like asking, "Was there no swab used?" No, the wetting the joint receives is as if by chance the fellow on the other side of the house wetting down the floor should, in turning around carelessly, throw a stream of water over the joint. I do not wish to be understood as saying that because pigs can be made with such apparent carelessness, rapidity and little labor, the moulder should do the same in making "open sand" work in a foundry; but nevertheless the principles involved should be studied by those moulders who require a whole hour to make about a dozen cast "gaggers."

Modern moulding and casting of pig metal involve points which the founder can often utilize to advantage. The principle involved in using open grades of sand and having deep floors to afford a chance for excessive moisture or water to pass downward, is one the founder having much "open sand" work to do can often well adopt. How frequently do we find moulders making "open sand" castings that "kick" and "bubble" in such a manner that, when the castings come out, it is a question whether they came from a foundry or furnace "boil." Drop close grades of moulding sand and adopt a sharp open sand, and use regular moulding sand only where the metal from the pouring basin strikes the flat surface of the mould, and the trouble as above described with "open sand" work in a foundry will decrease.

CHAPTER XIV.

CHILLED OR SANDLESS PIG IRON AND ITS ADVANTAGES.

Casting pig iron in sand moulds is objectionable in many ways. To overcome these objections there have, since 1896, been several different methods adopted for casting the metal in chills instead of sand moulds, aside from the practice of casting in chills placed in the floor of a casting house, which some follow, especially as used for making basic pig iron. The principle involved in the latest improvement lies in having iron moulds, the form of pigs arranged on a movable table, etc., so that the metal first running from the furnace into ladles can be poured into the pig moulds; after which, by self-dumping devices, they may carry the pig iron into cars ready for shipment. This saves the arduous labor of breaking the hot pigs and sows in the casting house and then handling them by hand to remove the pigs from the casting floors, and, aside from this, produces pigs which do not require breaking, and is also free of sand and scale, the advantages of which are stated on the next page.

There are several machines on the market, among which are those patented by Mr. E. A. Uehling, Mr. R. W. Davies, and Mr. H. R. Geer. A large number of furnaces are now using these different machines, and it is probable that many more will do so in the future.

The first edition of this work recommended the adoption of these casting machines, and all that was said in their favor has been verified by practice.

The economy and advantage to be obtained by using chilled or sandless pig metal in foundries, steel works, etc., may be stated as follows: First, being a harder iron by reason of its chill or density, which holds the carbon more in a combined form, as well as having pigs free of sand (silica), less time and fuel will be required to melt it. Second, the pig being sandless there will be less fluxing needed and less slag to take care of in large heats; this will also give a cleaner iron to pour moulds, whether for small or large heats. Third, being a chilled iron or more dense it will give a softer re-melt than if the furnace iron had been cast in sand moulds. This is a discovery made by the author, the details of which are found on page 338. Fourth, by pouring furnace metal from ladles, better mixed metal will be obtained in a car or cast of pig iron than by casting pigs in sand moulds. The value of this will be better understood by reading Chapter XVIII.

Some founders, understanding by experience the value of having the iron charged into cupolas as free of sand, scale, or dirt as possible, go to the labor of tumbling all their gates, etc. Could such founders also secure their pig iron free of sand, they could derive still greater benefit by having clean iron to re-melt and pour into their castings. What sandless pig the author has used proved much preferable to sand pigs in several ways. This experience is endorsed by others, as can be seen by the following extracts from a few letters which he obtained during 1899 by courtesy of Mr. Edgar S. Cook, president of the Warwick Iron Co. of Pottstown, Pa.

A stove manufacturer says: "From the experience we have had we believe, thus far, that you can be sure there is one foundryman who does not fear the sandless pig."

A prominent tool builder says: "We have tried the sandless iron and find it very nice. You may ship more on our orders."

The head of a large ship-building concern says: "I am pleased to say that your sandless pig is very satisfactory. I hope hereafter you will always ship me sandless pig, it saves a good bit of trouble in the cupola."

A stove works says: "We have watched the results very carefully thus far, and find it most satisfactory. The only objection we have to the 'sandless iron' is that the pigs are too heavy and hard to break. Our cupola men can hardly handle them, as our facilities are such that the short, heavy pigs of the sandless iron cannot be broken, otherwise we are very much pleased with it."

With reference to the complaint that sandless pigs are too large, this has been remedied in some of the machines so as to make the pigs of a convenient size for all cupolas over thirty inches inside diameter. It is not to be understood that all chilled or sandless pig will show white fractures should they be broken; this will largely depend upon the percentage of silicon and sulphur in the iron. Iron above 1.20 silicon and not over .04 in sulphur, with manganese below 1.25, will rarely show any chill, but, of course, be more dense or higher in combined carbon than if the same iron was cast in sand moulds. Cuts of sand and chilled cast pig are shown in Figs. 35 and 36. These cuts were originally presented by Mr. Alfred Ladd Colby in the *Iron Trade Review*, June 13, 1901.

As far as saving of labor and other expenses is concerned, the casting machines do not prove as advantageous as some other improvements in making pig iron; however, they dispense with the hardest labor and give a product that, in many cases, is much more desirable than sand pig. For this reason their use will continue to increase, but probably will not do away with sand pigs entirely; at least, most of the furnaces not using floor chills will be required to keep sand beds in order to take care of their metal in case of accidents to the machine. For this and other reasons the author has thought it well to retain, in this revision, the information in the preceding chapter.

FIG. 35.—SAND CAST PIG.

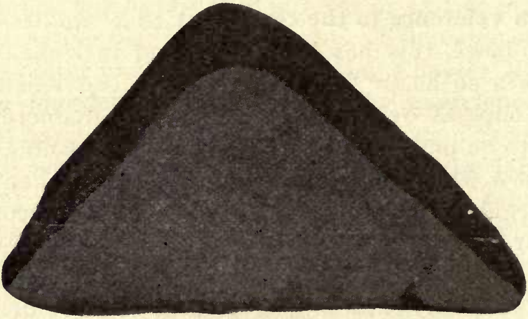

FIG. 36.—MACHINE CAST PIG IRON.

CHAPTER XV.

UTILITY OF DIRECT METAL FOR FOUNDING.

In the first days of founding, castings were made from metal taken directly from the furnace making the iron. The difficulty and uncertainty of obtaining the grade of iron desired and the fluidity necessary to insure good work, as well as the advantage of having metal at the time best suited to the founder's needs, gave rise to the origination of the cupola to re-melt iron. Had the furnace advanced anywhere near the degree in assuring a uniformity of "grade" that it has in increasing its output many more castings would now be made direct from furnace iron. While some may question the ability of the furnace to ever achieve any better results in always obtaining a uniformity of product, competition may strongly influence an effort for improvement in this direction. Aside from the above evil is that of the trouble caused by the "kish" found with some metals that throw out graphite excessively. Often after a furnace "cast" of Foundry or Bessemer the floor of the house will be covered with "kish," which resembles in appearance flakes of silver lead or plumbago, and are like the flakes of carbon so often found between grains of pig metal and castings. It can be removed from fractures by means of a stiff brush or rubbing.

The evils to be expected from metal possessing much "kish" are mainly in "cold shuts," spongy, porous spots in castings, or the separation of the grains of the metal at places where "kish" is confined. One might as well try to make a union of oil and water as of kish and cast iron. Were it possible to collect or skim off all the "kish" created on top of direct metal, little damage might be expected; but this is not practical, as the "kish" keeps rising to the surface as long as the metal is in a fairly fluid condition. Appliances have been invented with a view to collect the "kish" in pouring runners, etc., before the metal would enter the moulds, but these have proven of little value. It may be said that metal possessing much "kish" is unfit for pouring castings.

Direct metal free of "kish" can make very good castings, and for some classes of work might often prove more desirable than cupola iron, as less sulphur can be obtained in direct metal than with iron remelted. Iron cannot be re-melted in the cupola, with coke or coal, without increasing its sulphur from .02 to .06 points. The re-melting of pig metal entirely destroys the "kish" that appears in direct metal.

The life and fluidity of direct metal, compared to cupola iron, are qualities some will question. If a furnace is working properly, its product will compare very favorably, as regards these qualities, with cupola iron. The author has seen hotter iron from a furnace than is generally obtained from cupolas that hold its life or fluidity exceptionally long. In fact, the author is of the opinion that direct metal can have such an initial heat imparted to it as to create a much greater life to the fluidity of the metal than can be obtained in re-melted iron.

To utilize direct metal, some have thought it would be a good plan, in order to overcome the difficulty from "kish" and obtain a more uniform product, to first pour the metal coming from two or more furnaces into a large receiver or reservoir so arranged as to closely confine from 50 to 100 tons of iron, one idea being that if the metal should have "kish" in one furnace, another would be free of it to mix with it, and hence an average could be obtained which would be sufficiently free from "kish" to obviate any defects in the casting. The information which the writer has obtained as to the success of this plan is not very favorable. The difficulty found consisted in the metal losing too much fluidity and life by the extra handling and detention of the metal in the fluid state. Where work is very massive, not requiring good "hot iron," this reservoir method may be of much value; but the difference which exists in the cost of direct metal and cupola iron does not warrant any very great chances being taken in losing castings on account of the fluidity and uniformity of a "grade" not being as desired. However, for castings like ingot moulds and pipes, "direct metal" in days of close margins may command attention in some cases.

It is no uncommon thing for us in our foundry to make small castings with direct metal carried by three men in a "bull ladle," taken from a furnace close by us. The plan which we adopt to obtain such small bodies of metal is simply to catch the metal with a "hand ladle" by dipping the iron out of the main runner as it flows to the pigs and pouring it into a "bull ladle." We have made very good castings by this plan. We have also taken "direct metal" in crane ladles by having a car run on a track sunk sufficiently below the main runner to receive the metal from a branch runner extending beyond the casting house. With iron containing silicon under 1.00, manganese up to 1.00, the higher the better, and sulphur above .03, it is rare that any kish is seen, and when such direct metal can be obtained very good castings can be produced. Of course, with a low silicon and high sulphur iron it is not to be expected that any work less than half an inch thick, requiring any fine finishing in the machine shop, can be satisfactorily obtained, but for bodies over the above thickness very little trouble should be experienced, as long as the metal does not get over one per cent. in silicon and keeps up in manganese and sulphur. As seen by study of Chapter XVII., it is the changeable percentages of silicon and sulphur which, as a rule, alter the grade in the product of a furnace when running on one kind of ore, flux, and fuel. Late improvements and a better understanding of furnace work is doing much to lessen irregularity in the percentages of silicon and sulphur. In fact, some furnacemen have so mastered the art of making iron that they can run weeks at a time without varying 30 per cent. in silicon or three points in sulphur, when making iron having less than 1.25 silicon. It is with silicon above 1.50 per cent.—also in very hot weather, as shown by Chapter XVII.—that the greatest difficulty is experienced, at present, in regularly obtaining a uniform grade of pig metal.

CHAPTER XVI.

BANKING FURNACES AND CUPOLAS.

The principle involved in "banking" is simply to do everything possible to prevent air finding access through the body of a furnace to the fuel, so as to stop rapid combustion and sustain the fire only in a dormant state until it is found desirable to again "blow in" the furnace. This is similar in principle to the practice of smothering a fire in a stove over night so that next morning little labor or fuel would be required to start a good fire and provide a quick breakfast. The old plan of "banking" a furnace involves considerable labor and expense. One system followed is to encircle the furnace with a curbing of plates bolted together, or planks stood on end, projecting 2 or 3 feet above the tuyeres, the planks being held together by means of hemp or wire ropes, the space between the furnace and the curbing being about 2 feet, which is filled up with a close grade of sand. Before encircling the furnace with this curbing, the slag pipe and the tuyeres are all taken out and all their pipe connections removed. (The pipe connections to the coolers are not disturbed, as water is left on them during the time of "banking.") After this the tuyere holes in the brickwork, etc., are filled with clay. This system makes it almost impossible for any air to find access to fuel in the hearth, where so many openings for tuyeres, etc., would leave crevices for air to enter. The stack portion being practically a solid body enclosed by a tight shell of iron, no attention is given to it; so also with the bell and hopper at the top of the furnace, as some ventilation is desirable at the top to allow any excess of gas to freely escape. For this purpose, the "bleeder" pipe valve can be forced open, as in no case is the "down comer" valve opened. From this "bleeder" the state of the fire in the furnace can also be fairly judged. Nearly all furnacemen differ somewhat in their methods of "banking." At the present day many have abandoned the practice of encircling a furnace with a curbing above described, and after removal of the tuyeres and pipes they simply pack all holes and crevices with clay rammed tightly in place, and then occasionally wash the outside of the lining or brickwork, which is exposed to the air, with a thick coat of clay wash, thus closing up all crevices or pores which might admit air to the fuel. This plan, while costing much less than the curbing system, has been found sufficiently effective to answer all purposes. In preparing the furnace for being "banked," it is essential to free it as much as possible from its regular charges, and any liquid metal which may be in the hearth below the tapping hole.

To liberate the liquid metal all that is possible from the bed of the furnace, a hole is sometimes made from one to two feet below the level of the top of the regular tapping hole, which permits the metal to run out into an excavation in the ground in the form of a long runner, so that what flows out below the level of the tap-hole can be broken up. This plan is one adopted for "blowing-out" as well as "banking." As will be seen by Fig. 19, page 93, there are often very large bodies of metal below the tap-hole. Even by the plan just described these are rarely ever all drained from a furnace, always leaving some to solidify that will have to be brought back to a liquid state when the furnace is "blown in," requiring as a general thing but a few days.

The first move in preparing to "bank" a furnace is to discontinue its charges of ore and lime in the regular way and to admit chiefly fuel, in order to keep the furnace filled, occasionally dumping a little ore and lime to divide the fuel and to destroy the union of a solid combustible body of fuel and thereby assist in smothering combustion. As soon as it is found that the last regular charge of ore, lime and coke has passed the level of the tuyeres, the furnace is tapped and an extra pressure of blast applied so as to force out all metal possible. This done, the blast is shut off and the "banking" operation commenced. When this is completed the furnace is filled up with fuel, etc., as above described, and in some cases the surface of the last charge is covered over with fine ore or loam sand to assist in shutting off draft, in which state the furnace is left standing. As a general thing, wherever sand can be used for banking, it is preferable to clay, as the latter is apt to crack in drying and leave crevices whereby air can find access to the fire to excite combustion.

In some cases the fire may lie dormant in a good condition for six months or more without any renewal of fuel, but this is seldom done. If, after three or six months of banking, it is found that conditions of trade, etc., will not demand "blowing in," as anticipated when first banking the furnace, the fires will often be allowed to die out, in order to make preparations for "shoveling out," so as to discover if a furnace requires re-lining in parts or as a whole.

A good illustration of the extent to which banking a furnace may be carried is that conducted under the able management of Mr. C. I. Rader, during the years 1893–95, at the Paxton Furnace, Harrisburgh, Pa. Furnace No. 1 at this place was banked August, 1893, and not opened until June, 1895, a period of one year and ten months, at which time the furnace was found in a condition to be successfully "blown in." Mr. Rader says a light ore burden and half coke and anthracite were used in banking down the furnace, and the top covered with a layer of fine ore. This is the longest period of successful "banking" of which the author has any record.

When "blowing in" a "banked furnace," the first operation is to clean out the tuyere holes, etc., of their clay and sand packing, after which the refuse and dead ash in the furnace are pulled and shoveled out through the tuyere openings and slag holes, so far as possible. This done, the tuyeres are replaced and their water and blast connections completed. A heavy bed of fuel is now charged, after which charges of ore, lime and fuel are delivered into the furnace. The burden of ore and lime is gradually increased in weight in the first charges until several are delivered, when the regular burden is then charged on. The blast being on, the furnace is again in condition to make iron. For the first two "casts" or day's run a furnace is liable to work cold, which results in giving a low-grade metal or iron high in sulphur and low in silicon. As a general thing, furnaces are compelled to use cold blast when "blowing in," for the reason that there is no gas to make the hot blast ovens operative until after a furnace becomes sufficiently heated to have gas pass down the "down-comer" to the ovens. A few plants, like that of the Carnegie Steel Co., having several furnaces connected or in close vicinity, can bring hot blast from other furnaces until the "blown in" furnace gets under way. Where cold blast has to be used at the start, it takes much longer to get a high-grade iron than where hot blast can be obtained. With hot blast they may often, at the very first "cast," secure high grade iron, whereas with cold blast it may take a dozen "casts" or more to do so, and in either case, the largest output is not generally obtained until a furnace has been in blast from one to three months.

Those founders inexperienced in furnace work can well imagine from the description here cited that although "banking" is a compromise to "blowing out," which means a complete shut-down, the furnace manager is desirous of avoiding such manipulations so far as possible, as the expense is by no means light, and many sacrifices will generally be made in having capital lying idle in piles of pig iron in order to run a furnace steadily, rather than "banking" to await increase of orders or a demand for their product. If furnacemen have any assurance that they will not "blow in" after three months' "banking," they will generally "blow out," as the accumulation of ash and dirt from a furnace banked to exceed three months is such as to be very apt to make it difficult to get a furnace working well for a week or more after it is "blown in."

Banking is generally done in cases where a shut-down is thought to be only temporary. If a furnace "blows out," which means a clear shut-down, nearly the same amount of fuel and lime is often charged to follow the stock down as if the furnace was being "banked." This is done so as to burden the blast and keep the heat or flame of the furnace from escaping and thus better reduce the stock of ore to metal and also cause less heat to affect the upper lining as well as the bell and hopper from melting, and makes a cleaner furnace when "shoveled out." There are a few that will "blow out" a furnace without covering the last charge of ore well with fuel and lime, but this plan is not considered good and safe furnace practice.

In "blowing out" a furnace, the fuel used to follow the stock down can be largely saved, for as soon as the last tap of iron is made, and the blast shut off, the tuyeres P, Fig. 10, page 49, can be all pulled out and the incandescent fuel raked out on to the ground floor, where with a hose, water will soon dampen the fire in the fuel, which will be found to be but little burned, so that it can be used over again. After the fuel is all pulled out level with the tuyere, water can then be thrown by a hose to dampen the fire in the hearth, so that in six to ten hours after the blast is stopped all fire can be extinguished.

Where banking a cupola might be thought of, as referred to at the close of this paper, it is generally well to have a charge of fuel follow the last charge of iron, as this would better assist closing off all draft than were the last charge all iron, as a fine dust fuel, ore, etc., could be used on the surface to close up all cavities without calling for enough to cause injury, as would be the case with fine stock used to close up the cavities between pieces of iron, instead of fuel.

The principle involved in "banking" a furnace is one that has to a slight degree been practiced by some founders, as is seen in "American Foundry Practice," page 301. The author is so sanguine that the principles involved in banking are practical for application in cupola work, that he lately remodeled one of his cupolas with a view of experimenting to find out how many heats he could run without dropping the bottom. At this writing conditions in our shop work have not permitted giving it a trial, the reason for which lies in the fact that the cupola which was prepared for this experiment was not large enough to run the heats demanded. The plans followed in remodeling this cupola consist simply in making all tuyere connections air-tight, raising the spout so as to permit of from two to four inches of a heavier sand bottom, also in providing a double slide arrangement facing the tuyere openings which, when both were closed, left a space between them to be filled with loose sand that could be readily removed by a little slide pocket in the bottom of the sand space. These two factors, combined with an arrangement to positively shut off the admission of any air where the main blast-pipe is connected with the wind-box, completed the arrangements. With this device it is the intention, after the first heat has been run off, if not a large one, to thoroughly melt down any iron that may be in the cupola, after which the breast will be opened and all dead ash and refuse lying in the "bed" will be raked out. After all dead material has been thus cleaned out, the breast will be firmly sealed up with tightly rammed sand, and all tuyere connections, etc., closed as above described. A little extra fuel being now put in and the top charging door closely sealed, the cupola will be allowed to stand in this condition until time to charge for the next heat, when the "bed" will be "replenished," the cupola re-charged, and, after the breast has been replaced, the heat proceeded with as usual. How many times this operation can be repeated without "dropping the bottom" can only be told by practice. In endeavoring to follow such a practice the management of the cupola must be in intelligent hands, as it can be readily seen that to charge a cupola ignorantly or carelessly, as is often done, would result in leaving iron at a level with the tuyeres, or all on one side of the cupola, so that it could not be melted at the end of a heat. These ideas are not presented with the expectation that all founders are going to drop their present methods to adopt the plans outlined; they are simply offered as suggestions to evolve ideas which may favor the inauguration of new practices that to-day might seem absurd and impracticable.

John C. Knoeppel, of the Buffalo Forge Co., Buffalo, N. Y., recently related to the author an experience in banking a cupola, which may often prove of benefit. In brief it is as follows: The blast had just been started and the iron was not yet down, when an accident occurred to the machinery, stopping the blast. As the damage could not be repaired within the lapse of many hours, Mr. Knoeppel simply closed all air openings tightly with clay and sand, and covered the top of the stock at the charging door with fine dust coke. When the blast was started, about sixteen hours after the shut-down, the melting went on in good shape, as in the usual practice. This was done in a cupola of about 56 inches inside diameter. One factor assisting to make Mr. Knoeppel's plan so successful was the fact of the iron not having started to melt when the break-down occurred. Mr. Knoeppel's experience, combined with that recited by the author in "American Foundry Practice," above noted, may suggest expedients which may often be profitably adopted.

CHAPTER XVII.

CONSTANT AND CHANGEABLE METALLOIDS IN MAKING IRON.

If, in making iron, all the metalloids remained fairly constant, not varying in their percentage one cast from another, we could obtain a uniform product and have no such thing as different grades of iron from like mixtures of ore, fuel, and flux. But this condition does not exist; instead, we find that a furnace, at the present state of advancement, seldom makes two casts of iron exactly alike in analysis or grade from the same mixtures of like ores, fuels, and fluxes. The elements that vary the most and effect the greatest change in the grade or the carbons of iron are silicon and sulphur. A furnaceman can be most particular and have all conditions alike as far as lies in his power, but for all this he may have some casts which will differ widely in silicon and sulphur contents, especially when making iron over 1.50 silicon and in all grades during very hot weather. It is true there will be changes in the total carbon, manganese, and phosphorus, but these rarely cause radical changes in the grade of an iron coming from like mixtures. Some experiences on this latter point are related in Chapter XVIII., page 136. It is to be remembered that the author is not claiming that manganese and phosphorus cannot effect a change in the grade of an iron. Variations of either of these two elements can change the grade similar as variations in silicon or sulphur, but we must look to the furnaceman in preparing his mixtures of ores, etc., when making iron. If he desires an iron high, medium, or low in manganese or phosphorus, he can generally obtain it so evenly, in iron below 3.00 per cent. silicon, as not to affect in a practical way the grade of the iron which he desires to obtain, as long as the furnace uses the same ores, fuel, and fluxes. On the other hand, the silicon and sulphur may vary considerably at times. However, future advancement in obtaining more uniform temperatures and distribution of blast in a furnace, which is now being gradually secured by some, will bring about improvement in this line. Nevertheless, silicon and sulphur will always be the metalloids which will most largely change the grade of iron to a greater or less degree where the same ores, fluxes, and fuels are used.

Changes in the total carbon. It is thought by some furnacemen that the higher the temperature, and the more slowly the ore passes down in its reduction to iron, to the hearth of a furnace, the greater total carbon will be found in like irons. However, the author has failed to find where there were changes in total carbon, by the use of the same ores, etc., sufficient to radically change the grade of iron.

Ores from the same mines or locality are liable to differ in their composition sufficiently to occasionally change the percentage of manganese and phosphorus, to some extent, in the same brand of iron. Nevertheless, such changes would generally call for an alteration of about half of one per cent. in manganese or one-fifth to one-third per cent. of phosphorus to change the grade, similar as the alteration of one-quarter of one per cent. in silicon would do. The author believes that furnacemen will agree that it would be very rare to have such a variation as above in manganese and phosphorus, in irons made from ore that comes from one mine or locality. As there is a liability, on rare occasions, of manganese and phosphorus varying to an effective degree from similar ores, and then again a change in the total carbon to alter the grade of an iron, it may often pay those who are manufacturing castings, where such changes as above would seriously affect their iron, to always have an analysis of the total carbon, manganese, and phosphorus in connection with the silicon and sulphur. There is one thing to be remembered and that is, that a furnaceman has far less difficulty in obtaining a uniform grade when making low silicon irons, or that under 1.50, than above this percentage; and also that there is much more difficulty in obtaining a uniform grade in very hot weather, due to humidity of the air, than when the thermometer is below 85 degrees F. More on this point is seen in Chapters X. and XLV., pages 78 and 306. Furnacemen are finding that if they are not called upon to increase temperatures of blast over 1,000 degrees F. (some find it best to keep between 850 to 900 degrees F.), and have a good uniform distribution of the blast, they can secure a more uniform product than otherwise. Largely for these reasons furnacemen prefer to run on low silicon iron.

One is most impressed with the uncertainty of furnace workings when in urgent need of ten hundred tons or more of any certain grade of iron over 1.50 in silicon from a furnace that is trying to make it, and no stock of iron in that special furnace yard to draw from. Anybody placed in this position might soon be forced to realize by reason of waiting for the shipments they desired, that furnacemen cannot, as yet, always perfectly control a furnace to obtain the grade they desire at every cast.

CHAPTER XVIII.

SEGREGATION OF IRON AT FURNACE AND FOUNDRY.

We often find a segregation of metalloids in pig iron, but rarely, if ever, in re-melted iron or castings. One peculiarity in this respect lies in the difference often found in the upper cast body or face of pig iron containing the highest sulphur, as shown by the following four samples, Table 18:

TABLE 18.— SEGREGATION OF SULPHUR IN PIG IRON.

	No. 1.	No. 2.	No. 3.	No. 4.
Top	.117	.115	.084	.055
Bottom	.083	.094	.070	.047

The above analysis shows that "direct metal," or iron coming from a blast furnace, tends to favor the escape of sulphur, but that owing to the top surface of the pig chilling so as to form a crust at an early stage of the solidification of the metal in the pig beds, the sulphur in rising to escape was caught and hence the higher sulphur found in the top body of the pig, as shown.

Silicon also segregates in pig metal. Wherever pig iron shows soft gray spots, analysis will generally show these to be higher in silicon than the surrounding metal. Then again, it has been found that the first metal from a furnace is generally lower in silicon than that which flows afterward, in a manner often so uniform as to show that there is a gradual increase of silicon in the metal from the bottom upwards as it lies in a furnace before being tapped.

Variations in the working of a furnace make a radical difference in diffusion of the metalloids silicon and sulphur, as can be seen by the following analyses, which the writer has also secured for this work through the courtesy of Mr. C. C. Jones, an able, experienced furnace manager, operating two furnaces at Sharpsville, Pa. The pig beds are numbered in the following Table 19 according as they were cast, No. 1 being that farthest from the furnace, receiving the first iron and No. 6 the last:

TABLE 19.—ANALYSES OF PIG BEDS IN A CHANGEABLE FURNACE.

	1	2	3	4	5	6
Silicon	.60	.68	.70	1.00	1.25	2.20
Sulphur	.084	.071	.062	.050	.042	.027
With the furnace normal the result was as follows:						
Silicon	2.18	2.18	2.22	2.23	2.25	2.25
Sulphur	.021	.021	.020	.019	.019	.019

The above analyses of the normal working of a furnace present the best uniform distribution of silicon and sulphur which has come under the writer's notice. As this is a question of no little importance to the founder, attention is called to Table No. 20, on next page, showing the analyses of eight (8) different "casts" giving the silicon contents from the bottom upward, subscribed by Mr. H. Rubricius in *Chemiken Zeitung* and the *Journal of the Iron and Steel Institute, No. 2, 1894*.

The exhibits treat only of silicon and sulphur. With regard to the segregation, etc., of phosphorus and manganese, the only experiments which the writer has observed are those by Mr. A. P. Bjerregaard, commented upon in the *Iron Age*, November 30, 1895. He states his conclusions as follows: "There is often a slight variation in the amount of phosphorus and manganese in the different grades formed in the same 'cast,' but so far, no regular occurring progression variation has been observed. At best, the difference is only a few hundredths of one per cent." The author could present several more tables showing uneven distribution of silicon, etc., but those shown are sufficient to illustrate the necessity for reform in the lines advocated by the author.

When the founder considers that a difference of one-quarter of one per cent. in silicon and a few hundredths of one per cent. in sulphur will seriously alter the "grade" of his mixture so as to either make his "cast" too soft or too hard, and may often cause him great trouble or loss in the castings produced, he should at once perceive that the uneven distribution of silicon and sulphur which occurs more or less in every "cast" of a furnace is a quality seriously affecting his interests. Especially is this so, when he is aware that the one analysis which may be given is simply an average of the whole, generally taken from the two ends and

TABLE 20.—SILICON ANALYSES OF EIGHT CASTS.

Test of pig iron.	1st bed.	2d bed.	3d bed.	4th bed.	5th bed.	6th bed.	7th bed.
1 cast.	1.13	1 15	1.15	1.19	1.23	1.40	1.42
2 cast.	1.38	1.44	1 45	1.60	1 63	1.72	1.79
3 cast.	1.15	1.34	1.43	1.57	2 17	2.18	2.20
4 cast.	1 29	1.50	1.54	1.66	1.82	1.84	1.88
5 cast.	1.95	2.09	2.13	2.45	2.70	2.72	2.76
6 cast.	1.81	1.83	1.84	1.86	1.89	2.16	2.20
7 cast.	2.72	2.74	2.77	2.79	2.85	2.88	2.89
8 cast.	2.46	2.48	2.50	2.53	2.54	2.58	2.60

middle of a "cast," and that a car of iron may come to him from a "cast" having one portion from one-half to one per cent. higher in silicon than another. This is fully verified by Mr. Rubricius's table which shows that the two ends of a "cast" may vary one per cent. in silicon. Mr. Rubricius also states that "notwithstanding the large number of experiments made, it was not possible to correlate the initial percentage of silicon and the rate of increase, as iron poor in silicon presents, in some cases, a large increase in silicon in the upper parts. This can only be due to the difference in specific gravity between silicon and iron."

The uneven distribution of silicon and sulphur in pig metal is largely due to conditions over which furnace managers have, as a rule, not perfect control, while with castings the moulder or founder can, at will or through methods in casting, give rise to an ill diffusion of the carbons that could often be prevented were he only aware of the conditions which effect such results in castings. The moulder when turning out a casting having hard or soft spots often finds the word "segregation" very convenient to disguise evil effects of hard ramming, wet sands, or ill-vented moulds. When a mould has been properly made and the iron well mixed and melted hot and poured as it should be, there is generally little to fear, in a practical way, from segregation in castings that can be charged to the iron, aside from what effects degrees in cooling or casting in a chill can have in causing different proportions of combined or graphitic carbon A rammer should never be allowed to hit a pattern, as this causes a hard spot on the mould which, in light castings, can change the character of the carbons or the iron at that spot. And the same is to be said where the swab or ill "tempered" sand causes one spot or portion of the mould to be different from another, or the venting is inadequate for the free escape of gas or steam. Hard grades of iron are more liable to an ill diffusion of the carbons than soft grades, especially so where the former is melted or poured dull. Light castings are also much more liable to an ill diffusion of the state of the carbon than heavy castings. The above statements also give additional reasons why test bars as small as one-half inch square, or any having square corners, are not the best standards for making comparison of mixtures, etc.

By re-melting pig iron we effect a mixing process in which the chemical constituents of the castings will be uniform unless they are distorted by means of dull iron, hard ramming, wet sands, ill venting, or "chills," as above stated. The metalloids most liable to segregate are the carbons and silicon. Chiefly with the first named lie most of the phenomena which effect segregation in castings, and which are defined simply by one part being higher in graphitic or combined carbon than another. Some have claimed the existence of "sulphur spots" in castings. With iron melted or poured dull these may exist, but with the reverse conditions the writer has reason to believe, from analyses which he has conducted, that sulphur will generally be found uniformly distributed throughout a casting that has not blown or from any cause been chilled.

CHAPTER XIX.

MIXING CASTS OF PIG IRON AT FURNACE AND FOUNDRY.

A difference of one per cent. in silicon which can exist between the ends of a cast of pig iron, as shown in the last chapter, should cause any thoughtful person to perceive the wisdom of thoroughly mixing a furnace cast or pile of iron before it is charged into a cupola. This is where the most uniform results in obtaining an even grade of iron are desired in any special line of castings. As an example, if an ill-mixed cast of pig averaging 2.00 per cent. in silicon, with its extreme ends varying 1.00 in silicon, was charged without being mixed, one part of the iron charged would contain but 1.50 of silicon while the other portion would contain 2.50 silicon. It is impossible to expect uniform results in castings from such an ill-mixed cast or pile of iron. Some foundrymen, when first adopting chemistry in making mixtures of iron, have had just such experiences as the above, but, not knowing, it condemned the principle of working by analysis, when, in truth, it was not chemistry that was at fault, but the evils of ill-mixing or ill-diffusion of the silicon in a cast or pile of iron and no attention having been paid to the question of mixing it thoroughly before it was charged into the cupola. The founder adopting chemistry must have his practice based upon correct principles, or he cannot expect the results he desires in making mixtures of iron. An ill-mixed cast of pig iron can, generally, mislead any founder in determining the cause of failure to obtain the grade of iron he felt so confident of securing.

A thorough mixing of a cast of pig iron is not a difficult task; it requires but a recognition of its necessity, and means can be readily devised to accomplish the end. One plan, practicable of adoption by most furnaces, would be when loading cars for shipment to consumers to have every other buggy load, or pig if handled by men, placed at the opposite ends of the car. When the foundryman unloads the car he should follow the plan pursued in loading, which means to take a pig from each end of the car alternately and load onto buggies or in piles. By such a method a cast or car of iron should be pretty well mixed by the time it was charged into a cupola.

Where a founder has yard room, a good plan is to load several cars of the iron closely alike in analysis, or for one mixture, on top of each other in a long pile, being careful to have each car load distributed evenly in height the whole length of the pile, and in taking the iron from the car take a pig from each end alternately as near as practicable. A pile of any certain grade or brand of this character can be made to hold six or more cars of iron, and then when using the iron from the piles it is taken from the two ends as uniformly as practicable. A little study of this method will show that drillings taken from four to six pieces of pig, pulled from a fair division of the two ends would, when thoroughly mixed and analyzed, give an analysis that would be a very close estimate of the silicon or other metalloids to be found in any such body of iron in that special grade, brand, or pile of iron.

Very often the founder has not room to pile iron, or is compelled to use it direct from cars or small piles already in his yard. In such cases the different casts, or parts of such, could, after being mixed in loading it on buggies as described, be conveyed to the cupola stage and stacked in distinct piles according to variations that exist in the percentages of silicon, etc. When charging the iron that amount necessary to make a mixture would be taken from the different piles in an alternate manner; this would insure a good mixing of the grades as they lay in the cupola. For an example, if an average of 1.90 in silicon was desired in a mixture, and the only iron that could be obtained were casts or piles containing 1.60 and 2.20 silicon, with sulphur about uniform, then each pile would be piled separately on the cupola stage and a pig taken from each pile alternately when charging the cupola. This is a plan which works well, providing a trusty man is in control of the charging. If such is not in command, there are times when this practice leaves a chance for error. Such can be brought about by new men, or old ones, making errors in sorting or placing the iron on the staging or in charging it into the cupola.

A plan which avoids risks, wherever two or more grades must be used to obtain the average desired, as described in the last paragraph, is to have different brands or grades go to the stage at the same time on independent buggies, and then instead of piling each grade separately as is done in the above plan, they are mixed, pig about, in the same pile of ten hundred to a ton each, so that when charging time comes there are no distinct iron piles of high and low silicon to make a mixture of, which must be carefully guarded in order that no more of one than another, as desired, goes into the cupola; but it allows any pile to be used, and if the men are careless and make blunders they can do no harm, as with the former plan. This latter method involves no more labor in piling the iron on a cupola stage than the former and is superior in giving a uniform mixture, if stage room will permit of such a practice.

The gradual introduction of sandless pig, cast from ladles, is a step which will greatly help in giving the founder uniform casts of pig iron, as first catching the metal in large ladles before pouring the pig moulds cannot but act as a mixer and cause the one ladle or cast of pigs to be more uniform in their chemical composition than is possible by casting them in sand moulds, after the old method. By this plan each ladle's cast of pig could be analyzed. This would give positive assurance of obtaining certain bodies of iron that would be uniform in analysis, without having to resort to mixing each cast of iron. These are all factors which strongly recommend the use of sandless pig iron. For methods of calculating percentages of silicon, sulphur, etc., as found in iron, to obtain averages for making mixtures, see Chapter XXXVI.

Another evil practice, aside from ill-mixing of sand cast pig iron, is the practice which some furnacemen making foundry iron have followed of only taking one analysis of one of the four to five casts a furnace may make during twenty-four hours, and letting the analysis of that one cast stand for the chemical properties of the four or five casts which the furnace has made that day. It is not to be understood that many furnaces follow this practice. However, such a practice should not be tolerated by any furnace claiming to grade iron by analysis, and is little better than trying to achieve desired results in re-melting by judging the grade of pig iron by its fracture or hardness. Every furnace cast should be analyzed and the metal of each cast kept separate when piled in the yard or shipped on cars, so that when the founder receives the iron he has not, in connection with an ill-mixed cast of iron, a chemical guess, but a true analysis to guide him aright in re-melting his pig iron. Give the founder a true analysis of a well sampled cast of pig iron, in connection with having it well mixed, or cast from one ladle, as in sandless pig, before the pig iron is charged into a cupola, and he will find that chemistry is a guide that can be relied upon in assisting him to obtain the grades of iron he desires in his castings.

CHAPTER XX.

DIFFERENT KINDS OF PIG IRON USED AND DEFINITION OF BRAND AND GRADE.

The brand of an iron refers to some characteristics peculiar to itself or distinct from what can be found in some other irons; as, for example, in the difference found between charcoal and coke iron, and often made by the use of different ores and fluxes, although the same fuel may be used.

The grade of an iron refers to the different degrees of hardness, strength, or contraction and chill which may be obtained from any special brand of iron. In a general way high silicon or soft irons are called high grade irons, and low silicon or hard irons low grades. It has been claimed that the amount of silicon in pig iron, and which element chiefly regulates the grade, could be told by the contraction of test bars. This is impractical. The only sensible way to define the silicon or any other metalloid contents of any test bar or casting is by chemical analysis. The contraction merely assists in defining the grade of iron and nothing more.

Grading pig iron should mean sorting it into cars or piles, according to the degree of strength or hardness thought obtainable from it when re-melted to make castings. A few years back every furnace had its "graders," whose special business it was to separate the casts of iron into different piles, according to the grade of the pig iron by fracture. The most open pigs went into piles as a No. 1 iron, the smaller grained as Nos. 2, 3, and 4 and upward, according as the grain decreased in size. The greatest care was exercised in thus grading iron, not only because it was believed that the size of the grain revealed the grade, but also because the "grader" had a reputation to sustain in making his various piles of even grain, and the furnaceman was anxious to have every piece of the open grained iron collected by itself; for No. 1 iron brought him more money than a No. 2. With the advent of selling by chemical analysis all this was changed. The graders were replaced by the chemists, and the iron as it comes from a furnace cast is now thrown into one pile or car, and neither furnaceman nor progressive founder as a rule pays any attention to the color or the size of the grain of iron in the pig. The different brands are now generally piled, by progressive furnacemen, according to the percentage of silicon and sulphur the iron contains, as they now concede these to be the elements or metalloids that vary the grade of any iron made from like ores, fuel, and fluxes — a system which was advocated by the author in earlier writings, and the first edition of this work.

The different brands of pig iron are classed as foundry, charcoal, bessemer, gray forge, basic, silvery or ferro-silicon, mottled, and white iron.

Foundry iron is made with coke or anthracite fuel. Its silicon generally ranges from 1.00 to 4.00, sulphur .01 to .05, manganese from a trace to 1.50, phosphorus from .20 to 1.50, and is a class of iron used in the construction of chilled as well as unchilled castings.

Charcoal iron is made with charcoal fuel. Its silicon generally ranges from .50 to 2.00, although it is made with silicon as high as 5.00 per cent. The sulphur ranges from a trace up to .08, manganese from a trace to 1.50, phosphorus .15 to .75. On the whole it can be made richer in iron and poorer in silicon, phosphorus, and sulphur than a coke or anthracite iron. It is chiefly used for the manufacture of such castings as guns and chilled work, and for which it can excel all other brands of iron when melted in an air furnace.

Bessemer is made with coke and anthracite fuel. Its silicon ranges from .75 to 2.50, sulphur .01 to .05, manganese .20 to 1.00, with phosphorus under .10. If it exceeds .10 phosphorus, it is then called "off-Bessemer" and may be used as a Foundry iron. This pig metal is chiefly used at steel works for making steel and in foundries for ingot moulds, and can often be well used in the place of "foundry iron" in general castings not requiring good or extra fluid metal to run them.

Gray forge iron is a metal of gray fracture with little or no grain, ranging from .50 to 2.00 silicon and from .03 to .20 in sulphur and which is usually high, with low silicon. Its manganese and phosphorus can range as found in general iron. This brand of iron is chiefly used as mill iron in puddling furnaces producing wrought iron, and also for the manufacture of water pipes, etc., often being mixed with higher silicon irons.

Basic iron is of a similar character as gray forge, only its sulphur should not exceed .05, and is generally desired to be low in phosphorus, although it may range from .20 to 2.50. Its silicon is generally desired under 1.00, and manganese may range from .30 to 1.00 or higher. This brand of iron is cast in chill molds or magnesia sand and is used chiefly in the basic open-hearth furnace to make steel.

Silvery or ferro-silicon iron is sometimes made with all coke, and then again with coal and coke. The silicon ranges from 6.00 to 16.00. It is derived from high silicious ores and excessive fuel to give high temperatures in the furnace.

Mottled and white iron is made with both coke, anthracite, and charcoal fuels. Its silicon ranges from .10 to 1.00, sulphur from .05 to .30, manganese .10 to 1.50 or over, phosphorus .03 to .50 and upward, and usually high in carbon. These irons are generally the off product of a furnace that has not been working well, and are used for hard or chilled castings, or at rolling mills to be mixed with gray forge irons.

CHAPTER XXI.

GRADING PIG IRON BY ANALYSES.

Previous to 1890 almost all pig iron was graded by fracture and piled according to the open character of the grain, the most open iron being used for the softest castings and the close grained for the hard ones, as shown in the last chapter. Furnacemen and founders gradually came to learn, by means of following chemical analysis, that such was not reliable and could often be deceptive. This has been so thoroughly demonstrated that it is now (1901) rare to find a furnaceman paying any attention to the appearances of fracture, unless a customer asks him to, and instead being wholly guided by a knowledge of the chemical constituents of the iron. While this is now the current practice of most all furnacemen and about 75 per cent. of foundrymen, we have the evil of disabusing the general sense of numbering the grades which certain analyses will give. For example, a No. 1 iron is generally supposed to be such as will give soft castings in those ranging from one inch in thickness down to stove plate. Nevertheless, we have today (1901) furnacemen designating pig iron as No. 1 that would run white in stove plate and require castings to be a foot thick or more in order to be sufficiently soft to be drilled, etc. An iron to be No. 1 by analysis should contain at least from

2.75 to 3.00 per cent. of silicon and sulphur from .01 to .04, with manganese below 1.00 and phosphorus ranging from .30 to 1.00. Evidence of evils to come from the above practice of irregularity in grading pig iron by analysis can be found in Mr. Seymour R. Church's first edition of "Analysis of Pig Iron." In this work we find pig irons called No. 1 by their makers ranging in silicon from one-half of one per cent. (.50) to four per cent. (4.00). Furthermore, the wildest kind of confusion exists as to numbers and trademarks, etc., supposed to designate the special qualities of the different grades of pig iron reported.

To correct this evil and to establish uniform methods for grading, the author presented a paper on the subject to the Pittsburg Foundrymen's Association, March, 1901. This paper embodied the table seen on page 152 and some of the arguments presented in this chapter. The Pittsburg Foundrymen's Association was so impressed with the importance of this work that a committee was appointed, with the author as chairman, to advance the work and carry it to the American Foundrymen's Association Convention at Buffalo, N. Y., June, 1901. To this end, circulars were issued regarding the work and replies requested as to opinion of the methods presented or suggestions for others. Fully two-thirds of the many replies received endorsed the author's method, shown in this chapter, and which differs only (Table 22) in permitting higher sulphurs in grades Nos. 1 to 3, whereas the original plan restricted it not to exceed .02 for No. 1 and .03 for Nos. 2 and 3. However, it should be born in mind that if sulphur reaches .04 the silicon might often be required at the highest point of any one grade, as, for example, an iron with 2.75 per cent. of silicon and but .01 of sulphur would give nearly as soft a casting as one that might contain 3.00 silicon with .04 sulphur, and which is a system upon which all the various grades seen in Table 22, page 152, are divided.

Great interest was manifested in the subject of this chapter at the American Foundrymen's Association Convention in 1901 and several plans, aside from the author's, were presented. A committee was appointed, with the author as chairman, to continue the work and report progress at the convention to be held in 1902. It is with a view of assisting this work as much as possible that the author presents this chapter, and he would like to publish all the methods presented at the convention did space permit. However, any one desiring to read what others presented to the convention on the subject can do so by procuring copies of the American Foundrymen's Association Journal for July, or the *Iron Trade Review* of June 13, 1901.

The author's extended experience, obtained by closely following variations in the hardness of castings or test bars due to changes in silicon and sulphur, with the other elements fairly constant, is such that he can safely say that where sulphur is kept constant every increase of .25 per cent. silicon should change the grade of pig iron one number in all iron ranging to 3.00 or 4.00 per cent. in silicon. It takes less sulphur than any other element to effect a change in the grade or hardness of a casting. A change of one point of sulphur (.01) can often neutralize the effect of eight to fifteen points of silicon. This will be better understood by referring to Table 21 which shows, approximately, the increase in silicon and sulphur necessary to maintain a uniform hardness (or a fairly constant condition of the carbons) in re-melted pig iron that will not vary thirty points in manganese and fifteen points in phosphorus, a range that is within the limits of what generally exists in irons made from similar ores, fuels, and fluxes. In brief, Table 21 shows that if an iron containing 2.00 per cent. silicon should have its sulphur increased from .01 to .06, then in order to maintain an approximately equal hardness in similar test bars or castings the silicon would have to be increased fifty (.50) points. In coke irons, as a rule, the lower the silicon the higher the sulphur will be found. In establishing standards the amount of sulphur, therefore, should be considered as well as the silicon. Recognizing this fact in connection with the statement above, which makes a distinction in grade at every .25 per cent. of silicon, Table 22 is presented by the author as a method for numbering grades, which, if adopted, would greatly lessen the confusion and trouble we find the practice created previous to 1901.

TABLE 21.

Sulphur................	.01	.02	.03	.04	.05	.06
Silicon................	2.00	2.10	2.20	2.30	2.40	2.50

By the method seen in Table 22, page 152, one can form some fair idea of the hardness to be expected in castings from pig iron, when ordering by number in different grades of iron. Then again, if adopted, it would give a fair knowledge of the value of an iron from a reading of the market reports of prices, by numbers, for as a rule the more silicon in iron the greater its value in any special brand. Even if the trade should not, in time to come, require a numbering of grades on account of the practicability of ordering by specified analysis in purchasing foundry, bessemer, gray forge, mill, or basic pig irons, it will be essential to have some means of brevity as by numbers in denoting grades in the market reports of prices: And the method presented by the author in Table 22 seems to him as simple and practical as could be offered or enforced by practice for such ends.

TABLE 22.

	No. 1 Iron.	No. 2.	No. 3.	No. 4.
Silicon	2.75 to 3.00	2.50 to 2.75	2.25 to 2.50	2.00 to 2.25
Sulphur	.01 to .04	.01 to .04	.01 to .04	.01 to .04
	No. 5.	No. 6.	No. 7.	No. 8.
Silicon	1.75 to 2.00	1.50 to 1.75	1.25 to 1.50	1.00 to 1.25
Sulphur	.02 to .05	.02 to .05	.03 to .06	.03 to .06
	No. 9.	No. 10.		
Silicon	.75 to 1.00	.50 to .75		
Sulphur	.04 to .07	.04 to .10		

Numbering the grades from 1 to 10, advancing in silicon .25 and sulphur .01 to .04 or more in each grade, as shown in Table 22, gives a range that may be said to include all the necessary irons that are now used in making castings, or for the manufacture of steel or wrought iron, except the so-called softeners or ferro-silicon irons. When purchasing ferro-silicons or softeners one should also know, aside from the silicon, the amount of sulphur, phosphorus, manganese, and total carbon they contain, as these elements can vary greatly in the same brand, or similar percentages of high silicon iron, vary much more than in irons having less than the 3.00 per cent. of silicon shown in Table 22.

It is not to be understood by the above that no attention is to be paid to the manganese, phosphorus, or total carbon when ordering iron by numbers, as in Table 22. In some cases such will be very necessary, as one founder may require very high or low manganese, phosphorus, or total carbon, while another may stand a wide variation in these elements as long as the silicon and sulphur are best suited for the work. To designate the manganese, phosphorus, or total carbon in any system of grading by analysis in numbers, that is intended for universal use, could meet with little favor for the reason that furnacemen cannot vary these in unison with variations of silicon and sulphur in obtaining different grades.

The manganese, phosphorus, and total carbon, the author believes, will be found to be best omitted from any universal system of numbering grades. When a founder desires any special percentages in one or all of these three elements in purchasing foundry, bessemer, gray forge, mill, or basic irons, he can designate just what he would like, aside from stating the number of the grade desired, and if he cannot get what he desires at one furnace he will have to try others. The manganese phosphorus, and total carbon will not, as a rule (as shown in Chapter XVII.), vary to any injurious extent for the general run of ordinary castings, in any one brand of iron made from like ores, fuels, and fluxes, in irons having less than 4.00 of silicon, as the silicon and sulphur can; and hence the reason why the author suggests confining grading by analysis in numbers to the silicon and sulphur, as seen in Table 22. The class of castings in which it is generally most desirable to know the manganese, phosphorus, and total carbon contents are such as stove plate, light work, and the general run of chilled castings. From the above it can be seen that it would generally be advisable for furnacemen in advertising their irons to state, together with the numbers of the grades or brands they make, what percentage or range of manganese, phosphorus, and total carbon their irons generally contain, as there are conditions demanding varying percentages of these elements met with that would the greater enhance the sale of the irons were these points made known. As, for example, a founder making very thin castings would require higher phosphorus, which gives more fluidity to iron than is available in some regular No. 1 grades. Then again, it is often necessary to know what manganese an iron contains, as when it is more than .50 its influence is to harden. With regard to the carbon, the "total" is all that is generally required. Giving the percentage of what is combined or free carbon in pig iron generally tells nothing further than the melting qualities of the metal. In this, the more the carbon is combined the easier or quicker the iron melts — a fact discovered by the writer several years ago, and confirmed by Dr. R. Moldenke by further experiment. If a knowledge of the combined or graphitic carbon contents of pig iron was of any real value in grading pig iron by analysis, grading could be done effectually by fracture or hardness, and the only determination required would be that of the total carbon, phosphorus, or manganese, according as information might be desired of one or all of these ingredients. It is not the author's idea, that because the grades are divided at every quarter of one per cent. in silicon and the sulphur ranging from .01 to .10 per cent., as shown by Table 22, that any furnaceman should be compelled to fill orders from any one particular grade or number of iron. It is intended that the number ordered should indicate the grade of iron the consumer desired, and to fill the order the furnaceman could ship any number of grades from which an average might be obtained which corresponds to the grade order. If, for example, in following the method of grading advanced in Table 22 one should desire a No. 4 iron, he can accept irons ranging from No. 1 to No. 8 to make an average which would give the grade No. 4 desired, provided he knew the grade of every car delivered at his yard. There is surely sufficient margin in this method to permit the furnaceman to fill an order for any particular grade of iron for the great majority of purchasers.

When foundrymen, as a rule, desire to produce castings that are to be of some particular softness or hardness, and we know that a change of twenty-five points in silicon and two points in sulphur can cause them to vary from the best grade which should exist in their castings, the author fails to perceive the impracticability of any furnaceman accepting orders for foundry, bessemer, gray forge, mill, or basic pig irons by the method of numbering the grades from 1 to 10, which he has advanced in Table 22. In fact, any greater margin would fail to denote the true character of the iron desired and could cause such misunderstanding as to result seriously for both furnaceman and founder. What is required is a method of numbering that will denote when the character of iron is noticeably changed, and not something that is so flexible that any change from one number to another would make a mixture which would vary so greatly as to make castings so unfit for their use that they would be condemned; and this some of the methods that have been advanced would do.

One objection made to the author's method of grading, seen in Table 22, is that errors in analysis could make a difference of .25 per cent. silicon and .01 in sulphur. Granting this to be true, as has often been the case, does this offer any just cause for the consumer not defining as closely as he may the grade he desires to correspond with any range in numbers from one to ten in Table 22? If such difference in analysis continued to exist they could injure the consumer as much as if grades were divided by one per cent. of silicon, instead of .25 per cent. as shown. To the author's view, this is a factor that should have no weight in deciding the division of grades. However, by the use of the American Foundrymen's Association standardized drillings, and the adoption of more uniform methods of making analyses — which is sure to come and for which work the author is chairman of a committee appointed by the American Foundrymen's Association in 1901 to advance such improvement — there will be little excuse for any great difference in the chemical analysis of one sample of drillings by different chemists. There is much more that might be said on the subject of this chapter, but the author trusts that the principles herein advanced will aid the work of bringing about the reform in grading or buying pig iron by analysis which this chapter advocates, and which almost all now concede should be accomplished.

CHAPTER XXII.

BESSEMER VS. FOUNDRY IRON.

That "Bessemer iron" can often take the place of "Foundry," and in some cases prove a better product to make castings with, is a fact which few founders have up to this writing discovered. In the years 1893 and 1894 of business depression, Bessemer pig was selling cheaper than Foundry pig. A few founders, who did not require high phosphorus and knew it, took advantage of the low price of Bessemer. Founders never having had an experience with Bessemer pig metal will be somewhat surprised to learn that the best experts cannot tell "Bessemer" from "Foundry" by judging of its fracture; nevertheless this is true. It is only by analysis that the difference is to be made known, and that mainly exists in the phosphorus being lower in Bessemer than Foundry, as illustrated in Table 30, page 215.

Regular Bessemer ranging from 1.40 to 1.60 in silicon, .010 to .030 in sulphur and about .45 in manganese, can often be well used for hydraulic or steam cylinders, heavy dies, machinery castings, and for gear wheels of one and one-half inch pitch and upwards.

For ordinary machinery castings that average from one and one-half inches up to two inches thickness of metal, Bessemer ranging from 1.60 to 1.90 in silicon would be found to work very well. The author has used Bessemer 1.85 to 2.00 in silicon with excellent success in making electric street car motor gear wheels. These wheels, as many know, are cast in a "blank" and the teeth are milled out. When first starting in to make these castings it was a "trick" of ours to take a pin hammer and strike upon the teeth of a spoiled wheel until the tooth would flatten out as if one were pounding a piece of wrought iron. This was partly due to low phosphorus, causing the iron to possess a malleable toughness. Bessemer containing from 1.95 to 2.25 silicon would make an excellent iron for all castings such as ordinary weight of lathes and planers. For heavy punches and shears it would be well to have the iron range from 1.10 to 1.30 in silicon, with sulphur about .030 in the pig. It is to be remembered that owing to Bessemer being low in phosphorus it is not as fluid and does not run a mould as well as Foundry iron. Nevertheless, it can be melted "hot" enough to run castings as thin as "stove plate," if the liquid metal is not retained too long in the ladle or has not to run up too far in a mould, or a long distance from the "gate;" but cannot be recommended for such light work.

A founder can utilize common scrap with Bessemer pig metal for all work above stove plate thickness, as in this respect sufficient silicon can be obtained in "Bessemer," as well as in "Foundry," to soften scrap, and thus often assist in cheapening a mixture. Silicon does not, as a general thing, go as high in Bessemer as in Foundry. When silicon exceeds 2.50 per cent. in Bessemer, it is generally called an "off Bessemer," the same as when it exceeds .10 in phosphorus. To be over 2.50, the limit for silicon in regular Bessemer, is not so objectionable to steel men as it is for the phosphorus to be over .10. Steel works will often accept Bessemer over 2.50 in silicon, but seldom accept phosphorus over .10, unless the iron is used to make steel by the "basic process," a method by which phosphorus can be greatly eliminated from the iron by reason of qualities in the lining having an affinity for phosphorus. Bessemer iron, to be such, in the regular sense, must not have over one-tenth of one per cent. of phosphorus, which is a small quantity compared with one per cent. often utilized in Foundry iron in order to give the molten metal good life and fluidity.

It is to be understood that in all the mixtures shown on pages 157 and 158 the sulphur is not to exceed .030 or the manganese .50 in the pig; if it does, then higher silicon will be necessary in proportion to their increase; also, that no scrap is intended to be mixed with the percentages of silicon given. Should it be desirable to mix scrap with the pig, which, of course, if not Bessemer scrap, would raise the phosphorus, to take the mixture out of the category of Bessemer iron, and in either case with any kind of scrap, it would call for an increase of silicon in the pig metal, so as to prevent the mixture from producing too hard a "grade," as defined in the last paragraph, page 158. For further notes on Bessemer, see pages 146 and 215.

CHAPTER XXIII.

CHARCOAL vs. COKE AND ANTHRACITE IRON.

The past advancement in utilizing chemistry in making mixtures of cast iron has, among other changes in founding, resulted in causing many firms to make castings of various types from coke irons, whereas for years past it has been thought that charcoal was the only brand permissible to be used. It is no reason because malleable iron founders and some car wheel and chill roll makers have discovered that coke and anthracite iron can be made to answer their purpose that charcoal iron is sure to pass into oblivion.

A peculiarity between "Bessemer" and "Foundry" iron lies in the fact that one cannot be told from the other in yards, single pigs or piles, in judging them by fracture. This cannot be held to be true of charcoal vs. coke iron. If there were two yards of pig metal, one being charcoal and the other being all coke or anthracite iron, any one at all familiar with such irons can generally tell the class of iron each yard contains. We may occasionally see single pieces or piles of coke or anthracite pig iron which will resemble charcoal so closely as to make it difficult to decide its true brand, but, in a general way, charcoal iron is distinguishable from coke or anthracite iron.

The greater the temperature in a blast furnace, the more silicon can iron absorb. The lower heat derived from charcoal furnaces causes less silicon to be taken up than by iron in coke or anthracite furnaces. From this circumstance, combined with the fact that charcoal fuel is free from sulphur, we find that charcoal iron generally contains very little sulphur, with low silicon. The more general uniform workings of charcoal over coke furnaces and absence of sulphur in charcoal iron, leaves much less chance for the other elements—silicon, manganese, phosphorus, etc., to cause radical variation in the size of the grains; and hence we find, as a general rule, that charcoal iron is more uniform in grain than coke or anthracite irons.

The greater strength and homogeneity of charcoal over the present coke or anthracite iron, also in its possessing very low sulphur, as a rule, will, in the author's estimation, forbid its expulsion from the market. There are certain kinds of work for which charcoal will generally prove superior over other irons. These can be classed in the following order: (1) Chilled work, (2) gun manufacture, (3) hydraulic and steam cylinder castings. Heavy gearings and large castings require high strength, combined with softness sufficient to permit finishing. Coke iron is now used in nearly all the specialties, but where it is intended to replace charcoal special care is often necessary to watch the sulphur contents in order to get them as low as possible. Where the coke or coal fuel and ore are very low in sulphur, coke or anthracite iron can be made which may often answer many purposes of charcoal pig. Charcoal pig iron, on the whole, is poorer in silicon and phosphorus, as well as sulphur, than a coke or anthracite pig metal.

Charcoal fuel contains no sulphur, and if the ore and flux are likewise free from it an iron will be obtained free of sulphur — something which cannot be said of coke or anthracite iron. Let charcoal iron be melted in an "air furnace" instead of a cupola, where the iron must be mixed with coke or coal, and it can then clearly demonstrate its superiority over coke or anthracite iron. To melt charcoal in a cupola greatly impairs its superior qualities and brings it largely on a level with coke or anthracite iron. Coke or anthracite will often answer well for an approximation, but to obtain the very best mixture for chilled work, guns, etc., charcoal iron will ever remain the king metal of cast irons, when melted in an air furnace, unless modern advance arranges to eliminate sulphur, etc., from metal and "refine" the iron before it is cast into pigs in such a manner as to be relied upon, or while being re-melted in the cupola. For analyses of charcoal iron, see pages 268, 269 and 299.

Refining iron means the lowering or removal of some impurities — carbon, silicon, and manganese being classed with them in this instance. The process, of course, increases the percentage of iron in the product but, for casting purposes, should not be carried too far. Unfortunately, sulphur and phosphorus will not go as readily as manganese and silicon, in fact, in the ordinary refining of a bed they will not go at all; hence the value of refining is to be looked for in the removal of the mechanically mixed slag, the lowering of the silicon and manganese, and, in some cases, the carbon contents, with the consequent increase in the combined carbon of the product and the closing up of the grain.

CHAPTER XXIV.

THE DECEPTIVE APPEARANCE OF THE FRACTURE OF PIG IRON.*

Progressive furnacemen and foundrymen have experienced few changes in their practice that have been more radical in character or far-reaching in benefit, than those made by the adoption of chemical analysis to correctly define the grade of pig iron. The change was such a sensible one that many are annoyed that in this age of science they have not always utilized chemistry in their practice. And not until we bring to mind the old-time prices paid for castings, can we realize why commercial success was at all possible to many following the old school methods of judging the grade of pig iron. While the benefits obtained by adopting chemical analysis in foundry practice are generally very great, the advance has been slow. This is on account of the prejudice, selfishness, and conservatism that all new departures in any calling must meet and set aside. The opposition that existed, and is yet in force, against the adoption of grading by chemical analysis has caused the author to expend much time and money in its defence. It is often interesting to investigate the reasons for rejecting the new-school practice that members

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* A revised edition of a paper presented by the author to the Pittsburg meeting of the American Foundrymen's Association, May, 1899.

of the old set up against its advocates.* Not long ago, as an example, in discussing the merits of working by chemical analysis with an old experienced founder who had never mixed his metals by this method, he expressed the belief that if a cast of nice open-grained pig iron did not give a softer iron than a close-grained pig mixture it was because of some local condition not being controlled; as, for example, he claimed that the cupola might not have been daubed properly, or the bed not well lighted before the iron was charged, or the charge might not have been placed evenly, or that the stock hung up. Then again, he claimed that it might be due to other conditions, such as are found in bad scrap iron, changeable weather, difference in fuels, fluxes, or variable blast pressures, to cause fast or slow melting, etc. When, as practical foundrymen, we know that such varying conditions may at all times affect mixtures and cause a soft iron to be hard, we are forced to confess that the old-school fellows may continue their method for years, if they are in any way prejudiced against the new-school practice, before events may transpire to convince them that by following chemical analysis they will greatly decrease their mishaps, for the simple reason that if an open cast of pig metal does happen to give them a hard iron they have nearly a dozen evils or excuses to which they can charge their poor results.

There are several ways in which self-interest can retard the progress of chemical analysis in founding. As an example we will cite two cases. The first lies in the power of furnacemen knowing the utility of chemical analysis, and lack of that knowledge by the

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* For the latest in support of old-school fallacies and retarding the advance of the new, see page 179.

old-school foundrymen. To illustrate how the latter may be duped by making them think their practice correct: A well-known firm, standing high in its ability to cast heavy machinery, recently sent an order to a furnaceman for one car of strictly all open-grade iron, to make strong castings for a special job. The author was consulted as to the analysis necessary, as the furnaceman knew he could select the open iron in almost any grade of silicon. Upon learning the character of the castings required from the furnaceman, the author recommended silicon between 1.00 and 1.25, with sulphur about .030. A car of as beautiful open-grained coke iron as was ever seen was sent to the founder. Its results pleased him so much that in a few weeks the second order, "Send me another car of strictly open-grade iron, same as last," came in. The furnaceman, knowing the utility of chemical analysis, referred to his books and duplicated his last analysis, being careful, of course, to load nothing but an all open-grained iron, as, if he had sent a close-grained iron it would have been condemned. Now, this furnaceman is not going out of his way to advocate the utility of chemical analysis to that foundryman, and it would be almost useless for anyone else to attempt to do so, as the founder is stubborn in the belief that it is the open-grained iron of that peculiar brand which was wholly responsible for obtaining the results he desired. Then again, should this founder, on account of a difference in price, change to another furnaceman who was not thoroughly posted in making mixtures for different castings, and who might not have had the forethought to consult some expert of the new school in regard to analysis, the chances are that his open-grained iron would have given him too weak a result in his castings, on account of there being chances of its being too high in silicon; or again, by ignoring analysis and taking open iron wherever found, he might receive some so low in silicon as to make his casting white iron. The author has heard shippers say, "Well, if the fool does not know better than to order iron by fracture, let him suffer his losses." The author has known cars of nice open iron to have but .75 up to 1.25 in silicon go to founders wishing soft light castings, simply because they insisted that the iron be opened-grained and ignored analysis. Such iron could do nothing other than give hard iron in any castings less than 2 inches thick. But as long as this founder had his open-grained iron he could turn to changes in the fuel, scrap irons, blast, weather, methods of charging, etc., to make excuses for his ill results, and not until such a paper as this, exposing the true cause of his trouble, might by chance fall into his hands is there any hope of his being made a follower of the new-school practice.

The second illustration of where self-interest has retarded the advance of chemical analysis lies in advocating the use of testing machines, as affording the founder sufficient means to regulate his mixtures without resorting to chemical analysis. Testing machines have their place, and most founders should possess one, but the practice of taking advantage of the prejudice, etc., of the old-school methods to antagonize the advance and true utility of chemical analysis in the self-interest of a more rapid sale of testing machines, is to be deplored.

The foundation of the old-school method in regulating mixtures is based on the belief that the appearance of pig fractures, or their hardness, truly defines the character of iron as to the degree of hardness it will give in castings. The founder's own experience in knowing that he can make soft and hard castings from the same ladle, and at one pouring, if he choose to so construct his molds as to make a difference in the casting rate of cooling, should be sufficient to prove to him why it is possible for two furnace casts of pig metal that are alike in chemical analysis, or will give the same results when melted, to differ so widely in appearance that a fracture from one furnace cast will seem close-grained or hard in the pig, while the other will be the reverse. A founder can take the same ladle of iron, and by pouring part of the metal into a sand mold and part into one that will

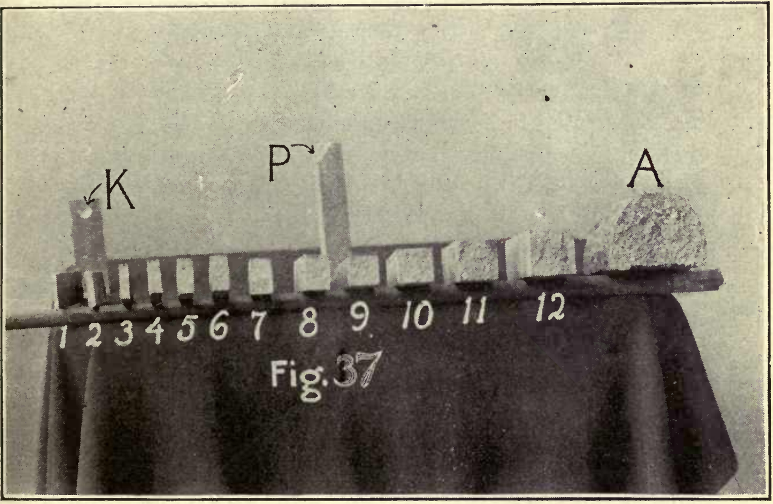

Fig. 37

chill or solidify it quickly, produce a fracture that will be close-grained in the one case and open in the other. This is just what the furnaceman does in making sand cast pig iron. One part of his tap, or cast of iron, may run so slowly from his furnace as to "chill the metal," as it is called, before it reaches the pig beds, while another tap or cast may come so fast as to fill the pig beds so rapidly, or make the pigs larger, that it will take much longer for the metal to solidify, and thus make the pigs more open grained than "casts" poured slower, or pouring smaller pigs. Again, one tap or cast at a furnace may give much hotter iron than another, and it is natural that the dull iron should cool faster than the hot, and, if both run at the same speed from the furnace down the long runners to the pig beds, the duller metal will

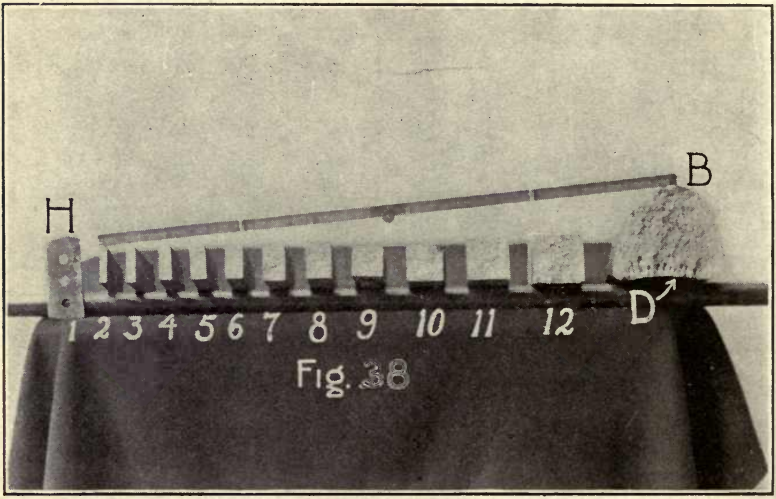

Fig. 38

give the closer grained iron. All should perceive from this why the same kind of iron may have in one cast a close grain, and in another an open grain. As there are but few molders or founders who have ever had the opportunity of witnessing a furnace cast, this explanation of its workings, combined with their own foundry experience, should assist many to realize why the fracture or hardness of pig metal is an unreliable guide to the iron's true grade.

As there are those who are still sure to contend that open pig fractures mean a soft iron and a close-grained iron a hard one, and if different results are obtained in castings to charge such to changes in fuel, scrap iron, fluxes, blast, weather, etc., the author has selected samples of pig iron shown in Figs. 37, 38, and 39, coming from two different casts, that are a fair representation of the whole cast or car of iron. If any of the old-school founders were asked to select from these a cast or car of iron to give soft castings, they would pick out iron such as sample A, seen in Figs. 37 and 39, while if they desire to make strong or hard castings they would select such irons as are represented by sample B, seen in Figs. 38 and 39. In fact, if they were asked to use such a cast or car of iron as that represented by B, they would claim that on account of its close grain and the blow-holes seen at D, the iron was hardly fit for sash-weights, let alone to think it of any value to make soft castings.

In order to convince the skeptical, or those not conversant with chemical analysis, or the effect of one metalloid upon another, that they are in error, the writer melted down about one hundred pounds of each of the grades A and B in his twin-shaft cupola, seen on page 241. In melting these irons A and B to make the castings seen in Figs. 37 and 38, which range from one-eighth to two inches in thickness, all conditions were alike as near as it was possible to have them, so that if the open-grained iron, A, gave a hard casting, changes in fuel, scrap, blast, weather, etc.—the old excuse—could not be offered as an explanation to befog the true cause A sample of the pig used and sections of the castings made from them the author displayed at the meeting at which this paper was read so that all might see them, and all were invited to take drillings from the specimens and report whether their analyses agreed with those presented in Table 23, in which the letter A represents the analysis obtained

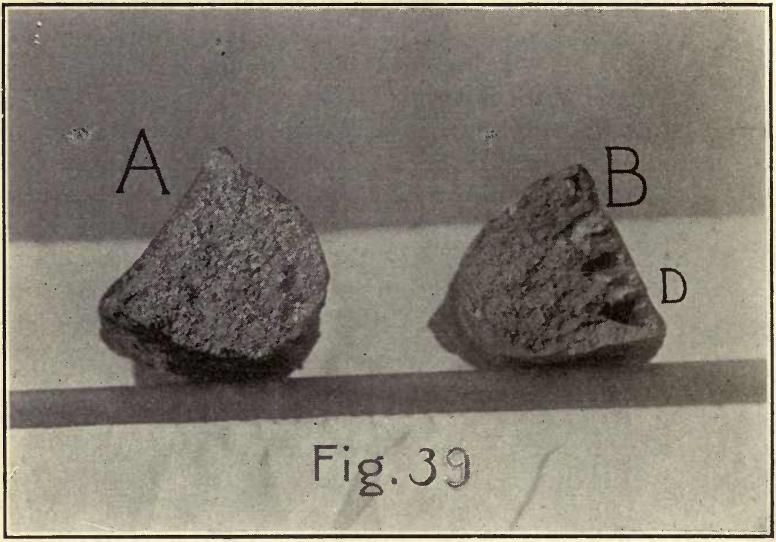

Fig. 39

from the pig and the castings seen in Fig. 37, while B gives that secured from Fig. 38.

TABLE 23.

Samples.		Silicon.	Sulphur.
A—	Pig	1.25	.035
	Castings	1.15	.070
B—	Pig	2.86	.040
	Castings	2.67	.060

The fracture seen in Fig. 39 being enlarged will afford a better study of the difference existing between the grain of the pig, samples A and B. To the new-school founder Table 23 is sufficient to define the results, or whether samples A and B would give the soft or hard iron upon being re-melted; but for the old-school of founders Tables 24 and 25 will best serve such ends. A study of these latter tables will show them that the pig B which would have been condemned by those wishing to make soft castings, gave by far the least contraction and chill, so much so that the test pieces, only one-eighth inch thick, as seen at H, Fig. 38, are so soft as to be readily drilled, while at K, Fig. 37, made from sample A, a drill was broken in trying to get a hole through the thin piece one-eighth inch thick. In fact, we were foolish to try to touch it with a drill, as the metal was nearly all chilled or white in color. It is also to be said that all the other test pieces ranging from Nos. 2 to 12 that were made from the pig, sample A, were also much harder than those made from sample B. In measuring the depth of the chill, pieces were broken off one end of the test bars as seen at P, Fig. 37.

TABLE 24.

RECORD OF TESTS TAKEN FROM IRON SEEN IN FIG. 37.

No. of Bars.	Size of Bars.	Contraction.	Chill.
1	⅛ x 1½	.293	Nearly white.
2	¼ x 1½	.266	¼ deep.
3	⅜ x 1½	.242	¼ deep.
4	½ x 1½	.220	3-16 deep.
5	⅝ x 1½	.200	3-16 deep.
6	¾ x 1½	.182	⅛ deep.
7	⅞ x 1½	.165	⅛ deep.
8	1 x 1½	.150	3-32 deep.
9	1¼ x 1¼	.148	3-32 deep.

TABLE 25.

RECORD OF TESTS TAKEN FROM IRON SEEN IN FIG. 38.

No. of Bars.	Size of Bars.	Contraction.	Chill.
1	⅛ x 1½	.178	.03 deep.
2	¼ x 1½	.163	.02 deep.
3	⅜ x 1½	.150	.01 deep.
4	½ x 1½	.137	Hardly perceptible.
5	⅝ x 1½	.125	No chill.
6	¾ x 1½	.112	No chill.
7	⅞ x 1½	.101	No chill.
8	1 x 1½	.92	No chill.
9	1¼ x 1¼	.88	No chill.

This chill was obtained by causing the end of the test bars farthest from the gate to be formed by a wrought iron bar three-fourths by two inches wide. The twelve test bars of each set were molded in green sand and poured from one gate. The same "temper" of sand was used for both flasks, and the iron was alike in fluidity at the time of pouring. Only nine tests out of each of the twelve bars seen in Figs. 37 and 38 are given.

To further demonstrate the deceptive appearance of fractures in pig iron, analyses of three pieces of pig

FIG. 40.—NO. I IRON BY FRACTURE, BUT NO. 8 BY ANALYSIS.

FIG. 41.—NO. 7 IRON BY FRACTURE, BUT NO. 4 BY ANALYSIS.

FIG. 42.—NO. 9 IRON BY FRACTURE, BUT NO. I BY ANALYSIS.

samples are given in Table 26 and illustrated in Figs. 40, 41, and 42.

TABLE 26.—CHEMICAL ANALYSES OF PIG SPECIMENS.

Fig.	Silicon.	Sulphur.	Manganese.	Phosphorus.
40	.98	.015	.30	.092
41	1.82	.018	.35	.096
42	3.30	.017	.34	.080

The author has numbered the above irons from the appearance of their fracture and not from the chemical analysis, as an iron 3.30 (Fig. 42) in silicon with sulphur as shown would prove a good No. 1 iron when re-melted, but the fracture would assert it to make No. 9 or hard iron. Then again, in judging by fracture Fig. 41 would make a very hard iron, while Fig. 40 would make a very soft casting, when in truth the reverse results would be obtained by both as shown by the analyses. It will be seen by the Table 26 that the chemical analyses of these three samples are practically all the same excepting in the silicon contents. The author could present any number of specimens which would be as deceptive to the eye in judging their grade by fractures, etc., but what is given in this chapter should be sufficient to illustrate that we cannot be always correctly guided by the appearance of the fracture (or hardness of pig iron, as treated in the next chapter) to define the grade of iron when re-melted or poured in castings. The pig samples seen in Figs. 40, 41 and 42 are numbered after the method advanced in table 22, page 152.

CHAPTER XXV.

THE IMPRACTICABILITY OF HARDNESS TESTS FOR GRADING PIG IRON.

A drill test was advocated, at the close of 1900, as being practical to define the grade of pig iron or the degree of hardness it would impart to castings. There are foundrymen today who could be misled into believing such a system practical, and would buy the machine advocated for this work. A hardness test for pig iron is no more or less than judging iron by the appearance of its fracture, a method which has been in vogue for a century but now known to be wholly erroneous. There are two ways of producing different degrees of hardness in pig iron or castings, one is by varying the percentages of silicon, sulphur, manganese, and phosphorus in iron, the other by varying the rate of solidification and cooling to a cold state, also shown on pages 167 and 168. Alterations in either of these factors can cause the carbon to take the combined or graphitic form. The higher the combined carbon the harder the iron, and the more the graphitic carbon is in evidence the softer the iron.

An illustration of what may often be expected in the differences of hardness between two casts of pig iron that would give like grades or softness in like castings, is seen in Nos. 1 and 2, Fig. 43. Were these samples tested for hardness they would be found so different that anyone, guided by hardness tests, would say that No. 1 would make a very soft casting while No. 2 would make a very hard one, when in fact each will give like softness in like castings and treatment in cooling. These samples were drilled with a press running at uniform speed and pressure. It took eight minutes to drill No. 1 and twenty-two minutes to drill No. 2, a difference of fourteen minutes. A half-inch twist drill was used and the method of drilling will be seen by the half holes on the back of the specimen seen in No. 3. The difference in the hardness of these samples, it is to be remembered, is found in samples of like analysis, excepting in combined carbon and in iron, coming from the same tap and cast in sand moulds. As long as uniformity in making iron cannot be achieved, as is illustrated in Chapter XXIV., we may expect that the state of the carbon or hardness of pig iron will vary, and often not be in accordance with the grade results as shown by the percentages of silicon, sulphur, manganese, and phosphorus which will be in the pig iron. It will appear ridiculous to those who know, by experience and research, the deceptive nature of the appearance and hardness of sand-cast pigs that any one should now, at this day of advancement in the metallurgy of cast iron, try to introduce a hardness test to define the grade of pig iron as now being generally cast.

It is not to be understood that every cast of pig metal is deceptive to the eye, or hardness test. It may be that three-fourths of all the iron cast at some furnaces may possess a true fracture of hardness or accord with the amount of silicon, sulphur, etc., an

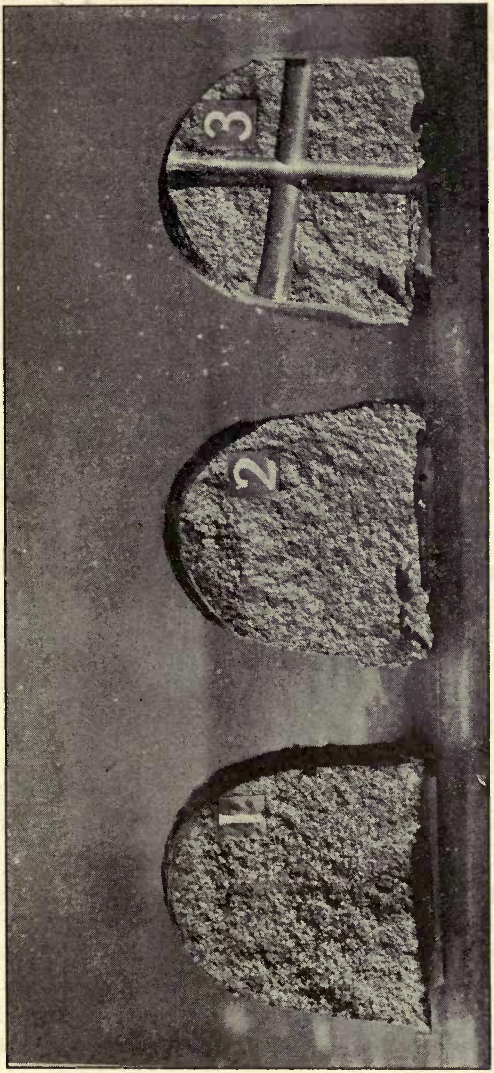

FIG. 43.—SAMPLES OF PIG IRON DIFFERING IN HARDNESS UNDER TEST, BUT MAKING CASTINGS OF LIKE SOFTNESS.

iron contains. Then again, it may be that nine-tenths of all casts would possess true fractures of hardness. Even if this latter were so, are we not justified in condemning the practice of being guided by the appearance of fractures or hardness, especially when there exists another method (chemical analysis) which is known to be positively correct in defining the grade of any brand of iron every time it is employed? At the best, what sense is there of any foundryman taking chances of having one out of ten heats result in wrong grades of iron in his castings when, by following chemical analyses, he can have not only all his heats acceptable but also have them far nearer the grade he desires than is ever possible by being guided by fractures or hardness?

From careful observation in contrasting appearances of fractures with chemical analysis, with heats melting from 70 to 100 tons, the author can say that fully one-half of the furnace casts of pig which he used would have given him grades of iron different than what he desired in his castings, and some of the heats would have been practically worthless and caused a loss of much money and trade, had he been guided by the old-school method of judging by fracture or hardness. From the author's observation and experience, he believes it safe to say that from a third to half of the iron made will not, at the present day, agree in the appearance of fracture or hardness with the analysis. The margin that some founders possess in having their castings accepted when the grade of iron is not what it should be, causes them to often be indifferent in exacting the best obtainable. However, the day is coming when such practice will not be tolerated and all founders will, as a rule, be forced by competition to obtain that which is best to exist in their castings as nearly as possible. When this day arrives we will hear no more of being guided by the appearance of fractures or hardness, unless, by better regulation of furnace workings and the casting of metal from ladles into iron chill moulds may, in years to come, cause the appearance and hardness of fractures to agree with the chemical analysis; but this is doubtful of achievement to the perfection that should be obtained.

In the "Foundry" of November, 1901, a statement is made, under the head of "Cast Iron Notes," inferring that two furnace casts of gray pig iron of the same analyses and brand, but of different grain or fracture, would give a different grade or character of iron in like castings. This is practically the same as thinking to correctly judge pig iron by its hardness, as, in either case, the hard or close grained pig has more combined carbon than the soft or open grained pig and as a fact, the samples Nos. 1 and 2, Fig. 43, are of like analyses, excepting the graphitic and combined carbon, but, if remelted under like conditions, as could be done in the cupola shown on page 241, castings of like softness would be produced; at least, so close that there would require to be a much more radical difference in the grain of two furnace casts, of like analyses in the same brand, than is shown by the samples Nos. 1 and 2, Fig. 43. The difference that a very open and very close grained iron of the same analyses and brand could make would be in the most close grained iron giving a slightly softer casting than the open iron, after the principles presented in Chapter 47, pages 337 to 339. However, there is no reason why any one should make it a point to insist on accepting only open or close grained iron in connection with exacting any certain specified analyses from blast furnaces, as the slight difference possible in the most radical cases of open and close grained iron can be regulated by a slight variation in silicon when making a mixture, and which anyone can easily do, if they so desire.

CHAPTER XXVI.

ORIGIN AND UTILITY OF STANDARDIZED DRILLINGS.

To test the practicability of obtaining uniform analyses of one quarter piece of pig iron, samples of well mixed pig drillings were sent out by the author, during the summer of 1897, to twenty leading chemists in different parts of the country to be analyzed, with a view of ascertaining how closely their results would agree. The reports were such as were anticipated. No two were alike, and the difference between the extremes was so great that a founder being guided by one extreme, in forming a comparative measure for making mixtures, could, should he accept the other, sustain great losses, or obtain a grade of metal far different than what should exist in his castings. The evil results obtained from such variations of analysis were such as to prevent chemistry ever being universally established in founding. Exhibiting the weakness of chemical methods, as did the author by the publication of the reports obtained, caused another party to send out samples of drillings to fifty chemists with the view of getting better results. No. 1 of Table 27 shows the difference in the greatest variations of the analyses reported to the author, and No. 2 shows the greatest variation in the analyses obtained by the second party:

TABLE 27.

	Sil.	Sul.	Phos.	Mang.	C. C.	G. C.	T. C.
Variation 1	.19	.028	.029	.19	.34	.82	.48
Variation 2	.21	.015	.031	.23	.59	.77	1.09

Those making a study of the reasons for such differences in results as shown by Table 27, will find that it is due to the fact that chemists are unable to know positively the correctness of their results without checking them by some known standard. Almost every trade possesses some standard by which its artisans can tell whether their labors have been productive of the perfection desired. The appearance of the finished casting indicates to the furnaceman or founder the result obtained from his iron. A trial of a machine or an engine demonstrates to the machinist or engineer the perfection he has attained, but the completion of an analysis by a chemist presents no tangible evidence of the accuracy of his results. The only way a chemist can know the correctness of his results, or give others any assurance that his work is correct, is by having them checked by others, or by analyzing standardized drillings that have been determined by competent chemists to find whether results agree. The latter method of checking is similar to the use of standard weights to test the accuracy of scales. No laboratory is complete without its standardized drillings, any more than would be a furnace or foundry without standard weights for occasional testing of scales. This necessity has led many chemists heretofore to make their own standards. An observing person having the opportunity to visit chemical laboratories would often find the chemist using these standards, to test chemicals, short-cut methods, or the correctness of results that had been questioned. The process by which individual chemists obtained their own standards was, as a rule, long and tedious. It often took from four to six months to get in all the results. Then again, as a rule the results varied so much that the average accepted for a standard seemed more like guesswork than the result of accurate work and methods. The variation in analyses thus obtained has often caused great difference in standards in use in different circles and perplexed managers of steel works, furnaces, founders, and chemists rather than helped them to correct evils and prevent losses. It was the opportunity of observing the practice of blast furnace chemists making their own standards that caused the author to conceive the idea of one central agency, from which all could obtain standardized drillings, which had been determined by a few of our best known chemists.

After devising a plan for a central agency or bureau for the distribution of standardized drillings, the author presented a paper to the Pittsburg Foundrymen's Association, April 25, 1898, setting forth the need of greater uniformity in analysis and suggesting, in outline, his plan for establishing a central agency. At this meeting a committee was appointed with the author as chairman to introduce the project before the American Foundrymen's Association at Cincinnati, June, 1898. This convention unanimously approved the project, and appointed a committee to proceed with the work. This committee consisted of Dr. Richard Moldenke, now secretary of the A. F. A., New

York; James Scott, superintendent of the Lucy Furnace, Pittsburg; P. W. Gates, president of the Gates Iron Works, Chicago, and E. H. Putnam, superintendent of the Moline Plow Works, Moline, Ill., with the author as chairman. The appointment of the committee gave a sound basis on which to work, but the importance of the reform and the obstacles which had to be overcome before the same could be established were realized by but few. The first work of the committee was to adopt the plans advanced by the author in his paper before the Pittsburg Foundrymen's Association, April, 1898, and which secured for us the services of Prof. C. H. Benjamin to supervise the work of making the drillings, and of Prof. A. W. Smith to carry forward the work of preparing, standardizing, and packing the samples; also, the services of Booth, Garrett & Blair, Andrew S. McCreath, Cremer & Bicknell to analyze the drillings, the average of the four results being accepted as a standard.

One of the greatest obstacles in the way of establishing and maintaining a central standardizing agency lay in the difficulty of obtaining a sufficient amount of uniform turnings or drillings from one sample of iron, free of sand, grit, slag, etc., to permit all laboratories to obtain a pound or more of them. As a rule, chemists have found it difficult to obtain twenty-five pounds of clean, uniform, and reliable samples. A study of this phase of the subject will show that the practicability of establishing and maintaining a central standardizing bureau is largely dependent upon the ability of the founder to make large castings weighing five hundred pounds or more, from which could be obtained a large amount of clean, uniform drillings. For this reason, a well-known writer has aptly said that the establishing and maintaining of a central standardizing agency is properly foundrymen's work. As the making of these castings involves principles of founding interesting to many, we illustrate the plan used, which is as follows: A mold of dry sand, for the outer body and a dried core for the inner, are made as seen in the plan and section view of Figs. 44 and 46. The construction of the mold explains itself. The secret of getting a clean, solid casting lies mainly in the method of gating and pouring it. At A is a gate leading down to the bottom of the mold at an inlet at D. The round gates B, seen at the top of the mold, are placed about four inches apart and are one-half inch in diameter. A riser is seen at E. In starting to pour the mould, the molten metal is directed to drop from the ladle into the basin at the point marked W, in a way that will allow it to flow gently down the gate A and enter the mould at D to prevent the bottom being cut by the top gates. When from thirty to fifty pounds of metal has entered the mould, a quick turn of the ladle empties a large body of the metal into the pouring basin, quickly filling all the gates at B; this then drops the metal down upon that which is rising from the stream flowing in at D. This action is kept up until the mould is filled and the metal runs out at the riser E. After this point is attained, the pouring is slackened and a steady stream maintained until from three hundred to five hundred pounds of metal has flown through the riser E to run down the incline seen at S into the scrap hole X. The effect of allowing such a large body of metal to flow through the mould by making it enter the gate at A is to keep up an agitation after the mould has been filled, which in turn is most beneficial in causing the metal in the mould to mix well and counteract variations in structure that might otherwise take place. The metal dropping from the top gates B causes a disintegrating action, cutting into fine particles any dirt that might accumulate upon the surface of the rising metal, and which, were it not thus chopped up, as it were, into fine particles, would gather in large lumps and be caught and held fast in the mold walls, with the result that dirt spots,

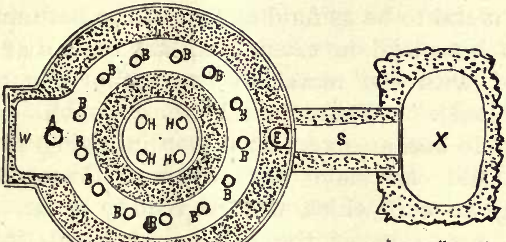

FIG. 44.

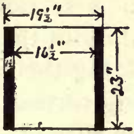

FIG. 45.

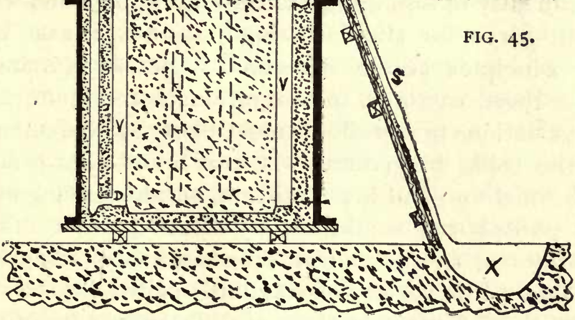

FIG. 46.

etc., would be found in the casting when the skin was removed by a drill, lathe, or planer. Again, the fact that the metal drops from the top of the mold besides entering at the bottom, causes the top body of the rising metal to be as fluid as that at the bottom, which is also beneficial in causing all scum and dirt to float upward with the metal to the top of the mold or "riser head." Where metal fills a mold all from the bottom it becomes rapidly duller in rising to fill the mould and can leave dirt scattered throughout the casting, an evil which will be readily seen. Fig. 45 shows a section of the casting obtained from the mould, with the exception of four lugs cast on to assist in holding the cylinder or casting in the lathe while it is being turned. It will be well to state that there is no difficulty in obtaining castings weighing tons which might serve for standardizing purposes, if cast upon the principles herein described. Before starting to make these castings, investigations were made as to the variations in metalloids most likely to be demanded by the trade in general. It was found that samples high, medium, and low in silicon, sulphur, manganese, and phosphorus would satisfy most of our country's laboratories as far as iron standards were concerned. To obtain this variety of standards called for the making of three distinct castings of different grades of iron. These were cast with iron melted in a small cupola, under the direction of the author, at the Thos. D. West Foundry Co., after the plan herein described.

To obtain the turnings or drillings, which had to be fine enough to pass a 20-mesh sieve, was no easy matter and rather a costly affair. To get one pound of drillings per hour was thought to be good work. The plan of securing these turnings or drillings was first to take off about one-eighth of an inch from the surface of the casting. These first turnings were cast aside, as they contained more or less scale or refuse formed on the surface of the casting by the fusing action of the molten metal upon the sand forming the face of the mould. After this surface had been turned off and all debris removed carefully from the lathe, the cylinder was turned until about a one-quarter inch thickness of the inner shell remained. The turnings obtained from the body after the one-eighth inch thickness was removed from the surface were the ones taken for standardizing purposes. It should be stated that about a one-half inch thickness at the botom and the "riser head" of two inches at the top were not disturbed, so as not to have the scale on the bottom of the casting, or any dirt that would be collected at the top end mixed with the turnings obtained from the inner body of the casting. After the turnings had been thus obtained they were passed through a 20- and 40-mesh sieve. This done, the drillings were then spread out on a large carbonized cloth and thoroughly mixed. The mixing having been perfected, bottles holding one-third of a pound were placed in convenient position and filled with the drillings, by having a scoop holding sufficient drillings to give each bottle an equal portion from every filling of the scoop. In filling the scoop, drillings are taken from different parts of the spread so that all bottles will contain some of every portion of the drillings. Repeated analyses of different bottles or samples have proved the mixing to be all that could be desired.

The samples made up to 1902 are designated as A, B,

C, and D. Sample A, which has been ground to pass a 40-mesh sieve, gives one total, combined carbon and one graphite. Sample B gives a low silicon, a medium sulphur, a low manganese, a phosphorus which is within the Bessemer limit, and a titanium. This has been passed through a 20-mesh sieve. Sample C gives a medium silicon, high sulphur, medium manganese, medium phosphorus, and a titanium. This has also passed a 20-mesh sieve. Sample D gives a high silicon, low sulphur, high manganese, and high phosphorus, and has passed through a 40-mesh sieve.

The standards are sold at the price of $5.00 per pound (a discount of 40 per cent. is allowed to colleges and dealers), and in no instance will less than one pound be sold. The samples are packed in bottles holding one-third of a pound and delivered in cases, as illustrated on page 189, holding three or four bottles according to the desires of a subscriber. One pound of the samples should furnish enough material for 36 complete analyses, or at least 200 separate determinations. The exact analyses of the samples A, B, C, and D are sent separately by mail, so that they may be placed upon bottles or kept private, as desired by the subscriber.

By addressing any member of the committee (see page 183), all orders for drillings will receive prompt attention. Money may accompany orders or be sent after receipt of drillings, as best suits the pleasure of the buyer.

To secure the first orders for standardized drillings, the author found it necessary to call upon many managers and chemists at their offices, but the good work once well under way advanced so rapidly

The Spearman Iron Co.
Sharpsville
Penna

FROM
American Foundrymen's Association
STANDARDIZING BUREAU
ALBERT W. SMITH,
Case School of Applied Science, CLEVELAND, O.

Glass. With Care.

oundrymen's Ass
RDIZING BUREA
andardized Iron.
SAMPLE
A

American Foundrymen's Association.

Standardized Sample of Cast Iron.

The castings from which these samples were taken were made by THOS. D. WEST. Their preparation was under the supervision of Prof. C. H. Benjamin and Prof. A. W. Smith. The analytical work was carried out by Booth, Garret & Blair, Philadelphia, Pa., Prof. A. W. Smith, and Cramer & Bicknell, of Cleveland, O., and A. S. McCreath, Harrisburg, Pa.

NOTICE.—The direction of the Standardizing Bureau of the American Foundrymen's Association is in the care of Professors C. H. Benjamin and A. W. Smith, Case School of Applied Science, Cleveland, O., who will arrange for the preparation and distribution of the standardized drillings. Business communications may also be addressed to

THOS. D. WEST, Chairman,
SHARPSVILLE, PA.

FIG. 47.

that today (Oct., 1901) we have over two hundred laboratories in this country and in Europe using these standardized drillings. To show the character of concerns using these standards, we publish the following list in alphabetical order, followed by extracts from a few of many testimonials in the possession of the author, which indicate the success of the work and the esteem in which it is held:

Ashland Coal, Iron & Railway Co., Andrew Brothers Co., Allegheny Iron Co., Alabama Consolidated Coal & Iron Co., Andover Iron Co., Ashland Steel Co., Atlanta Iron & Steel Co., Allentown Rolling Mill Co., Air Brake Co., New York; Atlantic Iron & Steel Co., Bellefonte Furnace Co., Brier Hill Iron & Coal Co., Buffalo Iron Co., E. & G. Brooks Iron Co., Bethlehem Iron Co., Bell City Malleable Iron Co., Builders' Iron Foundry Co., Lucius Brown, Blodgett, Britton & Co., Boulder University, Burgess Steel & Iron Works, Bellaire Works, National Steel Co., Canada Iron Furnace Co. (Radner Forges and Midland), Colonial Iron Co., Chickies Iron Foundry, Carbon Steel Co., Carbon Iron & Steel Co., Camden Iron Works, Carteret Steel Co., Carnegie Steel Co., Chicago & Burlington Railway, Clinton Iron & Steel Co., James Clow & Sons, William Cramp & Sons, J. I. Case T. M. Co., Cooper Union, Cornell University, Columbia University, Dunbar Furnace Co., Danville Bessemer Co., Dora Furnace Co., Deutsche Niles-Werzeugmasschinen-Fabrik, Draper Co., Dickmen & McKensie, Dayton Coal & Iron Co., Deseronto Iron Co., Everett Furnace Co., Embreville Iron Co., Elk's Rapid Iron Co., Emma Furnace, Empire Steel & Iron Co., Eimer & Amend (four laboratories), F. A. Emmerton, Franklin Iron Works, Farrell Foundry & Machine Co., Davenport Fischer, Frank-Kneeland Machine Co., Fort Wayne High School, The Falk Co., Girard Iron Co., Gates Iron Works, E. Grindrod, M. A. Hanna & Co., Hamilton Blast Furnace Co., Heckscher & Sons, Hecla Works, England; R. C. Hindley, M. Hoskins, Harvard College, Havemeyer University, Henry Hiels Chemical Co., Isabella Furnace, Iron Gate Furnace, Iroquois Iron Co., Illinois Steel Co., Jefferson Iron Co., Kittanning Iron & Steel Co., C. A. Kelly Plow Co., Lebanon Furnace, Longdale Iron Co., Lackawanna Iron & Steel Co., Logan Iron

Mfg. Co., C. E. Linebarger, Ludw. Loewe & Co., Berlin; Lehigh University, A. R. Ludlow, Lowmoor Iron Co., Minerva Pig Iron Co., Missouri Furnace Co., Monongahela Furnace Co., Mable Furnace Co., S. McCreath, McNary & DeCamp Co., Martin Iron & Steel Co., Missouri Malleable Iron Co., McConway & Torley Co., C. F. McKinney, J. McGavok, Massachusetts Institute of Technology, Michigan School of Mines, Northwestern Iron Co., New River Mineral Co., Noyes Bros., Sydney, Australia; Nova Scotia Steel Co., Niagara University; Nicopol, Mariopol, Sartana, Russia; Ohio Iron & Steel Co., Oil City Boiler Works, Ohio State University, Pickands, Mather & Co., Penn Iron & Steel Co., Pioneer Mining & Mfg. Co., Pennsylvania Steel Co., Pennsylvania Malleable Co., Pittsburg Locomotive & Car Works, Purdue University, Pioneer Iron Co., Princess Iron Co., Punxutawney Iron Co., River Furnace & Dock Co., Reading Iron Co., Rome Testing Laboratory, Sharpsville Furnace Co., Spearmand Iron Co., Stewart Iron Co., Salem Iron Co., Shickle, Harrison & Howard Co., Sharon Iron Works, Sloss Iron & Steel Co., Syracuse Chill Plow Co., Snow Steam Pump Co., Sargent Co., M. Strong, O. Sowers, W. M. Sanders, Stevens Institute of Technology, D. A. Sandburn, Tennessee Coal, Iron & Railroad Co., Towanda Iron & Steel Co., Thomas Iron Co., E. Tonseda, Union Iron & Steel Co., Union Iron Works, United States Cast Iron & Foundry Co. (three laboratories), University of Buffalo, University of Pennsylvania, University of Michigan, University of Minnesota, Virginia Iron, Coal & Coke Co., Virginia Polytechnical Institute, Warwick Iron Co., Woodward Iron Co., Watt Iron & Steel Co., D. Woodman, E. J. Wheeler, Wooster Polytechnical Institute, Webster University, Westinghouse Machine Co., Wisconsin Malleable Iron Co., Westinghouse Air Brake Co., Youngstown Steel Co., Yale University.

EXTRACTS OF TESTIMONIALS IN PRAISE OF STANDARDIZED DRILLINGS.

"We take pleasure in saying that our chemist states he has used the standardized drillings in standardizing solutions and found them to be very exact; and adds that too much praise cannot be accorded the standardized drillings you recently sent us.

ELK RAPIDS IRON CO.,
H. B. Lewis, Pres."

"It is no little comfort to have the standardized samples and to know that the work of our laboratory is correct and reliable.

EDGAR S. COOK,
Pres. Warwick Iron Co., Pottstown, Pa."

"We are pleased with samples. They will, without doubt, greatly promote increasing accuracy in methods of iron analysis.

J. BLODGET BRITTON CO., Warrentown, Va."

"We are using the standardized drillings and find them very useful in our laboratory. We think it very necessary that laboratories should be supplied with standardized drillings, especially those working on blast furnace products.

L. C. PHIPPS,
Second Vice-president Carnegie Steel Co., Pittsburg, Pa."

"It has always been a task to get standards, especially standards that would check up with those from different concerns. It will simplify matters considerably if chemists will use standards from one party of the same value, as I have found that most of the errors in sulphur and phosphorus come from different chemists' standards not checking.

J. O. MATHERSON, Chemist,
Ashland Coal, Iron & Railway Co."

"I think the method of selling standardized iron samples from a central laboratory, such as the Standardizing Bureau of the American Foundrymen's Association, is one to be commended. The confidence I have in my work after checking with these drillings is very gratifying.

WALTER M. SAUNDERS,
Analytical and Consulting Chemist, Providence, R. I."

"In connection with the use of the standardized drillings, I wish to say that I believe the plan will result in attaining greater accuracy, will inspire confidence, and will enhance the value of analytical chemical work in connection with foundry practice.

W. P. Rickells,
Columbia University."

"The standard samples are a grand idea and the confidence they impart is worth ten times the cost. W. G. Scott."

"I have noticed with pleasure your praiseworthy efforts to establish uniformity in pig iron analysis. . . . Thanking you for your endeavors to mitigate the perplexities of both the furnace manager and the chemist, John P. Marshall,
Supt. Missouri Furnace, Carondelet."

"It is the greatest move for improvement in many years.
Erastus C. Wheeler."

"We have checked our routine laboratory work from time to time since receipt of drillings and have found them to be of inestimable value to us. Kittanning Iron & Steel Mfg. Co.,
W. L. Scott, Chemist."

"Permit me to express my belief that this work of your association of distributing carefully analyzed samples of pig iron is of great value to the metallurgists and chemists of this country.

H. L. Mills,
Professor Analytical Chemistry, Sheffield Scientific School of Yale University."

CHAPTER XXVII.

INTELLIGENT PURCHASE AND SAMPLING OF PIG IRON.

There were comparatively few founders using chemical analysis in making mixtures of cast iron when the first edition of this work appeared, in 1897. At this time, Oct., 1901, about three-fourths of the founders are dependent upon a knowledge of the chemical constituents of their pig irons, and ignore the appearance of fractures or hardness of pig iron. There have been some ups and downs in the experience of founders working up to the present advancement. Nevertheless, as founders come to intelligently understand the science of, and methods necessary to be followed in working by chemical analysis, they become adherents of its practice. One great drawback has been in the evils resulting from practices described in Chapters XIX. and XXIV., and in the fact of depending wholly upon furnace reports of chemical analysis which would sometimes prove erroneous by reason of mistakes, and cause beginners, in trying to utilize chemical analyses to make mixtures, condemn the plan of working by analysis.

It is not safe, as a rule, to depend wholly upon furnace reports of analyses, for the reason that there are several chances for mistakes being made aside from what the chemists might make. These are mistakes that may be made in numbering iron piles, transferring records of analyses from one book to another, etc., and in incorrectly carding the cars when shipping the iron to consumers. The author, being surrounded by blast furnaces, has seen serious mistakes made in all of the above points and is confident that it will pay to recognize existing conditions. The only way to decrease the chance of errors in receiving a furnace report of analysis is for the founder to have all such reports checked after the iron is received into his yard. To do this he should take two or three pieces of pig iron from each end, and two or three from the middle of every car of iron received, or from the ends of piles after it is taken from the car as described on page 140. These pieces of pig should be about one-quarter the length of a whole pig and drilled after one or the other of the plans seen at A, B, and C in Fig. 48. In drilling these samples the utmost care should be taken to prevent sand or scale from the pigs getting mixed

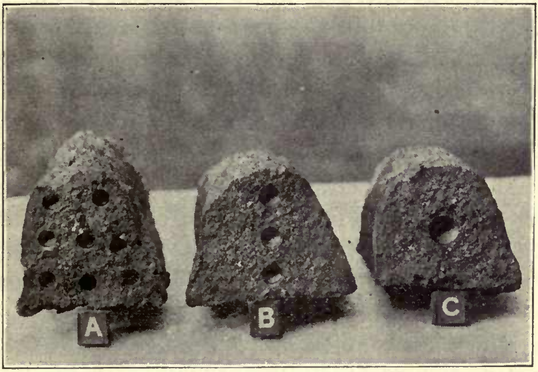

FIG. 48.

with the drillings. To prevent this the pigs should be thoroughly cleaned with a wire brush before being taken to the drill press, where they should be drilled with a flat drill, as a twist drill gives a large variation in the size of borings according as the hardness of the iron varies. Some drill six to ten holes to obtain samples as at A, others drill three holes as at B, while others drill but one hole in the center as at C. Where it is desired to obtain the best possible average of the composition of a piece of pig in securing drillings, the plan seen at A is followed. It may be said that, as a rule, the majority of samples are taken as at C, unless analyses of the carbons are required, when it is very essential to follow the plan at A or B. In drilling as at A or B the material from each hole should be kept separate, and after the drilling is completed the same weight of drillings from each hole should be taken, and the whole mixed together as thoroughly as possible to obtain an average of the composition of the pig. For each analysis about a large teaspoonful of drillings is ample, and such are best passed through a 20- or 40-mesh sieve before being used. To do this it may often be necessary to pulverize the drillings in an iron mortar. It is very important to properly sample a car or pile of iron and take proper precaution in obtaining a clean and thoroughly mixed sample of drillings, where one wishes an accurate analysis to show the average composition of a car or pile of pig iron.

The small foundry finds this method, necessary to check furnace reports of analyses, objectionable. This is on account of such founders not being in a position to support a laboratory. However, many small shops would find that it would pay them, in the end, to send samples of drillings of every car or pile of iron by mail to other localities where a chemist could be employed. Unless such shops are doing work of a character requiring delicacy in making mixtures, analyses of the silicon and sulphur are all that they may require of their pig metal, and these can be obtained for about one dollar for each analysis. This is a small sum compared to the assurance it affords such founders of correcting possible errors in furnace analysis reports. Many small founders are now beginning to recognize this and some are following the above plan and find that it pays them well. In cases where a small firm could give a chemist other employment they could install a laboratory at their own works for one hundred to one hundred and fifty dollars, and then be in a position not only to make analyses of their own irons but also those of what fuels, blackings, and sand they use, when found advisable.

Another evil of past practices has lain in the founder relying upon the furnaceman to advise him of the character of iron he should use. This is wrong. It is not a furnaceman's business to be responsible for the character of iron the founder should use, as his experience does not rightly afford him such knowledge. All founders should know their own needs and be able to order their irons intelligently. The first two editions of this work have achieved much in influencing founders to do this. A study of this work should cause the moulder or founder who may now look upon chemistry as something beyond his comprehension, to talk as intelligently and fluently about silicon, sulphur, manganese, phosphorus, and the carbons, etc., in iron, as he now can about moulding sand, ramming, venting, gating, pouring, etc. The grand point about all this is the practicability of its achievement by any ordinary mind that will make any effort to master this new science of founding.

A description of the methods followed at our foundry in Sharpsville, Pa., for delivering pig iron to the cupola and keeping a record of our heats, etc., may serve many well in giving them ideas to form plans for such work. Our pig iron, in being loaded from cars or iron piles in the yard, is placed on buggies and then pushed to the elevator by a locomotive or hand power, after which it is carried to the cupola stage and stored in piles after the plan described on pages 141 and 142. A record of the silicon, sulphur, etc., contents of each pile is kept by the cupola tender, so that he knows just what iron to charge. We make a specialty of castings that now require heats ranging from seventy to one hundred tons weight. Our castings are of such a character as to exact certain physical qualities. To know that they are right in our castings before leaving our shop, we have analyses of the silicon and sulphur, and occasionally of the other metalloids made for every heat; and when first starting to make these analyses we also conducted physical tests. A plan for obtaining both combined is shown by Tables 28 and 29. We largely dispense now with the physical test, owing to our experience being such as to enable us to judge of the physical properties by reason of chemical analysis and an examination of the castings. The tests given in Tables 28 and 29 were obtained from four round test bars cast on end at about equal divisions of the heat. The mixture for the heat here recorded was all pig iron, excepting about 5 per cent. shop scrap, the pig ranging from 1.30 to 2.00 per cent. of silicon and from .020 to .040 in sulphur. We have an arrangement for our office in which a record of the chemical and physical qualities obtained in our castings can be recorded. This enables us to work intelligently when wishing to refer to past results or experiences in repeating old or making new mixtures of iron. These records are also kept in such a manner as to show the loss in silicon and increase in sulphur, etc., in our heats, something which is very essential to be understood, and is treated in Chapter XLV.

TABLE 28.—PHYSICAL TESTS OF "HEAT" TAKEN SEPTEMBER 14, 1896.

Rotation tests in strength.	Fluidity.	Contraction.	Deflection.	Transverse strength in lbs.	Chill.	Diameter of test bar.	Strength per sq. inch in lbs.
1	2⅛″	.135″	.140″	1,955	8 64″	1.143″	1,907
2	2⅝″	.130″	.110″	1,625	6 64″	1.136″	1,604
3	1½″	.128″	.120″	1,520	5-64″	1.130″	1 515
4	2¾″	.124″	.150″	1,495	4-64″	1.142″	1,459

REMARKS.

The four test bars showed a perfect, solid fracture. The strongest test bar was the last cast and the weakest bar at the second pouring.

[Signature of Tester.] THOS. D. WEST.

TABLE 29.—CHEMICAL ANALYSIS OF STRONGEST TEST BAR.

Silicon.	Sulphur.	Combined Carbon.	Graphitic Carbon.	Phosphorus.	Manganese.
1.20	.079	.094	2.67	.089	0.40

CHEMICAL ANALYSIS OF WEAKEST TEST BAR.

Silicon.	Sulphur.	Combined Carbon.	Graphitic Carbon.	Phosphorus.	Manganese.
2.15	.060	.79	2.75	.091	.37

[Signature of Chemist.] D. K. SMITH.

In purchasing pig irons for any new class of work, or such as founders are inexperienced with and that others may be making, it is often a good plan to find out and deal with the furnace which can show dealings with founders making the same class of work which they desire to manufacture if they can. This starts a founder, in making a new class of work, to use brands of iron that have been tested and found suitable for the class of work he desires to produce, and may be the means of preventing some experimenting and loss of capital. IT WAS ADVANCED IN THE FOUNDRY, NOV., 1901, that buyers of foundry pig iron should consider the fracture of pig in being open or close grained in connection with specified analyses. How practical this proposition is will be found by reference to page 179. Methods for computing averages of silicon, sulphur, etc., that exist in different furnace casts or piles of iron, in making mixtures of any special brands or different grades, are given in Chapter XXXVI., Tables 39 to 42, pages 256 and 257. The net weight of sand and chill cast pig iron per ton of 2,268 lbs. and 2,240 lbs. respectively is given in the first two tables at the close of this work.

PART II.

CHAPTER XXVIII.

THE METALLIC AND NON-METALLIC ELEMENTS OF CAST IRON.

Having described processes followed in making cast iron and qualities affecting its character, etc., up to the time it arrives in pig form at foundries, ready for remelting to make castings, as seen in Chapters I. to XXVII., we will now treat of qualities which can affect cast iron when in the hands of founders, and of information which they should possess in order to make mixtures best suited for different kinds of gray and chilled castings; also on subjects pertaining to testing, etc.

While the effects of silicon and sulphur, manganese, phosphorus, and carbon have been referred to somewhat in the preceding chapters, it has only chiefly been done in a manner incidental to the manufacture of cast iron. It is when pig or cast iron is in the hands of founders that its peculiarities or characteristics are best displayed. For this reason, the second part of this work will be found the more important in imparting information on cast iron to those employed in the manufacture of castings or interested in their use. In taking up this second part of the work, it will be well to first treat of the metallic and non-metallic elements of cast iron.

An element is a substance composed of only one kind of atoms. An atom is the smallest sub-division of matter which cannot be divided. Every atom is exactly like every other atom of the same kind and is, as a rule, incapable of independent existence. Atoms unite to form molecules, which are the smallest particles of matter capable of independent existence to retain the properties of a mass, and which is any form of matter appreciable to the senses. Molecules can be formed of one or different kinds of atoms. Where molecules are formed of different kinds of atoms, the mass is called a compound. There are now about seventy different kinds of atoms or elements, among which are classed carbon, iron, manganese, phosphorus, silicon, and sulphur. Table 130, at the close of this work, gives the chemical and atomic weights of various elements.

One method of distinguishing the metallic elements or atoms from the non-metallic ones is as follows: Solutions of compounds are sometimes decomposed by an electric current. That element which will go to the positive pole is said to be the electro-negative or non-metallic, while that element which goes to the negative pole is said to be electro-positive or metallic. This division of elements among iron workers is more generally understood in being classed as metals and metalloids, the latter being limited to inflammable non-metallic elements, and which as a rule are lighter, bulk for bulk, than metals. With this conception of the elements, we can consider iron, manganese, and silicon as being metals, while the carbon, sulphur and phosphorus would be classed as metalloids. While this classification may be accepted, it is for convenience, with founders especially, considered that the term metalloids shall cover every element in cast iron excepting the iron. This implies that one or all of the elements — carbon, silicon, sulphur, manganese, and phosphorus — are classified as metalloids, but it is to be remembered that this is incorrect in regard to manganese. To have a clear understanding of the influence of these metalloids in affecting the character of iron or castings, a study of the following chapters is necessary.

CHAPTER XXIX.

CHEMICAL AND PHYSICAL PROPERTIES OF CAST IRON.

Without chemistry we could not define elements causing physical effects or be able to scientifically and intelligently direct mixtures. The physical test tells us what is obtained. The chemical test tells us the metalloids we must use to effect results, and each property is essential to an attainment of the desired end. The first to be noted is carbon, as its influence in the form of graphite or combined carbon is the greatest in determining the character or "grade" of cast iron.

The amount of carbon which iron will absorb depends upon the working conditions of a furnace and the amount of silicon, phosphorus and manganese taken up by the iron. Much silicon reduces the power of iron to absorb carbon. The greater the percentage of manganese the more carbon can iron absorb, as is shown by "spiegel" iron, which contains carbon as high as six per cent. When iron is below .75 in manganese, about 3.50 of carbon is all it contains, although it may possess as much as 4.50 per cent. of carbon in rare cases. It is claimed that chromium, when substituted for manganese, will cause iron to absorb carbon as high as 12 per cent. The carbon in iron is obtained from the fuel used in smelting. The more carbon iron contains, the greater influence silicon, etc., can have in affecting or changing the "grade" of iron. The carbon in gray iron is mostly in the form of graphite, and the iron may contain as much as three to four per cent. of it. Hard or "white iron" contains carbon in a different state from "gray iron." In white iron it is chiefly combined carbon, in which form it hardens the iron. The graphitic carbon in gray iron can have a large percentage made combined carbon, to harden iron, by casting it on a chill or suddenly cooling it. By this action the carbon, which in melted iron is in the state of combination, does not have time to separate in the form of graphite.

Combined carbon is ascertained in true chemical exhibits of pig metal by the fracture being small grained, of a close, compact nature, and tending to a light gray color in Nos. 1 to 5, and in the higher numbers to a white color. The higher its percentage in combined carbon, the greater the approach to white iron. The faster the iron cools and the more combined carbon it contains, the finer the crystals or grain. The lowest combined carbon is found in castings having from three to four per cent. of silicon, and low in sulphur.

Graphitic carbon can be told in iron by the fracture being large grained and its crystals of a deep, brilliant color, from which flakes of graphite can often be extracted by hand or brushed out. A large percentage of graphite in iron will make it very soft, unless retarded by the presence of some hardening substance, like manganese. The more slowly a casting cools, the more graphite in the iron, and the larger the grain. For characteristic determinations of combined carbon in a fluid state, see Chapter LX.

Total carbon is that composing the combined and graphitic carbon united. Where the total is known and only the combined is stated, the balance necessary to make the total would be the graphite, and the reverse where the graphite is only known.*

Woolwich's experiments have proved that variations in the percentage of combined carbon are more effective in changing the grade of an iron than equal variations in graphite carbon. A slight increase in graphite, with the combined carbon remaining constant, creates very little effect in changing the grade to make a softer iron, but if a like change should be made in the combined carbon, having the graphite remain constant, the ratio would be greatly changed or the "grade" of the iron would be very much altered.

Silicon's chief office is to soften iron and aid the founder to regulate or cheapen his mixture. This was first suggested by Dr. Percy in the year 1850, but it awaited experiments in 1885 by Mr. Charles Wood, a founder of Middlesbrough, assisted by Mr. John C. Stead, the expert chemist, both of England, to first practically demonstrate the value and utility of silicon as a softener and its application to founding, a work which, it should be said, had its foundation laid in experiments conducted by Prof. Thomas Turner, at Mason College, Birmingham, Eng., the same being presented a few months later at the Glasgow meeting of the Iron and Steel Institute. The extensive publication of this paper is really responsible for the universal adoption of silicon as a softener in making mixtures of iron. The next to take up

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* For further information regarding the "total carbon," see Chapter XXXIII.

this work was M. Fred Gautier, of Paris, who, at the next spring meeting of the above association, presented a paper on silicon in foundry iron. These two papers started many others experimenting, among the most prominent being Mr. W. J. Keep, of Detroit, Mich., and the author.

Not only is silicon a softener of iron and a great element in cheapening the mixture by permitting a large percentage of scrap or cheap iron being mixed with high-silicon iron, but it is also an element of value in increasing the fluidity of metal. Silicon possesses a property which, in a degree, reduces the percentage of total carbon which iron may take up, and which also can exceed in its percentage any other element in iron. It has found such a favor in the estimation of some as to make them unregardful of any other element in iron, a practice which is decidedly wrong, from the fact that one part of sulphur can often neutralize the effect of ten to fifteen parts of silicon, and hence for this reason it is as essential that the founder should be as watchful of sulphur as silicon, and the same may be said of the total carbon, phosphorus, and manganese, as all should be considered in making mixtures; but the silicon and sulphur should be considered the bases for changing the grade or character of iron, as seen by Chapter XVII.

The author's experience and study of silicon in its effect upon mixtures lead him to affirm that while it can achieve much good, it can also do great injury. It is an element which should only be used with a knowledge of the effect any percentage can produce, just as a physician can administer a poisonous drug to obtain beneficial results. Silicon is a very good thing, so is good whiskey, but either, if not carefully used, can cause more evil than good. For this reason, guesswork in judging the amount of silicon an iron contains is not to be commended. Only by a knowledge of its chemical analysis can constant, uniform or desired results in applying silicon to mixtures be best maintained. I have found that silicon had a softening effect up to about 4.00 per cent., or where it was possible to have castings jolted in safety over a pavement or rail track in transit for delivery.

This is as far as the founder ought to go in using such " poison " to strength. After the carbon has become graphitic all it will, any further addition of silicon only closes the grain and makes the casting "soft rotten," or brittle. If, by still further addition we would exceed four per cent. of silicon—which is a percentage no ordinary iron mixtures or casting requiring any strength at all should contain—we may then harden the iron to a slight degree. A mixture having 3.75 per cent. of silicon is as high in that element as it is practical to use, if we expect general castings to hold together, unless the sulphur or manganese is very high to harden the iron. It is not desirable to have ferro-silicon iron in castings. Very few general castings, excepting those for electrical purposes, require over three per cent. of silicon in their composition, if the sulphur or manganese is right, and the lower the silicon can practically be kept in most castings the better the results to be expected from its use.

In Russia, they have made light castings, as was shown in the exhibit at the World's Fair, 1893, with the silicon as low as .55, a little over one-half of one per cent., but in order to achieve this, we find the sulphur did not exceed .022. This is a good example in illustration of the effect of sulphur in hardening iron, for had the sulphur been .07, as is generally the case as an average for light castings in America, with the silicon only .55, such castings would be so hard or "white," that they would never hold together long enough for one to handle them. The low sulphur in the Russian castings would lead us to say that they were made from cold blast charcoal iron.*

Silicon can be absorbed by iron to as high as 20 per cent., and from 3 to 4 per cent. of silicon in mixture will generally change all the carbon found in ordinary irons to graphite that it is possible to change. The percentage it will require to do this is dependent upon the percentage of the other constituents present in the mixture. Silicon ranges from 1 to 5 per cent. in Foundry iron, in standard Bessemer iron from 1 to 2½ per cent., and in ferro-silicon pig iron from 5 to 14 per cent. In making mixtures of iron with pig containing 4 to 6 per cent. of silicon there is far less risk of over-dosing a mixture than with pig containing from 8 to 14 per cent. of silicon, for although we may figure out to a nicety just the percentage pig may contain and direct how many pounds should be charged, it cannot but be seen that with the higher percentage of silicon pig the least error in weighing it, etc., could be very disastrous in results. In cases where a founder has a cheap class of work and desires to use all the scrap, burnt or hard iron possible, he may often use

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* The Russian analysis was obtained by Mr. H. L. Hollis, of Chicago, and presented in a table with other analyses of American castings in a paper read before the Western Foundrymen's Association, May, 1894.

ferro-silicon pig very economically, or where a founder is running on a specialty of any kind that does not require different mixtures out of the same heat, with good judgment and care, ferro-silicon may often be well and profitably applied in mixture.* Four per cent. of silicon pig can often carry 80 per cent. of ordinary scrap to make soft, machinable castings in work not under one inch in thickness.

Silicon in the pig has a silver cast, and, with some grades, a · flaky, frost-on-the-window look. It has practically no grain and when broken has a fracture somewhat like glass. For its appearance in a liquid state, see Chapter LX.

Sulphur in iron is mainly derived from the fuel used to smelt it in the blast furnace and in remelting it in a cupola. It is the most uncontrollable, injurious element the furnaceman or founder has to contend with. There are, however, three qualities sometimes commendable in it: one is its influence in increasing the fusibility of iron, and another its strength, as shown in Chapter XXX., and the third its tendency to harden or chill iron by reason of its promoting combined carbon, which is often better obtained with low silicon or high manganese, since with these we have less injury from unyielding contraction strains. With the exception of the three qualities mentioned above, the effects of sulphur are greatly for evil, making light castings hard and molten iron sluggish, and giving rise to "blow holes" in iron solidifying rapidly. It is for these various reasons that charcoal iron, on account of its being low in sulphur, has been found superior to coke or anthracite iron for many kinds of castings.

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* Some keep a stock of ferro-silicon on hand to regulate mixtures in the absence of their 3.00 to 4.00 per cent. silicon irons, as a little goes a long ways and often prevents shutting down for the want of regular irons.

With charcoal iron castings we can have low silicon without much sulphur, whereas with coke and anthracite iron castings, if we have low silicon, we may generally expect high sulphur. Charcoal pig metal being the most free from sulphur and impurities, the softest strong castings are obtained from it, especially when melted in an air furnace. Sulphur is very deceptive in pig metal. It can lurk in hiding so as to be present to a much greater degree than the eye of an expert can suspect. For this reason chemical analysis is very essential in order to ferret it out. Sulphur can cause iron to be red short, as well as cold short.

Two points of sulphur are more effective in changing the character of iron than ten to fifteen points of any other constituent which iron possesses. Its influence in so greatly changing the character of iron is due to its ability to radically increase the percentage of combined carbon in iron. The alteration that a few points in sulphur can effect in the "grade" of iron is often surprising, and for this reason founders should be most watchful of sulphur. The amount of sulphur in pig metal generally ranges from .01 for No. 1 iron up to .10 for "white iron." For No. 1 pig metal it rarely exceeds 0.03; Nos. 3 to 4, 0.05, and for white pig iron 0.10. Sulphur in iron can cause excessive shrinkage as well as contraction, the former often being the cause for shrink holes and the latter for cracks in castings.*

Manganese, when increasing the combined carbon, will deepen the chill and cause greater shrinkage and contraction, and to a limit greatly strengthens iron.

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*For an article on the effects of sulphur in strengthening iron, see Chapter XLIII.

Manganese is readily absorbed by slag and can be carried off as oxide of manganese during a heat, and in cupola work will greatly assist in carrying off sulphur by means of " slagging out." Manganese ranges from a trace up to 3 per cent. in pig iron. The general run of good gray pig iron averages about .50; over 1.00 per cent. it would, in light work, unless proportionately higher than 2.50 per cent. in silicon, be injurious in causing hard castings, and it is seldom in massive work requiring strength that it would be beneficial for manganese to exceed 2.00 per cent. Manganese can counteract the red shortness caused by sulphur and greatly neutralize the effect of sulphur to harden iron mixtures. It can be used as a physic to purify liquid iron. If the iron is high in sulphur it will be beneficial in expelling it and thereby lessen the chances of " blow holes " by expelling oxides or occluded gases.

A very peculiar property that has been noticed in pig iron containing 2 to 3 per cent. of manganese is that while it may look open-grained, like a good No. 1 soft iron, it has been found so hard that it could only with difficulty be drilled. Manganese gives fluidity and life to molten metal, causing it to occupy greater time in solidifying. In pig metal, as well as in castings, it can cause the crystals to be coarse grained, though the iron can be hard, as above stated.

Manganese is often found as high as 2.50 per cent. in foundry pig metal and still make good machinable castings. This quality is partly due to the great activity which manganese has in expelling sulphur in remelting iron. Sulphur is the element of greatest power in causing hardness in castings; but, on the other hand, sulphur can often be so eliminated by manganese; that for this reason manganese can often be high and still soft castings be obtained. The better a cupola is fluxed and the higher its temperature, the more the manganese will be decreased. In making or remelting iron, manganese is affected in a manner somewhat similar to silicon. A hot working furnace will send the manganese into the pig, where a cold working furnace will send it into the slag, as it requires high heat to make manganese combine with the iron, when making it.

A phenomenon peculiar to manganese is to be cited in the opposite results which manganese exerts when in the pig, in process of being melted, and when it is added as ferro-manganese to soften hard grades of molten metal, as is practiced by some founders. The author cannot explain the phenomenon better than by here inserting comments by Mr. Alexander E. Outerbridge, Jr., in a paper presented by him before the Franklin Institute, February 2, 1888:

> A remarkable effect is produced upon the character of hard iron by adding to the molten metal, a moment before pouring it into a mould, a very small quantity of powdered ferro-manganese, say one pound of ferro-manganese in 600 pounds of iron, and thoroughly diffusing it through the mass by stirring with an iron rod. The result of several hundred carefully conducted experiments which I have made enables me to say that the traverse strength of the metal is increased from thirty to forty per cent., the shrinkage is decreased from twenty to thirty per cent., and the depth of the chill is decreased about twenty-five per cent., while nearly one-half of the combined carbon is changed into free carbon; the percentage of manganese in the iron is not sensibly increased by this dose, the small proportion of manganese which was added being found in the form of oxide in the scoria. The philosophical explanation of this extraordinary effect is, in my opinion, to be found in the fact that the ferro-manganese acts

simply as a de-oxidizing agent, the manganese seizing any oxygen which has combined with the iron, forming manganic oxide, which, being lighter than the molten metal, rises to the surface and floats off with the scoria. When a casting which has been artificially softened by this novel treatment is re-melted, the effects of the ferro-manganese disappear and hard iron results.

In the experiments conducted by the author (seen in Chapter XXXII.) he found that, in iron above 2.00 silicon, the addition of manganese to molten metal had a tendency to hold the carbon more in a combined form, which is the reverse of its action in low silicon irons, and partly in keeping with the above experience of Mr. Outerbridge.

Phosphorus is the element which differentiates "Bessemer" from "Foundry" iron, and generally ranges from a trace to 1½ per cent. in ordinary pig metal. In foundry iron it generally varies from 25 to 1.00, and it can be found in iron as high as 7 per cent. If iron exceeds .10 in phosphorus it is no longer regular Bessemer, and may be often classed as Foundry. To make this distinction between Bessemer and Foundry iron clear, Table 30 is presented:

TABLE 30—CHEMICAL ANALYSES OF FOUNDRY AND BESSEMER IRONS.

	No. 1 Foundry.	No. 3 Foundry.	No. 4 Bessemer.	No. 7 Bessemer.
Phosphorus	.60	.50	.09	.09
Graphitic Carbon	3 50	3.00	3.50	3.00
Combined Carbon	.15	.30	.35	.65
Silicon	3.00	2.25	2.00	1.25
Sulphur	.01	.02	.025	.050
Manganese	.30	.40	.50	.45

As can be seen by the above table, excepting phosphorus, the four analyses could pass as Foundry iron. Further comments on Foundry versus Bessemer will be found in Chapter XXII.

Over 0.75 per cent. of phosphorus can cause iron to be "cold short," which means brittle when cold, and it may harden iron if used in excess of 1.30 in castings.

By keeping phosphorus down to between 0.20 and 0.40, with silicon from 2.50 to 2.75 and sulphur about .05, thin castings can often be made so as to bend considerably before breaking, and also admit of cast iron being readily punched with holes, similarly in some degree as wrought iron would be affected by like treatment. It has been contended that phosphorus is in no wise beneficial to the strength of an iron, but Woolwich's experiments would show that phosphorus running from about 0.20 to 0.50 is beneficial in improving the ductile qualities in physical tests for cast iron work. Phosphorus is chiefly obtained from the ore and flux. It retards the saturation of iron for carbon and adds fluidity and life to metal. It is the most weakening element iron can possess when used in excess, and is often objectionable when it exceeds 1.00 per cent. in Foundry iron, in which it is best kept down to not exceed .80. Necessity for extra fluidity, or life, to the liquid metal is the only occasion where phosphorus should be permitted to exceed .80 in Foundry iron.

While phosphorus is an element very essential to the success of founding, it generally needs to be guarded as closely as sulphur or silicon, and an intelligent use of it will prove that it can strongly influence mixtures and the life and wear of castings. The author takes pleasure in citing here some experiences of Mr. James A. Beckett, of Hoosick Falls, N. Y., in experimenting in a practical way with phosphorus as an agent to regulate actual mixtures used in a foundry. He writes the author that he has found it to greatly counteract the tendency of sulphur to increase combined carbon and that he has, upon several occasions where high sulphur was giving trouble in making castings hard, by increasing the phosphorus from 0.50 to 0.75 made castings soft, that could not otherwise be machined. Of course, he could have attained the same end by increasing the silicon or reducing the sulphur, but conditions permitted Mr. Beckett to experiment with phosphorus in order to obtain knowledge as to its exact influence when the other metalloids were remaining fairly constant. His experience in this line is of much value, and it gives the author pleasure to record them here, as Mr. Beckett is known to be a good manager. Mr. Beckett's experience in regulating mixtures by phosphorus also affirms that generally each tenth of one per cent. increase of phosphorus will give about the same results, physically, that an increase of one-quarter of one per cent. silicon will give, if the phosphorus is unchanged, until the total quantity of phosphorus reaches the limit of safety, viz., 1.00 per cent., and that mixtures in which the fluidity is increased in this way within such limits will be found to produce castings freer from blow-holes and shrink spots than if silicon were entirely depended upon for giving fluidity. (See Chap. XXXI.)

Chromium, as shown by Thomas Turner,* is not uncommonly present in small quantities in ordinary iron ores. It has been found as high as .12 in samples of pig iron, by J. E. Stead.† It has increased the power of iron to absorb carbon up to 12 per cent.

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*Metallurgy of Iron, page 205.

†Iron and Steel Institute Journal, 1893, Vol. 1, p. 168.

Especial alloys of iron and chromium, called ferrochromes, containing as high as 84 per cent. of chromium, are shown by Turner to have been attained. He also says that though ferro-chrome is more refractory than ordinary cast iron, and is very fluid, it runs dead and solidifies rapidly and renders iron hard, white, and brittle, behaving in an exactly opposite manner from silicon or aluminum. Much more might be said of this constituent, but as it has been found up to the present time of little value to founding, space is reserved for more important elements.

The constituents of iron, carbon, silicon, sulphur, manganese, and phosphorus above described are recognized as the chief elements in controlling the character of iron. Aluminum, magnesium, sodium, potassium and calcium, as well as titanium, copper, and arsenic, are elements found in iron. But of late years little note is taken of them by chemists, as they have been regarded as having practically little if any weight in affecting mixtures or the character of commercial iron, and hence we have omitted to discuss their characteristic qualities to any length in this work. We may state that titanium ores were at one time used to some extent in obtaining strong iron, but owing to the titanic acid of titaniferous ores making an infusible slag and causing great trouble in smelting, they were seldom if ever used. However, by recent improvement, as seen on page 31, such ores may come more into practical use.

Commercially pure iron, the ideal held up by some works to be attained, is not the element iron free from every contamination, but iron with about 2 per cent. of carbon and free from sulphur, phosphorus, silicon, and manganese. In getting this iron to a fluid condition it will be so full of gas and run so sluggish that the casting, if obtained at all, will be full of blow holes. Add silicon to this iron and a good sound casting will result.

The physical properties of cast iron may be said to consist of density, tenacity, elasticity, strength, toughness, brittleness, and chill. These may all differ in having characteristic qualities in different brands or classes of iron. The first of these elements is to be attributed to what is called the "grain," and the degree of density is the basis of grading our iron by fracture from No. 1 (our most open, large-grained iron) up through Nos. 2, 3, 4, 5, 6 to 10; the latter two being almost as close-grained as a piece of glass, and generally called "white iron." A cubic foot of white iron weighs about sixty pounds more than a cubic foot of No. 1 iron. "White iron" will sink in a ladle of liquid No. 1 iron, whereas a piece of No. 1 would float on its surface.

Tenacity of cast iron is that element which resists a pulling apart of its body or a separation of its molecules, as by a tensile strength test.

Elasticity is that quality which permits cast iron to stretch or bend and then return to its original position or shape when the load is removed. Should the load be so great that the iron will not return to its original shape, it partakes of what is called a permanent set, or has overreached its limit of elasticity, a point which, when attained in cast iron, is very close to the breaking load.

Average cast iron, when sound, "stretches about .0018, or one part in 5,555 of its length; or ⅛ inch in 57.9 feet for every ton of tensile strength per square inch up to its elastic limit, which is at about one-half its break strength. The extent of stretching, however, varies much with the quality of the iron, as in wrought iron."* For further information on the stretching qualities of cast iron, see Chapter LV., page 422.

Toughness may be defined as strength, but applies more properly to that quality permitting cast iron to bend before it breaks, and in transverse testing, such is called "deflection."

Strength of cast iron is its ability to resist transverse, tensile crushing, and impact blows or strains, and, in a sense, includes tenacity, elasticity and toughness. It is very rare that castings are designed to resist other than transverse or crushing loads. For this reason transverse tests are the forms of testing mainly used to obtain knowledge of the strength of cast iron, as in securing the transverse strength of test bars, we can also note the "deflection," a quality which tells us of the ductility and toughness of iron better than any other present method can. Deflection also to a great degree informs us of the softness of iron.

Brittleness is that quality adverse to strength and is greatest in "white" or "chilled" grades of cast iron, also high-silicon or phosphorus mixtures.

Chill is that quality producing a "white" or crystalline body in iron. It can be produced by rapid cooling or by having high sulphur or low silicon, which produce, in the carbon, a state opposite that of graph-

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* Trautwine.

ite. It is a physical element desirable to exist in order to best resist friction surface wear, and is chiefly employed in such castings as rolls, car wheels and crushers. A special article on the "chill" will be found in Chapter LVI.

Whether the carbon in the iron is combined so as to create a "chill," or graphitic to make soft or open-grained iron, largely depends upon the time taken for the metal to cool down to solidification, or atmospheric temperature. We can take our softest irons, highest in graphitic carbon, and by pouring when liquid into water cause their carbon to be largely combined in the iron; and then, again, we can take our hardest or "white" irons, that are not high in manganese or chromium (qualities seldom to be found in general castings), and by pouring them into massive castings, like heavy anvil blocks, cause their carbon to appear largely of graphite, thus proving that it is chiefly a mechanical or physical condition, and not chemical, that ofttimes can cause iron to be soft or hard, or present peculiarities in its physical qualities.

The above illustration of pouring liquid iron into water and cooling off massive blocks or castings presents the radical extremes of any physical effects. In the rational, common practice of founding, conditions permit the chemical properties to have a control which compels us to recognize them as the chief factor in diminishing or increasing the combined carbon or the hardening qualities of an iron. Nevertheless, a study of what physical effects can produce will prove to many how two castings can often be poured from the same ladle of iron so as to have the same percentages of silicon, sulphur, phosphorus and manganese exist in the two castings, and still have the combined carbon much higher in one than in the other. (See pages 167 and 168.)

Concerning the principles involved in the strength of cast iron, we find the most lamentable ignorance exists. Some understand that there is such a thing as soft and strong grades of iron, but when you have the latter practice ignored and the first exacted until the product approaches lead, it is time to stop and see whither we are drifting. The machine builder, ignoring strength but finding his castings growing softer, has encouraged the foundryman in giving such soft castings, until to-day many of our machines might as well almost be made of so much glass. Such practice injures the reputation of cast iron and encourages its being replaced by steel, etc. It is not to disparage the founder that the author writes of this subject, but if possible to awaken thought and action toward a movement by the builders of machinery for the exercise of some reason and the attainment of knowledge as to where to draw the line at wanting softness at the sacrifice of strength. Before the founder knew so much about silicon, and had good luck in mixtures, his castings would generally show a rich, dark, open fracture, making a strong, soft casting, instead of being found, as to-day with many, in a close, silvery-grained grade, making a soft, rotten, leaden casting.

In using silvery or silicon pig to any extent in mixture there is a very fine line to be drawn in the use of just enough to attain the happy medium approaching strength and softness. Some would rather take their chances of being over the line than under it, and many have gone over the line so far as to have castings so weak as to break of their own accord.

CHAPTER XXX.

AFFINITY OF IRON FOR SULPHUR AND ITS STRENGTHENING EFFECTS.

Owing to a well-known writer having claimed that iron does not absorb sulphur, and that the founder has no need to fear its existence in castings, the author presents this chapter to prove that the contrary condition prevails. The following tests which the author made are such as can be repeated by any one who may be desirous of verifying this question:

TABLE 31—SULPHUR TEST.

No. of Test.	Quality in Casting.	Micrometer Measurement.	Contraction.	Deflection.	Broke at—in lbs.	Chill.	Strength per sq. inch.
18	Direct bar	1.100	6-32	.090	1385	½"	1457
19	Sulph. "	1.089	7-32	.050	1860	all.	1997

TABLE 32—CHEMICAL ANALYSIS.

No. of Test.		Silicon.	Sulphur.	Manganese.	Phosphorus.
	Iron charged.	.98	.015	.30	.092
18	Direct bar.	.77	.079	.31	.097
19	Sulph. bar.	.86	.175	.37	.097

Test bar No. 18 is one of four which were poured with iron direct from the cupola, with the ladle holding about 100 pounds of metal. After pouring these test bars, about 20 pounds of this metal was then poured into a hand ladle, the bottom lining of which was composed of fire clay mixed with about two and one-half ounces of pulverized brimstone. The 20 pounds of metal was allowed to stand in the hand ladle about forty seconds, when two test bars were poured, both of which, when broken, agreed very closely in strength. The stronger one of these is recorded as test bar No. 19. All of these test bars are of the round form and cast on end. It will be seen by a comparison of the analysis of these two test bars, Nos. 18 and 19, that the latter absorbed or contains .096 more sulphur than the bar which was poured direct from the cupola, and .160 more than the iron charged. In breaking these bars it will be seen that the high sulphur bar No. 19 stood 540 pounds more than the direct bar No. 18, thereby asserting that sulphur will strengthen iron. But whether or not such an increase in strength in test bars could be beneficial to castings will depend largely upon the internal strains which the addition of sulphur causes in increasing the contraction. This can be seen by Table No. 31, in which the sulphur bar will be seen to have contracted 1-32 inch more than the direct bar. I have conducted a number of experiments in adding sulphur to the molten metal with iron ranging from one per cent. to two per cent. of silicon, and have found it to increase the strength of the test bars. This is to be expected simply from the fact that sulphur increases the combined carbon. With two per cent. in silicon in testing one-and-one-eighth-inch round bars, I have found it to increase the strength only from 150 to 200 pounds, thus showing that the higher the silicon, the less effect the sulphur has in strengthening the iron to the limit of its absorption. Views of the fracture of the above bars, described in Tables 31 and

32, can be seen in Fig. 102, Chapter LX., page 473.

Iron absorbs sulphur most readily from the fuel when being re-melted. I have records of its increasing the percentage of sulphur in one re-melt from .030 to .105, with fuel below one per cent. of sulphur, and the iron charged averaging about 1.60 of silicon.

It is no uncommon occurrence for iron to be as high as three to four per cent. in silicon and to contain as high as .200 in sulphur, thereby proving that iron can be high in sulphur and at the same time high in silicon.

While sulphur can increase the strength of iron up to a certain limit, it is of such character as to greatly decrease resistance to deflection or elasticity of iron. On this account I would say that in such castings as chill rolls and ingot moulds, which have their surface and body subjected to high heat, requiring conditions in metal to admit of expansion and contraction following each other closely, excessive sulphur is to be guarded against, and in light or medium machinery it is injurious by increasing the contraction and chill or hardness of castings. The former element is injurious in causing internal strains, and the latter in causing castings to be harder than desired.

It is now (1901) universally conceded that iron has a great affinity for sulphur, and that it is an element often to be feared by both furnacemen and founders. The distribution of the first two editions of this work has done much in advancing the universal recognition of these two facts.

CHAPTER XXXI.

EFFECTS OF ADDING PHOSPHORUS TO MOLTEN IRON.

This chapter presents results which the author obtained by experimenting with phosphorus added to molten iron. Some of these experiments were originally presented in a paper by the author to the Pittsburg Foundrymen's Association, January, 1898. In conducting them the metal was caught at the cupola in a ladle holding about one hundred and fifty pounds. This was carried to the moulds and about thirty pounds was poured into a hand ladle into which sticks of phosphorus had been placed before pouring the metal, and then again by placing the sticks on top of the metal. This mixture was stirred with a small rod until the phosphorus was thought to have been all absorbed. In a natural way phosphorus increases the fluidity and life of molten metal, and can greatly weaken it. By the above method results are reversed and the metal made to lose its fluidity and solidify rapidly, and give stronger iron. For castings that can be poured with dull metal the addition of phosphorus may often be very beneficial in giving strong castings. The letters P.T. at the left of Table 33, page 231, designate the tests having the phosphorus added to the metal when in the ladle, and P. B. its being placed on the bottom of the ladle and the metal poured onto it, while R. I. refers to the metal free of the phosphorus addition.

All the bars were cast on end and tested 12 inches between supports. Those of tests Nos. 1 and 2 were made from patterns 1½ inches in diameter and the balance from 1⅛ inches diameter. The strength column of Table 33 shows the breaking load reduced to strength per square inch by the method shown on page 476. Each test shown is an average of from two to four bars. Tensile tests were made of tests Nos. 1, 2, 3, 4, 5, and 6. The 1½-inch bars with the phosphorus addition of No. 1 pulled 27,640 pounds, whereas the regular broke at 15,130 pounds, showing that the addition of phosphorus nearly doubled the strength of the iron in this case. Test No. 3, 1⅛-inch bars, averaged 23,790 pounds, whereas No. 4 averaged 17,617 pounds. Bars of test No. 5 averaged 26,070, and those of No. 6 16,890 pounds. A study of Table 33 will show that all tests were greatly strengthened by the slight addition of phosphorus to the molten iron, excepting test No. 10. The author believes this is due to the high silicon iron.

A study of the analysis of Table 33 shows that the addition of phosphorus drove out or decreased the silicon, manganese, and total carbon, the phosphorus acting as a flux to drive out oxides or impurities so as to leave a greater percentage of metallic iron in the higher phosphorus iron than existed in the regular iron, as is seen in the last column of the analysis at T. I. The effect of decreasing impurities, as shown, is in keeping with the treatment of Chapter XXXIV. Aside from the decrease of the impurities we find that the increase of combined carbon shown, caused by increasing the phosphorus, is also a factor that must have an effect in strengthening the iron. The increase of combined carbon causes greater contraction but less chill, a peculiarity due, no doubt, to the fact that hot metal will chill deeper than dull metal, as shown in Chapter LVI. However, the ends cast against chills were very dense and hard. Tests Nos. 1 to 6, with their analyses, were made by Dr. R. Moldenke at the McConway & Torley Co., Pittsburg, Pa., and tests Nos. 7 to 11 by the author, and the analyses by Mr. H. E. Diller at the Pennsylvania Malleable Co., Pittsburg, Pa.

There are several methods of adding phosphorus to molten iron. The simplest plan consists in introducing the phosphorus with the hand or with tongs. There need be no fear of the dampness on the sticks as they are taken from the water, for as long as water is on top of the metal no harm can result. Care should be taken in handling phosphorus by hand to do it quickly, as it ignites in a little more than one minute when exposed to the air and serious burns have resulted from careless handling. Another method used by some is to take a rod, to one end of which is secured a dried clay or graphitic core having a ⅝-inch hole extending into one end six to seven inches deep. Into this hole the phosphorus stick is inserted and held by means of sticking a few strips of tin or copper in the vacant space. Still another plan is to take a piece of gas pipe about three feet long, with a hole a little larger than the sticks of phosphorus, and after the phosphorus is inserted place a plug of tin about one-eighth of an inch thick to fit tightly into the end of the pipe. While introducing the end of the pipe into the molten metal the tin will melt quickly and allow the phosphorus to diffuse through the metal. To prevent the fumes of phosphorus escaping through the upper end of the pipe a plug of iron should be driven into the pipe some distance to permit the insertion of the phosphorus. Where several sticks of phosphorus are best inserted in the metal at one time, a device as seen in Fig. 50 may often be used. After quickly inserting the sticks of phosphorus into the receptacle A, Fig. 50, they are permitted to remain a few seconds until dry and showing signs of igniting, after which the receptacle is tilted gently to slide into the molten metal and held there until the phosphorus has been absorbed. A plan followed by some to permit sticks of phosphorus being handled without danger of taking fire is, to first prepare the sticks by placing them in a dilute solution of sulphate of copper, or a few crystals of blue vitriol placed in water held in a stone jar, for a period of thirty minutes or so. This process deposits a coating of copper on the sticks of phosphorus, which permits them to be handled without danger of taking fire as long as the copper coating is not disturbed. In removing the phosphorus from the solution in the jar some

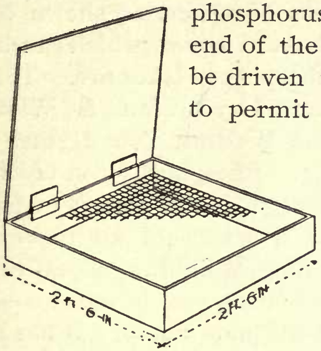


FIG. 49.—PAN FOR DRYING PHOSPHORUS.

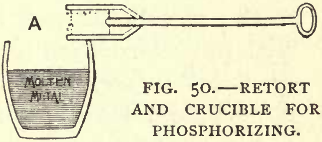


FIG. 50.—RETORT AND CRUCIBLE FOR PHOSPHORIZING.

The space between the iron rod and retort is made tight with a cement of mineral paint mixed to a stiff paste with linseed oil.

place the sticks on blotting paper resting on wire netting, supported in a pan four to six inches deep, containing about two inches of water, as shown by Fig. 49. This pan should have a cover, which can be closed air tight in case the phosphorus takes fire. This is a method which was presented by Mr. Max H. Wickhorst in a paper before the Western Foundrymen's Association, March 17, 1897. Phosphorus can be obtained from almost any druggist, and comes in the form of sticks about three-quarters of an inch in diameter and four inches long, weighing about two ounces, and is kept in corked bottles, etc., of water holding about half-a-dozen sticks of phosphorus. It has to be kept in water on account of its being a substance which will melt at about 111 degrees F., and ignite of its own accord if left exposed a few minutes to the drying influence of the air.

Another discovery of importance revealed by these tests is found in Table 34. This shows that an increase of phosphorus increases the fusibility of iron. This knowledge is valuable in showing that the lower the phosphorus the better, in castings such as annealing boxes and pots, ingot moulds, grate bars, etc., which are required to stand high temperatures. Up to the time the author presented his tests (see Table 34) there was no information obtainable designating what percentage of the metalloids was best in fire-resisting castings. With the information to be gleaned from pages 352 and 351 it will be seen that the lower the combined carbon, sulphur, and phosphorus, the better the iron to resist melting or high temperatures. This knowledge is very valuable in assisting to make mixtures for castings that are expected to resist high or melting temperatures.

TABLE 33.—COMPARATIVE TRANSVERSE PHOSPHORUS IRON TESTS AND ANALYSES.

	Test No.	Defl.	Str'gt	Phos.	Sil.	Sul.	Man.	G. C.	C. C.	T. C.	T. I.
1st cast, P. T.	1	.125	4,482	.161	1.48	.03	.65	2.10	1.85	3.95	6.271
1st cast, R. I.	2	.08	2,463	.088	1.53	.03	.68	2.90	1.20	4.10	6.428
2d cast, P. T.	3	.15	3,329	.136	1.46	.03	.58	1.80	2.44	4.24	6.446
2d cast, R. I.	4	.12	2,064	.095	1.48	.03	.60	2.48	1.84	4.32	6.525
3d cast, P. T.	5	.115	3,087	.173	1.32	.03	.63	1.84	2.19	4.03	6.183
3d cast, R. I.	6	.10	2,170	.093	1.37	.03	.65	2.66	1.50	4.16	6.303
4th cast, P. B.	7	.135	2,322	.144	1.20	.065	.63	3.30	.44	3.74	5.779
4th cast, P. T.	8	.125	2,001	.121	1.16	.068	.64	3.37	.43	3.80	5.789
4th cast, R. I.	9	.090	1,740	.090	1.40	.070	.65	3.45	.40	3 85	6.060
5th cast, P. B.	10	.070	1,386	.280	4.43	.090	.36	2.20	.82	3.02	8.180
5th cast, R. I.	11	.070	1,366	.213	4.45	.110	.41	3.06	.03	3.09	8.273

TABLE 34.—COMPARATIVE FUSION TESTS OF BARS RECORDED NOS. 1 TO 6, TABLE 33.

Diameter of Rolls.	1st Cast.		2nd Cast.		3rd Cast.	
	1½ ins.	2⅜ ins.	1½ ins.	2⅜ ins.	1½ ins.	2⅜ ins.
Time of dipping....	2:00	3:00	2:00	3:00	2:00	3:00
Time of total fusion lower phosph'us bars	2:03½	3:04¾	2:03	3:04¼	2:03¼	3:05
Time of total fusion higher phosph'us bars	2:02½	3:03½	2:02¾	3:03¼	2:02	3:03½
Differ'ce in time of melting........	1 min.	1¼ min.	¾ min.	1¼ min.	1 min.	1½ min.

The plan followed in testing the fusibility of the iron and phosphorus alloys in Table 34 and shown by Fig. 51, next page, displays two sizes of fusing test specimens. At H and K, on the left, are bars 1½ inches in diameter by 12 inches long, connected by a rod M. H and K, on the right of Fig. 49, are test specimens 2⅜ inches in diameter by 6 inches long. In casting these test specimens one was poured with a regular cupola metal, and the other with the metal after the phosphorus had been added in the manner described. By using a hook as at P, to let the test specimens sink into a ladle of molten metal, it will be readily seen that both bodies H and K must be subjected to exactly the same conditions of heat, etc., in testing their fusibility. By such a plan, if H melts down before K we have positive proof that H possesses a lower fusing point than K. The author has found this a very simple and inexpensive plan to test the fusion of mixtures, or the effect of any one of the metalloids on the fusibility of iron. Another good plan, devised and used by the author, is shown in Figs. 87 and 88, pages 416 and 417.

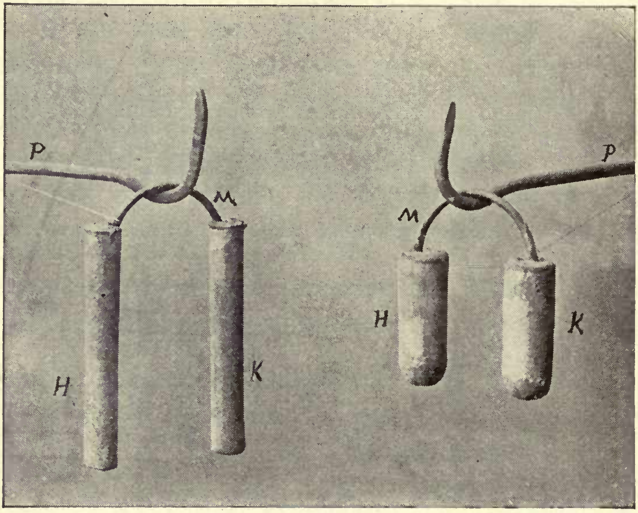


FIG. 51.

CHAPTER XXXII.

EFFECTS OF VARIATIONS IN MANGANESE ON DIFFERENT GRADES OF IRON.

This chapter presents the results of tests made by the author with a wide range of different grades of iron, having varying percentages of manganese, to give information that will be applicable to nearly all classes of founding. The tests far surpass anything previously presented for covering a broad field, and were originally presented by the author to the American Foundrymen's Association Convention at Buffalo, N. Y., June, 1901. The results shown in Tables 35 and 36 pages 236 and 237, verify some of the properties attributed to manganese and, the writer believes, amplify our knowledge of its effect on cast iron considerably. We shall first outline the methods of physical testing followed in this work.

The breaking strength and deflection given in columns 3 and 4, Table 35, are each the average of about four tests, two of the tests being from 1⅛-inch round bars cast on end, and two from 1-inch square bars cast flat, and used for obtaining the contraction and chill. All bars were tested 12 inches between supports.

The contraction tests recorded in column 5, Table 35, were obtained by casting square bars A and B in a frame C, Fig. 52. The contraction was measured by a graduated wedge D, the thickness of the point at which it settled between the bars and frame being measured by a micrometer, as at V, Fig. 55. The bars were 1 inch square by 24 inches long and poured by top gates, as shown. The chill was obtained by breaking off a piece at the ends as shown at E, Fig. 55.

To obtain the hardness tests, the writer arranged a drill press, as shown in Fig. 53. A bicycle cyclometer was attached to the upper body of the frame, at F, and then a light sheet iron ring was bolted to the upper shaft G, with an arm as at H. This arm came in contact with the cyclometer at every revolution of the shaft G, and recorded the exact number of revolutions made in a stated time, by a watch held in the hands of the operator as seen at I. In order to apply a constant pressure of the drill J on the test piece K, a weight L was suspended from the lower arm M, by a wire, at a given distance from the end, as shown. Three revolutions of the shaft G, equalled two of the drill. The machine could be stopped in a second by a lever at M. The same ½-inch drill was used for all tests, testing the softer specimens first, and the harder ones last. The drill was kept of a uniform sharpness for the bars of each cast. The drill ran 60 seconds for each test and the speed of the shaft G varied from 35 to 37 revolutions. An average of 36 revolutions was allowed in computing the depth of the holes made in 60 seconds and recorded in column 7. The tests obtained by this drill press proved very satisfactory. To obtain the depth of the hole a wooden pin O, Figs. 54 and 55, was set into the drilled holes, as seen at P, and a steel pin R, pressed into the wooden pin on a level with the top of the test specimen, as shown at R. After the

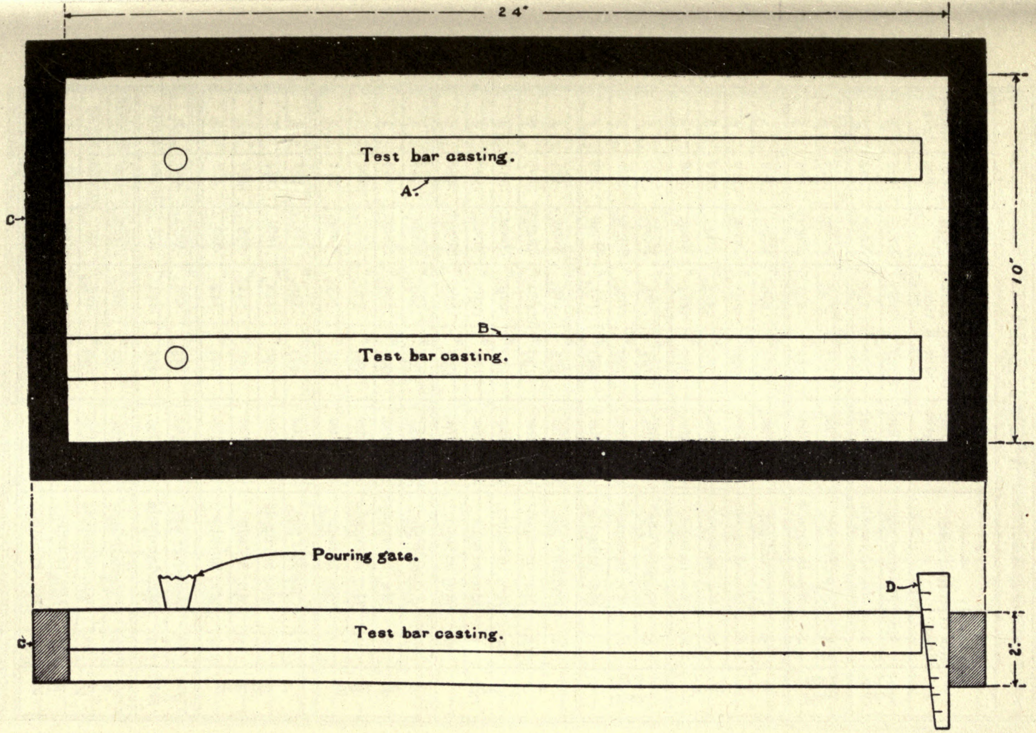

24"
Test bar casting.
A.
C
10"
B
Test bar casting.
Pouring gate.
D
Test bar casting.
C
2"

FIG. 52.

TABLE 35.

	1 No. of test	2 Iron used.	3 Breaking Strength.	4 Deflection	5 Contraction.	6 Chill.	7 Hardness.	8 Structure.
Heat No. 1	1.n	Foundry pig.	2,169 lbs.	.107″	.180″	None	.572	4
	2.	Mn. in cupola	2,268 lbs.	.110″	.231″	None	.122	5
Heat No. 2	3.	Foundry pig.	1,715 lbs.	.101″	.198″	None	.625	5
	4.	Mn. in cupola	1,808 lbs.	.082″	.237″	Slight	.415	5
Heat No. 3	5.	Charcoal pig.	1,510 lbs.	.075″	.276″	None	.438	3
	6.	Mn. in cupola	1,822 lbs.	.090″	.291″	None	.410	4
	7.	Mn. in cupola	1,654 lbs.	.072″	.315″	.025	.248	5
	8.	Mn. in ladle.	1,577 lbs.	.077″	.284″	None	.506	2
Heat No. 4	9.	Foundry pig.	1,428 lbs.	.101″	.125″	None	.730	3
	10.	Mn. in cupola	1,690 lbs.	.102″	.204″	Slight	.600	5
	11.	Mn. in ladle	1,763 lbs.	.083″	.161″	None	.705	4
Heat No. 5	12.	Foundry pig.	1,652 lbs.	.105″	.216″	None.	.553	3
	13.	Mn. in cupola	2,269 lbs.	.130″	.260″	Slight	.107	6
	14.	Mn. in ladle	1,995 lbs.	.100″	.229″	None	.532	4
	15.	Mn. in ladle	2,016 lbs.	.100″	.246″	None	.578	4
	16.	Mn. in ladle	2,122 lbs.	.095″	.279″	Slight	.490	5
Heat No. 6	17.	Foundry pig.	1,888 lbs.	.100″	.309″	None	.347	3
	18.	Mn. in cupola	1,794 lbs.	.097″	.320″	None	.282	3
	19.	Mn. in cupola	1,845 lbs.	.080″	.330″	.062	.204	3
	20.	Mn. in ladle	1,970 lbs.	.102″	.309″	None	.314	3
Heat No. 7.	21.	Charcoal pig.	2,355 lbs.	.095″	.339″	.128	.385	7
	22.	Mn. in cupola	2,331 lbs.	.090″	.348″	.166	.244	7
	23.	Mn. in ladle	2,394 lbs.	.100″	.341″	.055	.450	5
	24.	Mn. in ladle	2,310 lbs.	.102″	.340″	.040	.428	5
Heat No. 8	25.	Bessemer pig	1,701 lbs.	.125″	.226″	.300	.420	3
	26.	Mn. in cupola	1,497 lbs.	.055″	.242″	All	White	White
Heat No. 9	27.	Charcoal iron.	1,570 lbs.	.052″	.401″	1.375	.040	Mottled
	28.	Mn. in cupola	1,082 lbs.	.046″	.427″	All	White	White
	29.	Mn. in ladle	1,772 lbs.	.100″	.326″	1.100	.242	3
	30.	Mn. in ladle	2,066 lbs.	.095″	.322″	.830	.222	3

TABLE 36.

9 Sil.	10 Sul.	11 Mang.	12 Phos.	13 C.C.	14 G.C.	15 Total C.	1 No. of test
4.53	.025	.52	.194	.06	2.98	3.04	1.
4.40	.018	6.12	.178	.28	2.61	2.89	2.
4.51	.031	.48	.203	.07	3.19	3.26	3.
4.41	.023	2.62	.198	.23	3.01	3.24	4.
4.45	.110	.41	.213	.03	3.06	3.09	5.
4.31	.067	1.09	.210	.05	3.10	3.15	6.
4.30	.032	4.09	.192	.16	3.09	3.25	7.
4.52	.108	.51	.211	.03	3.05	3.08	8.
3.92	.034	.44	.164	.06	3.35	3.41	9.
3.88	.029	1.08	.156	.19	3.16	3.35	10
3.88	.029	.76	.162	.08	3.29	3.37	11
3.88	.031	.49	.194	.09	3.06	3.15	12
3.53	.020	3.53	.152	.30	2.87	3.17	13
3.82	.026	.68	.193	.11	3.22	3.33	14
3.62	.025	.87	.191	.11	3.39	3.50	15
3.74	.025	1.18	.192	.10	3.03	3.13	16
2.47	.030	.97	.255	.42	3.44	3.86	17
2.40	.022	2.26	.250	.45	3.38	3.83	18
2.41	.022	3.71	.231	.47	3.25	3.72	19
2.56	.038	1.16	.254	.40	3.44	3.84	20
1.88	.039	.26	.458	.61	2.92	3.53	21
1.69	.036	2.43	.435	.64	2.82	3.46	22
1.89	.035	.67	.455	.50	3.02	3.52	23
2.06	.033	.78	.457	.47	3.11	3.58	24
1.34	.076	.54	.087	.61	3.28	3.89	25
1.30	.061	5.11	.076	3.41	.17	3.58	26
.53	.070	.34	.407	1.14	2.66	3.80	27
.63	.042	2.84	.365	3.53	.15	3.68	28
.69	.068	.69	.420	.49	3.41	3.90	29
.74	.060	.74	.424	.62	3.28	3.90	30

pin O was removed it was set on a level clean surface, a wedge T passed along until it was stoppd by a pin, as at U. The distance the wedge passed under the pin U was measured by a micrometer at V, Fig. 55. The depth of such holes could also be measured by filling them with water and measuring it with a small graduate, shown at W, Fig. 55. The structure, column No. 8, is given merely to denote distinctions as made by the eye in judging the relative size of the crystals or grain of the fracture. For example, No. 2 stands for what would be expected of the grain in a piece of true No. 2 iron, and so on up with closer iron in the higher numbers.

The iron was melted in the twin shaft cupola seen in Fig. 56, the operation of which is explained in pages 325 to 327. The use of such a cupola is the most reliable one for making comparative tests, which involve delicate observations and affords a remarkably uniform conditions of fuel, blast, heat, etc., necessary to discover the true effects of changes in the elements composing cast iron. The fact that the tests in Table 35 were obtained with the use of the cupola, Fig. 56, gives the writer greater confidence in the results shown than he could place in any others obtained in the ordinary way of making separate comparative tests, that is, having one heat taken off one day and another some other day, with the differences in fuels, blast, and heat conditions that usually exist in making heats in ordinary cupolas.

In charging the cupola, Fig. 56, small pieces from the same pig were placed in each compartment and the ferro-manganese placed on one side only. For the second and fifth heats, shown in Table 35, two

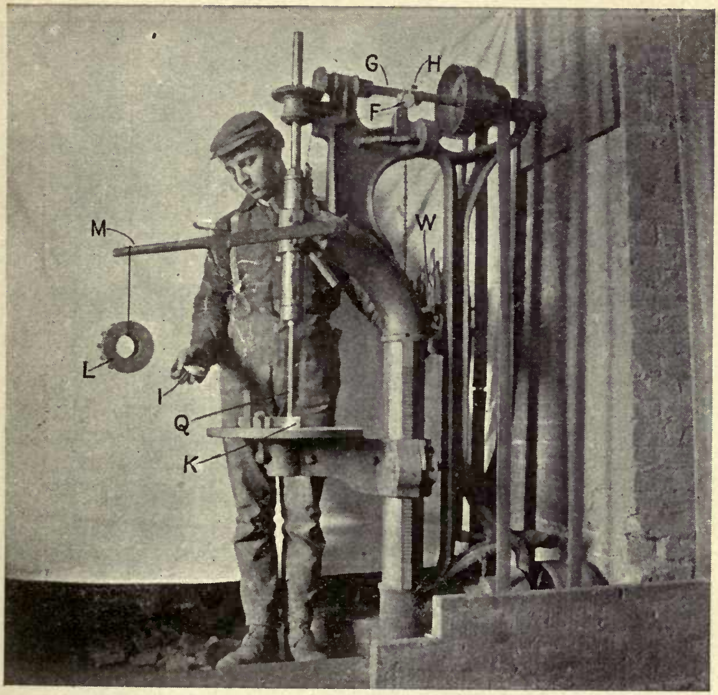


FIG. 53.

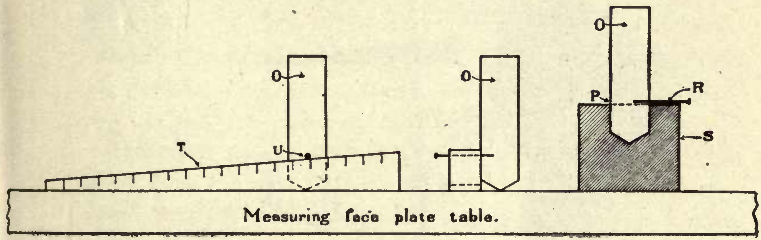
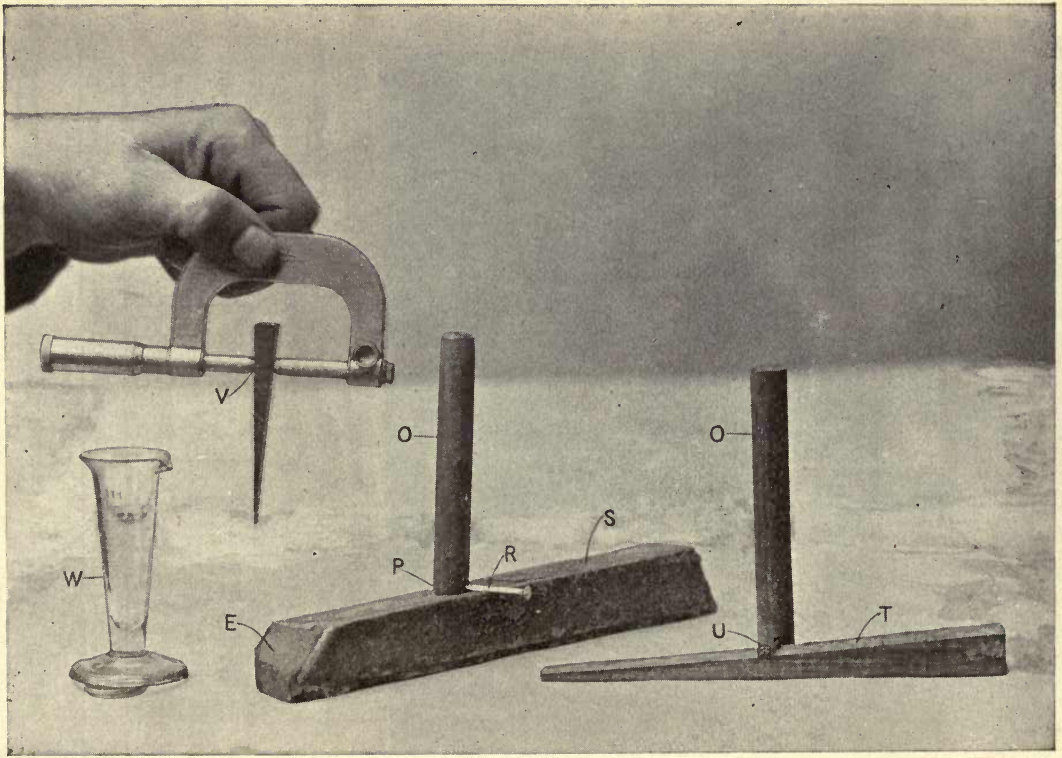


FIG. 54.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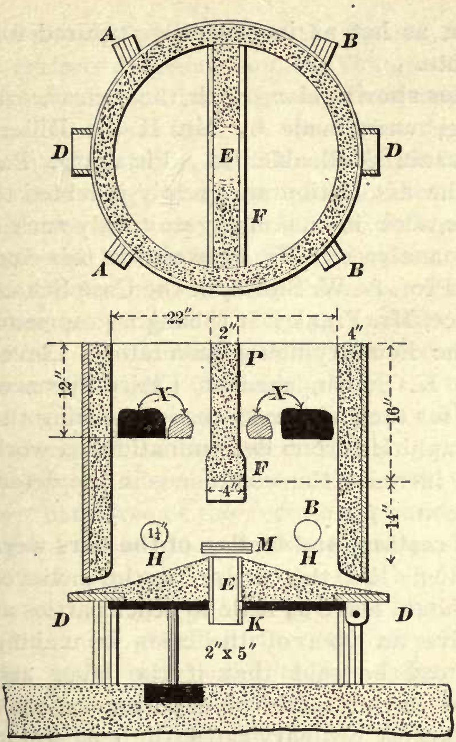

FIG. 56.

charges of pig iron with different percentages of manganese were made in the side containing the manganese. The weight of the charges was from 45 to 60 pounds of iron with a range of one to three pounds of manganese mixed with the charges. Heats Nos. 1, 2, 4, 5, and 6 were made of Foundry pig iron. Heats Nos. 3, 7, and 9 of Charcoal pig iron, and heat No. 8 of Bessemer pig iron. The analysis of the ferro-manganese was silicon 1.65, manganese 80.34, phosphorus .354, total carbon 5.85, and no sulphur.

In adding manganese to the metal in the ladle (this metal was always that coming from the side of the cupola free from the ferro-manganese mixture), it was broken to the size of a pea and thrown gently on top of the molten metal, and then stirred well with a half-inch rod until all melted and in mixture with the iron, which came down as hot as is generally required for pouring stove plate.

The 210 analyses shown, along with the extra work of cross-checking, were made by Mr. H. E. Diller, of the Pennsylvania Malleable Co., Pittsburg, Pa. The writer and the association are greatly indebted to Mr. Diller for his work in making gratuitously such a large number of analyses. We have also in this connection to thank Prof. A. W. Smith, of the Case School of Applied Science, Mr. Frank L. Crobaugh, proprietor and expert of the Foundrymen's Laboratory, Cleveland, O., and D. K. Smith, chemist, Claire Furnace, Sharpsville, Pa., for their able services in checking the combined and graphitic carbon determinations, a work done in order to increase the confidence in the determinations of carbon.

The moulding, casting, and testing of the bars were all performed chiefly by the writer, as he believes experimentors should leave as little to other parties as possible. To give an idea of the costs in making experiments, it can be said that if the labor and material involved in this series of experiments were computed at the lowest ordinary rates, the cost would reach about three hundred dollars.

In a general way, the addition of manganese to the iron in the cupola increases the hardness by raising the percentage of combined carbon, which means greater contraction and chill, with a decrease in deflection and elasticity. While it is true that manganese in cupola mixtures has the tendency just mentioned, a study of the tests given in Tables 35 and 36 will show that the variation of manganese generally existing in any one grade of pig iron will have very little if any effect on the physical properties of the casting, something which is entirely different from the changes due to the silicon and sulphur of irons coming from any one mixture of ores, flux, and fuel. A good test demonstrating this point is found in heat No. 6, which has 2.47 silicon in Foundry pig when remelted. Here we find that an increase from .97 to 2.26 — a difference of over 1.25 per cent. — of manganese in pieces of the same pig does not cause a chill in the ends of the square bars, when tested as at E, Fig. 55, and has only a difference of .011 in the contraction. By increasing the manganese still higher until we have 3.71 — nearly 3 per cent. of an increase — we then obtain a chill of only .062 in the ends of the bars, as at E, Fig. 55, and a difference of only .021 in the contraction over that found in the test bars free of the ferro-manganese mixture. Then again, the hardness tests, column 7, show a difference of but .065 and .143 in the depth of the drilled holes, as at P, Figs. 54 and 55, with the two variations in manganese. Still further, the structure, column 8, of the gray body exhibits no difference to the eye. Another point shown by this heat comes from the manganese placed on the molten metal in the ladle. Here we find that an increase of .19 in the percentage of manganese has made no difference in the contraction and a variation of but .033 in the depth in the hardness test. This shows that the addition of manganese in the ladle tends to slightly increase the hardness, which is contrary to what we have generally been led to believe by writers in the past. We are not confined to this one test to modify views of the past on this point, as the same result is also shown in heats Nos. 4, 5, and 6. However, when we get to low silicon irons, as in heats Nos. 7 and 9, we find that manganese in the ladle is very effective in softening the iron, or very sensitive in producing radical changes.

The effect of manganese on the strength of cast iron has a tendency, as a rule, to make iron stronger. In adding manganese to molten metal, the iron should never be dull, but as hot as practicable, in order that all the manganese may be melted in such a manner that a homogeneous mixture may result. Where iron is dull, a fracture may often show little bright spots or grains of manganese alloy that did not melt and mix properly with the iron. In such cases more harm is done than good. A study of the tests shows that the best results for strength were dependent upon certain percentages of increase. Anything above or below this was injurious. The increase of manganese in the molten metal ranged from 25 to 60 per cent. The effect of adding manganese to molten metal on the other elements shows an increase in the silicon and decrease in the sulphur, with phosphorus remaining fairly constant. With the manganese in the cupola, the silicon, sulphur, and phosphorus are decreased. The complete Table 36 of analyses affords one excellent material for study and information on these points.

One peculiarity noticed, in making these tests, was seen in the high manganese of tests Nos. 2 and 6 causing the sand to peel most freely from the castings and leaving a skin covered with flakes of graphite, whereas, with the same iron free from the ferro-manganese mixture the sand stuck strongly to the casting. All the bars poured with the iron having manganese added in the cupola showed this effect to a greater or less degree. No doubt this is the cause of some castings made of the same pattern peeling much more readily than others, with the use of the same grades of sand or facing and equal fluidity of metal, a phenomenon many have often been at a loss to understand. In regard to differences noticeable in the fluidity of the metal, there was little if any to be seen between the iron coming from either side of the cupola, but the addition of manganese to the molten metal in the ladle noticeably increased the fluidity.

Where founders desire a "white iron" of the best strength obtainable in castings, heats Nos. 8 and 9 would show that it can be readily obtained by mixing ferro-manganese with good strong grades of low silicon pig or scrap iron. Of course, white iron can be obtained with the cheapest grades of old scrap, but this will be much weaker than when good iron and ferro-manganese are used. The amount of manganese seen in heats Nos. 8 and 9, with the low silicon iron, is sufficient to make a casting having a section from three to five inches thick all white, when cast without the use of chill. Where sections are heavier a greater percentage of manganese will be required. It will appear rather strange to many to note the high silicon charcoal iron used in heat No. 3, as it is rare that such brands of iron exceed 2.00 per cent. in silicon. This iron was obtained from the Jefferson Iron Co., Jefferson, Texas. The charcoal iron in heats Nos. 7 and 9 was kindly donated by the Seaman-Sleeth Co., Pittsburg, Pa. Further information on the effects of manganese is found on pages 213 to 215.

CHAPTER XXXIII.

EFFECT OF VARIATIONS IN TOTAL CARBON IN IRON.

By utilizing the twin shaft cupola shown on page 241, the author has made comparative tests in several different ways, in an effort to discover the effect of changes in the total carbon in iron, all other elements being held fairly constant. This is a most difficult factor to determine, owing to the difficulty of adding carbon to iron as can be done with silicon and manganese. The author can now only present opinions founded on what might be called indirect tests. These tests, in brief, lead the author to say that an increase in the total carbon, with all other elements remaining fairly constant, increases the life or heat of molten metal, softens the iron, increases deflection and decreases its strength. Where high carbon exists it may cause a kish or scum to rise, which may often be the means of producing dirty or porous castings. Such results can often be remedied by lowering the carbon in mixtures, by the addition of low carbon pig metal or steels, etc.

It has been suggested that more interest should be taken in utilizing the changes in the percentages of carbon to effect changes in the grade of an iron, than in variations of silicon, as commonly practiced. This is an impractical proposition, for the reason that changes in the percentages of carbon in iron cannot be controlled sufficiently to regulate mixtures in everyday founding. This proposition is largely due to some advocating that the creation of the graphitic carbon is not regulated by silicon, but due chiefly to changes in the percentages of carbon. It is true that the higher the carbon, the more graphite there is in normally made and cooled pig iron or castings, other conditions being equal. Nevertheless, variations in the silicon and sulphur, especially the silicon, are chiefly responsible for variations in the graphite of different pig or castings. If those who think otherwise will take note of variations in the total carbon and the combined carbon they will find that, allowing for changes in the percentage of total carbon, the combined carbon varies closely with those of silicon and sulphur, especially the former; or, in other words, with a constant total carbon, sulphur, and manganese, etc., the higher the silicon, the lower the combined carbon and the higher the graphite, in normally made and cooled pig iron or castings.

Malleable founders notice that the heat of iron is to some extent dependent upon the carbon in it. As a rule the low silicon irons give them the highest carbon. When the exception to this rule takes place and they get low carbon in low silicon irons, which many prefer, they notice its heat effect in a very pronounced manner. Iron with less than 1 per cent. silicon may have carbon up to 4.50 per cent, while over 4.00 per cent. silicon iron may often not exceed 2.00 per cent. carbon.

To insure good fluidity it is not to be understood, by the above, that it is necessary to have carbon above 3.75. To obtain good fluidity, extra silicon, phosphorus, and often manganese are necessary to be combined with the carbon. It is by a proper combination of these four elements that the best fluidity and life in molten metal is obtained. Very high carbon or silicon can cause metal to be sluggish or thick on the surface, at either the furnace or foundry. Such iron can often be seen evolving a great deal of kish at the furnace, or a scum at the foundry, and makes it very difficult, when in iron, to obtain clean castings.

To obtain a thin or clean iron and one which will run quickly while it is hot, in making gray castings, use a mixture which will give castings having carbon 3.00 to 3.75, phosphorus .80 to 1.00, maganese .40 to .60, silicon 2.50 to 3.00; sulphur to be below .07. Such an iron, while running thin as long as it retains its heat, could be made softer and have longer life by increasing the carbon and silicon above the limits here shown, but by doing this the thinness, or quicksilver action, would be reduced unless phosphorus was increased, which would be liable to make the castings brittle. The higher the total carbon, the less silicon is required to maintain the grade and the higher can the carbon be held in a combined or graphitic state, other conditions being equal. See pages 280, 282.

CHAPTER XXXIV.

EVILS OF EXCESSIVE IMPURITIES IN IRON.

As a rule cast iron contains 92 to 96 per cent. of metallic iron, the balance being impurities such as carbon, silicon, sulphur, manganese, and phosphorus. While these latter five elements are essential in iron, an excess of their total percentages exceeding 6 per cent. of cast iron is generally injurious to the best strength. To illustrate how an excess of the above impurities can weaken iron, the following Table 37 is presented. The percentage of impurities and iron shown, also the strength tests, are obtained from the results seen in Tables 108 to 114, pages 536 and 537. By a study of the following Table 37, one should perceive that changes in the total percentages of the carbon, silicon, sulphur, manganese, and phosphorus can have quite an influence on the strength of castings. For example, the chilled roll mixture (Table 37) possessing only 4.803 impurities, as against 6.218 in the Bessemer mixture, with others between them showing a uniform decrease in strength, demonstrate that if the impurities exceed 6 per cent. of the total the iron generally decreases in strength according to the increase of impurities. One is not to be wholly guided by the results presented in Table 37, as any one can figure other tests, wherever found, and test the principles here set forth.

TABLE 37—PERCENTAGES OF IRON AND IMPURITIES IN WEAK AND STRONG CASTINGS.—SEEN ON PAGES 536 AND 537.

	Chill Roll.	Gun Metal.	Car Wheel.	General Machinery.	Stove Plate.	Bessemer Iron.
Iron..........................	95.197	95.120	94.988	94.100	92.473	93.782
Impurities............	4.803	4.880	5.012	5.900	7.527	6.218
Total	100.00	100.00	100.00	100.00	100.00	100.00
Strength of largest bar	5,013	4,355	4,263	3,786	3,011	2,860
Relative strength...	100.	87.	85.	75.	60.	57.
Relative estimated strength	100.	86.	84.	77.	81.5	68.

Impurities in charcoal pig iron are less, as a rule, than in coke or anthracite pig iron. This causes the "iron" to be higher in the former metal. It is now conceded that this is a great cause for charcoal irons excelling coke or anthracite pig metal in making strong castings, when intelligently used. The advantages of having high "iron" in castings requiring strength are illustrated in steel metal. This was ably set forth in a paper treating of the importance of having high "iron" in cast pig metal by the late Captain Henning of the Imperial Artillery, Berlin, Germany, before the local foundrymen's association, February 5, 1901, wherein he stated that steel castings show only .074 to 1.44 per cent. of impurities and 98.56 to 99.86 per cent. iron.

The results of the computation of iron as shown in Table 37 were first given by Mr. Whitney in a discussion of a paper by the author seen in Chapter LXIX. before the Foundrymen's association, Philadelphia, December 2, 1896. During the above discussion Mr.

Whitney dwelt at considerable length upon the practicability of estimating the strength of iron or castings by analyses, and was of the conviction that the day was not far distant when such would be generally accepted as being practical. How closely Mr. Whitney estimated the strength by analysis is shown by the relative estimated strength in Table 37.

The general method of estimating the iron in cast metal is by deducting the total of the silicon, sulphur, manganese, phosphorus, and carbon percentages from 100.00. If there have been any errors in figuring these various percentages they would, by the above calculating process, be then thrown all on to the iron, so that as a check to positively determine the iron in metal it is really necessary to weigh up the iron after the other elements are taken away from it, when making the analyses, or make an analysis of the iron only and then let such be recorded in a column adjoining that of the totals for the carbons. Of course, wherever the "iron" is not shown in analyses it can, by the above plan, be estimated as far as such is to be valued and thus be made to serve for obtaining the "iron" contained in any tests.

CHAPTER XXXV.

CHARACTER OF SPECIALTIES MADE OF CAST IRON.

The following table, No. 38, will afford a fair idea of the character of specialties now being made of cast iron:

TABLE 38.

1. Toys and statuary.
2. Locks and hinges.
3. Stoves and heating furnaces.
4. Hollow ware.
5. Bath tubs.
6. Furniture castings.
7. Piano plates.
8. Dynamos and Electrical Work.
9. Small pipe fitting and valves.
10. Radiators.
11. Pulleys.
12. Wood-working machinery.
13. Weaving machinery.
14. Farming implements.
15. Molding machines for founding.
16. Fans and blowers.
17. Printing presses.
18. Journal boxes, shaft hangers.
19. Lathes, planers, machine tools.
20. Street lamps and hitching posts.
21. Water and gas pipes.
22. Sidewalk grating and manholes.
23. Furnace and floor plate castings.
24. Sash weights.
25. Architectural castings.
26. Pneumatic hoists and machinery.
27. Gas engines.
28. Ammonia freezing machinery.
29. Air brakes and railway castings.
30. Steam and water pumps.
31. Hydraulic cylinders and machines.
32. Steam and blowing engines.
33. Hand and machine molded gears.
34. Mining machinery.
35. Punch, shears and dies.
36. Ingot molds and stools.
37. Annealing pots and pans.
38. Cannon, shot and shell.
39. Chilled car wheels.
40. Sand and chilled cast rolls.

Aside from the above classifications, there is a great variety of light and heavy castings used in different forms in the miscellaneous construction and use of castings. The list gives us about forty specialties, many of which call for different grades or mixtures of iron and some of which differ very radically. Those ranging from Nos. 1 to 9 generally call for variations in what is known as the softest grades of iron. Those ranging from Nos. 10 to 22 generally require variations in the medium soft grades of iron. No. 23 can generally be made of harder iron than permissible in the numbers above it. No. 24 is generally made of the poorest refuse of iron, consisting often of old rusty stove plate, burnt grate bars, and annealing pots, also tin sheet scrap iron. A mixture of these inferior grades generally gives a hard white, or very brittle grade of metal. Nos. 25 to 29 are a class of castings that will generally require a different mixture and a harder iron than those ranging from Nos. 10 to 22. Nos. 30 to 35 are specialties which generally call for as strong grades of iron as can be finished in lathes, planers, etc. Strong grades of iron can be made so hard as to make it difficult to turn or plane them in finishing such castings. Charcoal iron is often largely used in these latter grades, whereas, in Nos. 1 to 29 it is rare that such is used, as coke iron can generally be made to answer all purposes. Nos. 36 and 37 require a grade of iron very distinct from the other specialties shown, owing to such castings having to stand radical changes of temperatures, which cause an action of alternate expansion and contraction while the castings are in use. Iron of a medium soft character and low in phosphorus, or what is termed regular Bessemer, is found best for such castings. The cannon of No. 38 calls for a grade of iron that should be of fair ductility, but at the same time possess the greatest strength to be obtained. Cannons are generally made from the best brands of charcoal iron melted in an air furnace, which is superior to a cupola in giving the best grades of iron for such castings. Nos. 39 and 40 are made of what are called chilling irons, and which may be composed of a mixture of charcoal and coke irons, or of all charcoal iron. The rolls are best made of iron melted in an air furnace, although many are cast with iron melted in a cupola. Chilling irons differ most radically from the grades or brands generally used in the specialties Nos. 1 to 38. For information on making mixtures for specialties herein described, see Chapters XXXVI. to XLIII. pages 255 to 292.

CHAPTER XXXVI.

METHODS FOR CALCULATING THE ANALYSES OF MIXTURES.

Some adopting chemistry in making mixtures of iron have the impression that iron should come from the furnaceman to them possessing the exact analysis required for charging. It is rare that furnacemen can do this. In our practice, although surrounded by blast furnaces from which we may obtain iron, we are often compelled to accept two or more different grades of extreme variations of silicon, etc., in order to make a mixture desired. As a rule, two or three different grades will often have to be accepted, especially by those using a large amount of iron, in order to obtain the average which should be charged. (See Chapter XXI., page 155.)

To illustrate methods that will utilize iron of different grades as used by the author and others, we will suppose that a charge of 2,000 pounds having an average composition as shown in Tables 39 and 40 is desired. These tables show that by a mixture of three different grades of iron and two of scrap, an average of 2.00 silicon, .032 sulphur, .62 manganese, .435 phosphorus, and 3.80 carbon, as shown in Table 41, is obtained in the iron to be charged into the cupola Another plan is to divide the weight of each kind of iron into percentages, after the method seen in Table 42.

TABLE 39—CALCULATING THE SILICON.

Brand and Grade of Iron Used.	Weight of Iron Used.		Percentage Silicon.		Total Points of Silicon.
No. 1 Flora	600 lbs.	x	2.80	=	1680.00
No. 3 Clara	400 lbs.	x	2.26	=	904.00
No. 6 Frank	300 lbs.	x	1.50	=	450.00
Shop scrap	200 lbs.	x	1.80	=	360.00
Yard scrap	500 lbs.	x	1.25	=	625.00
	2,000 lbs.				4019.00

TABLE 40—PERCENTAGES OF SULPHUR, MANGANESE, PHOSPHORUS AND CARBON IN THE DIFFERENT IRONS.

Brand and Grade of Iron Used.	Weight of Iron Used.	Sulphur.	Manganese.	Phosphorus.	T. Carbon.
No. 1 Flora...	600 lbs.	.01	.60	.30	3.50
No. 3 Clara...	400 lbs.	.01	.70	.40	3.70
No. 6 Frank.	300 lbs.	.03	.80	.50	3.90
Shop scrap...	200 lbs.	.05	.60	.40	4.00
Yard scrap...	500 lbs.	.07	.50	.60	4.10

TABLE 41—RESULTS OF COMPUTATION OF TABLES 39 AND 40.

4019.00 pts. silicon -:- 2,000 lbs. = 2.00 per cent silicon.
64.00 pts. sulphur -:- 2.000 lbs. = .032 " sulphur.
1250.00 pts. manganese -:- 2,000 lbs. = .62 " manganese.
87.00 pts. phosphorus -:- 2,000 lbs. = .435 " phosphorus.
38400.00 pts. carbon -:- 2,000 lbs. = 3.80 " carbon.

TABLE 42—METHOD OF CHECKING TABLE 39.

Brand and Grade of Iron Used.	Per cent of Iron Used.		Per cent of Silicons.		Total per cent of Silicon in 100 Parts.
No. 1 Flora	30	x	2.80	=	84.00
No. 3 Clara	20	x	2.26	=	45.20
No. 6 Frank	15	x	1.50	=	22.50
Shop scrap	10	x	1.80	=	18.00
Yard Scrap	25	x	1.25	=	31.25
	100 parts			=	200.95

One part equals about 2.00 per cent of silicon.

The total of 1.00 parts giving us 200.95 of silicon, one part will equal about 2.00 per cent. of silicon, the same as obtained by the methods shown in Table 39, and shows one method to be an excellent check for the other. It is true Table 39 only deals with the silicon, but it can be seen by Table 41 that its principles will also hold good for figuring the percentages of any of the metalloids. It will be noticed that in obtaining the average percentages of the silicon, manganese, and carbon they are figured to the second decimal, and the sulphur and phosphorus to the third.

The grade of scrap iron used is judged by the appearance of its fracture after the plan described in Chapter XLII., and the change which takes place in remelting the iron to reduce the silicon and manganese and increase the sulphur and phosphorus of the mixture charged is described in Chapter XLIV. This change is such that, with a mixture as per Table 41 and charged into a cupola, the resulting castings would contain about 1.70 to 1.80 silicon, .05 to .06 sulphur, .45 to .55 manganese, .48 to .55 phosphorus, and 3.75 to 3.90 total carbon.

While for definite calculations Tables 39 to 42 are presented, there are cases where one may utilize different percentages of silicon, sulphur, etc., by mere mental calculation, after the ideas seen on page 141, that may answer all practical purposes. While the rules of Tables 39 to 42 may appear, at first, complicated, to those unaccustomed to such computations, they would, with a little practice, soon find the methods very simple.

CHAPTER XXXVII.

CONSTRUCTION OF CHEMICAL FORMULAS AND EFFECT OF PHYSICAL ELEMENTS IN CASTING CHILLED WORK.

Chemistry has proved of greater benefit in making mixtures for chilled castings than in any other line. When the progressive founder thinks back to the days when the chill roll, car wheel, and other manufacturers were guided wholly by judgment of fracture in selecting their pig metal to make a mixture, he is not at a loss to comprehend why such bad results in castings were then obtained, accompanied by heavy financial losses.

In making grey iron castings, there is a much greater margin for a divergency from the best point to be reached as regards the "grade" desired than with chilled work. In many cases where soft work is wanted it may be found very hard and still be passed, or do no injury other than cause extra labor in finishing the castings, etc.; but as a general thing if chilled mixtures diverge much from the best point to be attained, the castings will prove worthless by reason of "chill cracks" or the "chill" not be of the depth or quality of hardness desired. It is true that most chilled work founders would take "chill tests" of their mixture after they had melted their irons. This would to a great extent be a guide for their next "heat," providing the pig metal to be used was exactly the same. In melting iron in an "air furnace" there is a chance to change its composition from what a "chill test" might prove it, before the metal would be tapped or poured into a mould; but with cupola work such a practice is not permissible. Small cupolas may, in some cases, be used to test pig metal before it is used in regular cupola mixtures, but analyses are generally a cleaner and preferable plan. It is only where analyses cannot be obtained or relied on that testing pig metal in small cupolas, before being used in regular mixture, is a plan which it may, in some cases, be well to adopt.

The above treatment of this subject is not to be taken as decrying the plan of taking "chill tests" of mixture in any or all cases, as such course is advisable under all circumstances, since it enables a founder having experience to form a close estimate of what he has obtained in his castings and assists him to know whether a change in the chemical properties would be advisable for any following heats. Chilled work will always crystallize in planes at right angles to the chilling surface of the iron mould used for chilling the casting. A standard chill which the author has devised for testing the "chill" of iron can be seen in Chapter LXIX.

The factors most constant in testing the chill of an iron are heat and friction. Heat is the best factor for testing the durability of such castings as rolls, and friction those like car wheels. It is not to be taken for granted, as held by many, that "white" or chilled iron has no degree of hardness or that the depth of a chill determines the hardness, for this is not true. We may have two castings of exactly the same depth of a chill or that may be wholly "white iron" and still find a difference in the hardness of iron. A good article on testing hardness, etc., appears on page 434.

The success of chilled work is as dependent upon the degree of hardness of the chill as upon its depth. One set of conditions may exact a harder chill than another, and what may prove best in one line of work may be a failure in another; as, for example, the same kind of chill would not answer as well for paper or calender purposes as for steel or iron rolling. Variations in sulphur, manganese and phosphorus are chiefly potential in giving a special character to the hardness of a chill.

For "friction wear," as with car wheel, high sulphur will give better life than high manganese combined with low silicon, to cause chill. For "heat wear," hardness or chill is best obtained by high manganese in preference to sulphur combined with low silicon. Chilled iron is rarely, in any case, a homogeneous mass, and sulphur, more than any other element, retards the union of the molecules to best attain tenacity in the life and wear of iron subjected to heat. While it is true that we find in present practice that hardness is generally obtained by the higher sulphur, as can be seen from many of the analyses shown herein, and others recorded, still wherever manganese can be applied in preference to sulphur, to affect the carbon, in giving hardness to chill rolls, etc., better results in preventing surface cracks, etc., may be expected. A chill which is chiefly promoted by manganese will prove more yielding to strains and not so liable to chill-crack from heat as a chill which has been chiefly promoted by sulphur.

Then again, manganese causes a more gradual decline from the white to the grey in chilled castings than does sulphur. It is claimed that this same effect is caused by the use of low phosphorus iron, and is so radical that it makes the interlacing of the grey and chilled bodies very pronounced, as shown in Fig. 57, page 264. In referring again to manganese, it can be said that its effect to harden is often partly neutralized by the sulphur it expels, hence its power to increase hardness may sometimes be very small and often call for a large increase of manganese before it can produce any pronounced effect.

Professor Ledebur's division of carbon into four states, wherein he describes the elements (as seen in Table 44, page 267) existing in carbon as hardening, carbide, graphitic, and temper-carbon, is a factor that some believe may account, in some cases, for like depths of chill not presenting like degrees of hardness, also to account for other qualities in physical effects which at present are not clearly defined. The professor treated this subject in a paper before the Iron and Steel Institute, found in their Proceedings, No. 2, 1893. Some are of the opinion that the differences seen in the grain of charcoal from coke iron, although the former may carry higher graphitic carbon, is due to there being a relatively larger per cent. of graphitic temper-carbon in charcoal than in coke iron, which is formed while the carbon is in a transition state toward graphite. It is unfortunate, as stated by Professor Ledebur, that there is no known method of analyzing graphitic temper-carbon, or that it can only be determined by being estimated with the graphite. If this could be determined there would be much more interest taken to note its effect in castings.

In making chilled work, it is essential to understand the various effects which the different metalloids have in controlling the combined carbon, associated with a knowledge of the individual effect of each metalloid in regulating the character of the hardness best calculated to stand the wear of friction or heat, as outlined in the former part of this Chapter.

In a general way it can be said that the percentage of the chemical constituents which combine to make chill castings ranges in silicon from 0.50 to 1.10, manganese from 0.55 to 1.50 per cent., phosphorus from 0.20 to 0.70 and in sulphur from .02 to .10, with the total carbon from 2.50 to 3.75.

The quality to be first understood is the depth of the chill and hardness desired in a casting; second, the chilling properties of the iron to be used. To make a comparative test in order to learn of the chilling qualities of an iron by casting chill specimens, it should be remembered that "hot iron" will chill deeper than "dull iron," and that note should be taken of the same, in connection with the other elements of chilling, as outlined in Chapter LVI. It is also to be remembered that manganese will give longer life to the fluidity of metal than sulphur, where preference can be given either, in producing the combined carbon. It is very important in assisting to prevent "cold shuts" or "chill cracks," when pouring a mould, to have the metal run freely, and hence the advantage of manganese over sulphur, as above stated.*

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* Information on the thickness of chills, methods for making and pouring "chilled" castings, also making clean and smooth and perfect work, can be found on pages 272 and 276 in "American Foundry Practice," and page 234 in "Moulder's Text-Book."

CHAPTER XXXVIII.

MIXTURES FOR CHILLED ROLLS, CAR WHEELS, ETC.

The use of chilled castings has grown to such an extent that we find the following chilled specialties being manufactured: Rolls for various purposes, car wheels, crushers for breaking ore, etc., squeezers for balling iron, die presses, anvils, armor for inland fortification, shot and shell, axle bearings, grinding and grist machinery, switches for railroads, turn-tables and transfer plates, boiling pans for various chemical purposes, cutting tools, plows, and numerous other specialties that might be mentioned to illustrate the extent to which the manufacture of chilled castings is used.

In making mixtures for chilled rolls, it is generally necessary to consider the thickness through the neck and body of the rolls, the thickness of chill desired in the castings, and whether they are to be used for cold or hot rolling; also the thickness of the chill mould used and the temperature of the metal in pouring, as seen by Chapters LI. and LVI. The thickness of chill is, in some cases, desired from ½ to ¾ inch, and then again from ¾ to 1 inch. It is rare that more than 1¼ inches thickness of chill is desired in rolls. The founder is supposed to have such a control over mixtures that he can attain to within a ¼ inch of the chill thickness desired. Then again, some users prefer a sharply defined chill joining the gray body, while others prefer the chill and gray body to interlace or mingle with each other when combined. This feature is well displayed in the chilled section of car wheel seen at AB, Fig. 57, tendered the author by the Pennsylvania Car Wheel Co. of Pittsburg, Pa. This factor is further treated in Chapter XXXVII., page 260.

FIG. 57.—SECTION OF CHILLED CAST IRON CAR WHEEL.

Chilled rolls for hot rolling require different qualities than those used for cold rolling, and are a type of rolls subjected to the greatest abuse. This abuse lies in alternate expansion and contraction which takes place in the outer body of the rolls, being suddenly heated to about 500 degrees F. and then cooled to the atmosphere. The force of this power is often noticeable in remelting rolls in air furnaces, where from sudden heating of the outer body they will crack, in two or more pieces, with an explosion that can often be heard for quite a distance. Rolls for hot turning should not only be of such a character as to withstand the above alternate strains, but possess a solid, hard surface free of all defects, that will not spawl or shell off by usage, and a depth of chill which will permit the face being trued up occasionally until the chill is nearly worn off.

The character of iron used for chilled rolls consists largely of cold and hot blast charcoal iron, often mixed with broken rolls, car wheels, and sometimes steel scrap. Cold blast charcoal combines strength with ductility more than any other iron and excels all other brands for the manufacture of chilled rolls. Charcoal iron of Salisbury and Muirkirk brands are generally considered as excellent irons for chilled rolls, car wheels, etc. Many in making rolls will use a good deal of old car wheels and steel scrap in their mixtures. For an example, the author has used a mixture of 1,300 pounds of old car wheels and 300 pounds of steel rail butts for making rolls about 14 inches in diameter that required 1½-inch thickness of chill. Wherever scrap is used in mixture with pig, care must be taken to have it of as uniform a grade as practical. Another mixture consisted of 1,000 pounds of car wheel scrap, 500 pounds of No. 4, and 500 pounds of No. 5 charcoal iron. It is to be remembered, wherever we refer to grade numbers, that they are supposed to contain silicon and sulphur agreeing with table 22, page 152; and by referring to the analysis of the car wheel seen on page 268 one can perceive about what constituents the above scrap should contain. For further information on adding steel scrap to iron mixtures and melting it, see " Moulder's Text-Book." Some select car or other chilled scrap by the thickness of the chill, but since it has become known that the pouring temperature can vary the depth of a chill in castings, as seen by Chapters LI. and LVI., it is best to be guided by analyses of the grey body of the chilled castings or scrap.

The impracticability of formulating standard mixtures will be realized after a study of the varying conditions which must be met in actual practice. Each founder must formulate his own mixtures, based upon the principles shown in this and the preceding chapter. It may be stated that mixtures for chilled rolls, which include any scrap used as well as the pig, may often range in analysis when ready for charging as per Table 43. The wide variations in the sulphur, manganese, and phosphorus seen is given for the purpose of showing the range generally necessary to cause the different character of chills often required, as seen by a study of the preceding chapter.

TABLE 43—APPROXIMATE ANALYSES FOR CHILLED ROLL MIXTURES.

Diameter of Rolls.	Silicon.	Sulphur.	Manganese.	Phosphorus.	Total Carbon.
8″ to 10″	1.00	.01 to .06	.15 to 1.50	.20 to .80	2.60 to 3.25
12″ to 14″	.80	.01 to .06	.15 to 1 50	.20 to .80	2.60 to 3.25
16″ to 18″	.70	.01 to .06	.15 to 1.50	.20 to .80	2.60 to 3.25
20″ to 22″	.60	.01 to .06	.15 to 1.50	.20 to .80	2.60 to 3.25
24″ to 26″	.50	.01 to .06	.15 to 1.50	.20 to .80	2.60 to 3.25

To illustrate Professor Ledebur's division of carbon in rolls, referred to in Chapter XXXVII., page 261, Table 44 is given. Iron is melted in both air furnaces and cupolas for casting rolls. The air furnace is the best for melting such mixtures as it gives a purer metal, on account of not compelling the iron to be in contact with the fuel when being melted, as it is in cupola practice. In melting iron in air furnaces care must be exercised to avoid an oxidizing flame, as this can deteriorate the metal and often leave it no better than cupola iron. For sand roll mixtures, see page 273.

TABLE 44—ANALYSIS OF TWO ROLLS THAT STOOD WELL.
BY PROF. A. LEDEBUR.

	Roll 1.	Roll 2.
Hardening Carbon	0.58	0.45
Carbide Carbon	2.43	0.46
Graphite and Temper Carbon	0.19	1.93
Total Carbon	3.20	2.84
Silicon	0.83	0.80
Manganese	0.15	0.16
Phosphorus	0.88	0.88
Sulphur	0.10	0.10

The main difference between mixtures for chilled rolls and car wheels lies in coke iron being used in mixture with charcoal iron—or alone, for the latter—and the iron being melted in a cupola instead of an air furnace. A few have used steel scrap in mixture with pig iron for car wheels, but in such cases great care has to be exercised to procure a uniform product of steel. The more general practice is to depend upon pig iron that has been melted in a small cupola to test it physically as well as chemically before it is used in the regular cupola, where it may be mixed with old car wheels and shop scrap. The following Table 45, taken from an excellent paper on "The Manufacture of Car Wheels" by Mr. G. R. Henderson before the American Society of Mechanical Engineers, Washington, May, 1899, presents the analyses of seven wheels which had given from eight to eleven years of service. An analysis ot a good wheel by Mr. A. Whitney is also given in Table 46.

TABLE 45.

Graphitic carbon	2.56 per cent to 3.10 per cent.
Combined carbon	.63 " " " 1.01 " "
Silicon	.58 " " " .68 " "
Manganese	.15 " " " .27 " "
Sulphur	.05 " " " .08 " "
Phosphorus	.25 " " " .45 " "

TABLE 46—ANALYSIS OF A REMARKABLY STRONG CAR WHEEL.

BY MR. A. WHITNEY.

Combined Carbon.	Graphite.	Manganese.	Silicon.	Phosphor.	Sulphur.	Copper.
1.247	3.083	0.438	0.734	0.428	0.080	0.029

In Tables 47 to 50 we show an analysis of car wheels given in a paper by Mr. S. P. Bush before the Master Car Builders' Association, which were obtained through the labors of Mr. F. D. Casanave and Dr. C. B. Dudley, both of the Pennsylvania Railway Co. In referring to these wheels, Mr. Bush says: "Twenty wheels were selected from those in service, representing some of the principal makes of the country, all of which were subjected to the thermal test, ten passing it successfully and ten failing. Chemical analyses were made of the iron of which these twenty wheels were cast, two sets of samples being taken—one from the body, or gray iron, and the other from the chill. The result of these analyses is as follows:

TABLE 47—ANALYSES OF THE GRAY IRON. STOOD THERMAL TEST.

T. C.	G. C.	C. C.	Man.	Phos.	Silicon.	Sulphur.
3.68	3.00	0.68	0.64	0.30	0.56	0.11
3.54	2.74	0.80	0.28	0.47	0.65	0.10
3.50	3.48	0.02	0.35	0.40	0.45	0.13
3.65	2.41	1.24	0.31	0.53	0.57	0.16
3.73	2.89	0.84	0.88	0.38	0.50	0.11
3.63	3.03	0.60	0.44	0.43	0.56	0.12
3.67	2.70	0.97	0.24	0.38	0.53	0.10
3.67	3.03	0.64	0.32	0.42	0.47	0.16
3.64	2.53	1.11	0.33	0.50	0.62	0.12
3.86	3.31	0.55	0.30	0.36	0.63	0.11

TABLE 48—DID NOT STAND THREMAL TEST.

T. C.	G. C.	C. C.	Man.	Phos.	Silicon.	Sulphur.
3.64	2.41	1.23	0.30	0.35	0.71	0.14
3.22	1.98	1.24	0.34	0.51	0.77	0.16
3.51	2.56	0.95	0.31	0.44	0.75	0.12
3.64	2.30	1.34	0.21	0.39	0.65	0.13
3.61	2.52	1.09	0.17	0.35	0.60	0.11
3.61	2.94	0.67	0.33	0.42	0.79	0.12
3.72	2.60	1.13	0.23	0.35	0.66	0.11
3.68	2.54	1.14	0.19	0.39	0.88	0.12
3.74	2.57	1.17	0.30	0.41	0.60	0.13
3.45	2.39	1.06	0.40	0.36	0.68	0.19

TABLE 49—ANALYSES OF THE CHILLED IRON.

Stood Thermal Test.			Did Not Stand Thermal Test.		
Total Carbon.	Graphitic Carbon.	Com. Carbon.	Total Carbon.	Graphitic Carbon.	Com. Carbon.
3.90	0.43	3.47	3.90	0.34	3.56
3.71	0.32	3.39	3.37	0.32	3.05
3.73	0.42	3.31	3.71	0.43	3.28
3.70	0.55	3.15	3.75	0.78	2.97
3.87	0.41	3.46	3.74	0.49	2.25
3.77	0.55	3.22	3.77	0.30	3.47
3.84	0.35	3.49	3.86	0.48	3.38
3.84	0.40	3.44	3.80	0.41	3.39
3.71	0.49	3.22	3.82	0.29	3.53
4.01	0.30	3.71	3.56	0.36	3.20

"These figures cover determinations actually made. It was not deemed essential to determine the phosphorus, silicon, and manganese in the chills, as there was no reason to think that they would differ in proportion from the same elements in the gray iron. In reality all borings for the two analyses were obtained not over three or four inches apart in the same wheel, the one being from the gray iron in the plate and the other from the chill. It will be noted that in the gray iron the graphite is pretty well toward 3 per cent. and that the combined carbon is toward 1 per cent., while in the chill the figures are reversed, the variations being not far from one-half of 1 per cent. The figures giving the analysis of the gray iron are given for a comparison and as a matter of information."

"**The main point in these analyses** to which attention is called is the close agreement in the composition of the chills of these different wheels. If we take the averages of those that did and those that did not stand the thermal test, we find as follows:"

TABLE 50.

	Total Carbon.	Graphi'tc Carbon.	Com. Carbon.
Average of wheels which stood the thermal test	3.81	0.42	3.39
Average of wheels which did not stand thermal test	3.73	0.42	3.31

"It will be noted that the graphitic carbon is the same in both cases, and that the combined carbon only differs 0.08 per cent. Furthermore, the general agreement of the combined carbon of the chills in wheels from different makers is very noticeable and very remarkable. It is difficult to see how any other conclusion can be drawn from these figures than that there is no evidence, as far as the chemical composition is concerned, to show that the chills of wheels which stand the thermal test differ in their physical properties — so far at least as the physical properties depend on the chemistry of the metal — from the chill of wheels which do not stand the thermal test. Also, it seems fair to conclude that wheels made in different parts of the country and by different manufacturers do not differ very widely so far as chemical composition of the chill is concerned. It is quite obvious why this should be so, since the chill fixes the chemical composition within very narrow limits." In conclusion Mr. Bush says: "Therefore, to emphasize what has been stated previously, it seems reasonable to conclude that the wear of car wheels depends upon the chill, and if chills of various wheels are so closely alike as these analyses show them to be there is really no evidence that the wear of these wheels will differ to any appreciable extent." For further analyses of car wheels, see Chapter LVII., page 448.

The sulphur, it will be noticed, is much higher in Tables 47 and 48 than in Tables 45 and 46. Sulphur from .08 to .15 is now considered by many to give long life to car wheel chills. At the same time, it is also considered necessary to have manganese range from .30 to .80 in order to stand the thermal test described in Chapter LVII. This chapter also treats of methods of testing mixtures, car wheels, and annealing them. The depth of chill required in wheels ranges from ½ to ⅞ of an inch in the throat and ⅝ to 1 inch at the middle of the thread. Then again, there should not be over ¼ of an inch variation in the depth of chill in like sections of the rim. In making the mixtures, it must be remembered that Tables 45 to 50 show analyses of the iron after it is remelted or in the castings, so that the iron before being charged must be higher in silicon and manganese and lower in sulphur, after the principle described in Chapter 45.

Not only has steel and wrought scrap been mixed with cast iron pig mixtures, but steel and wrought iron scrap may, for some classes of chilled castings, be mixed wholly with cast iron scrap, no pig whatever being used. As an example, a mixture of 100 pounds of old horseshoes or any kind of light wrought scrap, mixed with 1,000 pounds of stove plate scrap, has been used to make mould boards for plows and which gave a chilled or white iron in the casting. This mixture was originally given in *The Foundry*, March, 1898. A study of this chapter in connection with the preceding one should permit founders to obtain mixtures for almost any line of chilled castings, but it must be borne in mind that to obtain the experience to successfully make chilled castings has cost founders more money, labor, and anxiety than any other line of castings.

CHAPTER XXXIX.

MIXTURES FOR HEAVY AND MEDIUM GRAY IRON CASTINGS.

Mixtures for heavy gray iron castings may consist of all charcoal pig iron or all coke iron; again, these pig irons may be mixed in almost any proportion, or with scrap. In cases where heavy castings require the best possible strength cold or hot blast charcoal irons are the best, and one may often have old rails, car wheels, steel or wrought scrap mixed with them to advantage. In the case of massive castings and utilizing large, heavy scrap with pig iron, the mixtures are generally melted in air furnaces. Cupolas are also often used where the scrap is not too large, and some obtain excellent strength in iron by their use; nevertheless, as a rule air furnaces should give the best results.

Mixtures for sand rolls are generally made of iron that is of a hard nature, and in some cases the same approximate analysis given for chilled rolls seen in Table 43 may be used. Then again, softer mixtures may be required than those shown in Table 43, and which can be obtained by raising the silicon or lowering the sulphur and manganese as shown. Sand rolls are often cast with cupola iron, and such can be made to give good service in many cases.

Mixtures for heavy guns should be made of iron possessing the greatest ductility, combined with strength, that can be obtained. Cold blast charcoal iron is the best for such castings and should be melted in an air furnace. General Rodman obtained from selected charcoal pig iron a very strong gun iron which had the following analysis: Silicon 1.34, sulphur .003, manganese 1.00, phosphorus .08, graphitic carbon 2.19, combined carbon .93. The casting is said to have been tough, with a fine granular fracture and a hard surface which machined easily; also that its elasticity was greatly due to its lowness in phosphorus and sulphur. Further analyses of gun mixtures are shown on pages 278 and 299.

Mixtures for gun carriages, etc., as given by Titus Ulke, M. E., in the *Iron Trade Review*, December 1, 1898, are found in the following four paragraphs and in Tables 51 to 54:

1. Castings weighing from 2 to 16 tons were made for the United States barbette and disappearing gun carriages by the Lorain Foundry Co., at Lorain, O., of the following mixtures (Table 51), melted in an air furnace, the charge weighing 17 tons:

TABLE 51.

Charcoal iron scrap	35 to 45 per cent.
Cold blast charcoal iron (Vesuvius and Salisbury)	10 to 20 "
Warm blast charcoal iron (Rome and Pine Grove)	15 to 25 "
Coke iron (Napier, Dover, etc.)	20 to 35 "
	34,000 lbs.

The average analysis of fifteen heats of the above mixture gave silicon .94, sulphur .05, manganese .31, phosphorus .44, graphitic carbon 2.40, combined carbon

.63. The average tensile strength is given as 31,350 pounds per square inch.

2. In making the chassis rails, base rings, hydraulic cylinders, and other parts of disappearing gun carriages at the Niles Tool Works, Hamilton, O., the following mixture (Table 52), melted in a cupola, was used:

TABLE 52.

No. 3 Muirkirk charcoal iron	5 to 15 per cent.
No. 4¼ Muirkirk charcoal iron	3⅓ to 15 "
No. 4 high Landon charcoal iron	25 to 30 "
No. 4 low Landon charcoal iron	30 "
Gun iron scrap	20 to 25 "
Total	100 per cent.

The analysis of this cupola iron gave silicon about 1.00, sulphur .05, manganese .6, phosphorus .3, graphitic carbon 1.40, combined carbon 1. to 1.20. The tensile strength is given as about 33,000 pounds, on an average, and the elongation from .5 to .6 of 1 per cent. The above Landon iron is made by the Salisbury Carbonate Iron Co. (See page 278.)

3. A mixture made at the Columbus Machine Co.'s works, Columbus, O., which gave very satisfactory results with the iron melted in a cupola is as follows:

TABLE 53.

Muirkirk charcoal iron	15 per cent.
Salisbury charcoal iron	25 "
Embreville coke iron (high in C)	20 "
Gun iron scrap	30 "
Steel (bloom ends)	10 "
Total	100 per cent.

The above gun mixture analyzed: Silicon 1.53, sulphur .05, manganese .45, phosphorus .29, graphitic carbon 3.01, combined carbon .42, and iron 93.98, making a total of 99.74. The tensile strength averaged over 30,000 pounds, and the elongation .4 per cent.

4. In making semi-steel, melted in a cupola at the Rarig Engineering Co., near Columbus, O., the following mixture (Table 54), was used:

TABLE 54.

Lawrence pig (No. 2)	59.3 to 69 per cent.
Homogeneous steel (boiler plate scrap).	39.6 to 30 "
Ferro-manganese, 12 to 15 lbs. per ton	.6 to 0.8 "
Alloy in ladle, 8 to 10 lbs. per ton	.4 to 0.5 "
Total	100 per cent.

An alloy composed of the following elements Al. 2.00, Mn. 8.71, Si. .22, P. .09, Fe. 89.06, which was in a granulated form, was put into the ladle to flux the metal as described on next page. The analysis of the "semi-steel" castings gave Si. .98, S. 06, Mn. .43, P. .43, G. Car. .96, C. Car. .75. This metal gave an average tensile strength in three castings of 34,700 lbs. per square inch. The castings are said to have been found free of blow holes and other defects which are sometimes found in semi-steel castings.

In commenting on "semi-steel," so called, Mr. Ulke says that it was used as far back as 1873. It was at that time made by Mr. Sleeth of Pittsburg, Pa., and cast into chilled or dry sand rolls and pinions of superior quality. Long before 1873, however, wrought iron or steel scrap had been used in making special grades of cast iron, such as tough cast iron for drop-hammer dies and for similar castings. Certainly the use of steel scrap or of similar material in a cupola, or in a ladle is not a modern or patentable idea. There is no fad or physic necessary, although a "secret" dope is sometimes used by so-called inventors, chiefly in order to throw a veil of mystery over a quite simple process. An analysis of one of these expensive "medicines," which, however, possibly serves a useful purpose by agitating or mixing the metal in the ladle and perhaps reducing its sulphur contents, is given in the preceding paragraph.

"The phenomenal tensile strength (49,000 pounds and above) claimed for certain gun iron and semi-steel castings is also misleading, if the size and treatment of the attached test coupons is not stated, as we shall see later. Tests have been and are frequently reported as correct — i.e., as fairly representing the pieces the physical qualities of which they are intended to determine — when in reality they are from 3,000 to 10,000 pounds per square inch too high. This is due to the fact that the coupons cast on are only 1 to 1½ inches round instead of 3 inches, on castings 3 inches in section, and therefore chill and harden more rapidly and show a correspondingly higher strength than the castings." In conclusion Mr. Ulke says: "The depth to which the 'chill' penetrates, as determined by special chill-blocks 6 x 4 x 1½ inches in size, cast in special moulds in the same heat as the pieces, is a good indication of the tensile strength of the semi-steel cast, and serves the foundryman as a simple and convenient guide for grading his metal."

Melting gun iron mixtures in cupolas has given some exceptional results, as will be seen by the excellent strengths shown in Tables 52 to 55. These Salisbury irons have been used by large concerns, and are spoken of in the *Iron Trade Review* of December 15, 1898, as having given very satisfactory results. The iron was melted with good Connellsville coke in a cupola after regular practice. This is a high-priced iron made by the Salisbury Carbonate Iron Co., one furnace being located at Chapinville, Conn. It is very evident by the extract seen below that the Salisbury and Muirkirk irons are rivals for the patronage of those making strong castings.

TABLE 55.—TENSILE STRENGTH TESTS OF HIGH GRADE SALISBURY CARBONATE IRON.

Heat Oct. 15th, 1898. Castings in weight from 500 to 18,000 lbs.	
½ Salisbury carbonate iron, No. 4 ½ " " " No. 4, high	34,850 lbs.
Heat Oct. 21, 1898. Castings as above.	
½ Salisbury carbonate iron, No. 4 ½ " " " No. 4, high	35,320 lbs.
Heat Oct. 29, 1898. Castings as above.	
50 per cent Salisbury carbonate, No. 4 30 " " " No. 4, high 20 " " " scrap	34,800 lbs.

Obtaining strong iron from cupolas is a subject which interests many, and to have others' experience than the author we give space to an extract of an article published in the *Iron Trade Review* December 29, 1898, as follows: "It is probably not known to the trade generally that Muirkirk pig iron was the first iron to be used successfully in the manufacture of gun iron castings for the United States Government, by melting in the cupola. Such, however, is the fact; and the credit of being able to make gun iron castings in the cupola that would stand the tests of the United States Government for gun carriage work rightfully belongs to Messrs. Robert Poole & Son Co. of Baltimore, Md., and Muirkirk pig iron made by me. This was in 1893. The War Department at first refused to accept cupola iron as gun iron, but when it was fully demonstrated that the iron was fully the equal of 'air furnace gun iron,' they were satisfied. The great strength and value of Muirkirk pig iron is not a question of a few years, but has been known since the building of the furnace in 1841, or over fifty years. Muirkirk was used during the Civil War for shot, shell, and cannon. It was used in the manufacture of the last cast gun iron mortars made for the United States War Department, and was used at the United States Navy Yard, Washington, D. C., for the manufacture of cast iron shells until steel was substituted. The fact is that until a few years ago there was no iron that could compete in any way with Muirkirk pig iron for strength and elasticity, and now there is none that would be preferred at the same price per ton. I have had charge of and practically owned this furnace for the past thirty-five years. I think I can truly say that I never have lost a customer except on account of price—never on account of quality.

CHAS. E. COFFIN."

Muirkirk, Prince George's County, Md.

The need of cheap mixtures for medium and heavy castings, often calls for the use of coke and anthracite irons which carry a large percentage of iron or steel scrap. Mixtures are made of these irons that often come close to the strength given in Tables 52 to 55 for charcoal iron mixtures. Such castings as given in Nos. 23, 25 to 35, Chapter XXXV., page 252, are largely made of coke or anthracite iron mixed with scrap. As much as 80 per cent. of ordinary unburnt clean gray scrap iron can be mixed with 20 per cent. of 4 per cent. silicon pig iron for many lines of castings more than 1½ inches in thickness, and requiring to be machined. In castings not requiring a finish, such a mixture may be used in castings as thin as ¾ of an inch and still be soft enough to permit being chipped in the cleaning.

The general run of castings ranging from ½ to 4 inches in thickness, that require to be sufficiently soft to be machined and possess similar strength per square inch, may often range in analysis of mixtures as seen in the approximate Table 56. It is understood that these analyses include pig iron and scrap mixed, or pig alone, as either mixture would stand ready for charging. It is not to be expected that the sulphur, manganese, phosphorus, and total carbon can be obtained in keeping with the increase of silicon shown. However, should the sulphur or manganese be increased from that shown in the Table, the silicon should be increased in such a proportion as to maintain a hardness similar to that obtainable by the analyses shown.

Should the total carbon be higher than shown for the larger thickness then the silicon would require to be proportionately lower to maintain similar strengths or hardness. It is to be remembered that as a rule the total carbon comes highest in low silicon irons, which is the reverse of the order shown for carbon in Table 56, see chapter XXXIII, page 247.

TABLE 56.—APPROXIMATE ANALYSES OF COKE IRON MIXTURES.

Thickness of Casting.	Silicon.	Sulphur.	Manganese.	Phosphorus.	Total Carbon.
½″	2.75	.02	.30	.70	3.75 to 4.00
1″	2.50	.02	.30	.65	3.50 to 3.75
1½″	2.25	.02	.40	.60	3.25 to 3.50
2″	2.00	.03	.40	.55	3.00 to 3.25
2½″	1.75	.03	.50	.50	2.75 to 3.00
3″	1.50	.03	.50	.45	2.50 to 3.00
3½″	1.25	.04	.60	.40	2.50 to 3.00
4″	1.00	.04	.70	.35	2.50 to 3.00

CHAPTER XL.

MIXTURES FOR LIGHT MACHINERY AND STOVE PLATE CASTINGS.

Mixtures for light machinery, sewing machines, stove plate, hollow ware, and hardware, etc., castings call for very soft grades of iron. In making such castings it is rarely wise to use any other iron than pig and shop scrap. As a rule there is much more shop scrap obtained from making light work castings than from heavy ones. In light work the shop scrap generally ranges from 25 to 40 per cent. of the weight necessary to be charged for a heat. As melting iron hardens it, there must of necessity be sufficient silicon added every heat to restore the scrap to the mixture's original softness. For this reason light work shops generally find that their own shop scrap is all they can wisely use.

The percentage of silicon in light work mixtures, as they stand ready for charging — which includes an average of the silicon in the pig and shop scrap — may range from 3.00 to 3.80. This would give a silicon in the castings resulting from the mixture of such pig and shop scrap of from 2.70 to 3.50, according to the grade of softness desired in the castings. When the silicon exceeds 3.75 in castings the body or surface may be often found harder than with lower silicon. This is much affected by the percentages of total carbon, sulphur, phosphorus, and manganese in the iron. The more total carbon the less silicon required, on account of carbon softening iron, as can be seen by a study of Chapter XXXIII. The following Table 57 gives an approximate idea of the highest silicon contents it is generally wise to have in soft or light castings, in combination with the total carbon; the other elements, sulphur, manganese, and phosphorus being fairly constant at the respective percentages considered best for making soft castings:

TABLE 57.

Silicon	3.75	3.70	3.65	3.60	3.55	3.50
Total Carbon	3.00	3.25	3.50	3.75	4.00	4.25

The percentage of sulphur, manganese, and phosphorus generally found in light castings is, as a rule, .06 to .08 sulphur, .40 to 1.00 manganese, and .50 to 1.25 phosphorus. It will be readily understood, from a study of Chapters XXIX. to XXXII., that an increase of sulphur and manganese hardens iron, while phosphorus increases fluidity and brittleness, and that for thin or light castings requiring very fluid metal high phosphorus is necessary. As iron for light castings must generally be soft, care should be taken not to let the sulphur and manganese exceed the above amounts in castings. To obtain these percentages in castings it will, of course, be necessary to have less sulphur and higher manganese in the mixtures before being charged, as is explained in Chapter XLV.

The same regular analyses in different mixtures of irons may not give like softness in castings. This may be due to the quality described on pages 161 and 261, or to some brands of iron possessing more of a chilling quality than others, often due to some special peculiarity of the ores from which the iron was made, or working of the furnace, and which might often be explained were analyses carried beyond determining the regular five elements. However, it is often well for a founder, in starting to make light or stove plate castings, to purchase pig iron (after the methods described in page 200) from the furnaces that can show their irons are being successfully used by other light work or stove plate foundries.

If any yard or foreign scrap iron is used, care should be taken to have it clean and free as possible from rust or oxide of iron; also, no burnt iron should be used, as such will greatly cause mixtures to give hard iron in light work. (Facts treated further in pages 295 to 297.) The best test for softness in light work castings generally lies in the castings themselves, as almost every light casting if not of a sufficiently soft character is readily told by means of a file, grindstone, or chisel. If light castings crack, it is generally evidence of the iron being too high in sulphur or phosphorus, or too low or high in silicon, which latter can be told readily by an examination of the fracture, as if they are too low in silicon the edges of the casting will show a greater chill than from an excessive use of silicon. Then again, the latter will give a very brittle body, while the former will be of a stronger character. It is to be remembered that there is a limit to the use of silicon in affording softness, and that it can make very brittle castings, as shown on page 209.

CHAPTER XLI.

MIXTURES AND ELEMENTS DESIRABLE FOR ELECTRICAL WORK.

Castings for electrical work were supplied by our foundry for several years to a leading manufacturer. It was with much surprise that we found, when first commencing this work, that no one in the plant using our castings knew what chemical properties were essential to exist in their dynamos, other than that the buyer wanted them soft, as it was found that a hard metal resisted the action of the current and did not form a good magnetic conductor. To give an idea of what properties are essential in castings for electric work, the following analyses of drillings which were taken from a dynamo casting for the author, which had proven to possess good electrical induction or magnetic permeability, is presented: *

TABLE 58.—CHEMICAL ANALYSIS OF DYNAMO IRON.

Silicon.	Sulphur.	Phosphorus.	Manganese.	Graph. Carbon.	Comb. Carbon.	Total Carbon.
3.190	.075	.890	.350	2.890	.060	2.950

A study of the above analysis will show the product to be a very soft iron, which in a general sense covers the requirements; and when it is said that all elements should be avoided which favor the formation of combined carbon, the founder has a key to guide him in

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* For the relative conductivity of different metals for heat and electricity, see Table 135, page 593.

making mixtures for castings expected to convey electric currents.

It will be seen that the silicon in the above analysis is as high as 3.190, a point rarely attained in other specialties of casting, but it will be noticed that the sulphur is also well up, so that it greatly neutralizes the softening effect of the silicon. If the sulphur were about .050, the same softness would be obtained with about 2.60 of silicon, so powerful is the effect of a few points in sulphur to promote combined carbon.

In testing a casting to discover its degree of softness by analysis, it is usually best to first find its percentage of combined carbon, which should not exceed .70 and is best kept down, if possible, to about .30. If an analysis shows the combined carbon to be too high, then determinations should be made of the sulphur and silicon contents of the iron, to learn if either of these elements is at fault, as these properties are the bases in changing the "grade" of iron to control the carbon in taking the graphitic or combined form. The higher the carbon, and the more it is thrown into the graphitic form, the better the iron for electric work.

The effect of high phosphorus is to slightly retard softness, and for this reason it is also best kept as low as is consistent in obtaining the fluidity desired. Phosphorus should not exceed .80, unless some very thin castings are to be made, or there are parts in heavy castings difficult to "run;" then phosphorus may be allowed to approach 1.00.

Manganese in iron for electric work is also a factor which requires watching, as its tendency is to promote hardness or combined carbon. It is best not to exceed .40, unless the silicon is over 3.00 and the sulphur under .060, then the managanese might be permitted to go higher. Manganese is somewhat deceptive, as it will permit a casting to arrange its crystals in large grains, giving the iron the appearance of being high in graphite when at the same time the metal is much harder than if the large grains were all the result of silicon in giving the iron large grains.

By a study of this Chapter it will be observed that the state of the combined carbon is the chief factor in determining the utility of a casting for electrical purposes. We have stated that it is desirable that combined carbon should not exceed .70 in any casting. It is to be remembered that the thickness of a casting and the time it takes the molten metal to solidify have also a great influence in determining what percentage of combined carbon a casting will contain. The more quickly a casting cools the higher will be its percentage in combined carbon. For this reason it will be evident that thin castings would require higher silicon and lower sulphur, also manganese, than thick castings.

With all the above elements to influence the formation of combined carbon, it is evident that it would not be practical to here attempt to prescribe what percentage of sulphur and silicon a mixture should contain. All that can be done is to illustrate the fundamental principles involved, and these, as here stated, taken in connection with the effect re-melting of iron has in increasing or decreasing the chemical properties of a mixture, as outlined in Chapter XLV., page 302, will permit any founder making a study of this chapter to intelligently formulate a mixture which will work well for any thickness of castings to be used for electrical purposes.

CHAPTER XLII.

MIXTURES FOR WHITE IRON CASTINGS AND EFFECTS OF ANNEALING THEM.

There are castings, such as are used for base plates in crushers, dies, etc., that are best made of all white iron. In making mixtures for such work the thickness of the casting as well as the character of the iron should be considered, as if this is not done castings that were desired to be white can be so thick as to cause the resulting iron to be mottled or gray. It must also be remembered that there is a difference in the strength of white irons, and that such castings can be made from burnt or oxidized iron, which will be weaker than those made of regular clean or unburned iron. Then again, charcoal iron can give stronger white iron than coke or anthracite iron. To give an approximate idea of the silicon in white iron mixtures, for making white castings, the following Table 59 is presented. The sulphur is supposed to be held at .10 to .15, manganese .50 to .75, and phosphorus .25 to .50. If sulphur or manganese are higher than shown, then the silicon could be increased, or vice versa. The following analysis is supposed to be that existing in the castings, and which would mean that the silicon should be .10 to .20 per cent. higher and the sulphur two to three points lower in the iron charged for making the casting:

TABLE 59.

Thickness of casting.	½″	1″	1½″	2″	2½″	3″	3½″	4″
Percentage of silicon.	.90	.70	.60	.50	.40	.30	.25	.20

In melting white iron mixtures the iron should be brought down "hot," and care taken not to let it get too near the danger point of becoming sluggish before pouring. White iron, being low in silicon, or high in sulphur, will cool very rapidly when it reaches a temperature where the eye can detect it commencing to lose fluidity. As a general thing the gates for pouring white iron castings should be made from one-third to one-half larger than for gray iron, in order that the iron may fill the mould rapidly. If castings over 2 inches thick are desired to be solid on their interior, feeding will be found necessary and much care and skill are required in the feeding, as white iron has great shrinkage and contraction. These two factors are about as great again as in gray iron. A contraction of about ¼ inch per foot is generally allowed for white iron in castings ¾-inch thick. As they increase in thickness the less of course the contraction.

White iron can be made gray and malleable by annealing; in fact, malleable castings are white iron annealed. The principle involved consists in packing the white iron castings in cast or wrought pots or boxes surrounded with iron oxides, generally in the form of rolling mill scale and wrought or steel turnings, the whole sometimes treated with a solution of sal ammoniac. Then again, hematite ores are used. In the selection of such iron oxides care is taken to have them as free of sulphur as possible, especially for small castings. The oxide withdraws carbon and what remains exists mainly as temper carbon, a form similar to graphite but not crystallized. The decarbonizing of castings is greatest near the surface. The interior of thick castings often gives up little if any carbon. This causes thin castings to appear much more malleable, or ductile, than thick ones. The reason of this will be better understood when it is stated, as shown by Dr. R. Moldenke, that in analyzing a ⅝-inch malleable casting with the ends broken off, which was placed in the shaper and 1-16-inch cuts taken off, the first cut analyzed .16 total carbon, the second .65, the third 1.84, the next 3.97, and the last 4.05 per cent. The original casting contained 4.08 per cent. of total carbon, thus showing that the interior of thick malleables may be but little changed. This has caused an impression that ⅜ of an inch was as thick as was practicable for good malleables. The process of annealing lengthens castings to such an extent as to expand them about ⅛ of an inch per foot. The lighter the casting, the relatively greater the expansion. This expansion greatly counteracts the excessive contraction which must be allowed in making patterns, and is such as to usually call for no greater contraction than in making patterns for gray iron castings

The percentage of silicon used for malleables to get white iron in castings ranges from .60 to 1.25, running lower with the thickness. The iron for making malleables is melted in the cupola, air, and open-hearth furnaces. The cupola is generally used for light castings as it gives a better opportunity to obtain very fluid iron, which will permit its being carried in small ladles to the moulds, than that coming from furnaces which are generally used for large castings which permit of refining, testing, and changing the character of the mixture somewhat before the metal is tapped into ladles. The Siemens-Martin acid open-hearth furnace is now being very successfully employed for heavy castings. These furnaces are much hotter than air furnaces. The temperature of metal in them rises, possibly, to 3,500 to 4,000 degrees F. This permits the practice of using much steel scrap in with the low silicon iron to lower the total carbon slightly, which is a desirable point in making malleables as it gives a metal, after annealing, softer and tougher on account of the lower total carbon than is practicable with air furnace or cupola irons. Small quantities of iron ore have been added by some thinking to assist in reducing the carbon but such is no longer practiced. One disadvantage of furnaces over cupolas lies in the loss of iron, as the former often causes a loss of 12 per cent. of the iron charged by reason of scintillation and oxidation of the metal's surface when exposed to the flame.

The process of annealing is one that varies greatly with different firms. One firm may anneal similar thicknesses of castings in half the time another will take. The changes effected by annealing are chiefly in lowering the total carbon in the skin and turning the combined that remains into temper carbon, the silicon, sulphur, manganese, and phosphorus remaining practically the same. The time occupied in annealing ranges from one to seven days, with castings packed in boxes, etc. This wide difference is due to different customs and the character of castings to be treated. The ovens used are of simple construction and generally of rectangular form, being in size about eight feet high in the center of the arch, by ten feet wide and eighteen feet long. The castings are placed in rectangular pots, which are set upon the bottom and often built four or five high until a furnace is filled. The ovens are heated with natural and producer gas; also coke and coal. The action is purely one of heating, and the temperature ranges from 1,400 to 1,900 degrees F.

Some firms anneal castings without packing them, placing them in the ovens singly and allowing the heat to come in direct contact with their surfaces. This is generally done only with work that is not particular, as the heat scales the castings badly. Malleable people in general, when an order is very urgent, will often anneal castings outright in the melting furnace. The results, however, are very unreliable and cause the surface to look badly. The effect is generally an incomplete conversion of the combined carbon to the temper carbon. Annealing is like other workings in iron, there are many little things that must be learned by experience before success can be had.

CHAPTER XLIII.

CHEMICAL FORMULA FOR MIXING AND MELTING SCRAP IRON.

Scrap iron, as a general thing, is a product which has been re-melted one or more times, and hence must fairly show its true grade in a clean fracture. The advent of chemistry in founding will naturally cause some to ask: is it not necessary to know the metalloids in scrap iron as well as in pig metal in order to obtain desired results from mixtures? It is, of course, well to have analyses of scrap the same as with pig metal, whenever this is practical, but owing to the fact that scrap generally comes to the founder in a promiscuous manner, often a little of everything, working by analysis becomes largely impractical, either as to obtaining actual analyses or attempting to guess the chemical properties. In reality, it is not practical to define any of the metalloids in scrap iron by guesswork. About the only practical plan which the author can suggest is to consider and class scrap in the order of "grades," by numbers: as, for example, build an imaginary base to define "grades" from the texture and grain which would be obtained by the remelting of pig metal, say, containing 1.00, 2.00, and 3.00 per cent. of silicon, respectively, with sulphur supposed to be constant at .030 and phosphorus and manganese as generally found in their foundry iron, in all the three mixtures. By such a method any founder having had experience in following chemistry to any degree will soon know what "grade" the above mixtures of pig metal would give were they poured into castings ranging from stove plate up to bodies six inches thick, and then, when sorting scrap in "grades," they would simply be contrasted with the "grade" produced by the imaginary pig mixture which had been taken to define a base for a grade desired. By following such a method as this, it is very evident that the grading of scrap iron could be reduced to a very satisfactory system, in all work where it is economical to utilize scrap iron.

As a general thing, founders are desirous of utilizing all the outside scrap possible in mixture with pig metal, because it can generally be bought for less than pig iron. With work that permits a good leeway in the grade or mixture obtained, such as floor plates, furnace castings and heavy machinery not requiring much finishing, etc., scrap iron can often compose the greater part of the mixture, especially so if silicon pig has been used to soften the scrap. In the case of stove plate or light machinery castings requiring much finishing, much more care is necessary in attempting to use much outside scrap iron. The same is to be said of chilled work where definite results are to be insured. In many chill work specialties it is often very poor economy to adopt the practice of utilizing any outside scrap; but, of course, shop scrap, such as gates,. etc., every shop must work up in mixture with its pig metal. An all-pig mixture, of which a correct analysis has been given, enables the founder to be much more positive in obtaining desired results than where he attempts such results by mixing promiscuous scrap with the pig metal. The loss of a few castings ofttimes more than counterbalances the difference in the price of pig and scrap metal, and in some cases, if the question of gross tons in pig metal is considered, the difference will be found strongly in favor of the straight pig mixture, as against that of a combination of scrap, which is generally sold by net tons.

In grading scrap that shows evidence of having been chilled, such as that in car wheels, rolls, dies, crushers, plows, etc., it is as essential to consider the texture of the grey body of the casting or scrap as it is that of the depth of the chill, for the reason that the depth of the chill part can be deceptive in denoting the true grade of the iron, from the fact that degrees in the pouring temperature of metal, as well as the thickness of the chill to the limit used for forming the chill part of the casting, has an effect in forming the depth of the chill, factors more clearly defined in Chapters XLI. and LVI.*

About the worst class of scrap to pass judgment upon, in an effort to grade it, is that coming under the head of "white iron." Where bodies of scrap are all white, the silicon contents may, in castings say from "stove plate" up to two inches thick, contain silicon all the way from .50 up to 1.50, and in more massive castings than three inches thick, it is generally safe to conclude that the silicon can range from .10 up to 0.40, with sulphur in any of these thicknesses ranging all the way from .050 up to .200. As a basis to guide the founder in an effort to grade such irons for mixture with softer metals, it can be taken for granted that the sulphur is generally very high and the silicon low

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*** For a discovery showing that chilled parts give a softer re-melt than gray parts of the same casting, see pages 338 and 339.**

in all white scrap iron as it comes to the foundry.

Burnt iron can be said to be the most undesirable class of scrap for a founder to handle, and there is a doubt in the author's mind that it pays any founder in the end to experiment with it, for making anything other than castings like sash weights, for, as a general thing, its loss in weight by re-melting will range all the way from 30 to 95 per cent. It is a very indefinite quality to judge of as to its chemical composition. It is safe to say it will greatly injure other irons when mixed with them in raising the sulphur and lowering the silicon so as to produce a "white iron," and can often spoil many castings.

Any intelligent foundry laborer should, with a little training, be able to select and pile scrap according to its grade. As some would prefer an approximation for the silicon and sulphur contents of grey scrap, the author would say that iron ranging from stove plate up to one inch in thickness may be considered as an approximate equivalent to remelted pig metal that has its silicon ranging from 1.50 up to 2.00 per cent., and for bodies above one inch thick up to three inches thick from 1.00 up to 1.75 in silicon, sulphur in all cases to be considered as constant at about .07, Above three inches in thickness a grey open fracture can range in silicon all the way from .75 up to 2.50, and the grading of such heavy bodies generally requires a more skilled eye than with scrap, which might be under three inches in thickness; but practice would soon bring one to an approximately close guessing of the grade of heavy, as well as light bodies. Where scrap comes to the foundry yard in the form of complete castings, which the founder will have to break, he can, by "sizing up" the general proportion and shape of the whole casting, judge more readily of the "grade" in the massive parts than if it came to his yard in a haphazard form.

We are compelled to analyze pig metal (as shown on page 178) simply because it is deceptive in showing its true "grade" to the certainty that scrap iron will permit, on account of its being a re-melted product. If one wishes to grade scrap by the plan suggested on pages 292 to 294, in this chapter, it is best to follow a silicon formula for a base, owing to the fact that silicon is the element generally largest in gray castings excepting carbon and affords a larger range or margin in guessing percentages, which if not close to the actual silicon contents cannot so greatly result in injury as it could if one used a guess of the sulphur for a base, and should err much. As scrap with many founders constitutes a third and often two-thirds of their total mixture, this chapter cannot but be of benefit to any who may be desirous of conducting their mixtures of scrap iron with the best assurance of obtaining desired results without resorting to analysis.

Much oxide of iron, or rust on scrap iron, is very injurious in lowering the silicon of a mixture and thus cause a hard iron where a soft one was expected. Burnt annealing boxes, old grate bars, etc., give off a great deal of oxide of iron. The good iron melts more readily than the oxide of iron. If any of the latter is not reduced to iron and is carried with the molten metal into castings, as it may be, blow holes may be formed which are generally to be found in the top surface of castings as they are poured. Where there is any apprehension of such difficulty, it is often well to add a little ferro-manganese to the molten metal. This will greatly combine with the oxide and come to the surface as slag, which can be skimmed off. Oxide of iron combines readily with silica, and for this reason when there is any rust on scrap, or old iron, it is often desirable to have some sand (which is silica) on pig iron, that it may be charged with the scrap iron to assist in forming a slag to be carried off by fluxing. This will greatly absorb the oxide and give a cleaner iron for pouring castings.

The oxide of iron caused by the oxidation created by the blast, in the case of strictly clean iron, may at times be insufficient for the amount of sand on pig iron, etc., to form the right combination for making a good fusible, or thin slag, to carry off the ash of the fuel and other dirt out of the cupola. In such cases an addition of rusty scrap, etc., may sometimes work well. However, it would be better to add limestone or other flux to make a fusible slag than to increase the oxide of iron or rust, etc., in a cupola. In cases of excessive oxide of iron being present, it is absolutely necessary to use limestone or other flux in order to make a good slag. It is claimed that high cupolas may have a reducing action on oxide of iron, so as to obtain more metal from rusty scrap, etc., than low cupolas. High cupolas should at least cause a greater loosening than low cupolas of the scale from iron, and often permit more of it being blown out of the stack to remove some of its evils. However, in striving to obtain very soft or clean castings, rusty or burnt scrap of all kinds is best avoided where practical.

CHAPTER XLIV.

CHEMICAL CONSTRUCTION AND STRENGTH OF TYPICAL FOUNDRY IRON MIXTURES.

The chemical construction and highest strength of all the prominent mixtures now being used in general founding, as obtained by the author for this work to illustrate in a concise and accurate manner true analyses of mixtures actually used by our leading founders, are shown in Tables 60 and 61. The specimens analyzed are taken from the respective tests described in Chapter LX. The determinations were made by the able and careful chemist, Mr. W. A. Barrows, Jr., of Sharpsville, Pa.:

Analyses Nos. 1 and 2 are obtained from "air furnace" iron and those of Nos. 3, 4, 5, 6 and 7 from cupola iron. A peculiarity which will attract the attention of those making a study of the following Table is that of the combined carbon being so high, with low sulphur and the silicon not far from 1.00 per cent. in analyses Nos. 1 and 2. This illustrates the benefit derived from melting iron in an "air furnace," where it is not brought in contact with the fuel to so radically change the character of iron, and clearly demonstrates the superiority of the "air furnace" over the cupola to refine or obtain the best strength possible in cast iron.

The author has not seen any analysis of cupola iron showing the combination of high combined carbon and silicon with the low sulphur shown in analyses Nos. 1 and 2. If any can closely duplicate such a combination of metalloids by cupola iron they should obtain about the same results in strength derived from the air furnace meltings. This may be closely approximated, but the uncertainty of cupola workings, on account of the iron being in contact with fuel and blast, makes it a difficult and a very unreliable method to adopt.

The state of the combined and graphitic carbon is the final resultant of the combined effects of all the other metalloids and chiefly defines what character the physical qualities will assume, as regards the strength, deflection, contraction, and chill of an iron. †

TABLE 60.—CHEMICAL ANALYSES OF SPECIALTY MIXTURES IN CAST IRON.*

Arranged according to degrees in strength.

No. of Analysis.	Specialty Mixture.	Sil.	Sulp.	Phos.	Mang.	Graph. Carbon	Comb. Carbon	Total Carbon
1	Gun Metal.	1.19	.055	.408	.420	2.050	1.130	3.180
2	Chill Roll.	.71	.058	.543	.390	1.620	1.380	3.000
3	Car Wheel.	.86	.127	.348	.490	2.550	.920	3.470
4	Heavy Machinery	1.05	.110	.543	.350	2.650	.330	2.980
5	Light Machinery	1.83	.078	.504	.310	2.500	.430	2.930
6	Stove Plate.	2.59	.072	.622	.370	2.950	.350	3.300
7	Sash Weight.	.18	.138	.094	.350	.150	2.940	3.090

*Nos. 1 and 2 are charcoal irons.

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† The rate of cooling is also to be considered in connection with the effects of the metalloids.

Iron of the analysis shown in gun metal can, in castings three inches thick and over, be readily machined and with greater ease than that composing the chill roll mixture. Next in hardness to the roll iron is the car wheel metal, the other specialties following in degrees of softness in the order shown, until sash weight iron is reached, which specialty excels all shown for being a hard metal as such is strictly a "white iron." The following Table is a summary of the best strength obtained from a series of about 100 tests taken with bars one and one-eighth inches in diameter, twelve inches between supports, in obtaining the transverse strength, more fully described in Chapter LX. A column is also given showing the tensile strength of all these specialties.

TABLE 61.—SUMMARY OF TYPICAL AMERICAN FOUNDRY IRON TESTS.

Taken with one square inch area test bars.

Specialties of Mixtures.	Transverse strength per square inch.	Tensile strength per square inch.
Gun Metal	3,686	37,110
Chill Roll	3,044	30,661
Car Wheel	2,819	25,782
Heavy Machinery	2,791	25,799
Light Machinery	2,115	20,655
Stove Plate	1,813	12,582
Sash Weight	1,480	7,044

The Table 61 is no discredit to American foundrymen. It displays to the world typical irons challenging competition in excellence for the various specialties shown.

Ductile cast iron is the term applied to a product that was manufactured by the East Chicago Foundry Co., for which a tensile strength of 50,000 to 60,000 pounds per square inch is claimed. The author has endeavored to obtain all particulars connected with its manufacture, but found the process one of which the manufacturers did not care to impart any knowledge. This was in 1897, but at this time—1902—as far as can be learned, the manufacture of this metal has ceased.

To obtain a knowledge of the strength of other metals in comparison to cast iron, see Table 137, page 594.

CHAPTER XLV.

EFFECT OF FUEL, FLUXES, TEMPERATURE AND HUMIDITY OF BLAST IN RE-MELTING CAST IRON.

It is as important to possess knowledge of changes caused by re-melting iron as it is to know the chemical constituents of the iron before it is charged into the cupola. For the past seven years the author has followed closely the records which were daily compiled at our foundry of the chemical properties in the iron charged and also the product received from the cupola in "heats" ranging from 40 to 100 tons. The following Table, No. 62, compiled from one week's melting in this foundry, with coke .80 to 1.00 in sulphur, will serve to illustrate the change due to silicon and sulphur in re-melting iron:

TABLE 62.—DECREASE IN SILICON, AND INCREASE IN SULPHUR, BY RE-MELTING IRON.

Silicon in pig.	Sulphur in pig.	Silicon in castings.	Sulphur in castings.	Loss in silicon.	Gain in sulphur.
1.93	.022	1.77	.040	.16	.018
1.84	.016	1.65	.046	.19	.030
1.78	.031	1.58	.056	.20	.025
1.52	.029	1.39	.061	.13	.032
1.46	.027	1.33	.056	.13	.029
1.28	.021	1.10	.067	.18	.046

The increase in sulphur in re-melting is dependent upon the amount of sulphur in the fuel, the silicon and manganese in the iron, the flux and the heat in the cupola. An increase of the sulphur in the fuel or flux will cause a corresponding increase of sulphur in the iron; while the less fuel used and the better a cupola is fluxed or " hot iron " produced, the less sulphur will the re-melted iron contain.

The reduction or oxidation of silicon is greater the higher the blast pressure and also the hotter the iron is melted. In a general way, it can be said that silicon is reduced from one to three-tenths of one per cent. and sulphur increased from one to six hundredths of one per cent., where the fuel holds .80 to 1.00 in sulphur. The author has, in a few rare cases, found the silicon to be but very little reduced, but never found a re-melt where the sulphur was not materially increased. The increase of one point of sulphur can often neutralize the effect of ten to fifteen points of silicon, and hence, owing to the increase of sulphur being so powerful in neutralizing the effects of silicon, it is very essential that all conditions influencing the increase of sulphur should be guarded and controlled so far as practical, in order to be best assured of obtaining any desired results in the castings.

The changes due to manganese in re-melting iron are toward its reduction. The hotter the metal, the higher the blast, the greater its reduction. The reduction can range from 10 to 30 points. The more manganese iron contains, the less the increase of sulphur, owing to the affinity manganese possesses for carrying off sulphur in the slag.

Phosphorus may be called a " sticker," as when once absorbed by iron it cannot be easily eliminated.

In re-melting iron, whatever phosphorus the fuel or flux may contain will largely go to the iron, and hence phosphorus has a tendency to be increased every time iron is re-melted. Its influence in effecting changes in the other elements is to favor the reduction of silicon, sulphur and manganese, owing to the quality of phosphorus which causes iron to have greater fluidity and life.

Total carbon is, as a general thing, increased by re-melting. The amount is chiefly dependent upon the percentage of fuel used, and the length of time the iron is in the cupola. Little fuel and quick melting may at times cause a slight reduction of the carbon. In the case of excessive fuel which can give hot iron and cause slow melting carbon may be increased. It is also, to some degree, dependent upon the silicon and manganese present. The former retards, while the latter promotes the increase of carbon.

Combined carbon with the silicon above four per cent., and sulphur not over .01, may sometimes be slightly reduced. After silicon has decreased to 4.00 with the sulphur above .02, every re-melt will surely increase the combined carbon until the silicon is so decreased and the sulphur increased that "white iron" will be produced, giving an iron which may have its carbon almost wholly in a combined form.

Graphitic carbon is increased accordingly as combined carbon is decreased, and the elements best calculated to promote its formation are silicon about 3.50 and phosphorus not above 1.25, with low sulphur.

In a general way it can be said that with iron melted in the cupola, the silicon, manganese and graphitic carbon are decreased, while the sulphur, phosphorus and combined carbon are increased.

In connection with a study of this chapter, readers are referred to tests showing losses of silicon and manganese, and gains in sulphur, phosphorus, and carbon found in Tables 73 and 76, pages 334 and 341. It is to be understood that the foregoing pages of this chapter deal with cupola practice only; and as the author has had no opportunity of late for experimenting with results to be derived from re-melting iron in an " air furnace,' he cites the following extract from Sir William Fairbairn's report before the British Association of Science on the effect of re-melting iron in an " air furnace" eighteen times, in which he describes the action of re-melting as follows:

> Phosphorus increased from 0.47 to 0.61. This was probably due to loss of metal by oxidation. Manganese decreased from 1.75 to .12. This would tend to improve the metal during the earlier meltings. Silicon was reduced from 4.22 to 1.88. The first effect of this reduction was to produce softer metal and lower combined carbon, since silicon was present in quantity in excess of that necessary for the softest metal. On further reduction of silicon the metal became stronger and harder. But in these experiments the reduction was not carried sufficiently far to cause any deterioration due to sufficiency of silicon. Sulphur increased from .03 to .20, and this is one of the most important changes which took place, the increase in sulphur tending in the same direction as the loss of silicon, viz., the production of high combined carbon. The combined carbon increased considerably after the eighth melting, ultimately reaching to over two per cent.

By Fairbairn's experiments we find that the results of re-melting in an air furnace are in part similar to those of a cupola, and in both cases it is a subject as necessary to be understood, in order to obtain desired ends, as is that of knowing the chemical properties of the iron before it is charged.

There have been experiments conducted in order to observe whether there would be any difference in the strength of iron taken from the beginning, middle, and end of "heats," where a uniform mixture was used throughout a heat. Results received affirm that some would obtain the strongest test at one part, while others would receive them from another part of a heat. In this practice the author cannot conceive of any uniformity being obtained unless the management is such as to insure a like temperature and fluxing at every part of a "heat," and in this quality generally lies the secret of the difference between one founder and another. One may have a cupola giving the hottest iron at the beginning of a heat while another will obtain this at the middle or the end. According to the variation of temperature when remelting iron, so is the combined carbon affected by changes in the silicon, sulphur and manganese; and taking this view of the subject the author believes that all can understand why we find founders disagreeing in such tests.

As the humidity of the air can, to some extent, produce changes in the smelting or melting of iron, one heat from another, the author appends the following excellent article written by Mr. A. Sorge, Jr., M. E., in the *Foundry*, April, 1896:

That variations in the humidity of the atmosphere and its temperature do affect the operation of melting iron in a cupola, will be conceded by foundrymen who have observed the difference in melted iron on different days. Iron is liable to be cold and sluggish with the same charges of fuel on cold and moist days, while it is hot and fluid on warm and bright days.

It is therefore reasonable to look for one cause of poor melting to the atmospheric conditions. Let us assume that we are melting at a ratio of eight iron to one coke on an ordinary bright day, when the temperature is 62 degrees F., and the percentage of moisture in the atmosphere about 0.52 per cent., which is about the average in Chicago.

It has been found by experience that about 33,000 cubic feet of air are required to melt 2,000 pounds of iron in ordinary cupola practice. This air will weigh about 2,500 pounds, and is heated originally to a high temperature by the ignited coke before it becomes active in supporting further combustion. Also any moisture contained in this air must be brought to the temperature of the gases which escape from the top of the cupola. This latter temperature varies greatly, but will be in the vicinity of 500 degrees F. for good practice.

If the temperature of the atmosphere should drop to 32 degrees F., this means that the air delivered to the cupola must be heated 30 degrees, so as to bring it to the normal. The specific heat of air being taken at 0.238, we obtain $2,500 \times 30 \times 0.238 = 17,850$ B. T. U. as the amount of heat required to do this work, or theoretically about 1⅜ pounds coke would be consumed if we obtained perfect combustion. The fact being that the actual amount of heat obtained from the combustion of coke in a cupola is only about ¼ of the theoretical, it follows that the actual coke consumed for this extra heating is about 5½ pounds, which should be added to the usual amount of 250 pounds per ton of iron, making 255½ pounds, or a ratio of about 7.8 iron to 1 coke.

If, at the same time, the air is charged with particles of moisture, as when a heavy snow-storm is in progress, it will contain, say, about 4-10 per cent. of frozen water. In the 2,500 pounds total this will amount to 10 pounds, which must be transformed into vapor at 500 degrees F., involving 14,740 B. T. U. of heat. On the other hand, this amount is reduced by the heat expended in raising the average vapor of 0.52 per cent. in 62 degrees air to 500 degrees F., which amounts to 2,714 B. T. U., leaving an extra amount of 12,036 B. T. U. consumed by the snow, which will again require about 3.6 pounds coke.

The total coke consumption in the above case will therefore be 259.1 pounds per ton of iron, or a ratio of 7.7 iron to 1 coke, in order to deliver the melted iron in the same condition as on an ordinary day. In other words, an additional fuel consumption of a little over 3.6 per cent. is needed under the above conditions, so as to obtain the iron in the same state of heat and fluidity as when ordinary dry air at 62 degrees is used.

On the other hand, a higher temperature and greater dryness of the atmosphere will operate in permitting the amount of fuel to be reduced.

In the above figures I have assumed ordinary conditions, but the actual practice must be carefully taken into consideration wherever it is desired to figure out the effects in any particular case, and it is well worth a foundryman's time to go into this question, figuring out the extra amounts of coke needed under various conditions of moisture and temperature, when a short observation of an ordinary hygrometer and thermometer will enable him to avoid the risk of cold and sluggish metal on any day.

Mr. W. H. Fryer has shown and published the statement* that air containing 0.8 per cent. of moisture will introduce about 89.6 pounds of water into a blast furnace per ton of iron made, using about 2,250 tons of coke for fuel. This is a factor the founder should not lose sight of. When air is moist, it is to some degree practically the same thing as fuel being water-logged. With very wet fuel, as many founders know, a larger percentage is necessary to re-melt iron than if the fuel were perfectly dry, and also that this can cause trouble much more readily in the line of "bunging up" a cupola. For further information of the effects of humidity, see Chapters IX. and X.

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* Journal of the Iron and Steel Institute, Vol. II., 1887.

CHAPTER XLVI.

LOSS OF IRON BY OXIDATION IN CUPOLAS.*

The amount of iron lost by melting is as important an item for consideration as that of any other material necessarily destroyed in the making of castings. Many founders endeavor to keep a close record of such losses, but there are many who cannot. Founders who can clean up each day's heat of castings and collect all their fine shot, scrap, and gates the day following each heat are in the best position to obtain the greatest accuracy in such records, but shops where castings lie in the sand from one to six days or more before they can be removed or cleaned up find the task a much more difficult one. In buying pig iron the furnaceman allows 268 pounds per ton for scale and sand on sand cast pig, and 240 pounds on chilled cast pig. How much of this is actual refuse is difficult to determine accurately. When first studying the method of casting pig metal in chills, the author could see nothing unfavorable to the universal adoption of metal so cast for founders and steel makers. It was not until at a meeting of the Pittsburg Foundrymen's Association, December 3, 1898, where a member made the claim that a greater loss would be incurred by the use of chilled cast pig iron, in re-melting iron, than by having sand and scale on it — which was said to afford

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*This chapter is a revised extract of a paper presented by the author to the Pittsburg Foundrymen's Association, January, 1898.

a protection to the iron against oxidation, or being burned away while being brought to a liquid state — that any disadvantage was apprehended. The author has no knowledge of the process by which the above member arrived at his conclusions, and can only say that to obtain definite proof of this claim steps differing from general practice in melting are necessary. The author, realizing this, made a series of original tests embodying sixteen heats, made in the twin shaft cupola Fig. 56, page 241, and shown in Tables 63 to 66. In making the comparative oxidation tests shown in these tables much care was necessary in preparing the cupola and collecting its refuse. In getting this cupola ready (Fig. 56) for a heat both departments were picked out and daubed up smoothly and then blacked over with graphitic or lead blacking. Such a plan insured that no iron stuck to the sides from the preceding "heats," to be melted down with, or change the irons obtained from the respective sides. The bottom was not dropped after heats, as in ordinary practice, but after the cupola had cooled down the refuse was picked out from the top downward by hand, and every particle carefully pounded in a pan to discover any fine shot or pieces of scrap that might exist in the burnt coke, dross, or slag remaining in the cupola at the close of a heat. This was then weighed on fine scales. By this plan not a single ounce of metal that remained as such could escape being found.

Heats Nos. 1 and 2, Table 63, were charged with rolls that were cast from the same ladle, half being made in sand and half in chill molds, such as seen at Fig. 59. The roll castings were after the pattern seen in Fig. 58, which it may be said was the same form in which the iron was charged in heats Nos. 3, 4, 5, 6, 7, and 8, as well as those shown in Tables 65 and 66, where rolls are cited. The loss from heats Nos. 1 and 2 ran about 5 per cent. for the sand rolls and 3 per cent. for the chilled iron. When the first two heats are compared with those of the chilled iron by the

TABLE 63.—COMPARATIVE OXIDATION TESTS OF PROTECTED AND UNPROTECTED IRON SURFACES.

	Heat No. 1.	Heat No. 2.	Heat No. 3.	Heat No. 4.	Heat No. 5.	Heat No. 6.	Heat No. 7.	Heat No. 8.
Kind of Metal Charged.	Sand and Chill Rolls.	Sand and Chill Rolls.	Chill Rolls.	Chill Rolls.	Chill Rolls.	Chill Rolls.	Chill Rolls.	Chill Rolls.
Kind of protection used on coated rolls...	* Sand Scale.	* Sand Scale.	Lead Wash.	Lead Wash.	Lime Wash.	Lime Wash.	Sil. Soda.	Sil. Soda.
Weight of unprotected and protected charges...........	114 lbs.	80 lbs.	84 lbs.	54 lbs.	81 lbs.	85 lbs.	78 lbs.	90 lbs.
Blast put on	3.36	3.18	3.47	2.20	3.17	2.54	3.04	3.43
Protected iron running..........	3.44¾	3.27¼	3.53¾	2.27	3.25	3.00¾	3.09¼	3.52¼
Unprotected iron running...	3.43	3.25	3.52½	2.26	3.23¾	3.00	3.09	3.52
Protected iron all down	4.03½	3.40	4.03¾	2.34½	3.37½	3.11½	3.20	4.07¼
Unprotected iron all down..	4.01	3.37½	4.02	2.33¼	3.37	3.11¼	3.19¾	4.06
Weight of protected iron obtained............	108 lbs. 3 oz.	75 lbs. 2 oz.	81 lbs. 1 oz.	52 lbs. 1 oz.	77 lbs. 13 oz.	81 lbs. 15 oz.	75 lbs. 11 oz.	87 lbs. 8 oz.
Weight of unprotected iron obtained	110 lbs. 2 oz.	77 lbs. 2 oz.	81 lbs. 1 oz.	52 lbs. 3 oz.	78 lbs. 3 oz.	81 lbs. 14 oz.	75 lbs. 12 oz.	87 lbs. 6 oz.
Loss of protected iron............	5 lbs. 13 oz.	4 lbs. 14 oz.	2 lbs. 15 oz.	1 lb. 15 oz.	3 lbs. 3 oz.	3 lbs. 1 oz.	2 lbs. 5 oz.	2 lbs. 8 oz.
Loss of unprotected iron......	3 lbs. 14 oz.	2 lbs. 14 oz.	2 lbs. 15 oz.	1 lb. 13 oz.	3 lbs. 1 oz.	3 lbs. 2 oz.	2 lbs. 4 oz.	2 lbs. 10 oz.

* This has reference to the sand that formed a scale on the sand cast rolls and which were charged on one side, while the chilled rolls were charged on the other, of the cupola, for heats Nos. 1 and 2. For heats Nos. 3 to 8 all chill rolls were used for both sides, the only difference being the chills for one side were coated as described on pages 313, 314 and 317.

TABLE 64.—COMPARATIVE FUSION TESTS BY IMMERSION OF IRONS SHOWN IN TABLE 63. SEE PAGE 314.

	Heat No. 1.	Heat No. 2.	Heat No. 3.	Heat No. 4.	Heat No. 5.	Heat No. 6.	Heat No. 7.	Heat No. 8.
Time of immersing rolls 2⅜″ diameter *	4:00	4:00	4:00	4:00	4:00	4:00	4:00	4:00
Time of total fusion of sand protected rolls	4:04¾	4:06	4:09½	4:10½	4:06	4:06½	4:04	4:04¾
Time of total fusion of unprotected rolls	4:03	4:03½	4:02½	4:02¾	4:03	4:03¼	4:02¾	4:03¼
Difference in time of melting	1¾ m.	2½ m.	7 m.	7½ m.	3 m.	3¼ m.	1¼ m.	1½ m.

*The time of dipping was changed to the unit of 4:00 o'clock shown so as to make the table easier of solution. The relative differences, however, were kept exactly the same as originally found.

FIG. 58.

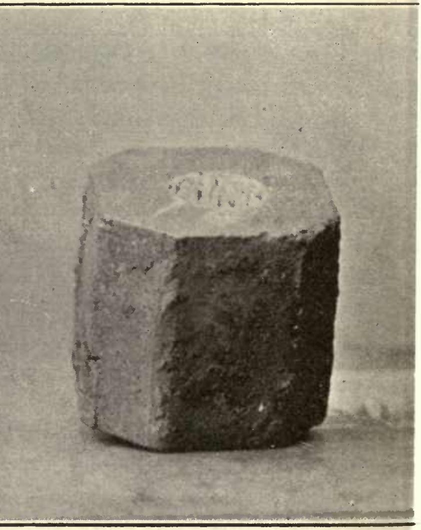

FIG. 59.

protected and unprotected plan seen in heats Nos. 3 to 8, it will appear how unreliable are the data as to how much sand or scale one is crediting to iron when weighing the charges of sand-coated pig irons for regular cupola practice. To avoid this uncertainty, I adopted the idea of taking gray iron cast in chill moulds for both sides of the cupola, coating that for one side heavily with some heat resisting material (by giving each three coats and drying them in an oven after every coating), and charging the other side with the surface of the chilled or sandless gray iron exposed. By weighing the iron before it was coated I knew exactly what weight of iron was going into the respective sides of the cupola. In reality, I consider this the only true way of making a comparison between chill

TABLE 65.—COMPARATIVE OXIDATION TEST OF IRONS CHARGED ON HIGH AND LOW BEDS OF FUEL. SEE PAGE 315.

	Heat No. 9.	Heat No. 10.	Heat No. 11.	Heat No. 12.
Kind of metal charged.	Chill rolls unprotected.	Chill rolls unprotected.	Chill rolls coated with lead wash.	Chill rolls coated with lead wash.
Weight of charges each side	64 lbs.	73 lbs.	75 lbs.	100 lbs.
Blast on	3.55	4.27	3.42	3.33
High bed running	4.02	4.38	3.50	3.45
Low bed running	4.00	4.33½	3.47¾	3.39
High bed all down	4.11½	4.48	3.03½	4 05
Low bed all down	4.08	4.44	4.56½	3.55
Weight of iron obtained from high bed	62 lbs. 6 oz.	70 lbs. 7 oz.	72 lbs. 9 oz.	96 lbs. 12 oz.
Weight of iron obtained from low bed	62 lbs. 10 oz.	70 lbs. 8 oz.	72 lbs. 14 oz.	96 lbs. 14 oz.
Loss of iron from high bed	1 lb. 10 oz.	2 lbs. 9 oz.	2 lbs. 7 oz.	3 lbs. 4 oz.
Loss of iron from low bed	1 lb. 6 oz.	2 lbs. 8 oz.	2 lbs. 2 oz.	3 lbs. 2 oz.

and sand-cast pig metals to judge whether scale or sand prevents a loss of iron by oxidation. For heats Nos. 3, 4, 5, 6, 7, and 8 all chilled irons were used, the only difference being that I used different materials for coating or protecting the surface of the chill, or sandless pig rolls, which were to be charged as protected irons. Of the three coatings used — lead wash wet with molasses water, lime wash which was hardened with salt, and silicate of soda — the lead wash afforded the best protection. This was proven by the less time required by unprotected chills to start and end in melting than the chill or sandless pig rolls having their surfaces protected or coated with the lead wash.

Believing an immersion test would furnish a good check on the action of the different protectors — lead,

TABLE 66.—COMPARATIVE OXIDATION TEST OF STOVE PLATE AND HEAVY IRON. SEE PAGE 316.

	Heat No. 13.	Heat No. 14.	Heat No. 15.	Heat No. 16.
Kind of metal charged.	Stove plate and rolls.	Stove plate and rolls,	¾-inch plate and rolls.	¾-inch plate and rolls.
Weight of charge each side	100 lbs.	65 lbs.	100 lbs.	65 lbs.
Blast on	3.34	3.06	2 20	3.11
Heavy iron running	3.39½	3.12	2.25	3.16¼
Plate running	3.35½	3.07¼	2.23½	3.15
Heavy iron all down	3.54	3.21	2.35	3.22½
Plate all down	3.44	3.13	2.33	3.21
Weight of heavy iron obtained	96 lbs. 15 oz.	62 lbs. 11 oz.	97 lbs. 2 oz.	63 lbs. 1 oz.
Weight of plate obtained	89 lbs. 14 oz.	57 lbs. 9 oz.	94 lbs. 5 oz.	61 lbs. 11 oz.
Loss of heavy iron	3 lbs. 1 oz.	2 lbs. 5 oz.	2 lbs. 14 oz.	1 lb. 15 oz.
Loss of plate	10 lbs. 2 oz.	7 lbs. 7 oz.	5 lbs. 11 oz.	3 lbs. 5 oz.

lime, and silicate of soda, shown in Table 63 — I cast and prepared two rolls from each heat, coating one and leaving the surface of the other bare, connecting the two for immersion in liquid iron by a rod M after the plan seen in Fig. 51, page 232. By a study of Table 64, one will perceive that the chilled rolls coated with lead best resist fusion by immersion, as well as the heat of melting in the cupola. In fact, all the immersion tests made coincided very closely with the results found by the twin shaft cupola experiments, and strongly confirm the conclusion to be drawn from Table 63, page 311.

TABLE 67.—ANALYSES OF SILICON AND MANGANESE IN LOW AND HIGH BED IRONS, OF TABLE 65. SEE PAGES 313 AND 317.

	Heat No. 10.		Heat No. 11.	
	Silicon.	Man.	Silicon.	Man.
Height of bed, low side	1.41	.34	1.46	.38
Height of bed, high side	1.36	.31	1.41	.32
Difference	.05	.03	.05	.06

After completing the tests illustrated in Tables 63 and 64, I thought it desirable to learn what difference, if any, high and low beds of fuel might cause in losses of iron. By referring to Table 65 it will be seen that tests Nos. 9 and 10 were heats having the chilled pig rolls charged without coating, whereas heats Nos. 11 and 12 had the surface of the iron protected with a wash of lead blacking. In all these four heats, it will be seen the loss was slightly greater with the iron charged on the high bed, or that side using the most fuel. While this is true, it is to be said that more fine shot and scrap was found in the side having the low bed. In general practice, the chances are that the majority of founders would not go to the labor and expense of endeavoring to collect all this fine shot and scrap so closely as was done with these tests. Hence the loss of iron to be experienced in actual practice can be reckoned as the greatest with founders aiming to economize fuel in an extreme measure, thereby not procuring good hot iron. All experienced founders know that high beds of fuel give hotter iron, but that it melts slower than iron charged on low beds. The difference in the heights of bed coke used in the experiments in Table 65 was about 10 inches.

The four heats seen in Table 65 having been completed, I next tested stove plate iron in comparison with the sandless roll iron as used in previous heats. In selecting the stove plate, I secured it as clean as I could, picking it out from the scrap pile. Notwithstanding this, its loss will be seen, by referring to Table 66, tests 13 and 14, to exceed by about 7 per cent. that of the more solid heavy iron used in comparison with it.

TABLE 68.—ANALYSES OF IRON IN SLAG FROM LOW AND HIGH BEDS, STOVE PLATE AND HEAVY IRONS. SEE PAGE 317.

	Per cent of iron in slag, Heat No. 10.	Kind of iron.	Per cent of iron in slag, Heat No. 13.	Per cent of iron in slag, Heat No. 14.
Height of bed, low side..	31.39	Heavy iron	25.13	26.78
Height of bed, high side.........	24.06	Stove plate	23.56	16.97
Difference..	7.33		1.57	9.81

After testing the stove plate referred to, I then ran two heats having a plate casting ¾ of an inch thick, broken in pieces about 4 inches square, and melted it in comparison with the rolls or heavier iron, as seen in tests 15 and 16. This ¾-inch plate iron was cast especially for the purpose and used the day following, so that it was perfectly free from all rust or dirt scale, its coat being only that of the film of oxide formed on its surface while in the green sand mould. The loss of this ¾-inch plate will be seen to be about 5 per cent., and this can be taken as a good test for this character of flat-faced surfaces, when charged in the form of clean scrap, not exceeding 1 inch in thickness. It will be well to state that the iron used for pouring the chilled or sandless gray roll bodies used throughout all the heats herein described (form shown in Fig. 58) were taken from one of our regular shop cupola heats and would average about 1.70 silicon, .045 sulphur, .50 manganese, and .10 phosphorus. Owing to this iron being moderately high in silicon and fairly low in sulphur, it would only chill to a depth of about ¼ of an inch in the small rolls shown. Such a depth of chill on the surface of the rolls used for the heats herein described, would agree fairly well with that found in general gray pig irons that had been cast in chills instead of sand molds, and I believe all will concede it to be an iron well suited for tests on the comparative oxidation of chilled and sand-cast pig metal. Table 67 would show that greater silicon and manganese were lost on the high beds than the low beds of fuel. Another interesting point, which may surprise many, is that the slag which came from the stove plate iron, as seen in Table 68, has a less percentage of iron in it than that which came from the heavier or sandless gray roll iron. While this is shown as such, it does not imply that there is a less total loss of iron with stove plate than heavier iron, as we know by actual practice the reverse to be true. The greater loss of iron by remelting stove plate than is found in heavier irons, is due to the films of oxide, or scales of rust and dirt which, when attacked by the high temperatures of a cupola, etc., in blast, either go to make extra slag or escape out of the stack in other forms. This phenomena in extra slag production is exhibited in actual practice whenever we melt dirty or burnt iron, as all founders well know.

The facts presented herewith suggest that opinions of the past in regard to oxidation of metal are in many cases not well founded, and that where losses of iron have been attributed to oxidation of the metallic iron proper, or a reduction of the metalloids, proper account has not been taken of the dirt, rust, or films of oxide that might have covered the surface of the pig or scrap iron used. We are led to conclude that if it were possible for us to secure clean iron, free of all sand, rust or scales, or oxide of iron, the loss of metallic iron due to oxidation proper is not as large as has been generally supposed.

During the discussion of this paper, Mr. Uehling showed the reliability of the author's experiments on oxidation by presenting the following losses (Table 69) calculated from the results given in Table 63, page 311:

TABLE 69.

Sand iron lost	5.595	per cent average.
Lime wash loss	3.765	" " "
Graphite wash loss	3.425	" " "
Chilled iron loss	3.395	" " "
Soda silicate wash loss	2.875	" " "

This table, it was contended, showed the remarkable accuracy attained with even such small heats. Mr. Uehling in explaining the reason why chilled pig would not waste as much as the sand pig, said it was due to the fact that a slight formation of oxide of iron in the case of the sand pig would immediately cause a slagging action, the iron thus being absolutely lost, whereas in a chilled pig the oxide coming in contact with incandescent carbon fuel would be reduced back to iron again. Here also, he said, would come the advantage of plenty of fuel to keep the flame as constantly up to the reducing action as possible.

LOSS OF IRON BY SLAGGING OUT.

The following data was first presented by the author before the Western Foundrymen's Association April 18, 1894. Iron is lost by being carried off with slag as well as by oxidation in a cupola. The author was led into an investigation of this subject on account of the peculiarities in slag foaming which came from three successive large heats, and was never known to occur before in the cupola used. In analyzing the slag to discover, if we could, the cause of the slag foaming, we also took note of the iron it contained. The slag coming from one of the foaming heats, when analyzed, was found to contain an oxide of iron equivalent to 26.80 per cent. metallic iron. In addition to this there was 1.97 per cent. of very fine shot iron in the sample of slag selected, which was an average of the whole heat. This, no doubt, was from droppings of melted iron, which elsewhere than at the slag hole would have greatly found its way to the bottom and constituted part of the liquid metal to be drawn off at each tap. The fine shot iron I consider is likely to occur in any heat, the quantity escaping with the slag being dependent on the pressure of the blast and the size of the slag hole.

A short time after the difficulty with foamy slag I gave considerable attention to iron in slags, and had analyses made by Mr. Mac Shiras, who found the following weights of iron to be lost through slags: In a heat of forty tons, March 15, 1894, we had slag coming from the slag-hole weighing 1,700 pounds. The analysis showed this slag to contain 3.34 per cent. of shot iron and oxide of iron equivalent to 17.25 per cent. metallic iron, a loss of 350 pounds of iron in the 1,700 pounds of slag, and to the total weight of iron charged the percentage of loss would be thirty-nine one-hundredths of one per cent.

Another heat of forty tons on March 19, 1894, which we followed up, showed the slag weighed 1,630 pounds. The analysis of this gave 2.70 per cent. shot iron and an equivalent of 15.69 per cent. of metallic iron, a loss of 300 pounds in 1,630 pounds of slag, and to the total weight of iron charged the percentage of loss would be thirty-three one-hundredths of one per cent., which, figuring the iron at $12 per ton, would show a loss of $1.58, or a little less than four cents per ton. One factor which it will be profitable to dwell upon before proceeding further is the reason for the difference of loss in the two forty-ton heats. As our metal is carried away from the cupola by a five-ton ladle, and there are often lulls in getting back with the crane ladle, I permitted the practice of leaving the slag-hole open all the time, so as to make sure that the slag or metal did not reach the tuyeres. Feeling satisfied we were losing some metal by letting the blast continually blow out of the slag hole, I decided to try, in the second heat quoted, to plug and tap the slag-hole at intervals, or just a few minutes before tapping out. By doing so we obtained, as shown, a saving of six one-hundredths of one per cent. of the total weight of iron charged, or in other words, we saved 29 cents in the heat of 40 tons at the risk of letting the iron or slag fill up the tuyeres, and hence bung up the cupola. By such a method of retarding melting, to save a little iron, we might have lost many dollars in castings through bad melting or dull iron.

Where conditions are favorable to tapping a slag-hole at intervals, or just before tapping out the iron, on account of having a greater distance between the tuyeres and slag-hole, then we had, the above figures clearly demonstrate the economy of such practice; and it is one that as a general thing can be safely followed; but in cases where the tapping out and plugging up of a slag-hole would require a man solely to look after it, nothing is to be saved by this practice. We used all pig; no scrap excepting a few "gates," which, for a 50-ton heat would weigh about two tons; and Connellsville coke for fuel, of which 2,000 pounds were used for the bed and 450 pounds between charges. The pig on bed was 8,000 pounds and between charges 6,000 pounds. We used limestone for a flux; for every three tons we used about 90 pounds, placed on top of every charge. There is no doubt that one or two hundredweight of slag could be added to the totals given above, which could be gathered from the skimming of the ladle and the dropping of the bottoms. Our apprehension as to loss of iron through slag was allayed when we discovered it was less than one-half of one per cent.

The loss of pig iron through oxidation in the cupola, iron in the slag and refuse wheeled out from under the bottom, etc., by melting in a cupola, will range from three to six per cent. of the total weight charged. The more sand scale on pig iron, the greater the loss. Unbroken pig iron will show a greater loss than broken, for the reason that the jar of breaking it over an iron block loosens the sand scale so that when the iron is thrown into a car for shipment from the furnace yard the purchaser receives less sand scale on his pig iron.

Loss of scrap iron by melting in a cupola is given in Table 66, page 314, and discussed on pages 316 to 318. This shows that the loss of stove plate may range from ten to fifteen per cent. or more and heavier scrap from four to eight per cent. or more, according to the scale and dirt conditions of the iron.

We can look to oxidation for much of the total loss incurred by remelting iron. There is little doubt but that most of the loss by oxidation is done above the tuyeres, as the metal is dropping from the melting point through the fuel down past the tuyeres to the bath of metal in the bottom, and from the surface of the solid metal, at or above the melting point, as it exposes a semi-molten surface to the effects of the blast. The more surface we expose to the effects of blast the faster the oxidation, hence, with light scrap, we must expect the greater loss. There are reasons why one founder should lose 10 per cent. and another only 3 per cent., in remelting cast iron. It will pay any founder to closely investigate his losses, and he may often lessen them by intelligently understanding the cause.

CHAPTER XLVII.

COMPARATIVE FUSIBILITY OF FOUNDRY METALS.*

In the advance of founding to a basis of greater exactness and assurance of successful workings, it is often as essential for us to have information on the fusibility of the metals we make mixtures from, as to know the effect of one metalloid upon another in changing the physical character of iron. This is realized when we consider how easily a formulated mixture can be prevented from giving calculated results, by one metal having a lower fusing point than another when charged into a cupola. While this is a subject of importance to the general and heavy-work founder, who is often called upon to take several different grades out of a cupola at one "heat," it is also of importance to the specialty and light-work founder who may be charging irons of different grades to make one or two mixtures for a whole heat, for when the latter knows that one combination of certain metalloids requires greater heat than others he is in a much better position to decide whether it is the iron, blast, atmosphere, fuel, mischance, or his own mismanage-

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*This chapter comprises two papers, revised for this work, which the author presented respectively to the Pittsburg Foundrymen's Association in June, 1897, and to the Western Foundrymen's Association at Cincinnati, in October of the same year.

ment that makes the cupola irregular in its meltings so that it produces hot iron one day and dullish iron the next, also harder iron than desired with resulting bad work or heavy losses in castings. Knowing how very important it is to possess definite knowledge concerning what causes grades of iron to differ in their fusibility, I decided to experiment and learn, if possible, the effect of different combinations of the metalloids on the fusing point of iron. In searching for appliances that would give reliable data I failed to find anything satisfactory, and therefore set to work to devise something that would meet the requirements and at the same time withstand criticism. One objection I have to past methods of testing the fusibility of metals, is the failure to provide conditions similar to those used in actual founding. To meet the conditions of actual practice, I studied out a design of cupola (see Fig. 56, page 241) which is an original arrangement, so far as I know. The method adopted gives only comparative results and does not show the degree of heat required to fuse any of the metals. Observations may be made and conclusions drawn from them as to the difference in the time of melting which any grade of metal requires over another, when the two kinds of iron are charged in the respective sides shown. It will appear upon examination that like conditions must prevail in both apartments, and that if one grade starts or comes down quicker than another we know it to have a lower fusing point. By a series of such tests we are in position to formulate a scale showing the combinations of metalloids requiring the highest heat, with the relative gradations of others, down to that most readily fused.

The comparative test cupola seen on page 241 is not an expensive affair, and is such as might often be a valuable adjunct to the laboratory of metallurgists, blast furnaces, foundries, etc., besides being useful for the production of repairs for breakdowns, etc., and then again for small castings, which it may be desirable to make of two separate grades of metal. It will be well to state that, where only one kind of iron is desired to be melted the center blast can be closed and the iron made to run to one tap hole by having one slanting bed as in regular cupola practice.

In designing the cupola (Fig. 56) I arranged for a center blast, besides having outside tuyeres on the plan shown. This permits the greatest possible uniformity of combustion throughout the area of the cupola and affords every opportunity of regulation should the heat, from any cause, be greater in one portion than in another. This regulation is secured by diminishing or increasing the volume of blast by valves attached to branch pipes, not shown, leading to the tuyere openings A A, B B, and E. It may be asked, How is it possible to know when there is perfect uniformity of heat all over the area of the cupola? This is indicated by the color of the flame emanating from the open top of the cupola. If any difference should exist there on either side, the eye will detect it as quickly as the steel maker can note changes taking place in a Bessemer converter by means of the spectroscope.

In operating this cupola the sand bed is put in with two slanting bottoms, as seen at H H, thus preventing either metal, as it comes down, from mingling with the other. The center tuyere has three pieces of ½-inch round iron laid over its opening, as seen at M, to prevent the fuel from dropping into it and stopping its blast passage. Good kindling is used up to within, say, 12 inches of the top. On this, coke broken to about double egg size, is then placed. The coke is poked down as the fire burns until there is a solid bed of live coals up to within 15 inches of the top. If the metal to be fused is of a light character, or easily melted, it is then charged at this height; but if it is heavy or hard to liquefy, then the bed of live fuel should extend up to about 12 inches from the top, as shown by the pigs at X. As this cupola has ample tuyere area evenly divided, it can be worked with a mild or strong blast, as may be desired. The tap holes at D D are left open so as to permit the metal to flow out as fast as it melts, thus allowing a record to be made of the metal's first and last appearance. Of course, should the cupola be used simply for the purpose of melting to get metal to pour a casting, it could then be stopped and tapped the same as any cupola used in ordinary practice. If the cupola is employed for testing the comparative fusibility of metals, it may often require about six men to operate it — one for timekeeper, one to charge on fuel evenly and press it down so as to preserve a solid fire until the iron is about half down, one at each tap hole to keep it open that the metal may flow freely, and then, if the metal is to be caught into moulds, two men on each side to take away the filled moulds and replace empty ones. If the cupola is only to be used to obtain metal to pour a small casting, or to record the time of fusing by letting the metal down into a ladle or "pig" as it comes out, then two men are sufficient to operate it. In charging any metal for a comparative test, care must be exercised to have the bed of the fuel the same height on both sides, also to have each grade of metal as nearly uniform in size as possible, and evenly charged. After this, coke is filled in until the cupola is stocked to its brim, when it is ready for the blast.

The first test heat made, as seen by the Table 70, consisted of 150 pounds on each side, it being put in with 50 pounds in two charges after the bed of 50 pounds was on. This plan was found to be objectionable for comparative testing, as it showed wherein errors might easily be made by reason of uneven charging, the escaping flame making it too hot for the charger to always place the iron in evenly. After this first heat no more metal was charged than the bed could carry well, thus permitting all iron to be carefully charged before the blast went on. The plan adopted for comparative tests of Table 70 was to make at least two casts of each grade, the first being that of the metal in its original state, each grade being broken to uniform size, as far as possible. This, in being melted down, was run into moulds that gave blocks weighing about 15 pounds each and in size 2½ x 4 x 6 inches. For the second cast of each grade these blocks, in the larger heats, were broken in two pieces, but where there were only two blocks for each side they were charged whole. The idea of running the first heat of pig metal or scrap into blocks, as stated, was to obtain metal that would be closely uniform in size and weight and better insure like conditions in making a comparative test, an important requisite. This appears in Table 70, in the columns marked alternately "pig" and "block." Up to the time of writing this paper I have made nineteen comparative tests, but only give results of eight of them here, for the reason that in the case of the others I desire to make experiments that will require much time, and that should be compiled with the second series to give complete results in that line of inquiry. As the first series of tests is distinct, in showing what effect low silicon and high sulphur have upon the fusibility of iron, as compared with high silicon and low sulphur with the total carbon and the "iron" closely constant, I permitted the appearance of this paper at the request of the secretary. The second series of tests is given in pages 332 to 344.

TABLE NO. 70—COMPARATIVE FUSING TESTS OF HIGH AND LOW SILICON AND LOW SULPHUR IRONS.

"Heat" Nos.	1	2	3	4	5	6	7	8
Form of iron charged	Pig.	Block.	Pig.	Block.	Pig.	Block.	Pig.	Block.
Weight of iron charged each side..	150	65	100	54	40	35	64	50
Blast turned on........	1:55	1:35	2:13	2:08½	4:21	1:56	1:44	2:26
Harder iron running	1:57	1:39	2:21	2:12½	4:27	2:02¼	1:50	2:32¾
Softer iron running..	1:57¾	1:40	2:21⅙	2:13¼	4:28	2:02	1:50½	2:34½
First mold of harder iron filled............	1:59	1:42	2:24	2:16	4:31¾	2:06½	2:55	2:37¾
First mold of softer iron filled..	2:01	1:43	2:24	2:15½	4:32¾	2:07	2:55½	2:38½
Second mold of harder iron filled...	....	1:43	2:26	2:17	4:36	....	2:57	2:40
Second mold of softer iron filled............	....	1:44	2:26	2:16½	4:38¾	....	2:58	2:41
Third mold of harder iron filled...	....	1:44	2:27½	2:17⅓	....	....	....	.. ..
Third mold of softer iron filled..	....	1:45	2:28	2:17¾	....	....	....	.. ..
Harder iron all down	2:19½	1:49	2:37½	2:18	4:37	2:09½	2:02¾	2:47½
Softer iron all down.	2:22	1:50	2:39	2:18½	4:40	2:11	2:05	2:48½
Time of melting.	25m.	11m.	16½m.	6m.	13m.	10m.	15m.	15¾m.
First iron to melt	Hard.	Hard.	Hard.	Hard.	Hard.	Hard.	Hard.	Hard.
Time exceeding its mate.	45 s.	1 m.	10 s.	45 s.	1 m.	15 s.	1m 30s	1m 45s
First iron all down...	Hard.	Hard.	Hard.	Hard.	Hard.	Hard.	Hard.	Hard.
Time exceeding its mate......................	2m 30s	1 m.	1m 30s	30s.	3m.	1m 30s	2m 15s	1 m.

TABLE 71.—CHEMICAL ANALYSIS OF TABLE 70.

Analysis Letter.	A	B	C	D
Total Carbon	4.25	4.03	4.15	4.10
Graphite Carbon	2.07	1.76	1.94	3.92
Combined Carbon	2.18	2.27	2.21	.18
Silicon	.85	.92	.99	2.70
Sulphur	.21	.19	.17	.03
Manganese	.18	.17	.26	.34
Phosphorus	.192	.129	.655	.085
Iron by difference	94.32	94.56	93.77	92.74

The importance of this work will be better understood when it is stated that at the present time (1897) some are laying claim to tests proving that soft grades of all irons will melt down faster than hard irons. The contrary results have chiefly been my experience, and appear to be the general expression on this question. Still, I hold, as stated in the early part of this paper, that results are often affected by combination of the metalloids as well as by the physical character of the iron, and I believe my second paper will bear me out in this assertion. I desire here to thank Dr. Richard Moldenke and the McConway & Torley Co. of Pittsburg for the assistance rendered me in this work by furnishing metals and complete analyses of the irons shown.

Referring to the preceding tables, attention is first called to the analyses. The column under A, Table 71, is that of hard iron in heats Nos. 1 and 2. B is that of a white iron used for heats Nos. 3 and 4, C is that of a mottled iron used for heats Nos. 5, 6, 7, and 8, while D is the analysis of a soft iron used as a comparative constant to the hard irons throughout the eight heats. It may be stated that drillings for analyses were all taken from the blocks as they came from the first casts of the original pig or scrap metal.

In all the heats the hard iron is seen to have come down first, excepting in one case which is found in heat No. 6, and that the flow of hard iron ended soonest in all the heats. Thus, as far as these tests go they show that hard iron will melt faster than soft, and confirm my past assertions and the general impression existing among old experienced founders that hard iron will melt more readily than soft grades.

An interesting discussion followed the reading of the paper. Dr. Richard Moldenke contributed the following: "Long experience with the melting of iron in Siemens-Martin furnaces having given me the impression that hard irons melt faster than soft ones, and knowing this to be the accepted view among the trade, I was not a little astonished to see claims advanced insisting on the contrary. At the time I thought it likely to be owing to some radical difference in the composition of the irons that were used, and was therefore more than pleased to hear Mr. West advance the idea of making comparative tests to settle the matter definitely. It has remained for him to devise a most excellent system of melting to accomplish this result, and I, for one, have been much interested in the working of his "twin shaft cupola" (Fig. 56), if I may so call it. It will give us ready means of comparing the fusibility of the required brands of iron going into our cupola charges. The few words I have to add relate to the melting of iron in the open-hearth furnace, where there is obviously no difficulty due to the rate of melting, since everything charged is supposed to make up a bath of uniform composition. I made two experiments, charging simultaneously in each case two pigs of equal weight and shape, one being soft, the other hard. It will be observed that in the open-hearth furnace, filled up with a charge just melting down, these two pigs thrown on top of the white hot metal, and in the full head of the furnace, could be closely watched with the aid of blue glass spectacles. In the first experiment I was surprised to find the soft pig melting first. It became soft and could be broken up by the bar, behaving much like a plumber's wiping metal when it is just soft enough to work. This soft pig, when thus crushed, looks like silver, and makes one wish for time and opportunity to study the characteristics of the carbons while in this state. The hard pig, on the contrary, retained its form remarkably well, not disintegrating like the soft one did, the melted portions dropping off like water. Further investigation developed the fact that the soft iron which melted first was about 55 points higher in the total carbon than the hard iron. (The author held that difference in the graphitic and combined carbons would affect results as seen on pages 154 and 329.) Mr. West, in his second paper, will go into this question fully, as he is making extended experiments in this line. The other trial was with two irons of the same brand, shape, and weight. They had very nearly the same manganese, sulphur, phosphorus, and total carbon, but one had twice as much silicon as the other, resulting in 3.37 per cent. graphite in the soft pig, and only .68 per cent. in the hard white one. In melting these two pigs under exactly the same conditions, the hard one went first. It held its form well, but in melting ran like water, and was melted before the soft iron was half gone. The soft iron melted sluggishly, and did not hold its form while melting as well as the hard iron. It was very interesting, even if trying to the eyes, to observe the whole process, and now that Mr. West has gone into the whole matter so thoroughly, we will certainly be able to crystallize our ideas and know what we may look for in making up important charges."

REVISION OF SECOND PAPER ON FUSIBILITY OF FOUNDRY METALS.

This second paper, aside from presenting several important discoveries made by the author, shows that a chilled body of iron will melt faster and require less heat than a gray body, both having been poured from the same ladles or cast of iron, and that steel proper requires higher heat than cast iron to fuse it; also that remelting of steel in contact with incandescent fuel wholly destroys its original character. Making comparisons of the fusibility of gray and chilled bodies, both of the same composition excepting the combined carbon, was accomplished by the following plan. A heat of chilling or low charcoal iron, designated as heat No. 9, Tables 72 and 73, was caught in hand ladles and then poured into sand and chill moulds, placed side by side. A view of the chill mould and chill roll cast in it is seen at Figs. 58 and 59, page 312. This gives a wholly gray body of iron in the casting coming from the sand mould, and a wholly chilled or white crystallized body of iron from the chill or all-iron mould; both, it is to be remembered, being poured from the same ladle of iron. The fractures of the gray and chilled iron are shown in Figs. 61 and 62, this page and 337.

The gray and sand rolls which were used in these comparative tests were all tumbled, so as to get the sand off them thoroughly before they were charged. Before explaining the results and tests shown by Tables 72 and 73, next page, we will describe the plan followed in conducting the heats shown:

FIG. 61.—GRAY ROLL.

Combined Carbon, 1.20. Graphitic Carbon, 2.90.

For heat No. 9, Table 72, charcoal pig iron was charged in both chambers of the cupola and run out of one tap

TABLE 72.—COMPARATIVE FUSION TESTS OF GRAY AND CHILLED IRONS.

Heat Nos.	9	10	11	12	13	14	15	16	17	18	19	20
Kind of Metal Charged.	Charcoal pig iron.	Sand and chill rolls.	Gray block re-melt.	Sand and chill rolls.	Charcoal pig iron.	Sand and chill rolls.	Charcoal pig iron.	Sand and chill rolls.	High manganese and phosphorus charcoal pig iron.	Sand and chill rolls.	Foundry pig iron.	Sand and chill rolls.
Weight of iron charged each side of cupola........	75 lbs.	48 lbs.	44 lbs.	32 lbs.	70 lbs.	53 lbs.	77 lbs.	58 lbs.	68 lbs.	40 lbs.	73 lbs.	55 lbs.
Blast put on....................	1:30	4:06	3:38	2:23	1:10	2:30	1:05	1:47	3:49	3:56	4:22	4:25
Chilled iron running	....	4:13	....	2:35½	....	2:38	....	1:52½	....	4:01	....	4:35
Gray iron running...........	1:39	4:15	4:11	2:39	1:18	2:40¼	1:15	1:54	3:57	4:01¾	4:33	4:35½
Chilled iron all down.......	....	4:21	....	2:44	....	2:51	....	2:02	....	4:08	....	4:38½
Gray iron all down.........	1:47	4:22½	4:22	2:47	1:26½	2:52¾	1:27	2:03	4:06	4:09¼	4:42	4:39¼
Chilled iron exceeded gray in starting............	....	2m.	....	3m. 30s.	....	2m. 15s.	....	1m. 30s.	....	45s.	....	30s.
Chilled iron exceeded gray in finishing...........	....	1m. 30s.	....	3m.	....	1m. 45s.	....	1m.	....	1m. 15s.	....	45s.

TABLE 73.—CHEMICAL ANALYSIS AND SPECIFIC GRAVITY OF GRAY AND CHILLED IRONS RAN FROM HEATS SHOWN IN TABLE 72.

Heat Nos.	9	10		11		12		Analysis of Castings obtained from the 12th heat.			
Kind of metal charged.	Charcoal pig iron.	Sand Rolls.	Chill Rolls.	Sand Rolls. Block.	Chill Rolls. Block.	Sand Rolls.	Chill Rolls.	Sand Rolls.	Chill Rolls.	Sand Rolls.	Chill Rolls.
Analysis letter......	A	B	C	*D	*E	F	G	H	I	J	K
Total Carbon...	3.94	4.10	4.06	4.30	4.30	4.47	4.40	4.68	4.62	4.76	4.70
Graphitic Carbon...	3.06	2.90	0.16	2.42	2.68	2.90	0.20	2.67	0.00	3.16	0.03
Combined Carbon .	.88	1.20	3.90	1.98	1.62	1.57	4.20	2.01	4.62	1.60	4.67
Silicon.	.82	.75	.75	.63	.68	.66	.63	.57	.56	.59	.57
Sulphur....	.02	.03	.03	.04	.035	.04	.04	.045	.046	.048	.044
Manganese	.78	.66	.66	.53	.54	.31	.33	.18	.19	.25	.22
Phosphorus....	.232	.248	.240	.274	.285	.237	.254	.254	.250	.271	.266
Specific Gravity...	7.01	7.30	7.61	7.35	....	7.40	7.70	7.47	7.76	7.46	7.79

hole, the metal being poured into sand and chill moulds from one ladle. For heat No. 10 the sand and chill rolls from heat No. 9 were charged in their respective sides and the two tap holes used. The iron as it ran from this heat through open tap holes dropped into sand moulds, one being set under each tap hole, to give a block of iron from each side about six inches diameter by six inches high. This tenth heat had both sides run into sand moulds for the purpose of learning which would be the harder iron when remelted, that which had been chilled or that which had not. Heat No. 11 melted down the gray blocks obtained from heat No. 10, and this iron was again run into sand and chill moulds. Heat No. 12 was a remelt of the sand and chill rolls obtained from heat No. 11, and was the

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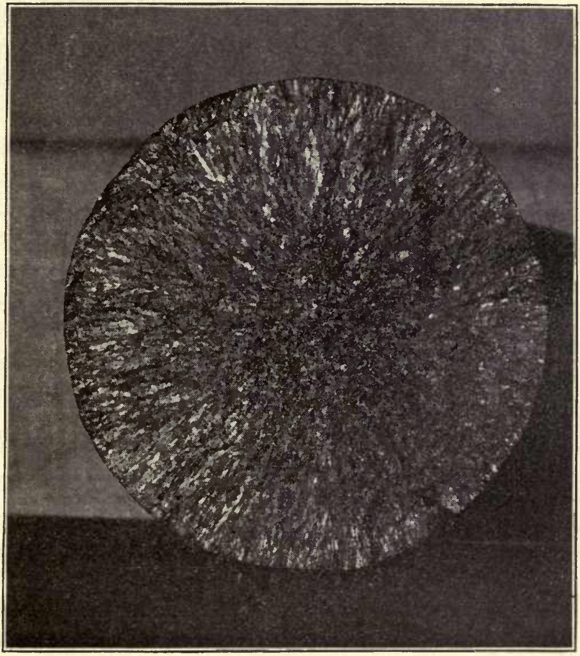
* The analyses D and E of the grey blocks coming from the sand and chilled rolls cast in heat No. 10 and melted down in heat No. 11 is also shown at A2 and B2, Table 74, page 336.

fourth and last heat of a continuous remelt of the original charcoal pig used in heat No. 9. The metal from heat No. 12 had each side poured into sand and chill moulds, and the analyses at H, I, J, and K, Table 73, show the chemical changes made by the twelfth heat. Heats 13 and 15 were casts in which the same grade of pig was used as in heat No. 9 as a check to learn if similar results would be obtained by further experiments, and heats 14 and 16 are used as a check on heat No. 10, in the same manner.

TABLE 74.—CHEMICAL ANALYSIS OF CHILLED AND GRAY IRON RE-MELTS, POURED INTO SAND MOLDS BY HEATS SHOWN IN TABLE 72, PAGE 334.

Description of iron and heat No.	Analysis of gray blocks obtained from 10th heat.		Analysis of gray blocks obtained from 16th heat.		Analysis of gray blocks obtained from 18th heat.		Analysis of chilled and sand rolls charged on 20th heat.		Analysis of gray blocks obtained from 20th heat.	
Classification of re-melts.	Sand roll re-melt.	Chill roll re-melt.	Sand roll re-melt.	Chill roll re-melt.	Sand roll re-melt.	Chill roll re-melt.	Sand rolls as charged.	Chill rolls as charged.	Sand roll re-melt.	Chill roll re-melt.
Analysis Letter.	A2	B2	C2	D2	E2	F2	G2	H2	I2	J2
Total Carbon....	4.30	4.30	4.30	4.30	2.94	3.15	3.55	3.60	3.88	3.95
Graphitic C'rb'n	2.42	2.68	2.20	3.20	2.41	2.73	2.63	2.05	2.15	2.40
Combined Carbon..	1.98	1.62	2.10	1.10	.53	.42	.92	1.55	1.73	1.55
Silicon.........	.63	.68	.75	.87	.55	.69	1.55	1.57	1.29	1.39
Sulphur	.04	.035	.04	.035	.045	.048	.030	.030	.042	.040
Manganese..	.53	.54	.48	.62	1.23	1.32	.133	.135	.126	.130
Phosphorus. ...	.274	.285	.283	.241	1.07	1.07	.343	.330	.364	.350

The analyses given under A, B, and C, Table 73, for heats Nos. 9 and 10 will also serve for heats 13 to 16. When running the sixteenth heat the sand and chill roll metal was run into sand moulds, as described for heat No. 10. Heat No. 17 is a high manganese and phosphorus pig, which was run into sand and chill moulds to make rolls that were used for heat No. 18, from which the gray and chilled metals, as they came down, were both run into sand moulds. Heat No. 19 is a No. 2 Foundry all-coke iron which was also run into sand and chill moulds. Heat No. 20 is made from



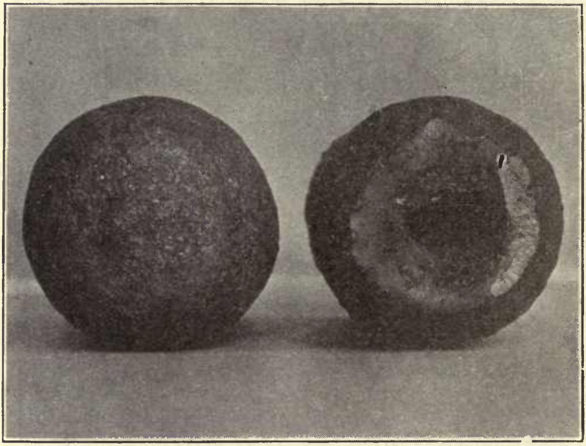
Combined Carbon, 3.90. Graphite Carbon, 0.16.

FIG. 62.—CHILLED ROLL.

the sand and chill rolls obtained from the nineteenth heat, both of which metals were run into sand moulds as heats Nos. 10, 16, and 18. Analyses of the gray and chill roll remelts, that were poured into sand moulds to test whether chilled or grey parts of the same casting would give the softer iron, are all shown in

Table 74. The analyses A2 and B2 are also shown in Table 73, at D and E, page 335.

It was the belief, until the author's discoveries proved the contrary, that an iron once chilled would, upon being remelted, produce a much harder casting than if the same iron had never been chilled. This belief was so strongly maintained by founders, prior to the author's discovery, that in selecting scrap iron for mixtures with pig metal to make light or heavy machinery castings, etc., founders would reject the scrap that had been chilled, if it could be done, lest it might cause hard spots in a casting or make the whole too hard. Of course, it is to be understood that if a casting shows a chill, it is evidence that the gray body of the casting, if used for scrap, is not accepted as a soft iron, as if no part of the casting exhibited a chill; for, as a rule, founders know such fractures are not to be graded as soft iron. Nevertheless, they did not



GRAY ROLL. FIG. 63. CHILLED ROLL.

know that a chilled iron body would give a casting slightly softer than if the chilled part had been rejected and only the gray body utilized. While this knowledge would always have been of much value to the founder, there has been no time that it could be turned to more profitable account than at the present. It may be asked what evidence there is aside from the drilling tests to prove that the chill roll remelt was softer than that of the gray. This is answered by referring to the columns B2, D2, F2, and J2, Table 74, and noting the greater silicon and graphitic carbon existing in the chill remelt than is found in the gray, as seen at A2, C2, E2, and I2. The author's attention was first drawn to the fact that the chill remelt was softer than that of the gray, by drilling to obtain material to make the analyses. The drill worked so much easier in the chill remelt than in the gray as to be a matter of much surprise. The drill press used is shown at Fig. 53, page 239. After a well sharpened twist drill was attached and all ready, the drill was started and allowed to run exactly half a minute. By drilling several holes in the manner described on page 234, alternately in each of the respective blocks, we could then, by measuring their depth, intelligently tell which of the two was the softer. It is to be said that the drillings of the whole four heats, Nos. 10, 16, 18, and 20, showed the chill remelt to be softer than those of the gray iron. It will be noticed also that these four remelts are distinct in testing different grades of iron, so as to cover a wide range of metals, from those that would take but a slight chill on the surface of pig metal or a casting up to those that would chill its whole body as displayed in Fig. 62.

Attention is again called to the specific gravity tests seen in Table 73, page 335, which, in four successive remelts, raised the density of the gray iron from 7.01 to 7.46, an increase of .45 in density, and in the chilled iron to 7.79, an increase of .78 from the original pig, showing that successive remelts greatly increase the density of irons. Another point to be noticed is that the chilled iron differs about .30 in density from the gray iron in the respective heats shown. For a comparison of the specific gravity of other metals with cast iron, see Table 136, page 593.

TABLE 75.—COMPARATIVE FUSION TEST OF CAST IRON WITH OPEN HEARTH STEEL.

Heat Nos.	21	22	23	24	25	26	27	28
Kind, Weight and Form of Metal Charged Each Side.	35 lbs. of iron and steel in block form.	29 lbs. of iron and steel in block form.	23 lbs. of iron and steel in block form.	61 lbs. of iron and steel in scrap form.	44 lbs. of iron and steel in block form.	52 lbs. of iron and steel in scrap form.	40 lbs. of iron and steel in block form.	58 lbs. of iron and steel in block form.
Blast put on	8:56	2:50	3:00	11:30	3:23	10:37	11:29	3:26
Steel running..	9:09½	2:59½	3:05	11:41¼	3:32	10:45¾	11:38¼	3:32
Iron running...	9:06½	2:58	3:04	11:38	3:30½	10:45	11:36¾	3:32¼
Steel all down.	9:21	3:08	3:11¼	11:51	3:41½	10:58½	11:49¾	....
Iron all down..	9:17½	3:05½	3:10	11:48	3:40	10:58	11:49	....
Iron exceeded steel in starting	3m.	1m. 30s.	1m.	3m. 15s.	1m. 30s.	45s.	1m. 30s.	15s.
Iron exceeded steel in finishing	3m. 30s.	2m. 30s.	1m. 15s.	3m.	1m. 15s.	30s.	45s.	....

Chemical changes due to remelting iron. In a study of Table No. 73 we are first struck by the increase of total carbon. We find that starting with the original pig containing 3.94 carbon, four re-melts increased it to 4.76, an increase of nearly one per cent. It is to be noted that in all cases the sand or gray rolls show more carbon than the chilled roll.

TABLE 76.—CHEMICAL ANALYSIS OF GRAY CAST IRON AND OPEN HEARTH STEEL RE-MELTS GIVEN IN TABLE 75, OPPOSITE PAGE.

Heat Nos.	21		22		23		Analysis of metal obtained from the 23d heat.		Analysis of metals charged in heats Nos. 24 to 26.	
Kind of Metal Charged.	Gray cast iron.	Open-hearth steel.	Gray cast iron.	Open-hearth steel.	Gray cast iron.	Open-hearth steel.	Gray cast iron.	Open-hearth steel.	Gray cast iron.	Open-hearth steel.
Analysis letter	L	M	N	O	P	Q	R	S	T	U
Total carbon...	4.02	.60		1.48		2.74	4.60	3.05	4.20	.70
Graphitic carbon......	2.90	......		...	....		3.30	.15	3.03	trace
Combined carbon	1.12	.60	....	1.48	....	2.74	1.30	2.90	1.17	.70
Silicon....	1.72	.31	....	.26		.14	1.15	.35	1.24	.38
Sulphur..........	.03	.026		.10		.14	.10	.18	.05	.12
Manganese	.35	.34	.....	.23	..	.15	.23	.06	.40	.59
Phosphorus	.073	.106		.167		.190	.103	.198	.092	.116

The effect of remelting upon the silicon, sulphur, manganese, and phosphorus is well shown in Tables 73, 74, and 76. We find the results are all in line with the varied experience of those who have kept close watch of remelts, to the effect that silicon and manganese decrease while sulphur and phosphorus increase. It may cause some surprise that more silicon was not lost or sulphur added than shown by the four continuous remelts in heats Nos. 9, 10, 11, and 12, Table 73. The author accounts for this in that the metal was held in the cupola but a short time, compared to that generally occupied in ordinary shop practice. The longer heated or semi-molten iron remains in contact with incandescent fuel or is exposed to gases, the more sulphur will be absorbed — up to the limit of the iron's affinity for it. The reverse is true of silicon, as the longer the iron is exposed to the effects of high heat and blast, the more silicon is lost.

STEELY IRON CASTINGS.

Remelting steel requires longer time to fuse than cast iron, as will be seen by Table No. 75, page 340, in which heats Nos. 21, 22, and 23 are continuous remelts of the same metals. The steel was a "riser-head" piece of scrap that was moulded to make a single piece of cast iron of the same form, so that conditions as to form and weight could be the same for both metals in making the comparative fusing test shown. Heats 24, 25, 26, and 27 are two remelts of different quantities of cast iron and steel metals, having similar composition, as will be noted by referring to columns T and U, Table 76, page 341.

Heats 24 and 26 had the metals in scrap form as nearly alike in size and bulk as they could be roughly made, and when melting they ran into moulds to give blocks 2½ x 4 x 6 inches, so as to insure a uniform size of stock for making the comparative heats 25 and 27. Heat 28 was a remelt of the blocks obtained from heats 25 and 27. In this heat, it will be noticed, the iron and steel came down closely together. The reason the closing time is not shown is on account of stopping up the tap holes after the iron had started to run, with a view to catching metal in a hand ladle to pour shrinkage and contraction tests (see page 410), which left the matter too indefinite to record the time of actually finishing first, although, as near as we could see or judge, they ended closely together. Table 75 shows that the more we remelt steel scrap the less difference exists in the iron starting and closing ahead of the steel. This is due to the fact that remelting steel raises its total and combined carbon and at the same time we find that steel remelts will be very spongy or filled with gas or blow-holes, which increase more in size and number with each successive heat, thus causing the steel product to be very porous and thereby permitting the heat to better penetrate its body and bring it quicker to a fluid state.

Table 76 shows the folly of trying to remelt steel and obtain from it the original metal, as can be closely done with cast iron. Nothing has led founders on more wild-goose chases than giving ear to some of the high-sounding claims made for remelts of steel or its mixture with cast iron. It is true that steel scrap mixed with cast iron can strengthen the latter to a limited degree, but the extreme claims some make for its mixture with cast irons are erroneous and unfounded. We have no metal that will deteriorate from its original state by reason of remelting, so much as steel scrap. The action taking place in remelting steel in a cupola increases the carbon in the metal, as shown in Table 76. We find that the first remelt raised the carbon from .60 to 1.48; the second sent it up to 2.74, and the third to 3.05—an increase in either of these three remelts sufficient to show that we are very far from retaining anything like the original steel in any remelts in a cupola which compels the steel to be in contact with the fuel from which it absorbs the carbon with avidity.

When steel is melted in a reverberatory or air furnace, in mixture with cast iron, we have more favorable conditions because of its being possible to keep the carbon lower and the better to add other metals, as spiegel and ferro-manganese, which alloy with the fluid metal without having their original properties destroyed to any great degree. Tensile strengths ranging from 45,000 to 50,000 pounds per square inch have been obtained by air furnace meltings with mixtures of iron, steel, etc., but to obtain castings equal to those of steel proper we must have them cast by regular steel founders. Whenever we desire to improve the strength of cast iron by mixture with steel, the lower carbon or soft steels will be found to give the best results, and air furnace meltings excel those of a cupola, especially if charcoal irons are used. In mixtures with the latter, from 15 to 30 per cent. of soft steel scrap may often be advantageously used. For further information on the steel question, see pages 265, 267, 271, 272 and 276, and the "Moulder's Text-Book."

THE MELTING POINT OF CAST IRON.

The following is an extract of a valuable paper which was presented by Dr. Richard Moldenke before the Pittsburg Foundrymen's Association, Oct. 24, 1898. This extract gives a description of the pyrometer which the doctor used for testing the temperature of molten metal, etc., and of its value in other lines, also of tests he made as found in Tables 77 to 81. In looking about for a pyrometer, the doctor's attention was naturally directed to the latest and admittedly the best form of a pyrometer for very high temperatures—the Le Chatelier. In referring to this instrument and to his tests, the doctor says: "This pyrometer consists essentially of two pieces of wire of a slightly varying composition, a heating of the junction of which produces a current of electricity proportioned to the degrees of heat applied. The amount of this current is measured by a suitably calibrated galvanometer, and thus we can read off the heat at any convenient distance rapidly and with a surprising degree of accuracy.

"Unfortunately, this wonderful instrument, one wire of which is of platinum, the other of an alloy of platinum and 10 per cent. of the rare metal rhodium, cannot be immersed directly in the melted iron — there would soon be an end to this expensive thermo-couple. The long porcelain tube which protects it when used in kilns is worse than useless in a ladle full of metal, and so at the suggestion of the writer the Pittsburg representatives, the Vulcan Mfg. Co. set about to remedy the matter and devise some protective cover which would allow experiments of this kind to be carried out readily. The outcome, while not having the advantage as yet of an extended period of trial, was nevertheless so happy a solution that it is presented, for the first time, with the hope that much of value may be learned from it, not only in our daily work but also in connection with the many intricate problems still before us which await solution at the hands of those willing to give their time and energy to such an exacting study.

"Fig. 64 shows a section through the instrument. The platinum wire will be noticed running from the terminal box through an iron pipe ending at the inner side of the point of the clay tip. Here is the button made by the fusion to the other wire of platinum and rhodium alloy which runs back, parallel to the platinum wire, to the terminal box. Both wires are covered

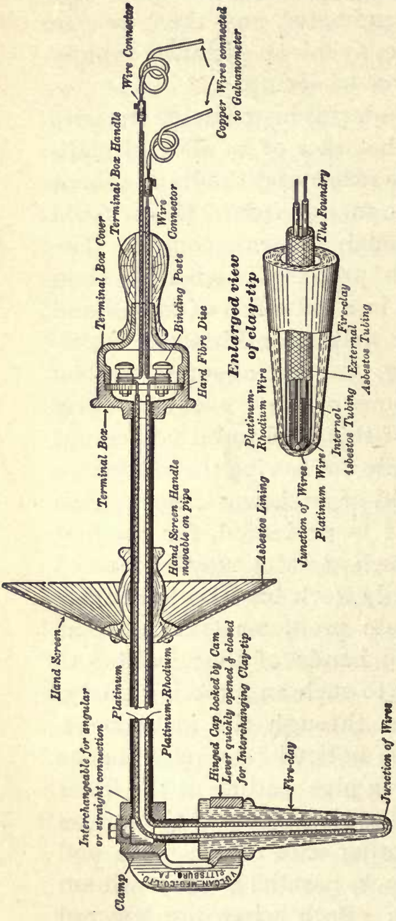


FIG. 64.—SECTION THROUGH PYROMETER.

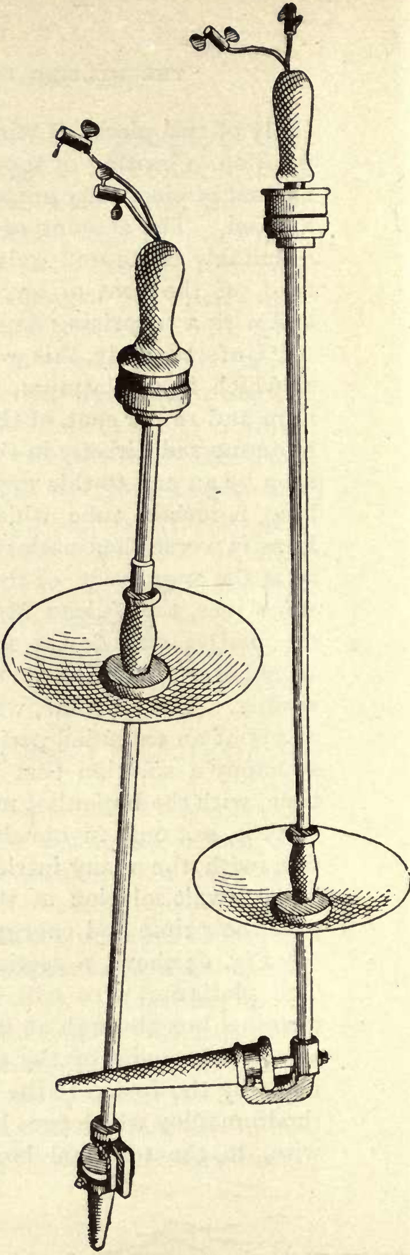


FIG. 65.—TWO FORMS OF LE CHATELIER PYROMETER.

with asbestos to insulate them from each other and from the iron frame, as well as to serve as a protection in case the tip breaks while in the molten iron. The interchangeable connection holding the clay tip allows it to point out straight for use in small ladles or in experimenting, or it may come down at right angles for taking temperatures in large ladles full of metal.

FIG. 66.—METHOD OF USING IN LADLE.

A third form, not completed in time for illustration purposes, has a ball and socket joint which allows the tip to stand out at any angle. A movable shield lined with asbestos protects the hand.

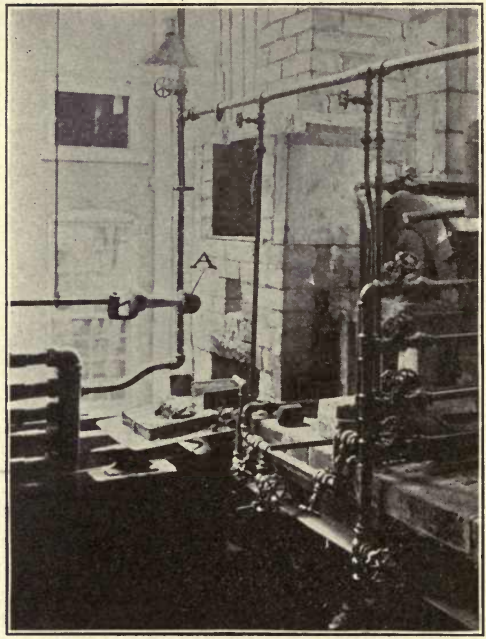


FIG. 67.—APPARATUS FOR DETERMINING THE MELTING POINT OF CAST IRON — SIDE VIEW.

"Fig. 65 shows two of the styles of the pyrometer, and Fig. 66 the method of using the angular form. In the terminal box are placed the connections which allow wires of any convenient length to run through the handle and connect with the galvanometer. The galvanometer itself is a 'D'Arsonville, specially gotten up and calibrated for industrial purposes. The original form with the reflecting mirror, and capable of reading to one-half of a degree at these high temperatures, was found too cumbersome and delicate for factory use.

"The sensitiveness of the couple, even though protected by a refractory material, is such that by plunging it cold into the melted iron the correct reading is obtained in one minute and three-quarters. When properly heated up to redness beforehand, however, this time is reduced to not many seconds.

"It would be beyond the scope of this paper to show the many uses to which such an instrument can be put in the steel and iron trade. On the question of annealing alone it will pay for itself in a short time.

"We come now to the subject matter itself. You will all remember the recent discussion on the melting of white and gray irons, Mr. West's elaborate experiments confirming our daily experience. Yet the correctness of the conclusions were questions, and while the peculiar phenomena observed in the behavior of carbon with iron make any positive statements rather hazardous, yet the melting down of a lump of iron, and taking its temperature while doing so, should stand as a final determination of its melting point as viewed from the entirely practical side of the question. This is the consideration we have to deal with daily in cupola and furnace.

"The material experimented with was gathered for several years, some of it being furnished by Mr. Jos. Seaman, Mr. Thos. D. West, and Mr. J. E. McDonald, members of this association, and the especially interesting alloys by Mr. R. McDonald, of the Crescent Steel Co.

"There were forty-eight pig irons, embracing both Foundry and Bessemer brands as well as softeners, made with coke and with charcoal, both cold and warm blast. Seven of the cast irons were of the shape seen at A, Fig. 67, being melted right from the tip. The balance of the fifteen specimens were of the sand and chill rolls made by Mr. West in his recent experiments.* Two steels and nine alloys of chromium, tungsten, and manganese, with iron, complete the list of seventy-three specimens.

"The melting was done in an assay furnace converted for the time into a cupola. Fig. 68 gives a front view of it while in full operation. A jet of steam entering the stack in the side near the top induced the blast, the air being drawn in all around the bottom. In this form it is really the 'Herberz' cupola of European fame and excellent for small diameters. A hole was broken into the wall just below the charging door, which must be kept closed when not used. This hole allows the introduction of the pieces of pig iron, etc. After heaping up enough coke to last for some time, the piece of pig iron (of full section and about five inches long), was driven into the bed, surrounded by incandescent coke, and the opening closed with a tile. After it was red hot the tile was removed, the pyrometer inserted and pushed against the center of the pig where the borings were taken for the analysis. The temperature as registered by the pyrometer rose rapidly, then more slowly, remaining stationary while the iron melted slowly. Then as the point finally became uncovered the temperature jumped up, going

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* This refers to the experiments seen on pages 332 to 339.

above 2,600 degrees F. In this way the results noted in the tables below were obtained.

"It took much patience, a loss of a few samples, and a number of broken tips to accomplish all this, but on the whole the results given are as good as could be gotten under the conditions prevailing. The coke burning up would let the iron drop a little, and a failure to adjust the pyrometer to suit (the opening being closed by a piece of sheet iron, to prevent undue cooling by air drawn in), meant a break in the tip, which, while not affecting the results, caused subsequent delay and trouble.

"The following general observations were made. The white irons held their shape, the iron running from the sides and bottom freely, leaving smooth surfaces. The gray irons became soft, dropped in lumps, leaving a ragged surface. Ferro-manganese samples became soft and mushy, exhibiting a consistency of putty before finally running down. Ferro-tungsten behaved in the most marked way. As it melted it acted like white iron, but instead of chilling quickly it ran through the coke, coming down the spout in thin streams like white hot quicksilver, only setting after collecting in a pool in the pan of sand. (The above description of melting points of white and gray irons was verified by other members, though under different conditions.) The cupola was fluxed heavily with fluor spar to take care of the ash, for it was a case of a furnace full of incandescent coke and only one piece of iron in it."

The following tables give the results. For melting points of other metals than shown in this chapter, see Table 134, page 593.

TABLE 77.—PIG IRONS.

No.	Melting Point.	Com. Carbon.	Graphite.	Silicon.	Manganese.	Phosphorus.	Sulphur.
1	2030°F.	3.98	.....	.14	.10	.220	.037
2	2040	3.90	.....	.28	.11	.216	.044
3	2040	3.74	.14	.38	.16	.172	.032
4	2070	3.70	......	.26	.09	.198	.033
5	2100	3.52	.54	.47	.20	.200	.036
6	2040	3.48	......	.36	.09	.249	.040
7	2055	3.22	.68	.71	.09	.142	.038
8	2010	3.21	.20	.45	.18	.198	.037
9	2110	2.28	1.14	.42	.13	.185	.026
10	2140	2.27	1.80	.45	1.10	1.465	.032
11	2150	2.23	1.58	.42	.16	.415	.045
12	2170	1.96	1.90	.75	.63	.097	.028
13	2170	1.93	1.69	.52	.16	.760	.036
14	2170	1.87	1.85	.56	.46	.713	.027
15	2150	1.84	1.95	.56	.34	.175	.022
16	2190	1.72	2.17	1.88	.54	.446	.028
17	2200	1.69	2.40	1.81	.49	1.602	.060
18	2230	1.71	2.08	2.02	.39	.632	.062
19	2190	1.49	2.26	2.54	.50	.349	.038
20	2210	1.48	2.30	1.41	1.39	.168	.033
21	2190	1.47	2.63	.89	.48	.164	.037
22	2190	1.36	2.41	1.65	.32	.160	.038
23	2210	1.31	2.70	1.25	.76	.170	.022
24	2210	1.31	2.40	1.69	.46	.085	.039
25	2230	1.24	2.68	.65	.26	.201	.020
26	2230	1.23	2.70	1.20	.37	.299	.022
27	2230	1.12	2.66	1.13	.24	.089	.027
28	2200	.90	3.07	1.09	.33	.176	.014
29	2230	.87	3.10	1.34	.42	.158	.030
30	2210	.84	3.07	2.58	.47	2.124	.051
31	2260	.83	3.26	1.97	.59	.210	.018
32	2230	.80	3.22	1.30	.59	.172	.042
33	2250	.80	3.16	1.29	.50	.218	.020
34	2250	.80	2.89	2.21	.25	.411	.041
35	2250	.67	3.60	1.32	.20	.205	.020
36	2240	.59	3.15	1.50	.61	.094	.032
37	2230	.47	2.84	2.19	.65	1.518	.042
38	2250	.38	3.43	2.44	.57	.422	.048
39	2250	.35	3.44	2.07	.28	.448	.039
40	2260	.35	3.70	3.29	.82	.501	.038
41	2260	.24	3.48	2.54	.30	060	.020
42	2280	.13	3.43	2.40	.90	.082	.032

TABLE 78.—SOFTENERS, FERROSILICONS, AND SILICO SPIEGEL.

43	2190	3.38	.37	12.30	16.98		
44	2040	1.82	.47	12.01	1.38		
45	2090	2.17	.72	10.96	1.34		
46	2155	1.35	1.60	9.40	.32		
47	2145	1.57	1.36	8.93	.39		
48	2170	1.77	1.80	4.96	.39		

TABLE 79.—CAST IRONS.

No.	Melting Point.	Com. Carbon.	Graphite.	Silicon.	Manganese.	Phosphorus.	Sulphur.	Remarks.
49	2000°F	4.67	.03	.57	.22	.266	.044	Cast into chill roll (Mr. West)
50	1990	4.20	.20	.63	.33	.254	.040	Cast into chill roll (Mr. West)
51	2010	4.08	....	.89	.06	.287	.040	Cast into dry sand.
52	2000	3.90	.16	.75	.66	.240	.030	Cast into chill roll (Mr. West)
53	2030	3.62	....	.72	.14	.93	.026	Cast into dry sand.
54	2030	3.48	....	.47	.09	.190	.032	Cast into dry sand.
55	2040	3.40	....	.42	.07	.196	.029	Cast into dry sand.
56	2170	1.63	2.27	1.46	.50	.092	.032	Cast into dry sand.
57	2210	1.60	3.16	.59	.25	.271	.048	No. 48 in sand rolls (Mr. West)
58	2250	1.57	2.90	.66	.31	.237	.040	No. 49 in sand rolls (Mr. West)
59	2240	1.22	2.66	1.69	.47	.274	.037	Cast into dry sand.
60	2250	1.20	2.90	.75	.66	.248	.030	No. 51 in sand rolls (Mr. West)
61	2260	.17	3.57	2.09	.43	.272	.042	Cast into green sand.
62	2080	1.95	1.28	1.64	.98	....	....	Re-melted ferro-silicon No. 5, cast into chill roll (Mr. West).
63	2080	1.81	1.36	11.70	1.00	....	....	Re-melted ferro-silicon No. 5, cast into sand roll (Mr. West).

"For a better comparison of the melting points of the same irons cast into sand and into chills, as made by Mr. West, the following table is subjoined:

TABLE 80.

No.	Combined Carbon.	Graphite.	Fracture.	Melting Point.	
57	1.60	3.16	Gray	2210°F.	
49	4.67	.03	White	2000	Same ladle.
58	1.57	2.90	Gray	2250	
50	4.20	.20	White	1990	Same ladle.
60	1.20	2.90	Gray	2250	
52	3.90	.16	White	2000	Same ladle.

TABLE 81.—ALLOYS AND STEEL.

No.	Melting Point.	Carbon.	Silicon.	Manganese.	Chromium.	Tungsten.	Remarks.
64	2450°F.	1.18	.21	.49	...		Steel.
65	2350	1.32	.29	1.27	3.40	6.21	Steel.
66	2280	....	......	......	......	39.02	Ferrotungsten.
67	2240	......	.....	......	......	11.84	Ferrotungsten.
68	2255	5.02	1.65	81.40	.....	......	Ferromanganese.
69	2210	6.48	.14	44.59		.....	Ferromanganese.
70	2400	6.80	......	.....	62.70	......	Ferrochrom.
71	2230	6.40	......	......	19.20	......	Ferrochrom.
72	2260	1.20	.....	......	19.10	.....	Ferrochrom.
73	2180	1.40	......	.....	5.40	......	Ferrochrom.

The tables of the pig and cast irons have been arranged according to their combined carbon contents, for it is evident that with few exceptions the melting

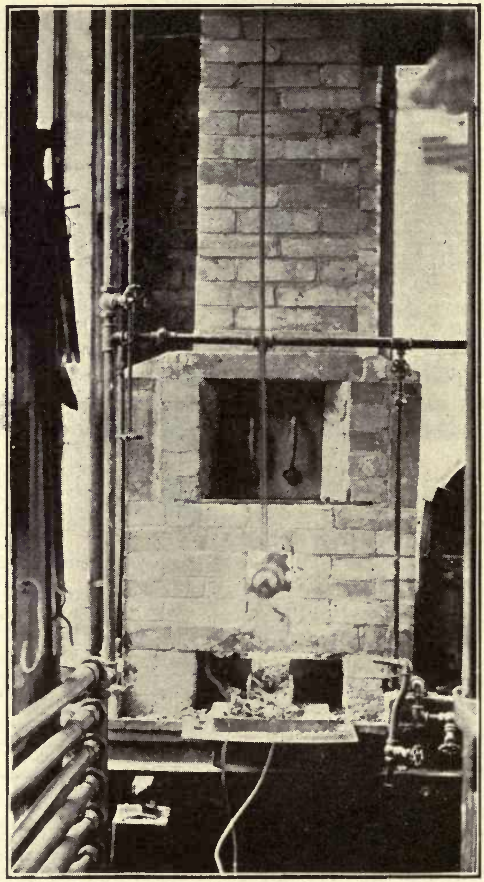

FIG. 68.—APPARATUS FOR DETERMINING THE MELTING POINT OF PIG IRONS, ETC.—FRONT VIEW.

points increase as the combined carbon goes down, this being the case independent of the amount of graphite present. One could hardly expect anything else, for that matter, gray cast iron being really a steel with a lot of mechanically mixed graphite, and white iron a combination of carbon with iron. Alloys melt at a lower temperature than any of their constituents, and so also white iron — really an alloy of carbon or some carbides of iron with iron — should melt sooner than the purer iron in the gray variety.

"The fact, however, that steel melts at a much higher temperature than the grayest of irons in the table, shows that there are other considerations not to be overlooked in studying the molecular physics of cast iron. The principal reason for this lowering of temperature is the supposed solution of the graphite in the iron before actual melting takes place. To what extent this occurs and under what circumstances is not known, but may account for the difference in the melting points of steel and gray iron.

"Again, in melting steel in the cupola commercially, an absorption of carbon from the fuel takes place, the melting point is doubtless lowered a little, and the results obtained are tangible, even though care must be taken to get the whole of the charge down before pouring. In the air furnace the steel absorbs carbon by contact with the pig iron charged and melts off, the wasting of wrought iron or steel poking bars used for rabbling giving evidence of this occurrence.

"The writer is especially pleased to see the full corroboration of Mr. West's elaborate experiments with the melting of white and gray irons. The contrast is remarkably sharp, and on the whole it shows us that science and practice go hand in hand admirably, no matter what the field may be. Whatever theories may develop regarding the melting of iron, whatever the effect of high or low phosphorus, silicon, manganese, and sulphur may be shown to be on the melting point of an iron eventually (the present series of irons not being well enough adapted for this phase of the question), the results here given are, it is hoped, of sufficient value to stimulate further research of practical value to the founders of cast iron."

CHAPTER XLVIII.

ALUMINUM ALLOYS IN FOUNDING.

Aluminum was discovered, it is claimed, by Frederick Wohler, a German professor, in 1827; but to St. Clair Deville, a Frenchman, belongs the honor of being the founder of the aluminum industry. The first article made of this metal, it is said, was in compliment to Louis Napoleon, the benefactor of Deville, and was a baby rattle for the infant Prince Imperial. About ten years ago it was thought that aluminum would revolutionize all metallurgy, but usage and practical tests have more closely defined its sphere. We find that to-day its adoption is chiefly limited to the manufacture of fancy commercial wares, also alloys of brass and bronze, the former being extended to an industry employing a large number of wage earners.

In the first days of the aluminum industry great difficulty was experienced in obtaining perfect castings with aluminum alloys. It was seldom that a sound casting could be obtained. The Cowles Electric Smelting and Aluminum Co., of Lockport, N. Y., one of the first to manufacture aluminum alloys, etc., engaged the author, in the year 1886, to go to Lockport for a short time. The author's experience in this foundry resulted in finding aluminum, as an alloy, very wild in its actions, and that the greatest difficulty might always be expected with it in obtaining strictly aluminum bronze castings. I have seen a pot of aluminum bronze kept for twelve hours in a furnace before tests had proven it to be the grade of metal desired, and the chances were that, had it proven all right, if a second test had been taken a few moments later it would have shown that a great change had taken place in the metal. The author succeeded in obtaining sound castings from some very complex patterns, but he was not able to make any formula or directions for a mixture which would insure like desired results every melting, as far as physical tests were concerned. It must be remembered that at this time pure aluminum was not obtained for commercial purposes, as it is at the present day. Then it was only obtainable by being alloyed with iron or copper containing from about 5 to 20 per cent. of aluminum. To obtain 5 to 20 per cent. of aluminum in any alloy of copper or iron, 80 to 95 per cent. of these latter elements had to be melted in mixture with what was in the pot in order to have a chance of securing the grade wanted. Since the advent of the Pittsburgh Reduction Co., about the year 1890, aluminum is obtainable for commercial purposes in a free state, without being alloyed with any other metal. This has proved more satisfactory in enabling a formula to be utilized to the end of securing like results at all times, but has not removed the difficulty of obtaining perfect castings of aluminum bronze alloys.

The author has tried aluminum in mixture with cast iron. In some cases it would slightly improve the strength, and again it would weaken the iron. The influence of aluminum is similar to that of silicon. Where the combined carbon is high, it will lower it so as to make the iron of a softer nature. Where the graphite is highest, it will close the grain and give the iron a leaden color and generally decrease its strength; whereas the reverse will generally be true if the combined carbon has overreached that point which would afford the iron the greatest strength. On a whole, aluminum, as far as strength is concerned, is only of value in use with very hard grades of iron, or those exceeding 1.65 in combined carbon. The percentage of aluminum which I used would range from one-quarter of one per cent. to 1¼ per cent. The aluminum was placed in the bottom of the ladle and the molten metal poured over it. I found this plan better than throwing it into the molten metal after the ladle had been filled. In both cases the metal would always be stirred with a rod to assist in mixing the metals. Aluminum will increase the fluidity of molten metal, but to obtain the best results in this line it must be used with care and judgment. To secure the greatest fluidity by means of aluminum depends upon the percentages of the elements which compose the iron designed to make it soft or hard. The harder the iron the more aluminum can be used to obtain the greatest degree of fluidity. With soft grades aluminum can make the metal sluggish, with excessive dross on its surface, just as can be the case by having too much silicon in a mixture.

While the way in which aluminum will generally work in affecting the different percentages of carbon in iron are above outlined, still, on the whole, it is very erratic and will often act contrary to expectations. One peculiarity about aluminum alloyed with iron is displayed where two ladles are used to pour a mould, often showing a "cold shut" or bad union of iron at the point where the streams of metal from the respective ladles meet each other. Aluminum is also alloyed with silver, nickel, tungsten, manganese and silicon, as well as copper, iron and steel.

Pure aluminum is the lightest of all known metals, except magnesium. Its specific gravity is from 2.6 to 2.7 and it melts at about 1500 degrees F. It is white in color, of a soft nature, possessing a strength of about one-third that of wrought iron. While pure aluminum melts at 1500 degrees F., still its reduction in the blast furnace from any ore is such as not to alloy with the iron to any extent. Why the iron will not take up aluminum to any degree in the process of reducing ores is a question still unanswered. It is a test that shows that iron possesses but little affinity for aluminum, so far as proving of any practical value to iron founding is concerned. In all the author's experience with aluminum in cast iron he cannot say that he ever knew it to accomplish anything which could not be obtained by means of silicon, which is much cheaper than aluminum.

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* For the specific gravity and weight per cubic inch of other metals, see Table 136, page 593.

PART III.

CHAPTER XLIX.

METHODS FOR MELTING CAST IRON TO TEST ITS PHYSICAL QUALITIES.

Owing to the impracticability of judging pig metal by its fracture, the author has thought a Chapter on methods for melting small quantities to test its physical qualities would, in many cases, prove of value, especially where a founder was not in position to utilize chemistry.

There are three methods by which iron can be melted for testing its physical properties. One is to take the regular "heats" mixture, another to have a very small cupola expressly for melting light "heats," weighing from 50 to 500 pounds, and the third by means of a furnace and crucible similar to the principle used for melting brass, etc. By using metal from the first, we can at any period of a heat tell the physical properties of any mixture poured at that time. By using the small cupola we can, by proportioning a mixture in light charges, obtain a good approximate knowledge of the product to result from a like mixture in regular "heats," and also where there are several brands or grades of pig metal, each can be tested separately, to ascertain its physical properties, thus enabling one to detect any brands that might be deceptive in appearance and thereby contaminate and prevent physical results being obtained from any desired mixture. By melting in the crucible, we can closely tell the physical properties in respect to what the chemical elements would define it in the original state, when not affected by the sulphur, etc., in fuel, but not what it would be when remelted. Why this is so involves elements most essential for the founder to understand and are treated further in Chapter XLV.

Melting a mixture in a crucible with the expectation of obtaining tests to denote what the physical qualities of a regular cupola mixture would be, is impractical. These can be told with fairness by taking tests from the regular cupola. Small cupolas ranging from fifteen to twenty inches inside diameter can often be well used to test single brands or grades or mixtures not having over four different kinds of iron. As there are cases where some would like to use a small cupola for crucible melting also, I have studied to the point of combining the two, and as a result present the following original device or small cupola, as seen in Fig. 69, next page. This cupola can be erected in any out-of-the-way place, or by the side of a regular " heat " cupola, so that the flue A can be attached to head off the sparks, etc., when used as a cupola, without risk of setting anything on fire, should there be any danger of this; if not, then the cover B could be dispensed with and the flame, etc., permitted to pass out at the top. B is a cover made of cast iron, and having prickers on the under side for the purpose of holding a daubing of clay to prevent the heat of the furnace burning the cover. The handle D is for convenience in lifting the cover on and off when desiring to change or take out a crucible. The staging H as shown is placed any height to suit the operator. The cupola has four tuyeres, two inches in diameter. In charging to run a "heat," have the coke ten inches above the tuyeres; if coal, seven inches above the tuyeres. The fuel should not be much larger than double egg size, and the bed well burned up before the first iron is charged. On the bed, place fifty to one hundred pounds of iron, which, if pig iron, should be broken in lengths of from five to eight inches. If the pigs were too strong to break by sledging, etc., one-inch holes could be drilled and a punch used to fracture. Should more than 100 pounds require melting, charge twenty pounds of coke or coal, and on this one hundred pounds of iron, and so continue as long as the cupola works all right. With a

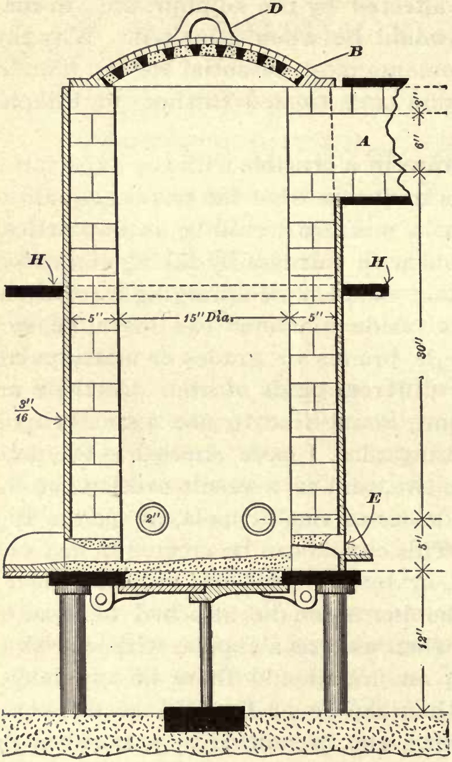

FIG. 69.—WEST'S COMBINED CUPOLA AND CRUCIBLE FURNACE.

slag-hole as at E, Fig. 69, and the use of flux, a "heat" can be prolonged to run several hours. If lime was used for a flux, about four pounds to every one hundred of iron charged should cause the slag to run freely. We are only entering into these details in order to illustrate the fact that the cupolas can be used for heavier "heats" than test bars would necessitate.*

In melting with a crucible in the cupola, Fig. 69, use a size like No. 18 Dixon's brass. In preparing the cupola for melting with crucibles, put in a sand bottom within two inches of the level of the tuyeres. Have a bed of coke, when well burnt up, ten inches high, and on this set the crucible charged with its burden of iron to be melted. Fill all around between the crucible and the cupola lining with small coke, level with the top of pot. Cover the pot over with a clay cover, which can be formed in a core box and rodded the same as one would a dry sand core to prevent its cracking, or the bottom of an old crucible can be used. The smaller the iron is broken the more quickly it will melt, and hence the easier will it be on the pot and more economical in fuel. After the pot is covered, the cover D is placed on to close the furnace. The blast is now put on the same as if iron were being melted direct in a cupola. The pressure should, for crucible work, range from two to three ounces; for cupola work, four to eight ounces can be used, and such

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* Should any desire plans, with complete specifications, for constructing small, permanent cupolas, ranging from twelve inches to eighteen inches diameter, strictly for melting light "heats" without crucible arrangements, we would refer them to "Moulder's Text-Book," page 265, and in the same work, page 248, will be found a cheap temporary arrangement for melting from fifty to one hundred pounds of iron.

blast can often be supplied from a blacksmith's forge fan. Should it be desirable to run steadily all day for crucible work, the breast should be dug out about twice during the "heat," and the ash and dross pulled out, so as to leave room for clean fuel. In making the breast for crucible work, have it formed of a sand that will not bake or cake hard and larger than shown. This will permit its being dug out readily.

Should it not be desired to use the device as a combination furnace and cupola, but strictly for crucible work, we would advise sinking the same in a pit, and instead of using the regular cupola drop bottom, which goes with this device, have the bottom consist of a regular grate, with an ash pit six inches deep, the diameter of the grate. Have the ash pit closed air-tight, and instead of admitting the blast into the body of the furnace, as is done with the cupola here shown, let it pass into the ash pit and enter the furnace through the grates. By having a pit three feet by five feet and three feet deep the combination cupola and furnace could be lowered to bring the staging line H level with the floor. This would make it more convenient for charging, or lifting a crucible in or out, and by having a handy step-ladder, ready access can be had to the pit for "tapping out" or cleaning the "dump." For raising a pot of metal up to the floor, employ a pair of tongs similar to those used for lifting a crucible out. The flue A should be lined with fire brick or clay for any distance the outer shell could be heated red hot were it not lined. This flue should be well bound with stays to prevent the heat cracking it open.

As very few founders have had opportunity for experience in crucible work, we will detail more points necessary to be followed. As melting progresses, the fuel around the sides of the pot will settle down. This must be replenished so as to keep the fuel about on the level with the top of the pot. To have it higher at the first would be an advantage. Judgment should be used not to fill in fuel when the pot is about ready to be pulled out, as this will tend to cool the metal and prevent the free use of the tongs in grasping the pot to remove it from the furnace. A pot will settle more or less in the fuel and it may be necessary to lift it up several times so that the fuel from around the sides can settle down and raise the pot, after which the sides, of course, would require fresh fuel. In charging the iron, the pot may not hold all that is desired at the first filling. In such case, additional iron can be charged as fast as the solid melts down. The crucible will average about forty heats, if handled carefully. The least moisture in a pot would cause it to crack in the fire. It must be thoroughly dry before being used for a "heat." A good practice is to place a crucible in an oven for several days before using it. While it is essential to have the moisture all out of the pot, it is also well to never permit it to cool off suddenly. If after a heat the pot is set back in the fire to cool down with it, its life will be prolonged. Iron melted in a crucible will be found to possess a quiet appearance, and it is generally not so hot as coming from a cupola. In operating either the cupola or the crucible, only the best of fuel should be used, and all work should be intelligently manipulated.

CHAPTER L.

JUDGING OF AND TESTING MOLTEN IRON.

In testing iron we have two properties, chemical and physical, to which we might add the phenomenon of fusion. An experienced eye can often very fairly tell what a casting will be, physically, by judging the appearance of the metal when running or at rest in a ladle.

In many cases the ability to judge liquid metal will often prove of value, for while we seldom have means for changing its character when fluid, we can often refrain from pouring work when our judgment asserts that a metal is radically wrong. There is this much that can be said of re-melted fluid iron: It will rarely, if ever, deceive an expert, as can the judging of iron in the pig before being melted. We can rest assured that if it looks radically soft in a liquid state, it will not prove hard in a solid one, and vice versa.

The ordinary moulder can, with a short experience, tell the degree of fluidity, or whether the iron is "hot" or "dull." Why he should be better able to do this than judge of its physical qualities when molten, is mainly due to present practice not often affording means to change or correct a metal that might not look right. The degree of the temperature before being poured he can often greatly control, and hence the advantage of practice in this factor causes study to train the eye, which very soon becomes expert in deciding the best moment at which to pour a mould. A like study of the molten character, combined with the temperature in a fluid state, may enable the moulder to judge as well in one case as the other, and this should be practiced more than it is, as no moulder or founder can tell when a knowledge of the former would not be as valuable as the latter.

Judging the grade of metal by its appearance in a fluid state is often done by experienced founders, and with a little study and observation the following description may often enable the inexperienced to soon become proficient in judging molten metal: A No. 1 or high graphite soft iron * will generally present a lively vibration of different colors having the appearance of coming up from below the surface, forming an oxidized crust. This crust has the appearance of struggling to break away from alloys, which do not take kindly to being associated with a grey or soft iron. When No. 1 iron is slowly cooling down from a high temperature to a low one, it will often be unable to hold all its carbon in a combined state. What cannot be retained will gradually rise to the surface as graphite in the form of a scum or kish, and in the latter state will float away in the air, often covering everything near at hand with thin flakes of shining material, looking like silver lead or plumbago. This can properly be called pure carbon freed from the metal. About blast furnaces, this latter phenomenon can often be seen, sometimes so active that the employes will be covered with "kish," making them look

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* This refers to iron possessing from 2.50 to 3.00 of silicon. For results of higher silicon, see next paragraph.

like a fishmonger covered with shining fish scales.

When metal is high in silicon, its surface may have a smooth, dead appearance devoid of life, and if the surface is disturbed with a rod or skimmer, it may act a great deal like cream upon milk. Were it not for its dull, silvery, quiet appearance and sparkless action, it might often be taken for hard iron. No. 1 iron, whether high in free carbon or silicon, when running from the cupola into a ladle or from the furnace to the pig beds, throws off very few sparks, and those that do fly are chiefly caused by vibration of the metal from the running or spluttering of the stream, and fall as ordinary sparks, very different from those which come from harder or lower grades of melted iron.

Irons low in silicon and high in sulphur, from No. 7 to No. 10, which can be termed hard iron and also can be strong and weak, have peculiarities very pronounced to distinguish them from soft grades or No. 1 irons. In the ladle, such irons will, when "hot," show a smooth, bright appearance, with hardly a break on the surface, and as the mass becomes cool or "dulls down," it presents a dull, hazy, plastic appearance, which, if disturbed by a skimmer or rod, will act as if it were covered with an oxide or scum. While hot, it will often boil in the ladle as if bubbles of gas were escaping from below. It also emits many sparks, which is the chief characteristic phenomenon of hard iron and cannot be better explained than in the language of Tomlinson, who says:

> From all parts of the fluid surface is thrown off a vast number of metallic sparks, from the absence of carbon, which renders the metal sensitive to the oxidizing influence of the atmospheric air.

Small spherules of iron are ejected from all parts of the surface to the height of five or six feet, and sometimes higher, when they inflame and separate with a slight hissing noise or explosion into a great many particles of brilliant fire, forming oxide of iron.

The blast furnaceman can often tell very closely the "grade" an iron will show by analysis when cold, by its appearance when fluid, and whatever practical methods a founder can utilize will, at some time or other, prove very beneficial, especially in "air furnace" workings and long "heats" in cupolas, for with the latter there is a chance given, if at the first tappings iron proves itself radically wrong, through any errors in figuring analyses, or in charging the iron, etc., to alter the charges in order to change the "grade" of the metal before a heat is finished.

CHAPTER LI.

RESULTS OF VARIATION IN THE FLUIDITY OF METAL AFFECTING PHYSICAL TESTS.

Variation in the fluidity of molten metal is a factor which the author has discovered to be very important to note in considering the depth of an iron's chill, taken by means of a test bar or "chill block." It is a point which does away with past records or statistics which have been compiled by some from deductions taken from the depth of a chill, by the pronounced manner in which it asserts itself in giving evidence of being affected by the degree of fluidity at which a test bar is poured. In experiments with iron poured "hot" and "dull," the author has made the thickness of chill as great again in one case as in the other. Take, for instance, two test bars and pour one hot so that the iron will run up in the fluidity strips described in Chapter LXVI., page 509, about six inches high, and then cool the iron so as it will only run up about an inch: it will be found upon breaking the bars to test the chill that the hot-poured bar will have chilled about as much again as the dull-poured one. I have not accepted this principle as a fact from a test or two, but have made many to fully assure myself that the principle is correct.

The Tables seen on page 376 show the difference in chill by reason of "hot" and "dull" poured iron, in test bars 1⅛ inch diameter cast on end. It will be noticed that the fluidity of the hottest poured bar in Table 82 was but four inches, and the dullest one, one inch, a difference of three inches, but this was sufficient to make a difference in the chill of five-sixty-fourths of an inch, and this was the same iron poured out of the same ladle. A chemical analysis of the iron charged in the cupola and that obtained in the test bars is also given in Table 82. In Fig. 70, K shows the fracture of the hot-poured bar, and P the fracture of the dull-poured one, from which a good realization can be received of the effects different degrees of fluidity can cause in giving different depths of chill from the same iron poured from the same ladle and which is forcibly shown by the Tables, page 376.

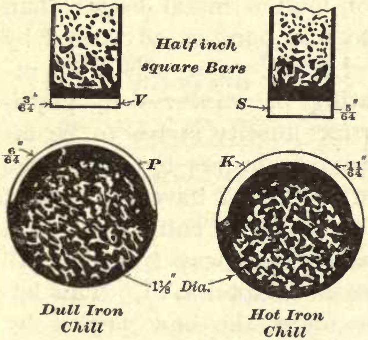

FIG. 70.

In the Table we find a difference of .078 inch in the chill of the two ½-inch bars which were poured out of the same hand ladle holding about fifteen pounds of metal. The first bar was poured as soon as the metal was carried to the "floor," and the second bar three minutes later. Here we find there is a difference in chill of .078, due to difference in fluidity of metal, or in rough figures $\frac{1}{32}$ inch, as seen at V and S, Fig. 70.

I state the time between the pourings to give an idea of how long the metal was held.

The fluidity strips are the practical guide to go by. Of what use is time in regulating or asserting the fluidity of irons between two foundries, or one heat from another? The iron in no two foundries is of the same fluidity, or for that matter the same foundry will seldom have two days' run in succession alike, and where one shop could only hold its metal for five minutes, another might do so for ten. There is no guide to register the fluidity of molten metal better than fluidity strips attached to test bars, as advocated by the author in Chapter LXVII. For scientific research and close regulating of mixtures by physical tests, it is essential for fluidity strips to be attached to test bars, where one desires to obtain true knowledge of irons or mixtures. I have shown that degrees in fluidity affect the depth of chill, also that it is incorrect for a test bar to pull away from its chill when contracting, as seen in Chapter LVI. This latter evil only aggravates more the one caused by different degrees in fluidity, as both elements are effective in causing erratic depths of chill.

I could have shown a much more radical difference in the chill obtained from the same ladle by different degrees of fluidity, and would here say that in one case I found with the same iron in pouring two ½-inch bars that the dull-poured one had a chill of $\frac{1}{16}$ inch, the hot-poured one ¼ inch, a difference of $\frac{3}{16}$ inch.

For any that desire to test the question of degrees of fluidity causing different thicknesses in chill, in ½-inch square test bars, I have presented the plan I used in my experimenting with a ½-inch square test bar.

which is seen below at Fig. 71. In using this device to get two test bars, I moulded two separate patterns, in a flask large enough to admit them and having four inches of space between them, so that the gas or heat from the first poured one could not affect the other bar. The flasks were leveled so as to afford like conditions for the running of the metal into the fluidity strips. For chills at the ends of the test bars I used pieces of ½-inch square wrought iron rods, cut to a length of two inches, and loosely set them against the ends of the pattern when moulding. Should any one desire to cast two bars at the same time in one flask, they would require, of course, but one gate, and it in the middle, leaving the fluidity strips on the outside of each bar. Fluidity-measuring testing tips, cast on test bars, are an entirely new departure originated by the author, and found by him to be of much value when very close records are desired for comparisons of chill records, etc. The plan devised for using fluidity strips with test bars cast on end is described and illustrated in Figs. 121, 122, pages 509 and 514.

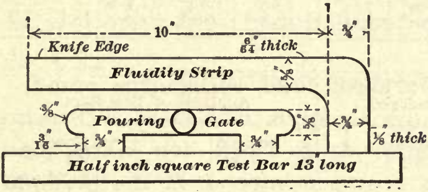

FIG. 71.

TABLE 82.—PHYSICAL TEST TAKEN WITH 1⅛-INCH ROUND BARS.

Micrometer Measurement.

No. of Test.	Fluidity.	Shrinkage.	Contraction.	Deflection.	Strength, broke in lbs.	Chill.	Diameter of test bar.	Strength per sq. inch in lbs.
1	4″	30	.156″	.120″	1,505	.172″	1.130″	1,501
2	1″	16	.156″	.110″	1,500	.094″	1.117″	1,531

Common Measurement.

No. of Test.	Fluidity.	Shrinkage.	Contraction.	Deflection.	Strength, broke in lbs.	Chill.	Diameter of test bar.	Strength per sq. inch in lbs.
1	4″	30	10-64″	7-64″	1,505	11-64″	1 8-64″	
2	1″	16	10-64″	6-64″	1,500	6-64″	1 7-64″	

Analysis of Pig Iron Charged.		Analysis of Test Bars.	
Silicon.	Sulphur.	Silicon.	Sulphur.
1.46	.039	1.26	.072

PHYSICAL TEST TAKEN WITH HALF-INCH SQUARE BARS.

No. of Test.	Fluidity.	Deflection.	Strength in lbs.	Chill.
1	1½″	.190″	300	.048
2	8″	.190″	290	.080

Analysis of Pig Iron Charged.		Analysis of Test Bars.	
Silicon.	Sulphur.	Silicon.	Sulphur.
1.82	.035	1.67	.056

CHAPTER LII.

SPECIFIC GRAVITY OF VERTICAL-POURED CASTINGS.

Below is given an extract from a paper by the author, read before the autumn meeting of the Iron and Steel Institute, at Birmingham, England, August 20-23, 1895:

Some authorities have asserted that a test bar cast on end, if placed on supports equidistant from either end, would not break at the point where the load is applied, but at a point an inch or so away from the point of pressure toward the uppermost cast end of the bar. In a long experience with bars cast on end, the author has failed to find any such condition. Indeed, he has not found any difference in this respect with bars that were cast flat or on end. With a view to thoroughly investigating the matter, he conducted the following experiment, and obtained the information given by the Builders' Iron Foundry of Providence, R. I., cited, and shown in Table 84, page 379. These are tests which the author first presented in a discussion on testing at the meeting of the American Society of Mechanical Engineers, held in New York City on December 3, 1894, and later gave them in a paper before the Iron and Steel Institute. In the first test of specific gravity, he wished to call attention to the fact that the specimen used was strictly a parallel gate test bar. He mentions this fact for the reason that in the discussion above cited, one member of the American Society took the position that the specific tests on page 379 were inadmissible proofs to establish any principle, owing to the bottom end of the gun which was cast down being of a more massive nature than the upper end, and hence there was good reason to expect metal to be less dense in the bottom than in the upper end of the gun. The following test of the parallel gate which the author conducted shows the fallacy of the idea that the lower end of vertical-poured castings must be of a greater specific gravity than the upper end. In the experiment which the author conducted at his own foundry, he took a "gate" 6½ feet long and 3 inches in diameter, which had been used for pouring an iron ingot mould casting, and took a test-piece 6 inches from the top, and another 5 feet from the top. The gate was practically parallel, so that, in turning these specimens in the lathe, the same amount of surface was carefully removed from each. The specimens were machined of exact size, and were then delivered to the laboratory of the Case School of Applied Science, of Cleveland, O., to be weighed. The determinations (Table 83) reported by Prof. C. H. Benjamin were as follows:

TABLE 83.

Weight of top end of gate in vacuum	**1169.468 grammes.**
Weight of bottom end of gate in vacuum	**1167.239 "**
Volume of top end of gate	**165.722 cubic centimetres.**
Volume of bottom end of gate	**165.768 " "**
Density of top end of gate	$= \frac{1169.468}{165.722} = 7.0568.$
Density of bottom end of gate	$= \frac{1167.239}{165.768} = 7.0414.$

Difference=0.0154 only. The plug from the upper end is the denser.

Table 84 presents a series of tests on the specific gravity of vertical-poured gun castings.

TABLE 84.—TESTS OF SPECIFIC GRAVITY OF FIRST AND LAST SIX MORTAR CASTINGS.

Number of Heat.	Specific gravity of muzzle or top end of gun.	Specific gravity of breech or bottom end of gun.
78	7·238	7·2478
79	7·2436	7 2447
80	7·256	7·269
87	7·2934	7·2882
88	7·278	7·285
89	7·335	7·329
185	7·3263	7·3182
186	7·3325	7·3252
187	7·3404	7·345
188	7·3636	7·3336
189	7·349	7·340
190	7·3345	7·3267
Total	87.6903	87 6524
Average	7·3075	7·3043

The lower test disc was taken about 11 feet from the top of the casting and the upper test 2½ feet from its upper end. The majority of the tests showed the specific gravity of the muzzle specimens to be higher than the breech specimens and also to be harder and of higher tensile strength. This is the reverse of what many would expect. Table 84 shows the average specific gravity of all the casts made for specific gravity of breech and muzzle specimens on the first six mortar castings and on the last six mortar castings made by the Builders' Iron Foundry, from whom the author received these tests, and wishes here to tender his thanks for the kindness rendered.

The tests and figures in Tables 83 and 84 indicate that there is no condition which will cause any practical difference in the lower and upper end of long vertically-poured castings, in the sense which has been generally accepted.

In considering the gun and gate tests of specific gravity in connection with those referring to the density of the lower side of flat-cast test bars being greater than the top side, discussed in Chapter LXV., it would at first seem as if the results were contradictory as far as they relate to the enunciation of any law or principle governing the quality of specific gravity in vertical-poured casting. The gate and gun tests show the upper end to have the greater specific gravity, and that of flat poured test bars to have the greater density in the side cast downwards. The latter is largely due to the bottom portion or surface of flat-cast test bars being most affected by the chilling qualities of the sand of the mould when it is filled with molten metal. If the specific gravity had been taken from the bottom surface of the gate test bar and gun castings, instead of a few inches in height from their bottom end, as was done, there might have been a difference found in favor of the lower end being the denser. This is, however, doubtful, as the gun and gate specimens had such a small area exposed to the mould's cooling influence, compared to the mass of metal comprising the castings. On the other hand, with test bars cast flat, the reverse occurred, and this is due to the fact that a fair percentage of the metal comprising the test bars is distributed over a large area of mould surface and is affected by the cooling qualities of damp sand, which is an unnatural effect that cannot be charged to specific gravity proper.

When the specific gravities of long vertical-poured castings are tested a few inches from the bottom and a few inches from the top, the reason for finding the upper end the denser, as exhibited by the tests recorded, the author defines as being largely due to the law of metal expanding at the moment of solidification. Expansion tending to make the upper end of castings as dense as the lower may be better understood when it is stated that molten metal begins to solidify at the bottom of a mould and rises in height as the solidification continues. The effect of expansion at the moment of solidification, as castings "freeze" from the bottom upwards, has a crowding action, tending to make the molecules denser as solidification increases, thereby partly neutralizing the effect in the difference of the specific gravity naturally expected to exist while the metal is in a fluid state. The author has obtained the following Table 85 of analyses of the top and bottom piece of the vertical-poured parallel gate test bar from E. D. Estrada, M. E., of Pittsburgh, Pa.:

TABLE 85.

	Carbon.	Phosphorus.	Manganese.	Silicon.	Sulphur.
Top piece.........	3.72	0.091	0.31	1.32	0.046
Bottom piece...	3.81	0.085	0.33	1.32	0.047

These results show that practically there is little difference in any chemical constituent that might tend to equalize the specific gravity of the two ends of the vertical-poured parallel gate test bar, and that we are left to accept the author's theory of such results being due to the principles involved in the rate of cooling and by expansion at the moment of solidification.

CHAPTER LIII.

EXPANSION OF IRON AT THE MOMENT OF SOLIDIFICATION.

The question of iron expanding at the moment of solidification was, up to about the year 1897, affirmed by some and questioned by others. It remained for Mr. John R. Whitney, of Philadelphia, Pa., to first demonstrate in a practical way that iron truly expanded at the moment of solidification. This was fully verified by the author in experiments which he conducted immediately after Mr. Whitney published his results in the *National Car and Locomotive Builder* of May, 1889, of which the following is an extract, and by later experiments shown on pages 384, 387 and 424:

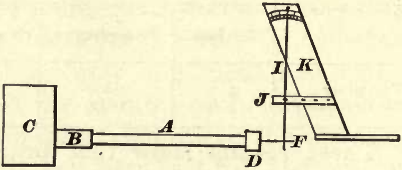

FIG. 72.

On a more recent occasion the following experiment was made with an apparatus more carefully prepared, as shown, Fig. 72. A pattern, A, 4 feet long, 3⅞ inches deep and 2¾ inches wide, was moulded in open sand; one end of the mould being closed by fire brick B, and the other end by a piece of gas carbon D, which was suitably connected with a small battery and galvanometer. The fire brick B rested at one end against a block of iron C, weighing about half a ton. The gas carbon block D was carefully secured in the sand, so that the weight of iron in the mould should not be sufficient to move it. The stand K, bearing an arm J, on which the pointer I was delicately pivoted, was then adjusted so that the needle F should press against the gas carbon D, and the pointer stand at zero on the scale. The long arm of the pointer was 24 inches, and the short one 6 inches long, or as 1 to 4. The scale was graduated to 1-16 inch.

A, casting; B, fire brick; C, weight; D, gas carbon block; K, stand; I, pointer; J, supporting arm; F, adjusting needle.

The mould was filled with very fluid hot iron in 17 seconds, and then the following results were carefully noted:

For more than 1 minute after the mould was filled, pointer stood at zero.

At 1 minute 30 seconds after the mould was filled it moved 1-16.

At 1 minute 50 seconds after the mould was filled had moved ⅛.

At 3 minutes 10 seconds after the mould was filled had moved ¼.

At 5 minutes 20 seconds after the mould was filled had moved ⅜.

At 8 minutes 5 seconds after the mould was filled had moved 7-16.

At 11 minutes 30 seconds after the mould was filled had moved 15-32.

At 12 minutes 5 seconds after the mould was filled had moved ½.

From that time the pointer stood perfectly still at ½ inch until 25 minutes 15 seconds after the mould was filled, when the galvanometer showed that contact with the gas carbon was broken and contraction had begun.

I have made several other equally convincing experiments, but the length of this article forbids that they should be repeated here.

Long before these experiments were instituted the fact that iron follows essentially the same law as water in solidifying was well known and published. I need cite only two authorities: Prof. Edward Turner, in his "Elements of Chemistry, "published in Philadelphia in 1835, by Desilver, Thomas & Co., says, page 20: "Water is not the only liquid which expands under the reduction of temperature, as the same effect has been observed in a few others which assume a highly crystalline structure in becoming solid; fused iron, antimony, zinc and bismuth are examples of it." Prof. Thomas Graham, also, in his "Elements of Chemistry," published in Philadelphia in 1843, by Lee & Blanchard, says, page 385: "Iron expands in becoming solid, and therefore takes the impression of a mould with exactness."

As the observation of this law was the basis upon which my experiments leading to the successful development of the contracting chill for cast iron car wheels was based, I am persuaded it will lead to many other practical results of great importance. This is my apology for trespassing upon your space and calling special attention to the matter.

The illustration seen in Fig. 73 is one the author displayed in the *American Machinist*, November 1, 1894, to prove that the practice of casting bars between iron yokes, etc., prevented free action of the metal in expanding.

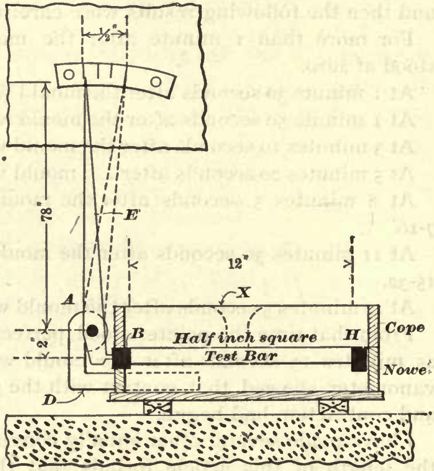

FIG. 73.

A one-half-inch square test bar, twelve inches long, was used for an illustration. The author has tried by this device one-half-inch test bars without "gates," pouring them in "open sand" or without a cope, and cannot say he found much difference in their expansion. If any difference, the one with the gate showed the more. H is an iron block fitting tightly against the closed end of the flask. B is an iron block fitted loosely into a hole in the open end of the flask, as shown. D is an arm of which there are two, one being attached to each side of the flask through which the pin A is inserted to give a fulcrum for the indicator arm E to revolve on as the one-half-inch square bar expands.

The length of the lever E is seventy-two inches at the long end and the short end should read one and one-quarter inches instead of two inches, as shown. The dotted line of the indicator shows what the arm moves at the time of expansion. It measures about one-half an inch, sometimes going over this mark, and sometimes a little under it, thus disproving the logic that small bodies or test bars will not expand, as claimed by some. It makes no difference how large or small a body is, the same law is effective in all cases of metal cooling from a liquid to a solid body.

By referring to Chapters LIV. and LV., pages 398 and 424, two other devices originated by the author for recording expansion can also be seen. These devices present expansion tests which show the reason for there being no practical difference in the specific gravity of the two ends of vertical-poured castings, as can be seen in Chapter LII., page 381. Then again, by referring to Chapter LIV., page 392, the effects of expansion in causing shrink holes in castings are fully outlined.

CHAPTER LIV.

THE EFFECT OF EXPANSION ON SHRINKAGE AND CONTRACTION IN IRON CASTINGS.*

The fact that iron expands, when heated, until fusion takes place, and that molten iron occupies more space than cold, solid iron of the same grade, is now universally admitted. It was proved by the extensive experiments of Mr. Thomas Wrightson, reported in the first volume of the *Journal of the Iron and Steel Institute* (1890 and 1891), and, in a manner, is illustrated in heavy founding by the shrinkage of the molten metal, which must be "fed" in order to obtain solid castings.

This decrease in volume requiring "feeding" while the metal is still liquid I call "shrinkage" (see pages 394 and 395), applying the term "contraction" to the decrease in volume which takes place after solidification, while the iron is cooling to atmospheric temperature. The light-work founder, not having the opportunity to make heavy castings, in which shrinkage can be observed, is apt to confound the two; but they are in fact distinct, and are separated by an act of expansion, which takes place at the moment of solidification.

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*(Contribution by the author to the Discussion of the Physics of Cast Iron, at the Pittsburgh Meeting, February, 1896.)

The fact of this expansion was first practically demonstrated by Mr. John R. Whitney, of Philadelphia, Pa., whose experiments are recorded in the *National Car and Locomotive Builder* of May, 1889, and cited in Chapter LIII., page 382.

Experiments carefully made by the writer indicate that there is a constant relation between this expansion and the preceding shrinkage and forcibly demonstrate the necessity of "feeding" a casting to make its interior solid. This is a matter with which all makers and users of castings have experienced difficulty. The founder being heretofore unable to define correctly the principles involving the urgent necessity of "feeding," has failed to impress the moulder with its importance in making sound castings. Heavy-work founders and moulders know that hard grades of iron shrink much more than soft grades, a fact for which no satisfactory explanation has heretofore been given.

By recent expansion experiments I have discovered that hard grades of iron expand more at the moment of solidification than soft ones. Fig. 74, page 389, is a diagram recording four such experiments.

The manner in which the automatic records were obtained will be described further on. It is sufficient to say at present that the scale of inches in the diagram measures the length of travel of the pencils on the long recording-arms of the apparatus employed, not the actual length of expansion. The end of the short arm of each lever, following actual expansion, travels $\frac{3}{32}$ inch for 1 inch traveled by the pencil, and the length of the test bars being 48 inches, 1 inch of the expansion or contraction record represents an actual expansion or contraction of 3 in 1536, or 0.195

per cent. For the purposes of these experiments, however, the actual expansion or contraction was not required.

The significance of these diagrams is qualitative and comparative; and for this use of them the reading of the pencil-travel in inches is accurate, the apparatus and operation being the same in all the tests recorded. With this explanation I return to Fig. 74, In each of the four casts shown, two test bars, 1 x 1¾ inches in section and 4 feet long, were cast "open-sand" side by side in the same mould. Tests Nos. 1, 3, 5 and 7 were poured from the respective ladles which brought about 100 pounds of the iron direct from the cupola. These tests comprised the softest iron of each cast and had the least expansion and contraction, as is shown by the diagram. For tests Nos. 2, 4, 6 and 8, the grade of the iron was changed, by means of pouring about half of the hundred pounds contained in the ladle coming direct from the cupola into an empty ladle, the bottom of which was covered with about three-quarters of a pound of brimstone. The metal in the ladle having the sulphur was then agitated with a half-inch wrought iron rod until fuming ceased, after which all dross was skimmed from the surface, when each ladle was poured into its respective test-mould. The addition of sulphur hardened the iron in these tests, thereby causing the increased expansion and contraction shown in the diagram.

In Fig. 75, page 390, tests Nos. 9 and 10 illustrate another discovery made by this method of comparative tests, namely, that where free expansion is prevented, a greater contraction is effected in that part.

Test bar No. 9 was cast between iron ends, so arranged that the power of expansion was not sufficient to extend the distance between them, whereas No. 10 had sand ends to compose the mould, which gave full freedom for expansion, the same as in all other tests displayed in Figs. 74 and 75. The fact that hard

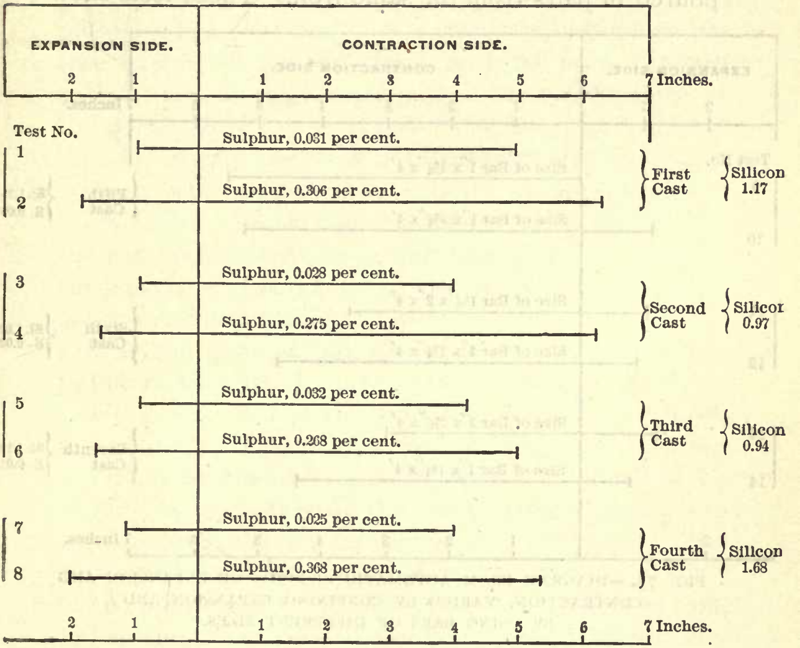

FIG. 74.—DIAGRAM FROM AUTOMATIC RECORDS OF EXPANSION AND CONTRACTION, VARIED BY ADDITIONS OF SULPHUR.

grades of iron expand more than soft ones, and the fact that retarding expansion gives rise to a greater contraction than where free expansion is permitted, are important as suggesting for works making such specialties as chilled rolls, car-wheels, etc., in which heavy losses are often experienced through chill-checks and cracks, the advisability of adopting expanding and contracting "chills" wherever this may be practicable.

Tests Nos. 11, 12, 13 and 14, in Fig. 75, illustrate the expansion and contraction of different sizes of bars poured in pairs from the same iron. These tests show that large bars expand so as to increase their interior space more than small ones, thereby calling for the greater "feeding" in massive castings. These tests indicate also that light bars contract more than heavy ones, an element not to be overlooked in proportioning casting so as to avoid internal strains so far as practicable, a quality also seen on page 420.

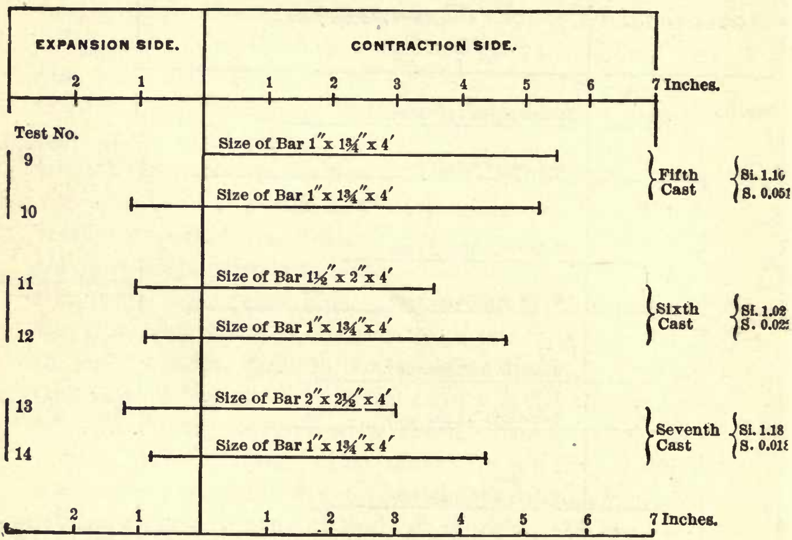

FIG. 75.—DIAGRAM FROM AUTOMATIC RECORDS OF EXPANSION AND CONTRACTION, VARIED BY CONFINING EXPANSION AND BY USING BARS OF DIFFERENT SIZES.

The "open-sand" method of casting test bars affords the means of making comparative tests under varied conditions and gives an excellent opportunity to observe characteristic phenomena at the moment of solidification, etc. In casting test bars of hard iron, a pronounced shrinkage along the upper surface is often noticed during the period of expansion; and often before expansion is over there may be seen through shrink-holes at the hottest part of the bar (namely, at the point where it was poured,) that the interior is still liquid, showing that it is not necessary that the whole body of the casting shall solidify before expansion takes place. In this phenomenon, we perceive also the simultaneous action in the casting of two opposite tendencies, shrinkage going on in some parts, while expansion is occurring in others.

It is the general impression among moulders and founders that the hotter the iron is poured, the more it will shrink, that is, the more the casting will require to be "fed." This is an error into which the moulder has fallen by reason of the longer time occupied in the cooling or shrinkage of the "hot"-poured metal, and consequently the longer period of "feeding." The total addition of iron required in the "feeding-heads" is no greater with "hot" than with "dull"-poured iron, unless the "hot"-poured metal has more largely penetrated, fused or strained the walls of the mould.

Numerous experiments have failed to show me any effect produced upon the total expansion by changes in the temperature of the metal when poured. Such an effect would not be naturally expected, since the expansion begins only with solidification, and the temperature of solidification, it is reasonable to say, is always the same for the same grade of iron, under the conditions of these tests; so that, however "hot" iron may have been poured, it will always have a certain temperature when it begins to expand. But it is, of course, clear that expansion will take place sooner in a "dull"-poured bar than in a "hot" one; and again, a light body will expand more quickly than a heavy one, as I have proved by my tests.

The length of the period of expansion varies with the size of the casting. The more massive the casting, the longer the period of expansion. In the bars shown in Figs. 74 and 75, the expansion lasted from one-half to one minute in the smallest bars, and, in the largest bars, from three to five minutes. The relation between the shrinkage and the expansion of solidification may now be indicated. The author's view is that the apparent shrinkage of liquid metal so familiar to heavy founders is not due chiefly to a change in the specific gravity of the liquid metal as it passes to a solid state, but largely to the effect of the expansion of the solidifying parts of the casting. That is to say, an outer shell of the casting being first formed, its expansion at the moment of solidification necessarily enlarges the interior space to be occupied by liquid metal; and either additional liquid metal must be applied or else cavities and shrink-holes will be found in the interior of medium and heavy castings, by reason of the progressive accretion of the solidifying metal upon the parts already solidified. Such cavities would, on this hypothesis, be likely to be most abundant in the portions which solidify last; and that this is in fact the case, is often proved by practice. Cavities are very liable to occur in the interior of massive castings, and even when castings are properly proportioned the portion around the "gates" which convey the metal to the mould is often very likely to be porous or to exhibit shrink-holes, due to the circumstance that the metal solidifies last at these points, and to the attraction of solidifying particles to the already solid mass. This hypothesis explains also the fact that, in heavy castings, poured "hot," shrinkage is not often exhibited in the "feeding-heads" until long after the pouring, and that when it does commence (which is not before some expansion has taken place, due to parts solidifying,) it is often so rapid as to require, for a short period, constant additions of molten metal.

Expansion at the moment of solidification being thus one cause of shrink-holes in castings, the practice (not uncommon among moulders) of placing "risers," not much larger than lead-pencils, so to speak, on massive castings, thinking thereby to make them solid, is to be discouraged as useless. It follows, moreover, that a casting should be "fed" until expansion is ended. It is not while a metal looks "hot" or fluid in a "feeding-head" that attention is specially necessary to secure a solid interior; it is when the metal is thickening or "freezing" in the "feeding-heads" that the greatest attention should be paid to the "feeding." It is a general practice among moulders, at present, to let their "feeding-heads" "bung up" at a time when the greatest effort should be made to keep them open, so as to insure a solid casting. It is at this time that expansion is taking place, to enlarge the surface area, and consequently the interior volume of a casting, thereby causing the hottest or most fluid portion of the casting to be robbed of metal, which must be supplied, in order to prevent shrink-holes at all such points.

According to the view here presented, it will be also easy to understand that the resistance offered by the mould may often effect the expansion and shrinkage as well as the subsequent contraction. Whether the power of expansion is as great as that of water in becoming frozen, is, as far as I know, undetermined. I do know that by casting between iron yokes or flask-ends, the longitudinal expansion of the bar may be prevented, as is seen in Test No. 9, Fig. 75, In such a case, of course, it is natural to suppose that the expansion must be in some other direction, and it may increase to a smaller degree the interior space necessary to be supplied with molten metal by feeding. The heat-conducting capacity of the mould, as determining the rate of solidification, may also effect the apparent result. Thus, a casting made in an "iron chill" mould may show less shrinkage than if the same iron had been poured into a sand mould, because, in the latter case, the solidifying iron could have time and opportunity, by reason of the nature of the mould, to more expand it outward, thus increasing the interior space to be supplied with molten metal as already explained.

To return to the fact discovered by the writer, that hard grades of iron expand in solidifying more than soft grades, it may be said that this is contrary, not only to the general impressions, but also to the current explanation of the fact of expansion, which would ascribe it to the creation of graphitic carbon. If this were the controlling cause, we should expect soft irons, which exhibit after solidification more graphite, to show the greater expansion.

The formation of graphite is confessedly promoted by silicon, and hindered by the metalloids which "harden" the iron. When these metalloids are present in such proportions as to overpower the effect of the silicon, combined carbon, instead of graphite, is produced in the solidified metal, and the individual grains, crystals, or structural elements of the cast iron are consequently smaller and more densely packed in hard than in soft grades of such iron. Expansion (and, perhaps, also contraction,) would be, therefore, exhibited by a larger number of such structural elements in a given volume of metal, to be effected by changes in their form and size. This may explain the greater expansion shown by the hard grades in Tests Nos. 2, 4, 6, and 8 in Fig. 74, where the largest percentages of the antagonistic constituents, silicon and sulphur, are presented. (See page 420.)

But any theory on the subject may be premature. Far more important at this time is the fact itself, which affects so directly our foundry practice. I attribute the failure to detect it heretofore to the circumstance that in the every-day work of the founder, the expansion of solidification does not force itself upon his attention. The shrinkage of the liquid mass, requiring "feeding," is obvious enough; and so is the final contraction of the solid mass, for which allowance has to be made in the pattern. But the intervening expansion, not being marked by the final contraction, has been overlooked.*

I may here observe that the tests illustrated in Fig. 74 refute the opinion heretofore advanced, that the

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*The subject of shrinkage is continued at the close of this chapter on pages 404 to 414.

silicon contents of an iron can be defined from the final contraction of a casting or test bar. In all the bars of each cast in Fig 74 the silicon percentage was nearly constant. The variation in contraction, therefore, certainly justifies the assertion that the amount of silicon cannot be thus determined. In fact, the contraction will simply indicate the "grade" of an iron, and no more. The metalloids producing this "grade" can only be determined by analysis.

The "grade" of a cast iron, as I use the term, is a practical name, familiar to heavy founders, though perhaps not capable of precise scientific definition. It is characterized by the degree of hardness, and incidentally by accompanying properties of contraction and of strength. This question of "grade" is further discussed in Chapter XX.

It has been maintained that it is difficult to make cast iron absorb sulphur and that the founder has no need to fear sulphur in general founding.* In the tests shown in Fig. 74, the amount of sulphur in the iron was easily increased by the method described, as is proved by the subsequent analysis. At all events, I am sure that up to 0.3 per cent. sulphur can be easily present in cast iron containing about 2.00 per cent. of silicon, which is a percentage of silicon often permissible and practicable as a maximum in light castings, where the sulphur can be kept below 0.06 in the castings produced. As 0.2 per cent. of sulphur is sufficient to injure or ruin almost any casting made for other purposes than sash-weights, the ability of cast iron to absorb as high as 0.3 per cent. of sulphur forcibly illustrates the great reason why the founder has to fear sulphur in fuel, high-sulphur iron, and to

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*This was advanced by reason of results derived from ½-inch test bars, in a lengthy paper seen in Volume XXIII. of the Transactions of the American Institute of Mining Engineers.

avoid any method in melting, favorable to the absorption of sulphur by iron in cupola or "air furnace" practice. These considerations are applicable also to the making of iron in the blast furnace.

The apparatus used for obtaining the expansion and contraction records, shown in Figs. 74 and 75, is shown in Figs. 76, 77, 78, and 79. It was designed by the author after much study of the conditions necessary for automatic record of the expansion and contraction of test bars, and also for the highly important purpose of simultaneous comparative tests.

The figures illustrating this apparatus (which is freely offered for use to all who may be interested in the matter) will be readily understood, with the aid of the following explanation:

In Figs. 76 and 77 the same letters indicate the same parts, namely:—

A, stationary or sliding recording face-plate board; B, float; D, float-receptacle; E, regulator, giving constant head of water; F, supporting arm for the water-supply vessel; H, over-flow pipe; K, L and M, recording arm levers; N, lead-pencil recorder; O, rubber-band lever-supporter; R, curve-recording face-plate board; S, slide-guides for recording curves; T, revolving sheave-wheel guide and support; U, fulcrum cross-bar; Y, supporter of fulcrum cross-bar.

In Fig. 78 the parts are indicated by letters, as follows:

A, counterbalance clock-weight; B, bed-plate, securing the base board; I, one-day "Pirate" alarm-clock; R, curve-recording face-plate board; S, removable casting-pin; U, fulcrum cross-bar; V, clock and recording face-board connecting-shaft.

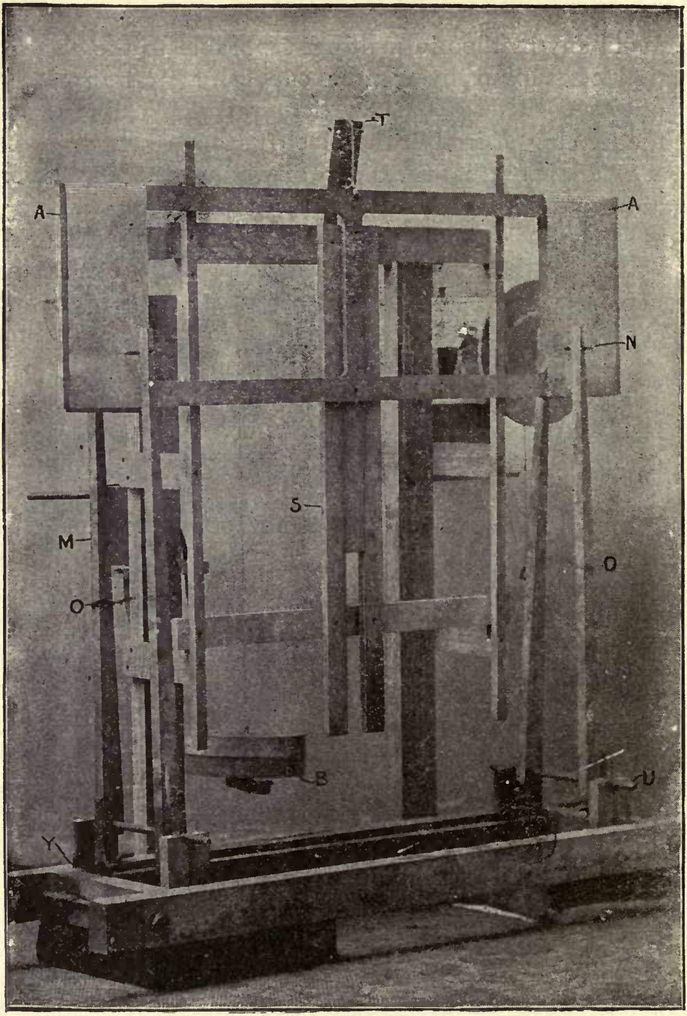

FIG. 76.—AUTOMATIC RECORDING APPARATUS FOR EXPANSION AND CONTRACTION.

In Fig. 79 the parts are indicated by letters as follows:

A, expansion and contraction-end equalizer; B, spring-clasp; D, flow-off recess; E, spring-clasp iron; F, lever-fulcrum bearing; H, casting-pin clasp-opening; K, removable casting-pin.

The levers of this apparatus are so delicately mounted as to be moved by a breath. As already stated, for every inch travel of the long arm, the short arm, moved by the actual expansion or contraction, travels three thirty-seconds of an inch in the straight line. The diagrams, Figs. 74 and 75, pages 389 and 390, were constructed by platting the sum of the readings given by the pencils at the two ends of the apparatus in straight lines, and consequently give only the total longitudinal expansion and contraction, without indicating rate or alternations. But the apparatus can be employed, with the aid of the float or clock, etc., shown in the figures, to record curves. For a straight line record, the face-plate, A, Figs. 76 and 77, is held stationary. To obtain curves, it is gradually lowered at any desired rate by means of the float B, in the receptacle, D, Fig. 77, a constant head of water being maintained in the reservoir, E, by a supply from a suspended vessel at F, and an overflow-pipe, H. A specially arranged strong spring clock might be used instead of the float B, to lower this face-board uniformly, so as to effect the same end, and with either plan introduce into the results the element of time. Incidentally, such experiments ought to settle the question whether there are, as has been declared, two periods of expansion in cast iron when it is cooling, after the liquid metal has "frozen," or solidified.

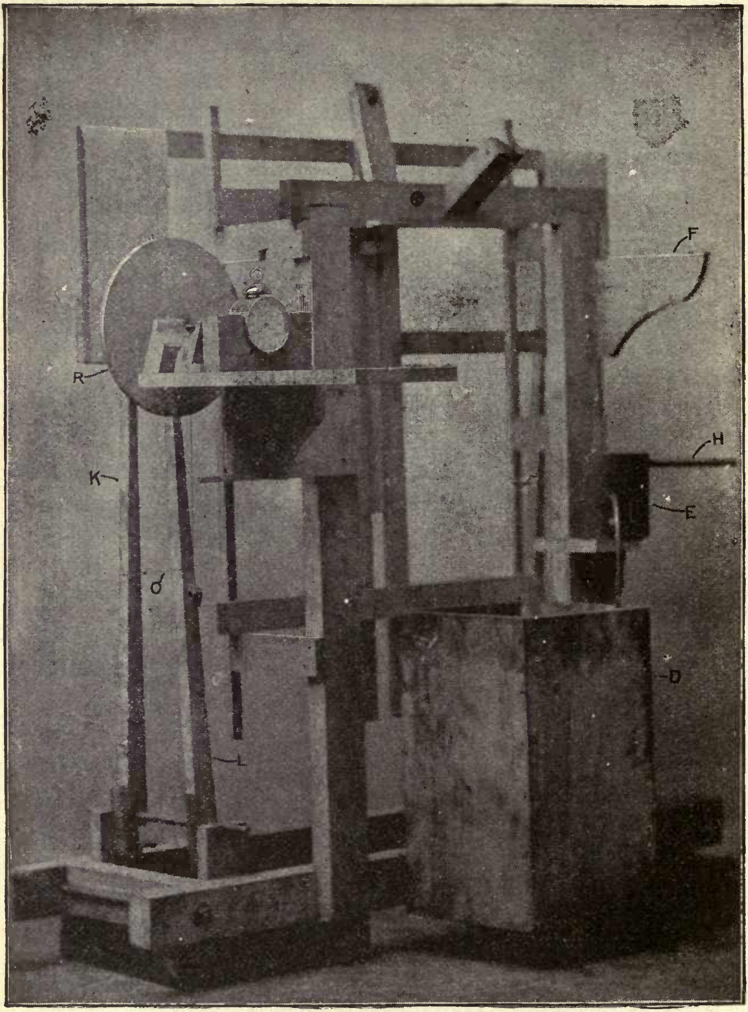

FIG. 77.—AUTOMATIC RECORDING APPARATUS (SEEN FROM OPPOSITE SIDE OF FIG. 76), WITH ARRANGEMENT FOR RECORD IN CURVES.

The lever-arms, K, L and M, Figs. 76 and 77, are held gently against the face-plate by light rubber bands, secured midway in their lengths at O, so that the very soft pencils at N may record all movements of these arms. The pencil-record may be made on paper, covering the face-plate, as indicated in the figures, or on the bare face of the recording-board.

It will be evident that the records of the independent levers at each end of the bar must be added together, in order to determine the total expansion or contraction. Thus, in the case of test No. 1, Fig. 74, the automatic record of the apparatus would show a travel in expansion of one-half an inch at each end, or one inch in all, followed by a contraction of two and one-half inches at each end, or five inches in all, not including the retracement of the previous expansion. In other words, after expansion was ended, the bar contracted longitudinally eighteen thirty-seconds of an inch (each inch of the pencil-line representing

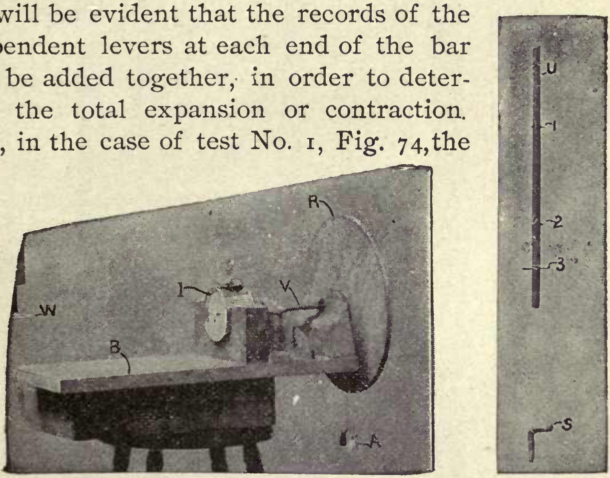

FIG. 78.—INDEPENDENT DIAL FOR RECORDING EXPANSION AND CONTRACTION IN CURVES.

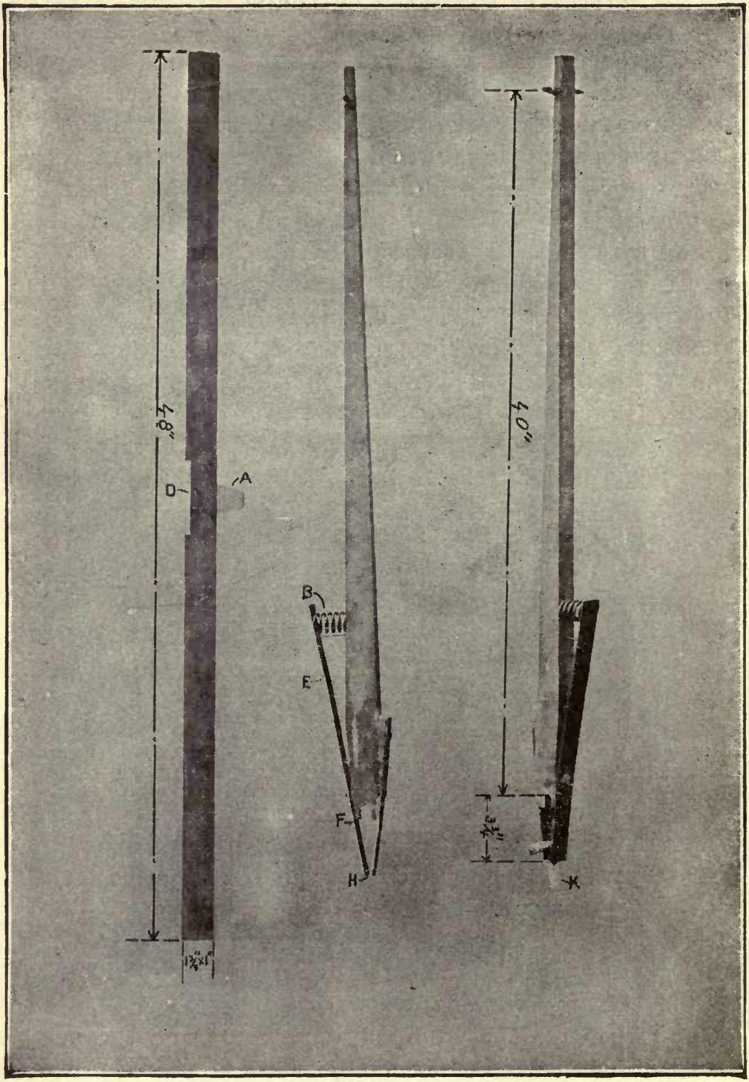

FIG. 79.—TEST BAR PATTERN AND LEVERS FOR RECORDING APPARATUS.

three thirty-seconds of an inch of the short-arm lever-movement, i. e., of actual extension of the bar); and consequently, the test bar, 48 inches long as poured, was elongated in solidification to $48\frac{3}{32}$ inches, and then contracted in cooling to $47\frac{17}{32}$ inches, its final length at atmospheric temperature.

The clock shown at I, Fig. 78, with its face-plate, R, can be set independently, with a single recording-lever, to receive on the revolving face expansion and contraction curves from one end of the bar only, or it can be supported, as shown in Figs. 76 and 77, so as to record curves in connection with the records made on the stationary or sliding face-board, A.

The whole apparatus is of wood, except the fulcrum bars, U, Figs. 76, 77, and 78, the casting-pin, S, Fig. 75, and the pin-holding plates, E, Fig. 76. By a study of these levers in Fig. 79 it will be seen that a little pressure on the spring side at B will instantly release the casting-pin seen at K. The ⅜″ casting-pins seen at S, Fig. 78, and in position at K, Fig. 79, are made tapering, so that they can be readily moved from a test-bar and used again. They cause the levers to record sensitively any movements due to expansion or contraction after the bars are poured. At the left of Fig. 79 is seen the form of pattern used for moulding the test bars. The projection at A is cast on, as shown, so as to insure equal action in recording the expansion and contraction at each end of the bar. At D is a recess, which gives guide to make the same in the mould, so that in pouring the bars "open-sand," the metal will "flow off" at this point when it comes to that level, and thereby insure all bars being cast closely to the same thickness.

APPENDIX TO CHAPTER LIV.

A few illustrations of shrinkage and blow holes which the author gave, with other subjects, in a lecture before the students of Cornell University, December 14, 1900, and published in the *Sibley Journal of Mechanical Engineering*, January and February, 1901, are presented here, as they contain illustrations that are important to be treated in connection with the subject of expansion, shrinkage, etc.

When a shrink hole or holes occur in a casting they will always be found in the part or parts which solidify last. To prevent such holes in castings, we must provide means to fill the void space with metal. It is often difficult and again it is impractical to do so. The chances for such holes occurring are often due to the design. There are times when, if the constructing engineer or designer thoroughly understood the cause of shrink holes and their remedy, he could design or proportion his castings to avoid such evils. The question might be asked, how is a person to know which will be the last part or parts of a casting to solidify, or where we may expect the shrink holes? Such holes will always be found in the upper cast part of uniform solid castings, as seen at E in sample No. 18, Fig. 80, and in the body of heavy sections having light ones joining them, as at F, sample No. 19; that is, if in both cases such bodies are not fed with additional metal to feed the shrinkage. Where light parts join heavy ones the light parts, solidifying first, will naturally obtain all the metal required to feed their shrinkage from the heavy part. For this reason if we do not, in turn, supply the heavier part with additional metal we may expect some excessive cavities or shrink holes in them, unless we have reason to suspect that the creation of graphite to enlarge the grains of iron is such as to compress the metal in such a manner as to prevent the existence of shrink holes. Then again, there are cases where the expansion of cores on the interior of castings, while the metal is in a molten state, will compress the metal so as to fill up any cavities that might be caused in a natural way.

FIG. 80.—CASTINGS SHOWING TYPICAL POSITIONS OF SHRINK HOLES.

A good illustration which shows how light parts will often draw metal from heavy ones and leave cavities in the latter, is a section of a locomotive pump casting made some years ago in Cleveland, Ohio, and causing such trouble that it went the rounds of several foundries before good castings were obtained. A section of this casting is seen in Fig. 81. It will seem strange to many unfamiliar with founding that moulders did not understand how to make such castings sound, but if any such ever come to have experience with foundries and moulders, they will find that too many of them are ignorant of the principles underlying the art of founding. The difficulty with the pump casting lay in there being cavities found at about G, as marked in Fig. 81, when the section was bored out to form a valve seat. These pumps were cast on end and at all angles; many were made with good large skimming gates to hold back the dirt, thinking such to be the cause of the imperfection found. Besides this, they went so far as to make them in dry sand, but all of no avail. Finally

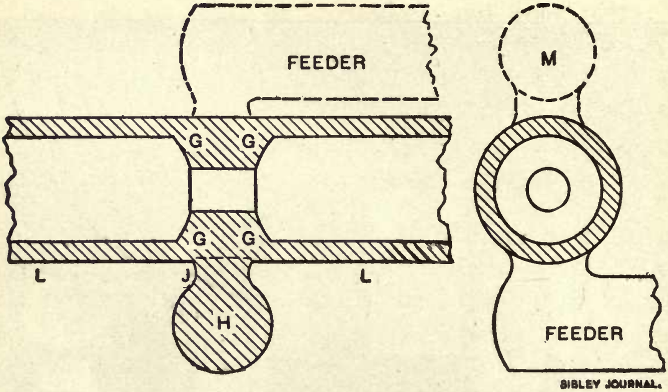

FIG. 81.—LOCOMOTIVE PUMP CYLINDER SHOWING POSITION OF SHRINK HOLES.

the castings came to the hands of a moulder who understood the cause of shrink holes and could tell such cavities from blow or dirt holes. After this moulder had made one mould and observed the proportion of thicknesses in the casting, there was no more trouble. The difficulty had lain in not providing means to convey hot metal to supply the shrinkage of the heavy part. This was done by attaching a feeder, as at H, having a connection with the casting, as at J, both bodies of which were so much larger in area than the section of the casting at G that assurance was afforded that the metal would solidify in the heaviest section of the casting at G before it would do so in the feeders H and J, thus giving a head of molten metal which could settle down from the feeder to make a solid casting. Pouring these castings on end, instead of on their flat, could do no good, as the metal would solidify first in the thin part of L long before it would do so in the heavy section of G. If a heavy feeder as at the dotted line M, made of the same proportions as J and H, had been carried down from the top of the up-ended mould to the heavy section, sound castings would have been produced, but otherwise they were as well made on their flat as on their end.

Another illustration of this principle of feeding is found in not obtaining sound flanges, as at N, Fig.

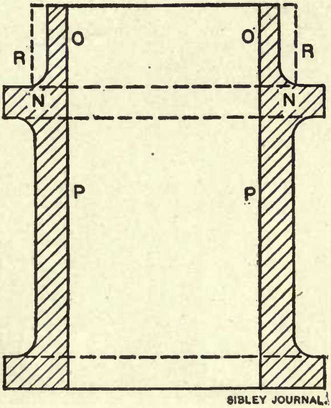

FIG. 82.—CYLINDER SHOWING POSITION OF SHRINK HOLES.

82, with cylinders cast on end. The feeding head O, which is intended to supply the shrinkage of all below it, is often made so small that it solidifies before the heavy portion at P, and then what metal settles to supply the shrinkage of the lower body of the casting P comes from the thicker or more fluid section at N, and leaves shrink holes at that point. This whole difficulty could be stopped by making the feeding head O larger, as per dotted line R, as then this would be the last to solidify, and when the feeding head O was cut off to give a finished flange a solid body of metal would be found under it, providing the feeding head O had been fed with hot iron by means of a feeder or heavy riser head (not shown) placed on top of the feeding head O as is the common practice.

Blow holes. Having treated the subject of shrink holes, we will say a few words on what are called blow holes. Such holes may often appear to some as shrink holes, but they generally differ in being found in lighter parts of castings, than where shrink holes are liable to be found, and are generally of a smoother character. Not only are blow holes found on the interior but the exterior as well; in either place, they are caused by gases

FIG. 83.—CASTINGS SHOWING BLOW HOLES.

that were not carried off from the mould through proper channels of venting the sand, or oxides and slag in the metal giving off gases that, in an effort to escape from the metal, become imprisoned in a casting, as seen at S, sample No. 22, Fig. 83. This is caused by reason of the metal solidifying before the gases could rise upward to find relief through the cope or top part of the mould, and which, if not well vented, or of a porous and fairly dry character, will then often hold the gases from going further and form cavities in the cope side of castings, such as seen at T in sample No. 23 of the same figure.

A description of some special tests on shrinkage, contraction, specific gravity, and fusion that the author made and presented in a paper to the Western Foundrymen's Association at Cincinnati, 1897, are given in the following. Prior to these tests we did not possess any information as to what percentage of shrinkage there existed in iron when cooling from a fluid to a solid state. Realizing the advisability of obtaining such information, the author devised the following method of testing the shrinkage of the different metals shown in Table 86, page 411, and illustrated by Figs. 84 and 85.

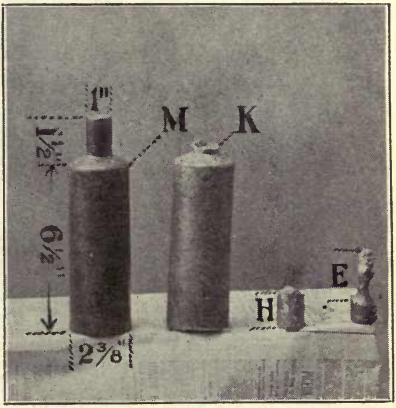

FIG. 84.—SHRINKAGE PATTERN AND TEST CASTING.

At M, Fig. 84, is seen an iron pattern from which sand or chill moulds may be made. At A, Fig. 85, is an iron box three inches square by eleven inches long, in which the pattern M has been moulded to make a dry sand mould and is filled with molten metal. The cut shows a moulder in the act of pouring the contents

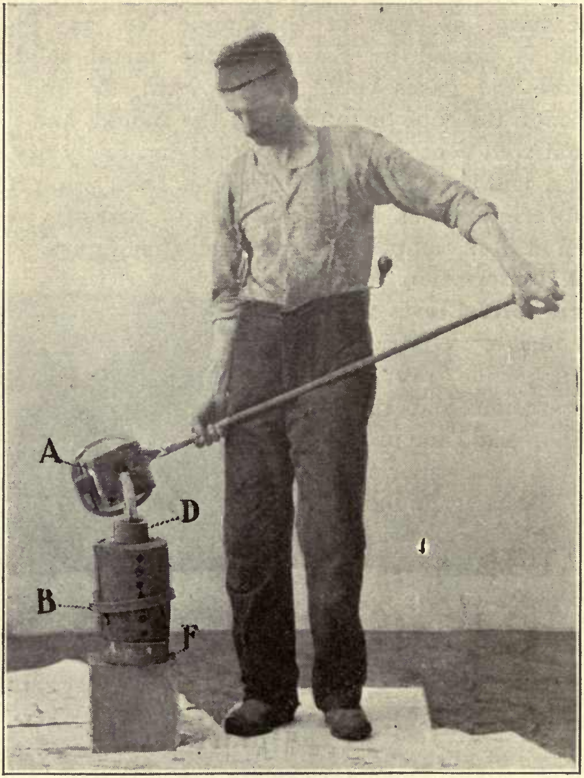

FIG. 85.

of the mold into a chill or all-iron mould. This is split in halves, as will be noticed, and a ring clamp, as at B, is used to hold it firmly together, E being a bottom block for the chill proper to rest on, and D a funnel cap placed loosely on the top of a chill to insure the stream of metal being guided directly into the chill mould without any being spilled. Before pouring these moulds they are tested to learn if their cubic contents for holding metal are exactly alike, by means of filling one with fine hour-glass sand, and then pouring the same into the other. This is done only as a precaution to make sure that no extra thickness of blacking or distortion of the dry sand mold has occurred in any manner while making it. There are three of these dry sand moulds made for each cast or test of any one grade of metal, two being called portable and one stationary. The plan of using these moulds is as follows: A portable mould is secured in the ladle shank and the small cupola (page 241) tapped to fill it direct, and it is then quickly poured into the chill mould as

TABLE 86.—SHRINKAGE AND CONTRACTION OF GRAY AND CHILLED IRONS.

Heat Nos.	1	2	3	4	5	6
Character of metal tested.	Ferro-silicon.	Foundry iron.	Bessemer iron.	15% steel with gray iron	Charcoal iron.	Charcoal iron.
Silicon	12.25	1.75	1.72	1.61	.75	.70
Sulphur	.021	.04	.054	.055	.03	.035
Shrinkage of chilled iron	3 oz. 240 gr.	2 oz. 240 gr.	2 oz. 180 gr.	2 oz. 290 gr.	6 oz.	6 oz. 280 gr.
Shrinkage of gray iron	3 oz.	1 oz. 210 gr.	1 oz. 140 gr.		1 oz. 460 gr.	2 oz. 120 gr.
Contraction of chilled iron	.270″	.262″	.271″	.322″	.446″	.460″
Contraction of gray iron	.24 ″	.205″	.211″	.227″	.229″	.235″

above described and seen in Fig. 85. This done, the first sand mould is removed from its ladle shank and another set in to replace it. This in turn is also filled with metal, and instead of pouring this into a chill it is poured into the stationary sand mould, after which it is then removed and placed with its mate. We now have two moulds, one a chill and the other a sand mould, that will have a sunken space at the neck K, Fig. 84. To learn the amount of shrinkage that has taken place, the shrunken and unfilled spaces at the necks of the chill and the dry sand castings are now filled with molten metal and separated from the main casting, views of which pieces are seen at E and H, Fig. 84. The straight portion at H is that created by the shrinkage, which takes place as the metal is being poured, and the portion at E, which is irregular in outline, is that created by the shrinkage of the molten metal in cooling to a solid, to leave a cavity in the main body of the roll as seen at the right of Fig. 63, page 338, after the moulds have been poured and are released by splitting the end of the roll at K. The piece at E is the other end up from that shown before being removed from the roll K. A little study of the sections E and H will show that their total weight (by fine apothecary scales), minus any thin wafer sheets of iron that might be found sticking to the walls of the dry sand mould, that had not run out as metal to test the shrinkage, would be the shrinkage of that iron under the conditions in which it had been poured.

By referring to Table 86, page 411, it will be seen that we have, in castings measuring about two and a quarter inches diameter by seven inches long (the actual form and size being seen at M, Fig. 84), weighing nearly eight pounds, a shrinkage in the chilled iron of about six ounces, and in the gray about two ounces. This means a shrinkage of about four and a half pounds per hundred for all chilled iron, and nearly two pounds per hundred for all gray iron. In larger figures, for example, with a twenty-ton casting, Table 86, would imply a shrinkage of about 1,800 pounds for all chilled iron were it possible for all of its body to be as thoroughly chilled as is the section of rolls seen in Fig. 62, page 337, and 800 pounds for the gray iron if the total body of the casting does not get up in graphite any higher than the rolls hold it, as seen in Fig. 61, page 333.

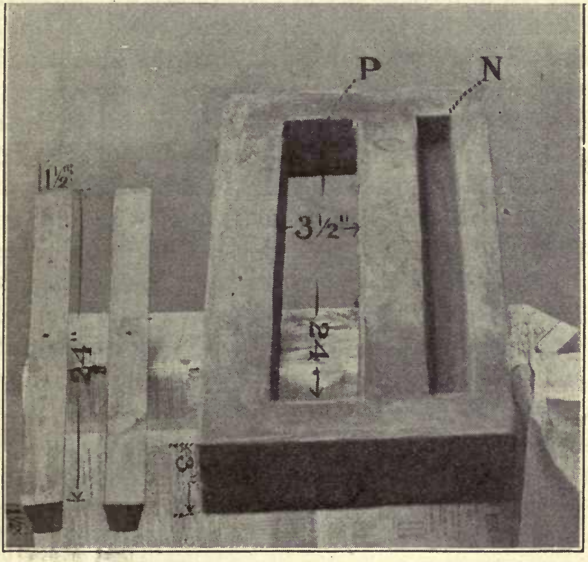

FIG. 86.—CONTRACTION TEST WITH CHILL AND SAND MOLDS, AND PATTERNS.

It is to be remembered that the tests of iron shown in Table 86 do not include an iron as soft as is necessary for stove plate or very light castings, and because such grades of iron are softer than any shown in Table 86 they would possess less shrinkage. The tests exhibited by Table 86 demonstrate positively that metal will shrink and cause trouble by leaving holes in the interior of castings, and also that the greatest shrinkage exists in the harder grades of iron.

The relation that contraction maintains to shrinkage, with the same metals (see page 386), was another point which the author thought well to obtain knowledge of while conducting the experiments on shrinkage. In order to test this factor the author devised the appliance seen in Fig. 86, and which permitted casting bars seen at the left of this figure in a sand and chill mould, to test, together with other qualities, the difference in contracting that would be caused by rapid and slow cooling of the same metal. By Table 86 we find that tests Nos. 1 and 6 give us the mean of .127 greater contraction for the fast cooled bars than for the slow cooled ones, each of the same cross section and length, patterns for which are seen at the left of Fig. 86. The greatest difference in Table 86 is .225 and the smallest .030. It is to be remembered that the respective tests seen in Table 86 were cast in their order with the same gate and hand ladle of iron. The cause of such a difference in the contraction of two bars is, as will be seen by Fig. 86 at N, that one is cast in a chill mold and the other in sand, P being the space for molding the sand bar. A study of the difference in contraction which the rate of cooling can cause by the device seen at Fig. 86 is instructive in more ways than one. Take the case of the charcoal iron heats Nos. 5 and 6, which will illustrate the great difficulties the makers of chill rolls, etc., are confronted with. Here we find that the chilled part of the casting will have as much again contraction as the body of the casting that is not chilled. It is no wonder that chill roll makers experience much trouble with the checking and cracking of the surfaces of chill rolls due to the excessive contraction of the chilled parts, which must leave or pull away from the chill mold supposed to support its enclosed body of liquid metal long before it has solidified, and, which by reason of its head pressure incased within the body of the shell, that has contracted from its chill or outer support, must be heavily strained to retain its enclosed body of still fluid metal. We can see by the chill and sand contraction tests, herein recorded, how a very slight difference in the dampness of sands or nature of a mould can affect the contraction of castings or test bars, and shows us the necessity of having uniform conditions in moulds and temper of sands in order to obtain a true comparative record of contraction tests. More on this subject is found on pages 454, 467 and 511.

Comparative fusion tests by immersion were conducted at the same time that the shrinkage and contraction tests were made. This was done chiefly to test which of the chilled or sand cast ends of one bar would melt first of the various metals used. The device the author designed for these tests is shown in Figs. 87 and 88, the former figure shows a three-quarter-inch rod in the hands of a moulder being held over a ladle that holds in its end a casting made in the mould seen at Fig. 88. The upper half S was all green sand held in a wooden box, and the lower a chill or iron mould made in halves and held together by a ring T, the whole resting on a bottom block U and the metal being poured in at Q. Now it will readily be seen that a casting made in such a mould would have one-half wholly chilled or body hardened, and the other of a softer or more complete gray mixture, which if held in a bath of molten iron or steel would be a very pronounced test to assist in showing whether hard or soft grades etc., of iron, when charged into a cupola or air

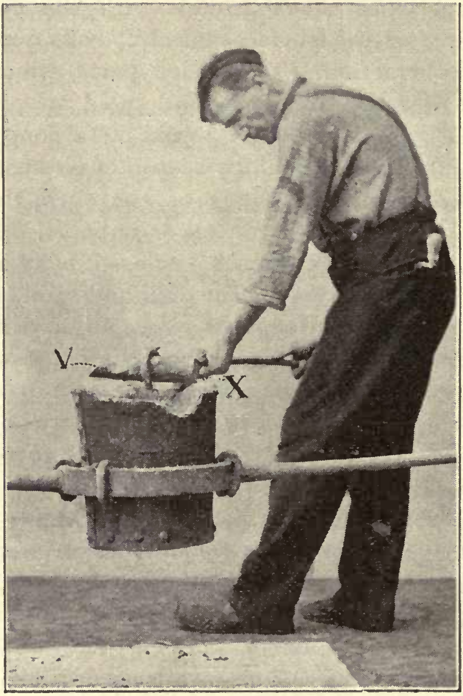

FIG. 87.—LIQUID BATH COMPARATIVE FUSION TEST.

furnace, etc., as such, would melt the faster. The cut at Fig. 87 shows the exact appearance of the specimen as it was taken out of a crane ladle bath of molten metal, just as the chill end V was about to disappear entirely, and which we have found in all cases to melt away five to ten minutes faster than the gray end X. As the question of encouraging the manufacture of chilled or sandless pig by the blast furnaceman, which this work advocates, is an important one, the author would advise all to try this experiment, and in doing so many will find themselves surprised at the rapidity with which the chill or body hardened end melts, compared to the gray or soft end of the test specimen. In using this device, some judgment will have to be used as to the size of the test roll and of the ladle for its immersion. For a roll of two to three inches diameter a one thousand pound ladle or larger will be necessary, but rolls about one inch in diameter can often be melted down in a bull ladle holding two to three hundred pounds of iron, before the metal would get too dull. These rolls are well made, about twelve inches long, and are secured by the end of the rod seen curved around it tightly in the center. All sand and scale should be well filed or ground off from the sand end of the roll so as to have it free from foreign matter, similar as in the chilled or hardened end, to make conditions alike in each end as far as possible. Another plan for testing fusion is given on pages 231 and 314.

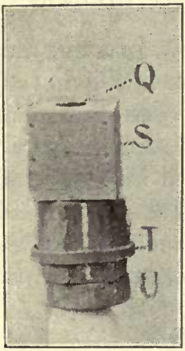

FIG. 88.—COMPARATIVE FUSION TEST MOLD.

CHAPTER LV.

STRETCHING CAST IRON AND ELEMENTS INVOLVED IN ITS CONTRACTION.*

What shall I allow for contraction? is a question which the experienced pattern-maker will generally ask the moulder or founder before any patterns of importance are begun. It is true, we have the stereotyped rule of allowing one-eighth of an inch per foot for contraction, and many pattern-makers and founders are so inexperienced as to accept such a rule for the contraction of every form and thickness of a pattern which their plant may be called on to make. It is possible with the class of work which they make that such a practice may never have led them into difficulties, and hence they obtain an experience which would lead them to believe that there are no conditions calling for anything else than the making of all patterns one-eighth of an inch per foot larger in every direction than the castings desired.

Moulders and founders of broad experience in general machinery work know that there will generally be a difference in the contraction in any two forms that differ in their proportions, even when poured with the same iron. Also the form of a mould and

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* Read by the author at the meeting of the Western Foundrymen's Association, at Chicago, Nov. 20, 1895.

the manner in which it is made and the casting is cooled, have much to do with the size of the casting, as compared with the pattern from which it was made. It is not the intention of the author to attempt to set forth fixed rules for the contraction of castings by the classification of the different kinds of work, as some have done, for this is not practical, but more to call attention to the principles involved and assist the engineer, founder, moulder and pattern-maker to best judge what contraction, if any, should be allowed for constructing patterns, to meet the various conditions in moulding, mixing of metals and cooling of castings. Not only has the experienced heavy-work founder found a great difference to exist in the contraction of the same kind of iron in different castings, but some will agree with the author in affirming that instead of allowing for contraction, the reverse conditions occasionally prevail and are elements frequently necessary to be considered in making patterns. It is nothing unusual for moulders and founders engaged in heavy or jobbing machinery to find their castings much larger than the patterns from which they were made, thus disclosing a condition in founding of which the light-work founder and "stove plater" would have no opportunity of obtaining any knowledge. Before the author discusses the qualities involved in stretching cast iron, which is an important part of this paper, he will consider those effecting a difference in thick and thin bodies cast under the same conditions or in the same flask with the same iron or "gates" and from which observing founders have learned that a heavy casting or parts will contract much less than a light one, where conditions permit of free contraction.

An experiment which the author conducted to demonstrate the fact just cited was to take a pattern 14 feet long by four inches by nine inches, and another exactly the same length but only one-half inch by two inches, and cast both together with the same gates. Although the bars were of the same iron, a difference of seven-eighths of an inch existed in their contraction. The thin casting contracted one and three-quarters of an inch, whereas the thick contracted seven-eighths of an inch. Why is this? is a natural question, and in answer the author would offer the following hypothesis:

The carbon held in fluid iron, authorities claim exists in a combined form. How much of this will change to graphite when the castings or iron has solidified and become cold enough to handle, depends first upon the time of cooling, and second, the percentage of sulphur, silicon, manganese, and phosphorus, which exists in the iron.* The greater the silicon up to nearly four per cent., also the phosphorus up to one per cent., and the lower the sulphur and manganese, taking account also of the time consumed in cooling, the higher we will find the graphitic carbon. The greater the formation of graphite, the larger the molecules and grain of the iron; and this is one secret of thin castings and hard iron contracting more than thick castings and soft iron, in cases where all conditions in moulding, cooling and freedom for contraction are substantially alike. For other qualities effecting this, see pages 394 to 396.

Two castings from one pattern, of the same iron, can, by cooling one more quickly than the other, be made to show considerable difference in their contraction, ow-

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* The total carbon is also to be included when thought to vary from any given standard.

ing to the one having a greater time than the other to change the combined carbon to graphite, a quality the author noted in a paper before the Foundrymen's Association at Philadelphia. See Chapter LIX., page 454. This Chapter also presents analyses of one-half inch and one inch square as well as one and one-eighth inch round test bars poured from the same ladle at the same time, showing that the graphite was much less in the one-half inch than in the one and one-eighth inch test bars, and on this account contraction was much less in the larger than the smaller bars.

The formation of graphite may be compared to the raising of bread. The longer time given for the yeast to act, the greater the bulk of the dough obtained, caused by the expansion of the wheat's molecules. This is similar to the cooling of liquid iron to a solidified cold state. The longer the period for cooling, the greater the expansion of the molecules and grain of the iron, which is defined chemically by our having higher graphite in slow than in fast cooling; this is also assisted by the heaviest parts of a casting or that last to solidify often containing silicon to have its percentage higher than will be found in the lightest portion or those first to solidify. (Expansion is also a quality affecting contraction which should be considered in connection with graphite. For effects of expansion, see Chapter LIV.)

We can take the worst kinds of scrap iron, and by pouring them into such heavy bodies, as anvil blocks, for example, obtain iron that presents a large, open-grained fracture, often of excellent texture, proper for being readily machined; whereas, were the same iron poured into a casting under three inches in thickness, it would be "white" and hard as flint. In the former case, also, it would show much less contraction than in the latter. The facts go to show that the length of time occupied in cooling a casting, or that molten metal has solidified, may often be more effective in causing different degrees of contraction and hardness of iron in a casting from ordinary used foundry iron, than any varying percentages of sulphur, silicon, etc., which exist in ordinary foundry iron. Any one giving due consideration to the points here raised will be led to concede the impracticability of formulating set rules for the contraction of castings, to be published as a universal guide to desired results in the dimensions of castings; but by a study of the phenomena here referred to, we will be in a fair position to determine what allowance should be made for contraction, etc., when we are on the ground of action. It is to be understood that reference is not made to the difference which may exist in the size of like castings from soft and hard iron, or variations due to the hardness of ramming and head pressure of molten metal on moulds, etc. We are mainly dealing with the elements involved in the question of contraction, as affected by rapidity of cooling, stretching of iron, and variations in the thickness of metal, etc., in castings.

Stretching is possible and due to influences exerted by conditions in casting, cooling, and forms of patterns, which overcome or retard free contraction. It can make castings larger than the patterns from which they were made, and it also makes it possible to obtain acceptable castings which could not be secured were it not for the fact that iron can be stretched.

The author will now describe a device which he has designed with the object of testing and proving that cast iron stretches as well as expands. While the cuts 89 and 90, pages 424 and 425, will explain clearly to some the exact working of the device, I will describe it in detail in order that all interested can criticise and fully understand its construction and working.

A, Fig. 90, is the pattern used. The shoulders at B and C are for the purpose of providing means to stretch the bar by clamping or holding one end to a support at D, Fig. 89, which has a recess forming a part of the iron frame at the end D into which the projection X of the test bar pattern A is inserted when moulding the bar, and which, when cast rigidly, prevents the test bar from contracting or pulling away from this end, the other end being pulled by weights as seen at E where one, two or more 50-pound standard weights are suspended over the roller H. There are two moulds cast side by side, "open sand" with independent runners R and T from the same ladle of iron as quickly as they can be poured. The only difference existing in these two moulds, lies in one being strained by the weights, while the other is free from any weight or restraint to prevent contraction, other than the restraint of the mould's sides, and this affords the most favorable arrangement to observe and record any difference which may exist in the contraction, etc., of free and restrained bars. Independent pointers are attached to these bars by means of levers and show their readings on scales behind them.

The first movement of the pointer to be noticed is its passing to the right of zero. This action commences about 30 seconds after the bars are cast and

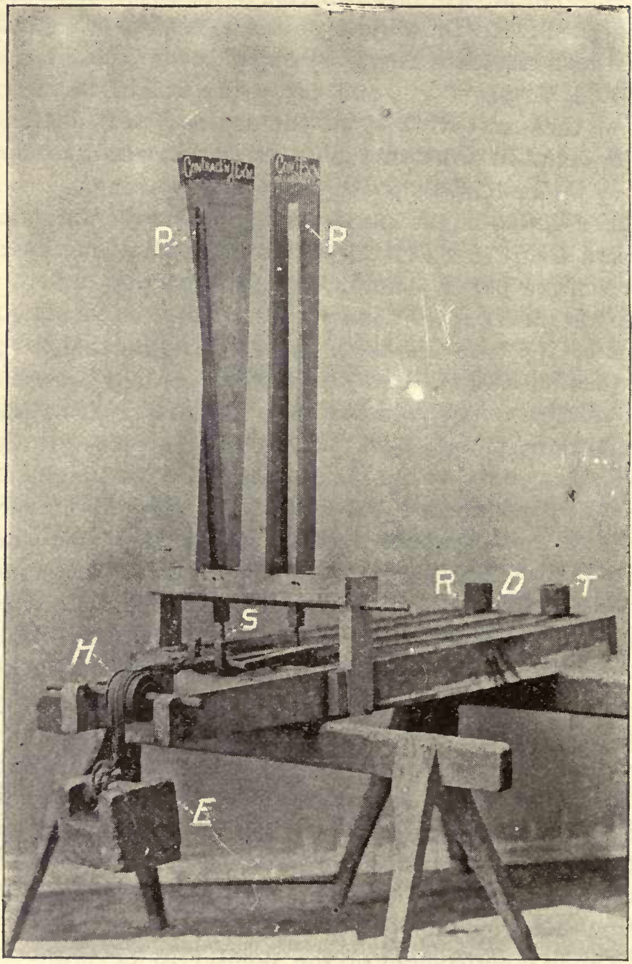


FIG. 89.—WEST'S STRETCHING RECORDER.

continues for about 90 seconds for a total travel of the pointer of about one and one-half degrees on the arc shown over the top of the pointer P. This is caused by the expansion of the metal at the moment of solidification, a quality, by the way, which some have disputed. After the expansion has fully recorded its influence, in lengthening the bar, the pointer P stands still for about two minutes, after which time contraction begins and the pointer P starts to move back to the left. The weights at E are now suspended, and it will be well to emphasize the fact that they exert no influence to suddenly move the pointer P backward to zero. Five minutes after the contraction commenced, the restrained bar's pointer will have moved about one degree and the pointer on the free bar two and one-half degrees to the left of their starting points. About fifteen minutes after the bars are poured the restrained bar will have moved the pointer one and one-half degrees and the free bar three and one-half degrees. At 30 minutes after the pouring, the restrained bar will have moved the pointer three degrees, and the free bar about five degrees, showing in the time be-

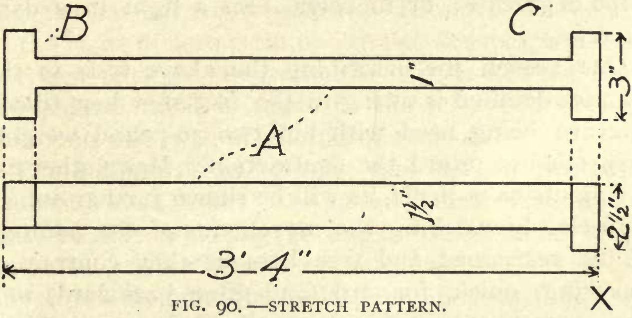


FIG. 90.—STRETCH PATTERN.

tween 15 and 30 minutes after the pouring that the restrained bar held about even pace with the free bar.

From this point on, the restrained bar keeps gaining on the free bar, until the end, when the free bar stands about one and one-half degrees ahead of the restrained or weighted bar's pointer, thus showing we can restrict contraction by power and that the period of the greatest stretching of cast iron, cooling from a solidified state to the temper coldness of the atmosphere, wherever there is any restraint upon its contraction, is that ranging from 1,600 degrees F. to 1,200 degrees F., or in color from a light to a dark cherry.

One reason for describing the above tests in the manner detailed is owing to the fact of a low silicon mixture being used with but two 50-pound weights suspended to retard the contraction. Many other experiments were made, as will be shown further on.

In closely watching the movements of the pointers of the restrained and free bars as they contract, a wavering, quick, forward (and often backward) motion, sometimes as far as one-half degree, will be plainly noticed in the restrained bar, while the free bar has a constant steady forward movement. The quick, wavering motion is occasioned by the resistance to free contraction, which the weights offer to the bar, and occurs when the contraction occasionally has sufficient power to overcome the influence of the weights to stretch out the cooling iron. The fact that cast iron can be stretched is also often exemplified in heavy foundry work in the cooling of castings, examples of which in every-day practice the writer will cite further on.

A factor not to be lost sight of at this point is the positive manner in which the device here described verifies that there is a moment of expansion in molten iron cooling down to a solidified state. To demonstrate this by the device shown, it is necessary to cast one bar between fixed iron ends which cannot be moved apart by the strain of the expansion, and another bar which shall have the end at the pointer P free in the sand to record any expansion which may take place.

Any one experimenting in this manner will find that the bar left free to expand will move the pointer to the right of zero from one to two degrees, while the bar cast between the iron ends or yoke will not move the pointer until it starts to the left, thus showing that iron will expand if left free to do so.

The author wishes to state that he is of the belief that with such a device as shown founders will eventually be able to utilize the expansion of metal to denote the grade of hardness, etc., in the short period of one minute after the molten metal has been poured. There are several ways in which such a quick determination of the grade, etc., of metals could be practically applied and prove of some value to the metallurgical world.

The author could detail all the tests which he has made to show the movements of the pointers at every few moments, but as what he has given is in a practical sense, all that is necessary to prove the theory advanced by this paper, such minute details have been omitted. Suffice it to say that the principles in expansion, contraction and stretching presented are not a result of one or two experiments, but of a large number of tests, and that with a weight of 500 pounds suspended at E and an iron of about 1.50 in silicon, .050 sulphur, he has made a difference of one-quarter inch in the final contraction of the free and restrained bars, and is of the opinion that with higher silicon, or a softer iron, he would be able to make the final stretching of the restrained bar exceed that of the free one over three-eighths of an inch. The size of pattern A is one inch by one and one-half inch, and three feet four inches long over all, as shown by the cut at A, Fig. 90, page 425.

Returning to the subject of stretching cast iron, the author will cite a few instances in every-day heavy founding that will further assist to demonstrate the existence of such a quality. As one illustration of this fact, I refer to the making of some large Martin pump castings which I made in the year 1879 at the Cleveland Rolling Mill Company's foundry, in Cleveland.

These were of a design requiring many large cores, and when the patterns were made the usual stereotyped contraction of one-eighth inch per foot was allowed for the castings. I had made about four of these castings when I was one day called upon by the manager to explain to him what I had done to cause the castings (cope as well as nowel parts) to be larger than the patterns, which had caused a great loss in other smaller castings that would have to be made over in order to correspond in size to the different parts of the large pump casting. The investigation simply resulted in showing that the designer, draftsman and pattern-maker were all ignorant of the qualities which exist in cast iron, permitting it to be stretched when cooling, after solidification has taken place.

It is natural to inquire as to the reason for the iron being stretched to such a large degree in these castings. The author's hypothesis is that owing to the castings being filled with large cores containing both slim and thick cast and wrought core rods, as soon as the cores became heated they and all the rods expanded and, by outward pressure which they exerted, overcame the resistance of the outer body of the green sand mould; and while the metal was in a fluid state, instead of shrinking, as is generally the case with heavy castings, some of it would actually flow back and run out over the flow-off gates. This action continued until solidification took place; then stretching of the half molten or solidified iron came into play, expanding all sides of the green sand mould until the force of the expanding cores and their rods gave way to that of the outer mould's body of metal, and the casting attained that point of cooling, as shown in the experiments illustrated with the author's device, Fig. 89, in which it had cooled sufficiently to overcome the influence of the power most greatly exerted to stretch the iron, thereby exerting an expanding power at a time when the cooling iron was most susceptible to stretching, which, of course, varies according to the thickness of a casting, its rate of cooling, etc., to obtain a temperature from 1,600 degrees F. down to 1,200 degrees F., as cited on page 426, in the stretching tests with the apparatus above described.

The case of the pump which has been cited exhibits a form of power, proper to be classed as expansion and compression resistance to contraction. We still have another form, which I will call heat resistance, and which displays its power to stretch iron by reason of the carbon being more completely transformed to graphite under slow cooling. An example of this is an experiment which was made by a New York City founder some years ago.

The feat achieved by the founder was that of casting a balance wheel of about 18 inches diameter, having a rim about two inches thick, with four to six arms only about one-quarter inch thick. The wheel was on exhibition for some time and the wonder of founders was how it held together. The author was informed that the secret lay in a heating device, so arranged as to keep the arms at a high temperature and to preserve the temperature close to that of the rim, as the latter was cooled off. The author would say that the feat was not achieved wholly by reason of extended heat, evolving greater graphite carbon in the arms. The element of stretching also assisted while keeping the arms hot, thus permitting the pulling power of the rim to extend them.

When we consider the difference that naturally exists in the contraction of light and heavy bodies, so clearly displayed in the test cited, pages 390 and 420, of a four by nine and one-half by two bar, it cannot but be evident that had the above wheel been left to cool off naturally, the arms would have pulled away from the rim. This founder's achievement involves a lesson not to be forgotten by any interested in the founding or designing of machinery.

The ignorance which prevails on the question of contraction is very often astonishing. It is only the fact that cast iron will stretch that saves many from having their ignorance on this subject exposed. There are many castings made that would not hold together were it not for the stretching property of cast iron. In this case, as in all else in mechanics, there is a limit to abuse, and it is not infrequent that we find this limit passed; but when it is, the iron founder is almost invariably held responsible for the results. When the casting cracks, the designer is the last man upon whom there is any suspicion of blame, when in reality he often is the one at fault.

This is not to be taken as relieving the founder of all responsibility in the question of cracked castings, etc. When the principles involved in the stretching and contraction of cast iron are understood, he can often, by methods of cooling and permitting freedom for contraction, do much to partly relieve disproportionate castings of internal strains, which, if they do not rupture a casting before it leaves the founder's door, may often do so after it has gone into use. It must be remembered that there is hardly a piece of machinery but has some part stretched, or held in strain, and if the latter is the case, we may often fear fracture or cracks, eventually causing injury to property and loss of life.

CHAPTER LVI.

UTILITY OF CHILL TESTS AND METHODS FOR TESTING HARDNESS.

In regard to the general utility of chill tests, some have believed that if a founder knew what an iron would "chill" in some test bars or block chills, he should be able to define what depth of chill any casting would have, no other qualities being known than that of the iron used and form of the casting.

There are numerous elements which affect the depth of chill in a casting, other than the chilling qualities of the iron used, which make it impracticable to say just what the depth of chill in a casting will be, from the depth of chill in a test bar or block. All we can do with a test bar or chill block is to get a relative knowledge of the natural chilling qualities of an iron. To illustrate this, I will state a few principles:

First. Any casting will show a deeper chilling by remaining in contact with its chill until all the metal in the casting has solidified or it becomes cold, than if the union of the casting or chill were broken before it had occurred.

Second. A hot-poured iron will remain longer in contact with a chill than a dull-poured iron, for as soon as the molten metal has solidified it commences to contract, and hence it must be plain to any one that the same grade of iron, if pulled away more quickly from a chill at one time than another, will give a different thickness of chill.

Third. The least difference in the grade of an iron causes a variation in its contraction, thereby causing one quality of iron to pull away from a side chill more than another.

Fourth. The thickness of chill used affects the depth of the chilling in the casting, up to the limit of the chill being affected, in suddenly extracting heat to counteract the carbon at the surface body of a casting being evolved into any graphitic carbon.

Fifth. The thickness of a casting affects the depth of a chill.

Sixth. Degrees of fluidity affect the chill. A hot-poured iron will chill deeper than a dull one. See page 373.

It is shown by the above that certain conditions have an effect in regulating the depth of a chill in castings, and that it is impossible for any one to tell what the exact " chill " will be in a casting by means of a chill test; but where one has had considerable experience with the special casting and takes into consideration all the elements in the case, he can closely draw his own deductions as to what depth of chill he may expect in the castings. To do this we must especially consider the thickness of our casting in connection with the iron used, also whether the casting will remain in contact with its chill mould, or pull away from it; also the fluidity of the metal with which a casting is poured. Further information on chilling is found on pages 258, 502 and 513.

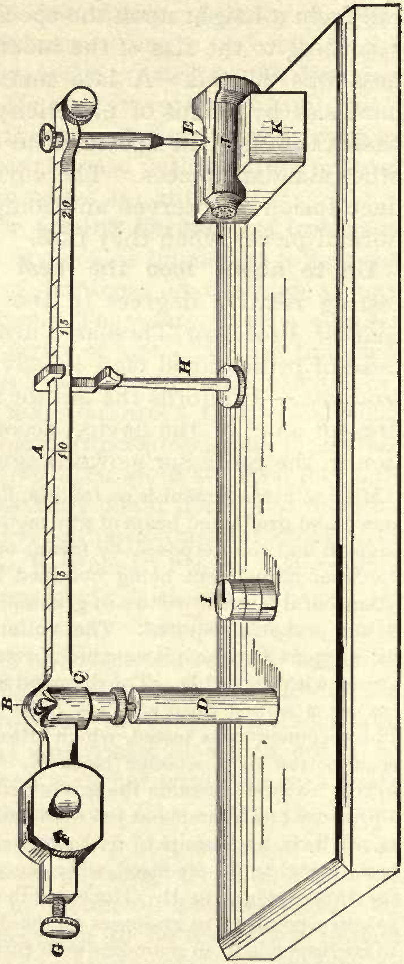
In reference to testing chilled iron, Mr. Asa W. Whitney, in a paper on "Chilled Iron," before the Philadelphia Foundrymen's Association, January 6, 1897, showed that the transverse strength, as well as the resilience of chilled iron, is the greatest in the direction of the chill crystals. He also shows that "tumbling" chilled or white iron is not as effective in increasing the strength of iron as is the case with medium or gray irons, qualities cited on pages 441 and 442.

Reliable methods for testing hardness of iron have long been needed. It is often as important to test the degree or character of hardness in castings as any other physical properties. There are quite a number of manufacturing industries of the character like chill roll founders, car wheel works, crushing machinery, die and brake shoe manufacturers, that could, had they but a good reliable hardness test, find it in time to be as important, if not often more so, than any tensile or transverse tests they could use. We have no physical test that has proven more unsatisfactory than that of obtaining the hardness of iron. However, improvements are being made as shown on pages 435 to 438 that may meet many requirements. Many plans have been used to ascertain the relative hardness of material. One, which was popular for a time, is said to have been proposed by Moh, and is classed under three heads: (1) Any material which could be scratched by a finger nail, (2) that scratched by a knife blade, (3) and that affected by a file. After the above came the weighted diamond point, followed by the punch struck with a given weight. The diamond point device was used by means of weights sliding on a lever, and as the specimen to be tested was moved the weighted diamond would trace a scratch or leave a cut the character of which recorded the hardness of the material. An apparatus was also used having an obtuse-angled hardened point which would fall from a height upon the specimen to be tested, and according to the size of the indentation made the hardness was defined. A late method is that of testing hardness by means of electricity, in which a current passes through the specimen to be tested and through other standard pieces. The current necessary to produce fusion is observed and compared with that of the normal pieces when they fuse.

Up to about 1900 the best device we had for testing relative degrees in the hardness of metals is that of Professor Thomas Turner, who stood at the head of professional men in advancing knowledge on iron, etc. It affords the author much pleasure to here present a cut of the device, accompanied by a description in the professor's own language:

> My first arrangement is as follows, Fig. 91: It consists of a balanced and graduated beam of gun metal A working on steel knife edges B and counterposed by means of a large sliding weight F, the final adjustment being obtained by the screw G. When balanced, it is sensitive to 0.01 gramme at E, though such delicacy is not probably required. The knife edges rest upon planes in the support C, which is capable of rotating on a steel pivot connected with the rod D. The diamond is mounted in a brass tube, having a milled head which is fixed by means of a screw at E. The specimen to be tested, which often takes the form shown, J, is supported by a wooden block K. The weight H is arranged so that each division on the graduated scale shall correspond to a pressure of a gramme at the diamond point. Thus, at division 12, we have a pressure of 12 grammes on the diamond. Three extra weights, I, are used when necessary. They are each of the same weight as H. Hence, with one weight, scale division 10 corresponds to 10 grammes on the diamond, with two weights 10 corresponds to 20 grammes, with three weights to 30 grammes, and with four weights to 40 grammes, the other scale divisions

being read in an exactly similar manner. It will be noticed that the specimen is stationary while the diamond is moved, thus differing from the sclerometer as applied to minerals; the method of supporting the beam and of applying the weight is also different. In ordinary experiments, where considerable weights are applied, the diamond may be moved by the finger, and as the apparatus is very steady in its actions, with a little care this gives very concordant results. For more delicate observations with smaller weights, the diamond may be drawn by means of a horizontal string running over a small pulley. The surface used is prepared roughly in the ordinary way by chipping, filing, etc., and then with a smooth file; it is finished with emery paper, using at last the finest variety, or flour emery, and oil, according to the material.



A. Beam.
B. Knife-edge.
C. Rotating Support.
D. Steel Rod and Pivot.
E. Diamond.
F. Sliding Weight.
G. Adjusting Screw.
H. Sliding Weight.
I. Extra Weights.
J. Test Piece.
K. Wooden Support.

FIG. 91.

It should be finished all one way, so as not to leave small, irregular scratches, and should be as smooth and bright as possible. As a rule, an experienced workman should not take more than half an hour in preparing such a specimen, although occasionally a hard material will take longer. If the surface tested be rough, the results are erroneous, being generally higher than with a good surface. It can, however, be told at once on inspection whether a surface is suitable for the purpose. If any doubt should exist, another smooth face must be prepared and the experiment continued until uniform results are obtained.

The following Table prepared by Professor Turner clearly presents the utility of his device and illustrates the thorough manner in which he completed his work. It has been thought by some inexperienced founders that there is no limit to silicon softening iron, but this is strongly refuted by the following Table 87 and sustains the author in statements made in other writings to the effect that silicon can harden as well as soften iron:

TABLE 87.—INFLUENCE OF SILICON ON THE HARDNESS AND TENACITY OF CAST IRON.

No.	Silicon per cent.	Tensile Strength.	Hardness.
1.	0.19	10.14 tons.	72
2.	0.45	12.31 "	52
3.	0.96	12.72 "	42
4.	1.96	15.70 "	22
5.	2.51	14.62 "	22
6.	2.96	12.23 "	22
7.	3.92	11.28 "	27
8.	4.75	10.16 "	32
9.	7.37	5.34 "	42
10.	9.80	4.75 "	57

WORKING QUALITIES.

1.—Very hard indeed.
2.—Very hard, though not so hard as No. 1.
3.—Hard, though softer than No. 2.
4.—Good, sound, ordinary, soft-cutting iron, of excellent quality.
5.—Rather harder than No. 4.
6.—Like No. 4.
7.—Like No. 6, but rather harder.
8.—Rather harder than No. 7, though not unusually hard.
9.—Still harder, cutting very like No. 10.
10.—Hard-cutting iron, though still softer than No. 1.

There have been several other machines designed for testing hardness since Professor Turner perfected his machine. One is a design by Mr. W. J. Keep, being an improvement on one designed by the late Mr. C. A. Bauer, M. E., and which was presented at the New York meeting of the American Society of Mechanical Engineers, December, 1900, and also described in the *American Machinist*, February 28, 1901. Fig. 53 shows an ordinary drill press which was fitted up by the author to test the hardness of metals, and which worked very satisfactorily for the class of testing it was intended for. A full description of this machine is given on pages 234 and 238.

CHAPTER LVII.

UTILITY OF TRANSVERSE, CRUSHING, IMPACT AND SHOCK TESTS.

The tests called for in our engineering and other scientific text books include transverse, tensile and crushing strength, a few giving impact. Of all these, none can surpass in value for general use the transverse test, with its accompaniment of "deflection" for foundry practice, simply because castings are chiefly subjected to such strains. The utility of tensile tests will be found discussed on page 449. The quality of cast iron to withstand crushing loads is also one often of much importance to the engineer and founder. The values found by the author from which the relation between crushing and tensile strength may be deduced lead him to affirm that the elements constituting a test in transverse, deflection and chill are, for general purposes, largely a good index as to the crushing strength. An iron having a high transverse strength combined with small deflection should prove the best to withstand crushing loads.

Impact tests on the side of bars are of little practical value in assisting to determine what castings can stand in shocks or blows.* If there is any form of tests with test bars, to demonstrate the power of iron to withstand shocks or blows, there is much more

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* This has reference to striking test bars until they break, and not to such tests as are outlined on the next two pages.

practical sense exhibited in looking to high transverse and deflection combined with a low contraction, than to impact blows on the side of a test bar. A practical way to apply an impact test is to the castings themselves. The car wheel men teach a lesson in this respect. Here we find that some select from a large stock one wheel out of every hundred, and if by dropping a 140-pound weight on the hubs of the sample wheels from a height of 12 feet the sample wheels stand five blows each, all the other wheels are then accepted, providing they have stood the thermal test described on page 443, and which shows, in connection with the above impact tests, the absurdity of thinking to be guided by impact blows on the side of test bars.

The power of castings to withstand shocks or blows is often far more affected by their proportion or design than by the quality of iron composing them. There is altogether too much indifference exhibited by designers of machinery in proportioning castings so as to have the least possible internal contraction strain in them. Some designers seem to ignore wholly the fact that a light body will contract more than a heavy one. Many castings have been made, the iron in which would test all right as far as test bars were concerned, but subjecting them to shocks or blows, would imply that the iron was not of the right character. This again illustrates the impracticability of some impact tests on bars and shows that a weak, high-contraction iron can often be of much more value in a well-proportioned casting than the reverse kind of iron in an ill-proportioned one.

A. E. Outerbridge's shock tests form an interesting study in this connection. In these tests, Mr. Outerbridge found that shocks or light blows delivered on test bars increased their strength, and therefore illustrate the benefits to be derived by the gradual increase of severity in shocks to strengthen castings, such as guns which are subjected to great strains from sudden jars or blows to the metal comprising their bodies. They also show wherein many castings long in use can have their durability increased, becoming really better than new castings.

These tests were made by means of twelve companion test bars that had been moulded in one flask and cast with the same gate and ladle of iron. Six of these test bars were subjected to shocks by reason of tumbling in a "tumbling barrel," and in other cases the shocks were transmitted to the test bars by means of tapping them on their ends with a hand hammer. The six bars not receiving shocks in any manner were invariably found the weakest. The bars receiving the shocks were shown by a large number of tests made by Mr. Outerbridge to have been increased in strength from ten to fifteen per cent. and the largest gain, in a few instances, was found to be about 19 per cent. The bars tested were one and one-eighth inch round, and also square bars of one inch section, both fifteen inches long. Mr. Outerbridge says the crucial test was in subjecting six bars to 3,000 taps each with a hand hammer upon one end only of each bar. The tumbling barrel process of giving shocks to bars continued for about four hours. The publication of Mr. Outerbridge's discoveries by trade papers has led many founders to experiment in testing his deductions, and all have found them to be true, some even exceeding the strength obtained by Mr. Outerbridge.

One case which has come to the writer's knowledge showed a gain of 29 per cent. by reason of tumbling test bars. For results with chilled bars, see page 434.

Mr. Outerbridge was led to demonstrate that shocks could increase the strength of cast iron by first observing that chilled car wheels rarely cracked in ordinary service, after having been used for a considerable length of time. He says if they did not crack when comparatively new, they usually lasted until worn out or condemned for other causes. Mr. Outerbridge found that, up to the point of the shock relieving the internal strains by permitting the individual metallic particles to re-arrange themselves and assume a new condition of molecular equilibrium, any further shock did not increase the strength. He does not say this would injure it, and, in speaking of a few practical deductions for universal application to be drawn from his tests and observation, he says: "Castings such as hammer frames, housings for rolls, cast iron mortars or guns, which are to be subjected to severe blows or strains in actual use, should never be tested to anything approaching the severity of intended service." Mr. Outerbridge's discovery is a valuable one, and can find practical application in many ways, especially in showing the light-work founder that "tumbling" castings is beneficial; but that it is best, when practical, where there are any fears of castings being broken, to start slowly and gradually increase the speed to the limit generally practiced when "tumbling."*

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* The paper giving all the tests, etc., was originally presented at the meeting of the American Institute of Mining Engineers, in Pittsburg, Pa., February, 1896, and can be found in its proceedings of that year.

METHODS FOR TESTING CAR WHEELS.

The Master Car Builders' Association requires that wheels should run for a period of forty-eight months in regular service. Before they are removed from the foundry they are subjected to a thermal and drop test, for which purpose two wheels are selected by an inspector from every lot of one hundred. We cannot better describe the methods of such testing than by an extract of Mr. G. W. Beebe's paper in which he cited the C. B. & Q. Ry. testing specifications, etc., before the Western Railway Club, and published in the *Iron Trade Review* of October 2, 1900.

"**In making a thermal test,** the test wheel (see Fig. 92) must be laid down in the sand and a channelway 1⅛ inches wide and 4 inches deep moulded with green sand around the wheel. The clean tread of the wheel should form one side of the channelway and the clear flange the bottom. (It will be noted that the width of the channelway is equal to the height of the flange, namely 1⅛ inches.) The channelway must be filled to the top with molten cast iron, which should be poured with two ladles directly into the channelway. The molten iron must be taken from the big ladle directly after a tap for pouring the wheels has been drawn from the cupola. The channelway must be filled with the molten iron in no greater time than one minute after the iron has been taken from the big ladle. No puddling or cooling of the iron will be allowed. If the molten iron boils in the ladles they must be refilled until all indications of boiling cease, before the channelway is filled. The time when the pouring ceases must be noted, and two minutes later an examination made, and if the wheel is found cracked in the plates or through the thread the wheels represented by the test wheel will be rejected. Wheels that are wet or have been exposed to the frost may be warmed sufficiently to dry or remove frost before testing. At the option of the manufacturer, if the test wheel fails under this thermal test, a second wheel showing the next lower contraction size to the wheel which failed, and cast on the same date as the rejected wheel, may be selected by the inspector and tested. If the second wheel stands the thermal test, all wheels of the same, and all lower contraction sizes, may be accepted; while the wheels of the same and higher contraction as the first wheel must be rejected."

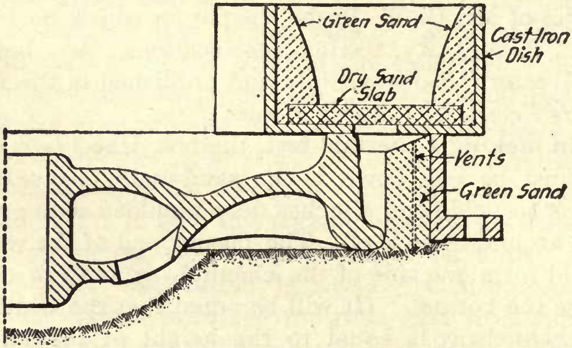

FIG. 92.—METHOD OF POURING FOR HEAT TEST, C. B. & Q. R. R.

"**The contraction allowed** on a cast iron wheel is ½ inch — ¼ inch above and ¼ inch below the mean circumference, divided into four tape sizes of ⅛ inch. The tape No. 1, or highest contraction, represents the weaker wheels, conditions being normal. The inspector being aware of this, almost invariably selects tape

No. 1, or highest contraction number, for the test. If tape No. 1 fails when in the thermal test, reject such, and allow the inspector to select one of tape No. 2, or next lower contraction number; and if the second wheel fails reject all of the wheels represented. Providing, however, the second wheel stands the thermal test, it seems hardly fair to the manufacturer to condemn the second and lower shrinkage numbers, the inspector being satisfied by the test on the second tape sizes that they are sufficiently strong and are hard enough to give the wear. An inspector should make a study of iron, so that he can readily designate at a glance whether the first wheel failing could be attributed to bad iron or abnormal conditions in the pitting or handling of the rejected wheel. A wheel can be made of a hard close grain iron that will stand the drop test or concussion in service, but if subjected to a severe and continued brake application is liable, as boys say, "to go up in smoke." A gritty, hard chill will not make the mileage that a tough chilled wheel will. A gritty chill will shell out quicker than a tough one, because it will not stand the heat that is caused by severe brake application. Good white iron is tough, as well as being hard enough. There is as great a difference in the quality of white iron as there is in gray iron; bad white iron has a large proportion of sulphur. I believe the steel-tired wheel proves that the toughness give the wear. I have not seen or heard of a steel-tired wheel shelling out. I have heard some railroad men say that when they can cut the chill of a wheel with a chisel, the wheel will not make good mileage. If this is the case the steel wheel could not make the mileage that is claimed for it, because the steel-tired wheel is turned before being put into service, and it certainly must be soft in order that it can be turned. These hard, gritty wheels will fail in the thermal test, or by severe brake application. Regarding the depth of chill, it should not exceed ¾ inch in the throat, or 15-16 inch in the center of the tread. The minimum should not be less than ¼ inch in the throat, or ⅜ inch in the center of the tread. Assuming that we have the maximum depth of chill — 15-16 inch — we get the blending of the white iron through the entire tread, and begin to crowd the danger line and gain nothing, as the highly chilled wheel will shell out and become capable of sliding more readily than a medium chilled wheel. In breaking up three hundred defective wheels that were removed on account of shelled spots, 95 per cent. showed a high chill.

"**The design of a pattern** is one of the essential factors in the manufacture of the cast wheel, other than the thickness of flange, shape of hub, and tread. The designing of the pattern should be left to the discretion of the manufacturer. A large percentage of wheels that fail in the brackets can be ascribed to a poorly designed pattern; too light brackets will crack because they cool more rapidly than the plate of the wheel, which would cause a strain on them; too heavy a bracket will throw the strain on the plates, causing the plates to crack. For those who are not familiar with the drop test used in testing wheels, Fig. 93 gives an illustration of the Barr drop, and Fig. 94 the M. C. B. drop. It will be noted that the hammer of the Barr drop strikes the single plate of the wheel (see letter A on Fig. 93). The hammer of the M. C. B. drop strikes the hub of the wheel (see letter A on Fig.

94). A wheel rarely fails in service in the hub, double plates, or at the intersection of the plates (see letters A, B, and C on Fig. 94). If a crack does occur at these points it does not necessarily cause the wheel to become dangerous. If a crack occurs in the single plate (see letter A on Fig. 93), we then have a dangerous wheel, and it will not run long before giving way entirely. It will also be noted that wheels tested under the M. C. B. drop are placed flange downward on an anvil block, having three supports for the flange of the wheel to rest upon. The hammer strikes the central part or hub and the whole of the wheel resists the concussion, while the wheels tested under the Barr drop are placed flange downward on a flat surface anvil block and the wheel receives the concussion at one point only. The Chicago, Burlington & Quincy specifications require wheels tested under the Barr drop to stand fifty blows

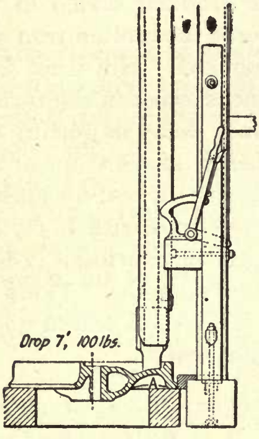

FIG. 93.—BARR DROP TESTING MACHINE.

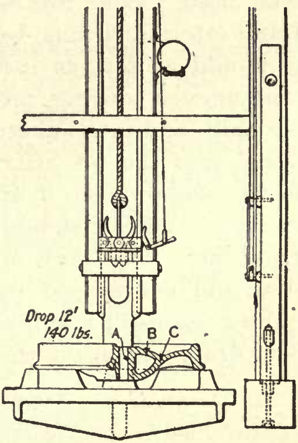

FIG. 94.—M. C. B. DROP TESTING MACHINE.

without breaking out a piece. The Pennsylvania Railroad specifications, I believe, require wheels tested to stand twelve blows under the M. C. B. drop without breaking out a piece. It would seem fair to assume that the Barr drop would find the weak or dangerous part of the wheel more readily than the M. C. B. drop. The treatment and handling of the hot wheel has nearly as much to do with the strength as has the material used. Cold iron will produce seams in the tread and internal strains, because the molten iron sets in the mould as fast as it is poured. Hot iron, with slow and uneven pouring, produces sweat in the throat, uneven chill, and internal strains; delay in getting the hot wheel into the pit after being shaken out of the mould will also produce strains in the wheel by uneven contraction. Wheels should be poured with fairly hot irons and fast. The limit of time in pouring a 33-inch wheel should not exceed twelve seconds. Table 88 gives the analysis of a number of wheels tested under the Barr drop, and in the thermal test:"

TABLE 88.

	Wheels that failed in thermal test.		Wheels that stood thermal test.		Wheels that failed under 50 blows, Barr drop.		Wheels that stood 50 blows and over, Barr drop.	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
Total carbon	3.91	3.63	3.90	3.38	3.87	3.42	3.93	3.49
Graphitic carbon	3.02	2.92	2.98	2.71	3.19	2.90	3.02	2.90
Combined carbon	.89	.71	.92	.67	.68	.52	.91	.59
Sulphur	.090	.042	.10	.080	.080	.020	.070	.05
Manganese	.60	.49	.58	.48	.62	.40	.72	.47
Silicon	.82	.50	.91	.50	.97	.67	1.10	.68
Phosphorus	.48	.39	.52	.26	.58	.30	.53	.28

A part of the wheels failing under these tests cannot be ascribed to the composition.

CHAPTER LVIII.

ACHIEVING UNIFORM RECORDS, AND UTILITY OF TENSILE TESTS.

Any research to discover uniformity between tensile and transverse tests, up to about 1895, shows that one plan of testing gave very different results than some others, and only bewilders instead of assuring an investigator that he has obtained any knowledge of the iron's true strength. There is no reason why the same iron should show such erratic records as have been evinced up to 1895, between tensile and transverse tests, that can be charged to the iron proper.

When evils due to casting test bars flat are considered as proven in Chapter LXV., one great cause for the wide difference recorded in the past is clearly displayed. How is it possible to expect other than erratic and unreliable records, when the fact of a flat-cast one-inch-area test bar being 200 to 400 pounds stronger on one side than the other is considered? Any one giving thought to this subject cannot but perceive the unreliable records which casting flat must cause, and become convinced that the plan of casting on end far surpasses past methods, in order to insure uniformity between tensile and transverse or either tests taken from bars cast off from the same ladle.

For foundry and engineering purposes it can be said that tensile tests are often valuable for comparative tests. With a standard length of a bar for transverse strength and one of equal area for tensile testing of the round form, not exceeding 1½ inches diameter and cast by the system advocated by the author, a study on comparisons leads him to say that transverse and tensile tests will be found to bear a very close relation to each other, and prove that the tensile test may, for some purposes, be of as much benefit for a comparative test as are transverse tests.

When test bars exceed one and one-half inch diameter the transverse and tensile strength tests commence to diverge radically in opposite directions, the tensile strength decreasing in strength per square inch while the transverse increases, a point more fully explained in Chapter LXX., page 571. With bars under 1½ inches diameter the tensile strength will closely average ten times the strength of transverse tests, in like areas.

One difficulty in obtaining tensile strength often lies in the method of obtaining them. Some machines can take such a rigid grip as to exert a strain on some portion of the specimen, instead of permitting the test bar to adjust itself centrally so as to insure a uniform pull over its entire breaking area. Cast iron requires different treatment to insure a uniform pull than steel or wrought iron, but with the use of specially designed test bars permitting a good area for gripping, or having shoulders cast on each end with holes in them at cross angles to each end whereby pins can be inserted to allow a specimen to adjust itself centrally to its load, very accurate tests may be obtained. Tensile, like transverse tests, can only be comparative in the same area or size of test bars, see page 528.

CHAPTER LIX.

CONTRACTION vs. STRENGTH OF CAST IRON.*

As to indicating unfitness of a test bar to record contraction of cast iron, when it has been proved of no value to record strength, experiments which the author has often conducted have demonstrated that the percentage of combined or graphitic carbon in a light casting or small test bar can often be regulated as much by varying conditions in the physical qualities of the mould as by varying percentages in the elements of sulphur, silicon, manganese, phosphorus, etc., generally contained in foundry pig metal. We will first consider the physical qualities which can affect the strength of an iron, according to the size of a casting or test bar, and which is chiefly (aside from the "iron") dependent upon the state of the carbon, whether it is in the combined or graphitic form. See page 206.

Believing from the results of previous experiments and every-day experience that if the corners and the central portion of square test bars were analyzed, a difference would be found existing in their percentage of combined or graphitic carbon; also that the combined carbon would be less in a one-inch square bar than in a one-half-inch square bar, both poured from the

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* Extract from a paper read before the Foundrymen's Association, Philadelphia, Pa., September 4. 1895.

same iron and gate, I forwarded the specimens of which the analyses are herewith given to the late C. A. Bauer, M. E., general manager of Warder, Bushnell & Glessner Co., Springfield, O., who had his son, Charles L. Bauer, a chemist, make the determinations shown in the following paragraphs:

The specimens were one-half inch square, one inch square and one and one-eighth inch round bars, belonging respectively to light machinery and chill roll iron tests, which were among those reported in my paper before the Western Foundrymen's Association, October 18, 1894, seen on pages 461 and 464. Paragraph No. 1 gives the combined carbon at the corners and center surface of the fracture of the one-inch square bars in the chill roll and light machinery mixtures.

Paragraph No. 2 is a report of the sulphur contents of the center of the bars shown in paragraph 1 and also that of the one-half inch square and one and one-eighth inch round bars shown in paragraph 3, which were poured with the same gate and iron as those in paragraph 1.

Paragraph No. 3 shows the difference in combined carbon existing in the center of the one-half inch square, one inch square and one and one-eighth inch round bars described in paragraphs Nos. 1 and 2.

DETERMINATION No. 1.—Combined carbon in chill roll iron: At the corners, 1.55 per cent., at the center of the fracture, 1.416 per cent., or .134 per cent. more combined carbon in the corners than in the middle of the test bars. In light machinery iron: At the corners, .72 per cent.; at the center, .65 per cent.; or .07 per cent. more combined carbon in the corners than in the center of the fracture.

DETERMINATION No. 2.—Sulphur in chill roll iron: At the center of fracture in one-half inch square, .046 per cent.; one inch square, .044 per cent.; one and one-eighth inch round, .046 per cent. In light machinery iron: At the center of fracture in one-half inch square bar, .0819 per cent.; one inch square, .079 per cent.; one and one-eighth round, .0825 per cent. Mr. Bauer writes that the difference in sulphur at the center and the corners of the different bars is not perceptible.

DETERMINATION No. 3.—Combined carbon in chill roll iron: In one-half inch square, 2.700 per cent.; one inch square, 1.416 per cent.; one and one-eighth inch round, 1.250 per cent. Difference in the extreme of the combined carbon in the one-half inch square and one and one-eighth inch round bar, 1.450 per cent. In light machinery iron: In one-half inch square, .854 per cent.; one-inch square, .650 per cent.; one and one-eighth inch round, .704 per cent. Difference in extremes, .204 per cent. of the combined carbon in the one-half inch and one and one-eighth inch round test bars at their center of fracture. The silicon in the light machinery is 1.83 per cent.; in the chill roll, .71 per cent.

The percentage of combined carbon and "iron" in a casting, etc., chiefly controls the strength of the iron and also its contraction. The percentages of sulphur, silicon, manganese and phosphorus in cast iron are but factors in connection with the time it takes a test bar or casting to solidify and become cold, determining the degree to which the carbon takes the combined form.

The above analyses plainly prove that a slight difference in the fluidity of metal, or dampness in the "temper" of sands, as commonly used in ordinary foundry practice, can cause a radical difference in the percentage of combined carbon, in the same size and form of small castings or test bars from the same mixture of iron, poured out of the same ladle. The determinations Nos. 1, 2, and 3 also indicate the necessity of adopting, for physical tests, the size and form of test bar least liable to irregularities in the combined carbon composing its shell or outer body, caused by varying conditions in the "temper" of sands and fluidity of metals, etc. As degrees in the strength of iron can be affected by the "temper" of sand and fluidity of metal at the moment it is poured, so can contraction records be likewise affected, making them deceptive. Experiments which I have conducted to discover if the same conditions which give erratic results in strength records would not do likewise in contraction, have only the more confirmed me in the advocacy of bars over one square inch in area, wherever one desires to be wholly or partially guided by physical tests.

To learn whether differences in the temper of sands could cause changes in the length of contraction in small bars of the same size, cast in the same mould with the same iron, out of the same ladle, and at the same moment, I took three patterns ½ inch square and 12 inches long, and cast two of them between yokes and a third bar in a divided chill to form two sides and bottom of the mould, the fourth side being formed by the sand of the cope. The two bars cast between yokes had drier sand for one than for the other. The dampest sand was not so damp but that a sound casting could be produced, and the two sands differed no more than can often be found between the "temper" of sands in one shop. All three bars were placed equidistant in the mould and gated by means of two upright "sprues" which led down to a runner in the cope extending over the three bars in the center, insuring the filling of the three moulds at the same time with the same hand ladle of iron. The test bars formed in the chill and dampest sand showed a greater contraction than the ones enclosed in the driest sand. I have conducted quite a number of these tests and always found in them the same results, those cast in the chill showing the greater contraction. In several cases, the extremes of one flask gave a full one-sixteenth inch difference in the contraction of the three bars. In the extremes between the "temper" of the wetter and drier sand, I have found a difference of fully one thirty-second part of an inch to exist in the contraction of two one-half inch bars poured from the same hand ladle at the same moment, thereby proving that a test bar as small as one-half inch square or round is altogether too sensitive to variation in the "temper" of moulding sand to be relied upon to afford any true knowledge of the natural contraction of an iron.

To discover what effect, if any, degrees in dampness or "temper" of sand have on a round bar cast on end, I took a pattern one and one-eighth inch in diameter and made a dry sand mould, using a piece of six-inch gas pipe to mould it in, leaving both ends open. After this little mould was dried in an oven, it was set on end upon a planed plate and the distance equally divided between two empty gas pipes. Each of these two latter pipes was then rammed up with "green sand" of a different temper. Each test bar had a projection cast on the upper end exactly two feet from the bottom of the mould, which was formed by the bottom plate to measure contraction by. The three bars were poured by one runner in the center of the three moulds, the iron dropping from the top. I made these three bars two feet long, so as to give a greater length than was in the one foot long by one-half inch square bars, to better detect any difference that might exist in the contraction of the bars due to variation in the "temper" of the sand. When these bars were measured, no difference could be found in their contraction—a further proof of the necessity of using a bar larger than one-half inch square or round to show the true contraction of an iron. I also made tests with one and one-eighth inch round bars cast flat, but did not find that the radical variation which existed in the "temper" of the sand made any difference in the length of their contraction. Previous to these tests, I also made some in our foundry in the presence of E. Duque Estrada, M. E., of Pittsburg, a member of the American Society of Mechanical Engineers' Testing Committee, to learn whether degrees in fluidity of iron would affect the contraction of large-sized test bars or thick castings. To test this point, two bars two inches square and forty-eight inches long were moulded together in the same mould. One was poured with the metal as "hot" as could be obtained from the cupola, and the other with the same ladle cooled down to pour the metal as "dull" as possible and still obtain a full-run bar. Two sets of these experiments were made, but no difference was found in their contraction. The fact of there being no visible difference in the contraction of the two-inch square bars cast flat, also the one and one-eighth inch round bar cast flat and on end, was dueto the body of the test bars being sufficiently massive to overcome any tendency which variations in the fluidity of metal or dampness of the sand could exert in causing a difference in the combined carbon. With large-sized test bars, properly cast, having no corners to be affected by the "temper" of sands and fluidity of metal, contrary to the conditions seen in a square or small test bar, we are justified in placing the utmost confidence in the record which they may present. And were it not that in accepting castings there is generally a large margin permitting the founder to often greatly disregard obtaining the best possible physical properties of the iron in his castings, the error of using bars as small as one-half inch square or below one square inch area would have been clearly demonstrated long before this. (See pages 454, 467, 484, 511 and 573.)

CHAPTER LX.

COMPARISONS OF STRENGTH IN SPECIALTY MIXTURES.*

This chapter is a revised extract from a report of the author's labors as a member of the Western Foundrymen's Association Testing Committee, and presents a series taken from about one hundred tests which he personally obtained, of irons such as are used for gun metal, chill rolls, car wheels, heavy machinery, light machinery, stove plates and sash weights, a list which can be seen to cover very nearly all mixtures or "grades" necessary to cast iron founding.

Each founder in casting a set of these test bars from the patterns which the author furnished made three one-half inch square, three one inch square, three one and one-eighth inch in the rough, and three one and one-eighth inch turned. These one and one-eighth inch round bars in the rough and turned are of an area as nearly equal to one square inch as it is practical to make them. The turned bars were cast with a swell on so as to measure about one and five-eighth inches in diameter for about four inches of their length in the center. This swell was turned down until the bars measured close to the size of their companion, one and one-eighth rough bars. The comparison between

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* Read at the meeting of the Western Foundrymen's Association, at Chicago, Wednesday evening, Oct. 24, 1894.

the rough round and the turned bar enables us to perceive the difference that may exist between the strength of the iron with its surface affected by the walls of a green sand mould and that of iron having its rough surface turned off.

It was first planned to have all these test bars cast on end, so as to afford the most favorable conditions to insure solid bars, etc., but in starting with car wheel mixtures, difficulty was found in getting the half-inch square test bars to "run," and as there were other strong irons I desired tests from, I had, on account of the one-half bars, to change the plan of casting and had all bars cast flat. The three test bars from each of the four sizes were cast all in one flask, poured from the same gate, and out of the same ladle.

These test bars were cast by some of the most prominent foundry specialists in this country. They are not a crucible melt of estimated mixtures or of a special heat, but are taken from "regular heats" "run" for making castings in the specialties herein mentioned, therefore represent the strength of the actual metal used in actual practice for the manufacture of the castings outlined as far as is practical with bars cast flat.* A complete chemical analysis of the various mixtures obtained in the tests shown in this Chapter can be seen on page 299. The analyses were all taken from the rough bars shown in the respective Tables.

The micrometer measurements given in the following tables are the average of dimensions taken from the four sides of the square and round bars and hence give the size of the test specimen in the thousandth part of an inch. The common rule measurements give the size as closely as it is practical to roughly

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*Views of the fractures of these various irons are seen in Figs. 95 to 102, at the close of this chapter.

state the dimensions. All the bars were cast 15 inches long and in breaking them for transverse strength they rested on pointed supports, 12 inches centers. The last two columns in the Tables give the computed relative strength. The outside column is used only for the half-inch square bars, so as to illustrate two methods of figuring, and is obtained by multiplying the breaking load by eight, a method advanced by some, for one-half-inch bars.* The inner is obtained by the rules shown in Chapter LXI., page 476. The area of a bar 1.1284 inch in diameter is equal to the area of one inch square; by keeping this in mind the figures in the micrometer columns can have their relation to a square inch readily defined.

TABLE 89.—TRANSVERSE TESTS OF GUN METAL.

No. Test.	Common rule measurement.	Microm't'r measurement.	Deflection.	Broke at in pounds.	Strength per square inch in pounds.	
	Rough bars.					
1	½ in. square.........	.491 in.	.120 in.	376	1,560	3,008
2	“ “	.501 “	.115 “	420	1,673	3,360
	Planed bars.					
3	½ in. square.........	.491 in.	.250 in.	384	1,593	3,072
4	“ “	.495 “	.270 “	360	1,469	2,880
5	“ “	.494 “	.200 “	316	1,295	2,582
	Rough bars.					
6	1 in. square...........	1.002 in.	.090 in.	3,500	3,486	......
7	“ “	.996 “	.085 “	3,380	3,400	......
8	“ “	1 044 “	.095 “	3,428	3,145	......
	Planed bars.					
9	1 in. square...........	1.007 in.	.130 in.	3,140	3,096	......
10	“ “	1.005 “	.120 “	3,095	3,064	......
11	“ “	1.005 “	.110 “	3,072	3,042	......
	Rough bar.					
12	1⅛ in. diam...........	1 132 in.	.125 in.	3,708	3,686	......
	Turned bar.					
13	1⅛ in. diam.	1.139 in.	.150 in.	3,320	3,258	......

Test bars, Table 44, were furnished by Builders' Iron Foundry, Providence, R. I. Tested by Thomas D. West, at the works of the T. D. West Foundry Co, Sharpsville, Pa., Sept. 18th, 1894. Witnesses, Geo. H. Boyd and G. M. McIlvain.

The first series of tests we will present is that recording the strongest mixture, seen in Table 89; the

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* By a study of Chapter LXI., it will be seen that the inner column referred to above is obtained by a rule that cannot be recommended for ½-inch bars; and while that used for the outside column is preferable, it would be still more satisfactory if it were known that the ½-inch bars did never vary from the size of their pattern—something which it is not practical to expect

second, the next best in strength, and so on, the last Table being the weakest iron.

The test of the gun metal, Table 89, page 460, showed the planed bars of a very coarse grain partaking of a fibrous nature, somewhat after a good grade of wrought iron, having a fracture of a dark color. The metal of the rough bars showed the fracture in the one-half-inch square bar to be strictly white and in the one-inch square test bars to be of a crystalline mottled nature, and in the rough one and one-eighth inch diameter bars of a similar character, but to a little less degree than shown in the one-inch square bars. The large open-grained bars, or those of numbers 3, 4, 5, 9, 10 and 11, illustrated in Table 89, were planed from the muzzle disc of a 12-inch mortar casting, and bars 1, 2, 6, 7, 8, 12 and 13 were cast with metal which was used to pour a lower base ring for a 12-inch spring return mortar carriage. The charge of iron for the mortar was very much harder than that used for the base ring, but as it was cast in a very

TABLE 90.—TRANSVERSE TESTS OF CHILL ROLL IRON.

No. Test.	Common rule measurement.	Microm't'r measurement.	Deflection.	Broke at in pounds.	Strength per square inch in pounds.
	Rough bars.				
14	½ in. square.........	.509 in.	.120 in.	230	888 1,840
15	" "	.518 "	.150 "	300	1,119 2,400
	Rough bar.				
16	1 in. square..... ...	1.032 in.	.120 in.	2,590	2,432 ......
	Rough bar.				
17	1⅛ in. diam..........	1.140 in	.150 in.	3,040	2,980 ......
	Turned bar.				
18	1⅛ in. diam..........	1.124 in.	.190 in.	3,020	3,044 ......

Test bars furnished by Lewis Foundry & Machine Co., Pittsburg, Pa. Tested at the works of McConway & Torley, Pittsburg, Pa., June 27th, 1894, by J. B. Nau, Allegheny, Pa. Witnessed by R. G. G. Moldenke, E. M , Ph. D.

large mass and cooled very slowly it is not surprising that the fracture shows the iron in the mortar body to be much softer (or open-grained) than that in the test bars from the base ring. The tensile strength of the two specimens taken for acceptance of the 12-inch return mortar or lower base casting as above described was as follows:

No. 1 . . . 37,100 lbs. No. 2 . . . 37,000 lbs.

TABLE 91.—TRANSVERSE TESTS OF CAR-WHEEL IRON.

No. Test.	Common rule measurement.	Microm't'r measurement.	Deflection.	Broke at in pounds.	Strength per square inch in pounds.
	Rough bars.				
19	½ in. square.........	.474 in.	.090 in.	273	1,213 2,184
20	" "	.496 "	.090 "	280	1,138 2,240
21	" "	.491 "	.090 "	278	1,158 2,224
	Rough bars.				
22	1 in. square..........	1.012 in.	.075 in.	2,535	2,476 ......
23	" "	1.022 "	.074 "	2,415	2,313 ......
24	" "	1.007 "	.075 "	2,294	2,262 ......
	Rough bars.				
25	1⅛ in. diam.	1.090 in.	.111 in.	2,340	2,508 ......
26	" "	1.072 "	.100 "	2,360	2,615 ......
27	" "	1.135 "	.100 "	2,568	2,538 ......
	Turned bar.				
28	1⅛ in. diam..........	1.174 in.	.170 in.	3,050	2,819 ......

Test bars furnished by A. Whitney & Sons, Philadelphia, Pa. Tested by John R. Matlock, Jr., at the works of Riehle Bros.' Testing Machine Co., Philadelphia, Pa., June 27th, 1894. Witness, W. C. Cutler.

In the chill roll iron, Table 90, page 461, a few of the pieces were selected after having been broken for transverse strength and pulled for the tensile strength. Bar No. 15 pulled 6,100 pounds; No. 16 pulled 23,700 pounds; and No. 17 pulled 30,100 pounds. The iron in the half-inch bars showed a white crystalline fracture, likewise the one-inch square. The one and one-eighth inch diameter rough bars showed a very close knit grain tending to a light color. The one and one-eighth inch turned bars are also very close grained, a little darker in color than the one and one-eighth inch bars, but both of the latter exhibit to an expert the appearance of great strength as being of exceptionally strong metal.

The iron in the car wheel, Table 91, page 462, shows the half-inch bars to be white and crystalline. In the one-inch square bar the iron is mottled, tending to white. In the one and one-eighth inch round rough bars the metal is more evenly mottled and less white than in the one-inch square. The one and one-eighth inch round turned bars show a very rich dark gray color. Bar No. 26 pulled tensile 23,270. This mixture proved to be an excellent iron.

TABLE 92.—TRANSVERSE TESTS OF HEAVY MACHINERY IRON.

No. Test.	Common rule measurement.	Microm't'r measurement.	Deflection.	Broke at in pounds.	Strength per square inch in pounds.
	Rough bars.				
29	½ in. square.........	.504 in.	.195 in.	380	1,496 3,040
30	" "	.503 "	.220 "	432	1,707 3 456
31	" "	.504 "	.185 "	372	1,465 2.976
	Rough bars.				
32	1 in. square...........	1 004 in.	.100 in.	2,464	2,444 ......
33	" "	1.009 "	.090 "	2,510	2,465 ......
34	" "	1.007 "	.100 "	2,640	2,604 ......
	Rough bars.				
35	1⅛ in. diam..........	1.137 in.	.100 in.	2,786	2,745 ......
36	" "	1.135 "	.120 "	2,824	2,791 ......
37	" "	1.143 "	.100 "	2,500	2,437 ......
	Turned bars.				
38	1⅛ in. diam..........	1.125 in.	.120 in.	2,257	2,271 ......
39	" "	1.125 "	.150 "	2,488	2,503 ......
40	" "	1.124 "	.140 "	2,344	2,363 ......

Test bars furnished by the Walker Manufacturing Company, of Cleveland, Ohio. Tested by Thomas D. West, at the T. D. West Foundry Co., Sept. 18th, 1894. Witnesses, Geo. H. Boyd and G. M. McIlvain.

The iron in the above half-inch test bars presents a very close, compact grain, tending to white. The one-inch square bars show a close, dense fracture, tending to a light gray color. The one and one-eighth inch round bars are less dense and present more of a dark gray color than the one-inch square bars. The turned bars show a fine, rich-colored, compact iron, such as would stand exceptional wear and resistance to fracture. Bar No. 34 pulled 26,160 pounds, and No. 35, 28,676 pounds. For medium to heavy machinery, this metal should make a most serviceable casting.

TABLE 93.—TRANSVERSE TESTS OF LIGHT MACHINERY IRON.

No. Test.	Common rule measurement.	Microm't'r measurement.	Deflection.	Broke at in pounds.	Strength per square inch in pounds.
	Rough bar.				
41	½ in. square.........	.499 in.	.2·0 in.	454	1,823 3,632
	Rough bars.				
42	1 in. square...........	1.016 in.	.130 in.	1,710	1,657 ......
43	" "	1.021 "	.125 "	1,760	1,688 ......
44	" "	1.008 "	.115 "	1,800	1,771 ......
	Rough bars.				
45	1⅛ in. diam.........	1.146 in.	.160 in.	1,795	1,741 ......
46	" "	1.156 "	.180 "	2,220	2,115 ......
47	" "	1.141 "	.180 "	1,980	1,938 ......
	Turned bars.				
48	1⅛ in. diam..........	1.162 in.	.200 in.	1,705	1,609 ......
49	" "	1 160 "	.210 "	1,720	1,628 ......
50	" "	1.175 "	.210 "	1,775	1,637 ......

Test bars furnished by Taylor, Wilson & Co , Ltd., Allegheny, Pa. Tested by J. B. Nau, at the works of McConway & Torley, June 19th, 1894. Witness, R. G. G. Moldenke, E. M., Ph. D.

The fracture of above set of tests shows an exceptionally good iron for light work. The tests record above the average for soft iron as regards strength. The color is a rich gray, devoid of that silver look many castings display that are desired to be of a soft quality. The half-inch bars are the closest grained, the one-inch square the next in order, then comes the one and one-eighth inch in the rough, followed by the turned one and one-eighth inch bars, which are the most open-grained, rich in color and graphite. A few of these bars were pulled for the tensile strength.

No. 41 stood 6,000 pounds; No. 43 stood a pull of 19,000 pounds, and No. 47 separated at 21,120 pounds.

TABLE 04.—TRANSVERSE TESTS OF STOVE PLATE IRON.

No. Test.	Common rule measurement.	Microm't'r measurement.	Deflection.	Broke at in pounds.	Strength per square inch in pounds.
	Rough bars.				
51	½ in. square.........	.475 in.	.220 in.	160	711 1,280
52	“ “	.476 “	.260 “	170	747 1,360
53	“ “	.474 “	.250 “	150	669 1,200
	Rough bars.				
54	1 in. square.....	.994 in.	.150 in.	1,757	1,778 ......
55	“ “	.975 “	.100 “	1,660	1,747 ......
	Rough bars.				
56	1⅛ in. diam.	1.118 in.	.170 in.	1,780	1,813 ......
57	“ “	1.126 “	.170 “	1,775	1,783 ......
	Turned bars.				
58	1⅛ in. diam..........	1.127 in.	.180 in.	1,320	1,322 ......
59	“ “	1.140 “	.180 “	1,440	1,412 ......
60	“ “	1.125 “	.180 “	1,335	1,343 ......

Test bars furnished by Bissell & Co., Allegheny, Pa. Tested by J. B. Nau, at the works of McConway & Torley, June 20th, 1894. Witness, R. G. G. Meldenke, E. M., Ph. D.

The above tests of the inch square and round bars assert this iron to be of good strength for the work intended. A factor in this series which will no doubt attract attention is the light load the half-inch bar stood in comparison with the larger sizes and only goes to further demonstrate the erratic and deceptive results which we may expect with small test bars. No. 53 stood 6,000 pounds tensile; No. 54 stood 16,600 pounds; and No. 60 stood 17,150 pounds.

In studying Table 95, one is impressed with the uniformity of the load the bars stood and also the weight necessary to break them, for as a general thing "white iron" exhibits little strength in castings. The tests would lead us to decide that the greatest weakening element in castings made of "white iron" is due to excessive contraction, which is characteristic of

TABLE 95.—TRANSVERSE TESTS OF SASH WEIGHT OR WHITE IRON.

No. Test.	Common rule measurement.	Microm't'r measurement.	Deflection.	Broke at in pounds.	Strength per square inch in pounds.
	Rough bars.				
61	½ in. square.........	.488 in.	.062 in.	175	735 1,400
62	" "	.484 "	.060 "	160	683 1,280
63	" "	.487 "	.062 "	170	717 1.360
	Rough bars.				
64	1 in. square...........	.992 in.	.050 in.	1,340	1,361 ......
65	" "	.994 "	.040 "	1,325	1,341 ......
66	" "	.992 "	.055 "	1,365	1,386 ......
	Rough bars.				
67	1⅛ in. diam.........	1.114 in.	.050 in.	1,355	1,392 ......
68	" "	1.113 "	.055 "	1,440	1,480 ......
69	" "	1.117 "	.050 "	1,320	1,346 ......

Test bars furnished by E. E. Brown & Co., Philadelphia, Pa. Tested by W. C. Cutler, at the works of Riehle Bros.' Testing Machine Co., Philadelphia, Pa., June 29th, 1894.

" white iron." Many castings made of white iron have been known to fly to pieces from internal contraction strains when cooling, without a jar or the least weight being placed upon them. The reason for not showing any turned bars in this test is due to the difficulty or rather the impracticability of machining such a hard metal. Bar No. 69 pulled 7,125 pounds. The fracture of all the bars is of a very pronounced crystalline white appearance, as can be seen in Fig. 101 on page 473.

TABLE 96.—SUMMARY OF THE STRONGEST TESTS.

No. of bar.	Transverse Strength per square inch.	No. of bar.	Tensile Strength per square inch.	Specialties of mixtures.
12	3,686	...	*37,100	Gun Metal.
17	2,980	17	30,100	Chill roll.
26	2,615	26	23,270	Car wheel.
36	2,791	35	28,676	Heavy machinery.
46	2,115	47	21,120	Light machinery.
56	1,813	60	17,150	Stove plate.
68	1,480	69	7,125	Sash weight.

*This tensile test is No. 1 of Mr. R. A. Robertson's gun metal report.

Having completed the record of tests, it is now in order to learn what they prove. It will require but little study of the Tables to find that the small bars do not record any true variation in degrees of strength, no matter what quality of iron is used. They assert that gun metal, chill roll, car wheel and heavy machinery are no stronger than light machinery or soft grades of irons. Any one experienced in the handling or use of cast iron knows that the first four grades of iron are stronger and have a higher commercial value for strength than the fifth one.

To further illustrate the impracticability of using bars below one square inch area, we show an average of the strength of the one-half inch square and one and one-eighth inch round rough bars of all such tests given in this Chapter in the following Table 97:

TABLE 97—STRONG IRONS.

Average of ½ in. square bars.		Average of 1⅛ in. round bars.
398 pounds.	Gun metal	3,686 pounds.
265 "	Chill roll	2,980 "
277 "	Car wheel	2,553 "
393 "	Heavy machinery	2,657 "

WEAK IRONS.

Average of ½ in. square bars.		Average of 1⅛ in. round bars.
454 pounds.	Light machinery	1,931 pounds.
160 "	Stove plate	1,798 "
167 "	Sash weight	1,406 "

It cannot but be plain from the averages in Table 97 that the half-inch square bar is a size readily affected by the least change in the dampness of sands or fluidity of metal, to afford any fair knowledge of the true relative differences in strength of cast iron. The half-inch bars from gun metal and the half-inch bars from heavy machinery practically show each to be of the same strength, where the one and one-eighth round bars indicate what we would naturally expect, namely, that the gun metal is materially stronger than the heavy machinery iron. Then again, the half-inch bars would indicate that the heavy machinery iron was very much stronger than the roll irons. The strength of the half-inch bars for light machinery, 454 pounds, indicates such iron to be stronger than gun metal, chill roll, car wheel or heavy machinery iron, while the one and one-eighth inch round bars show the light machinery to be but 1,931 pounds, as compared with 3,686 pounds for gun metal, 2,980 pounds for chill roll, 2,553 pounds for car wheel and 2,657 pounds for heavy machinery. The half-inch bars show a breaking load of 160 pounds for stove plate and 167 pounds for sash weight or "white iron," indicating that the latter is the stronger iron, while our one and one-eighth inch round bars show a strength of 1,798 pounds for stove plate, and only 1,406 pounds for sash weight iron, thus thoroughly demonstrating that one inch square area bars will fairly record the true relative degrees of strength of cast iron, whereas the half-inch square bar gives us absolutely little knowledge or indication of any difference in strength between one mixture and another, or any irons used in the different specialties of iron founding. A fact that further demonstrates the impracticability of using small test bars is that the tensile strength of the Table 96 records a uniformity in degrees of strength closely corresponding with the transverse load of one square inch area bars in the same Table, and which would have been still better could the bars only have been cast on end.

The next size and form of bar to consider is that of the one-inch square. In comparing the fracture of the square with those of the round bars (see pages 472 and 473), the grain of the former will average denser and all square bars, excepting those of "white iron" fracture, show the bars to be much denser at the corners than on the flat surface section of the bars, thereby giving a less uniform grain and causing more internal strains in a square bar. They are also weaker than a round bar. This point the records of Table 98 fully prove, by showing that the round bars record a greater strength than square bars of like areas. I do not wish to be understood as saying we should adopt the method which will show the greatest strength in the bar, but rather the one best to insure knowledge of the natural relative qualties of cast iron mixtures, and this the round bar will do.

TABLE 98.—SUMMARY OF BEST STRENGTH AVERAGES OF ROUGH ROUND VS. SQUARE TEST BARS.

Gun metal	Average of	1⅛ in. round bars	3,686 lbs.
" "	"	" 1 in. square bars	3,344 "
Chill roll	"	" 1⅛ in. round bars	2,980 "
" "	"	" 1 in. square bars	2,432 "
Car wheel	"	" 1⅛ in. round bars	2,553 "
" "	"	" 1 in. square bars	2,350 "
Heavy machinery	"	" 1⅛ in. round bars	2,657 "
" "	"	" 1 in square bars	2,504 "
Light machinery	"	" 1⅛ in. round bars	1,931 "
" "	"	" 1 in. square bars	1,705 "
Stove plate	"	" 1⅛ in. round bars	1,798 "
" "	"	" 1 in. square bars	1,763 "
Sash weight	"	" 1⅛ in. round bars	1,406 "
" "	"	" 1 in. square bars	1,362 "

This Chapter presents facts which should greatly aid in settling all disputes as to the value of the round over the square bar for recording the best natural strength of cast iron, and that we should not use a bar less than of one square inch area.* The tests exhibited are all of sound fracture, and in all bars but those for sash weight iron could be machined as described on page 300. For tests of larger round bars than one and one-eighth inch diameter, and a discussion on the utility of test bars, see pages 533, 536, 577 and 579.

Previous to this series of tests, etc., being first published, the author had no knowledge of any person thinking to advance information on the physical properties of cast iron, working other than in one "grade," and drawing conclusions from this as being applicable to anything that might come under the head of cast iron, which is a broad term and means any "grade" that the metalloids, silicon, sulphur, phosphorus and manganese when combined with metallic or "pure iron," make workable for conversion into castings. While it is true the quality of "grades" being in cast iron was not recognized as it should be by experimenters, etc., making or reporting physical tests, the author is pleased to note that this work has caused cognizance being taken of this, as such a course places all in a position to arrive at correct conclusions to the sooner fathom any phenomena that may puzzle or make mysterious the workings of cast iron. It would be well to study Chapter XX. in connection with this paragraph.

A study of the cuts seen in Figs. 95 and 102 will show how the metal is best permitted to have its

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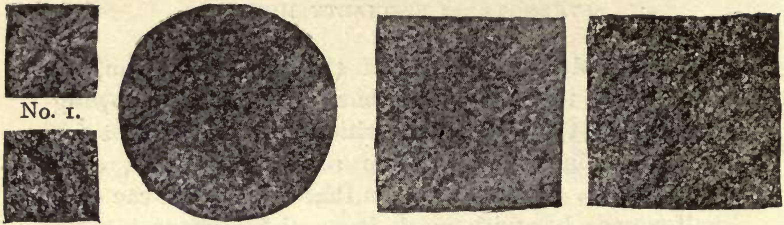
*The American Foundrymen's Association adopted resolutions that test bars smaller than 1½-inch diameter were not recognized, see pages 573, 577 and 579.

carbon evolve uniformly in the graphitic form, by the use of the round test bar, hence, again showing this to be the best form which we could adopt for obtaining knowledge of the relative strength, etc., of cast iron. It will be seen that by a use of the one-half square bar with weak irons, the carbons remain mostly in the combined state, and when used for strong iron, its body becomes "white" or crystalline. In the one-inch square bars the corners, as may be seen, are much deeper in combined carbon or dense in grain than on the flat surface, as seen at A B, Figs. 97 and 98, and instead of its skin or shell being an even thickness or of a uniform texture, as seen in the round bars at D and E, Figs. 97 and 98, it is very irregular. Furthermore, although the square bars are of about the same area as the round bars, still we find the latter has the greatest body of metal in the graphitic form.

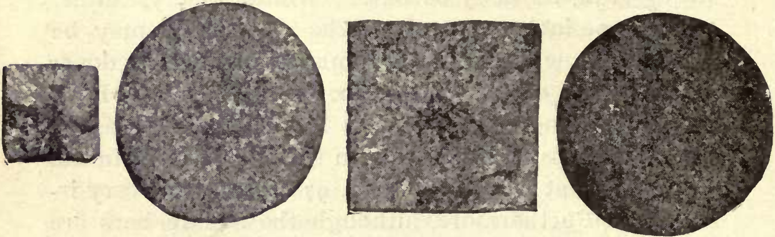
Complete analyses of all the specialties here exhibited in combination with others are presented in Chapter XLIV. These will assist in defining the percentage of chemical properties best to exist in an iron or mixtures to secure the various physical conditions and qualities desired in castings at the present day. Nos. 29 and 30, Fig. 102, illustrate the affinity of iron for sulphur, being the bars described in Chapter XXX., in which sulphur or brimstone was placed in the ladle after No. 30 had been poured. The white ring at H, No. 29, shows the hardening effect of sulphur.

FIG. 95.—GUN METAL. SILICON 1.19; SULPHUR .055.



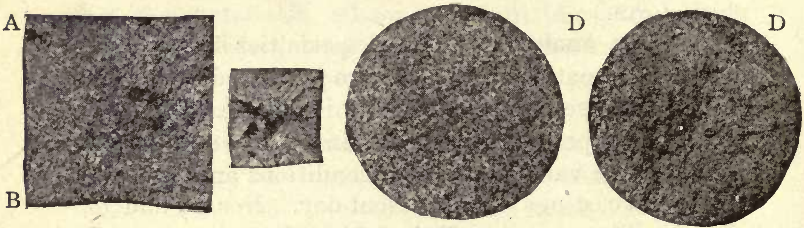
No. 1. No. 2. No. 3. No. 4. No. 5.

FIG. 96.—CHILL ROLL. SILICON .77; SULPHUR .058.



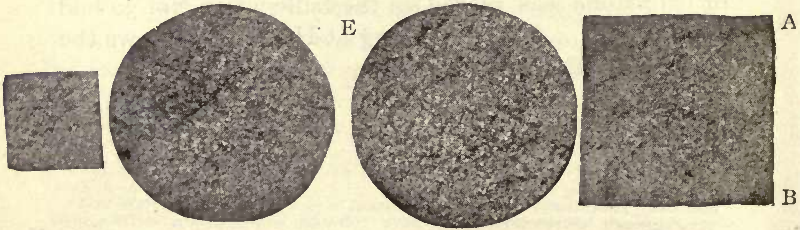
No. 6. No. 7. No. 8. No. 9.

FIG. 97.—CAR WHEEL IRON. SILICON .66; SULPHUR .127.



No. 10. No. 11. No. 12. No. 13.

FIG. 98.—HEAVY MACHINERY IRON. SILICON 1.50; SULPHUR .110.

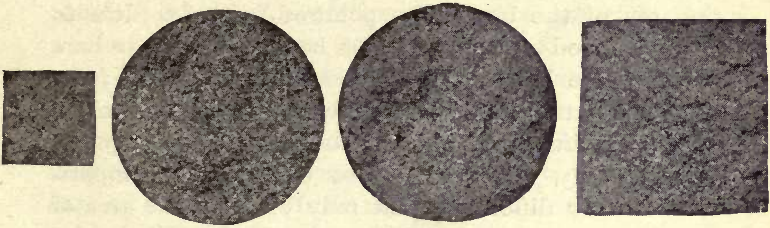


No. 14. No. 15. No. 16. No. 17.

FIG. 99.—LIGHT MACHINERY. SILICON 1.83; SULPHUR .078.

No. 18. No. 19. No. 20. No. 21.

FIG. 100.—STOVE PLATE IRON. SILICON 2.59; SULPHUR .072.



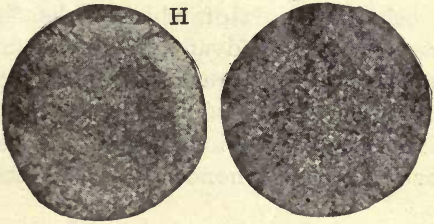
No. 22. No. 23. No. 24. No. 25.

FIG. 101.—SASH WEIGHT IRON. SILICON .180; SULPHUR .138.

No. 26. No. 27. No. 28.

FIG. 102.—SULPHUR TEST.

H



No. 29. No. 30.

CHAPTER LXI.

COMPUTATION OF RELATIVE STRENGTH OF TEST BARS.

The rule for computing the relative strength of test bars (see page 476) is to divide the breaking load by the area of the bar, at its point of fracture. It is to be understood that this rule can be applied only to bars of the same length and cross section, or made from the same pattern, in sizes or areas to equal 1⅛ inch to 2½ inches diameter or such bars as shown on pages 536 and 573, for the purpose of making comparisons of any difference that may exist in the area of test bars made from off the same pattern, due to a straining, etc., of the mould in which the bars were cast. While the compilation derived by the rules in Table 99, page 476, are placed under the head of "Strength per square inch" in most of the Tables of tests in this work, such is given as a matter of form, or for relative comparisons, and not as absolute strength per square inch. The author has presented the rule given in Table 99 for the reason that it is the simplest for ordinary shop testing, and takes better cognizance of the practical elements for everyday use in a standard bar than any other formula of which he has knowledge. Whatever systems are advanced for making relative comparisons in the transverse or tensile strength of iron, no matter what size of a bar we use, be it of one inch, two inches, or three inches area, square or round, the author claims that none should be recognized as worthy of any serious consideration as a standard that requires us to take into account more than one-eighth inch from the size of the test bar pattern used. The moment we attempt to figure up or down, to determine a metal's strength per square inch, or the more we are diverted from the exact size of the bar actually tested, the more we will err in drawing correct comparative deductions in any "grade" of iron. In order to obtain a relative knowledge of the strength of an iron we must confine tests to the use of one size of a bar (see page 534), let that be a one-inch, two-inch, or three-inch square area bar, and its computation should only be permitted in taking into account any variations which may exist due to irregular work in the moulding and casting of any one of the three sizes that may be used.

In testing bars, this effect from irregularity in moulding which can cause a variation in the size of test bars, made off from the same pattern, should be taken note of in compiling any records of strength filed for reference or comparison. Note should be taken of the least variation which might exist in the size of a standard test bar, as a few thousandths part of an inch in the diameter of a bar is multiplied about three times in its circumference. A little variation in the size of a test bar can make a bar considerably stronger or weaker, according as its diameter is decreased or increased from the size of the pattern from which the test bars are moulded. In compiling this work, it will be observed that the author has thought it correct to recognize this factor, and hence the adoption of the column, "Strength per square inch," seen with some of the tables given herewith. In order that the reader may understand how any difference in the relative strength of test bars was obtained for the tables, we give two examples seen on this page, as one method is necessary for a square bar and another for a round bar: The author could never perceive wherein the formulæ used for figuring the strength per square inch, as advanced by our text books, etc., had any bearing on the actual area of a test bar and the load at which it broke; in fact, if in 1901 a founder should send the area and tests of round and square test bars to recognized authorities on mathematics to have their strength per square inch computed, the chances are they would present such figures that he would be liable to wonder if present formulæ for cast iron were not invented rather for the purpose of distorting facts or making figures lie than for furnishing true data. The author has referred to this subject on several occasions since he published the methods for computation shown in table 99, and was pleased to note that at the meeting of the American Society of Mechanical Engineers, St. Louis, May, 1896, Prof. C. H. Benjamin came out openly in a letter discussing the testing of cast iron and attacked the usual formulæ for loaded beams as

TABLE 99.—SQUARE BAR. TEST NO. 6. PAGE 460.

Micrometer Meas. Square. Area of bar.
1.002 in. x 1.002 in. = 1.004 square inches.
Breaking load. Area.
3,500 lbs. ÷ 1.004 = 3,486 lbs. strength per sq. in.

ROUND BAR. TEST NO. 12. PAGE 460.

Diameter. Diameter. Square of diameter.
1.132 in. x 1.132 in. = 1.281424 square inches.
Square of diam. Decimal. Area.
1.281424 x .7854 = 1.006 square inches.
Breaking load. Area.
3,708 ÷ 1.006 = 3,686 lbs. strength per sq. in.

being incorrect, insisting that a reform should be enacted in this field of mathematics. In his letter he expressed the opinion, as stated by the *American Machinist*, that the terms "modulus of elasticity," "elastic limit," etc., were entirely out of place as applied to cast iron, and should not be used at all in connection with that material, and that the usually accepted formulæ for strength of beams would not hold good for cast iron beams, as had been shown by tests made by himself for the committee.

The author trusts that the good work started at St. Louis will result, before many years, in our having some standard for computing the strength of cast iron that can be recognized as more practical or more correct than our present formulas for figuring different lengths and sizes of bars or loaded beams. It is as essential to have correctness in formulas for figuring the strength of cast iron as it is to have correct systems for casting and testing such grades of metal. (See page 530.)

To any desiring to use larger bars than the one and one-eighth inch diameter shown in Table 99, and wishing to keep even figures as with a two-inch or three-inch area section, as some may desire to do, the only difference would be to have the figures 1.596 or 1.955, as the case may be, replace the 1.128, which is the diameter of a bar equal to the area of a one-inch square bar. It may be well to mention at this point that the Riehle Bros. of Philadelphia and others now use the method for computing the strength of test bars shown in Table 99, page 476.

CHAPTER LXII.

VALUE OF MICROMETER MEASUREMENTS IN TESTING.

"What is worth doing at all, is worth doing well," is an old maxim, and never more applicable than to the subject of testing. It can be readily observed that the author is an advocate of utilizing every factor that can, in any manner, assist in lessening erratic records and advance testing of cast iron to its highest perfection. Such advocacy would be inadequate did the author not argue for the adoption of the micrometer to measure the area of test bars at the point of fracture. The micrometer would be used much more than it is at the present time, did testers only more fully realize the difference a few thousandths of an inch in the diameter of a bar can make in the strength records, especially when the same are reduced to make relative comparison of strengths.

Many would be surprised to learn how often they have been deceived in according differences in strength to records obtained simply by calipers and common rule in considering the size of bars for comparisons. If the micrometer had been used and the area reduced to make relative comparisons as illustrated on page 475, testers would ofttimes have found bars, which were conceded by the breaking load records to be the strongest, to prove the weakest test of iron.

It is impossible to obtain rough bars of the same area. There is sure to be some difference in their sizes. It is not unusual to find one-inch area, etc., bars to be from one-sixteenth to one-eighth larger in diameter or the square than the pattern used and to find that testers make no note of such difference, but are wholly guided by the weight at which the bar broke. If one was one hundred or two hundred more than others, the highest was accepted as the strongest and best test, regardless of the bar's exact area.

To illustrate how a small bar breaking with a heavier load than the large bar (each differing but a few thousandths of an inch in their area), may often, if not reduced to relative strengths, etc., deceive a tester 200 to 400 pounds in accepting common rule measurement and the actual load in thinking he has a true record of the iron's strength, the reader is referred to Table 89, tests Nos. 6 and 8, on page 460, showing transverse tests of gun metal. There we find two bars which, if the actual breaking loads were accepted, would deceive the tester 269 pounds, or in other words, instead of his believing he had one bar only 72 pounds stronger than the other, he actually had a difference of 269 pounds, as stated above. This should aid to clearly illustrate the importance of micrometer measurements, wherever the tester desires to truly ascertain whether any difference actually exists in the strength of his mixtures or the character of the iron produced.

Another feature well to be noticed is that of the impractibility of obtaining bars exactly round or square, or exact duplicates of their pattern. Many testers take but one measurement of a bar, while others take no measurement at all. Any following either practice might almost as well omit their testing, for they are as liable to be misled as be correct in their conclusions. In obtaining the area of a round or square bar two measurements, at least, should be taken, added together, and then divided by two to obtain the average of their sizes to assure a tester that he has knowledge of what is closely the true total area of bars. Those desirous of closely following mixtures, etc., by physical tests to obtain true knowledge of the strength of their product, can not ignore the value of micrometer measurements. For scientific research, at least, such methods must be strictly followed. To find decimal equivalents for use in micrometer measurements, see Table 139, page 594.

CHAPTER LXIII.

OPERATING TESTING MACHINES.

Obtaining true results or close records in testing is often assisted as much by careful work and system in operating testing machines as by correct methods in the moulding, casting, etc., of test bars.

In obtaining the transverse strength and deflection of bars cast flat they should always be laid on the bearing blocks the same way. The importance of this is realized when we consider that the down or "nowel" side of a one-inch area round or square bar can be made to show a strength of 300 to 400 pounds more by having the "nowel" side resting on the blocks than where the cope side is so placed, a quality clearly proven in Chapter LXV., page 488.

If bars are cast on end, it is well to have the down or upper cast end always pointed the same direction.* To insure this in the methods advocated by this work, a small, flat depression is cast in the bars, so as to permit their always finding a good bearing at the same spot of the bars, as seen at X, Fig. 103, next page.

The same speed in testing should always be maintained as far as possible, as whether a bar is broken fast or slowly can make a difference in results. A comfortable speed, which can be always readily maintained, should be adopted. In obtaining tensile

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*This is essential, as it assists in obtaining an approximate area at the breaking point, as the taper of the patterns and straining of the mould from head pressure are liable to make the area of the bars vary at different heights.

strength of test bars, every care should be taken to prevent one side being strained or pulled more than the other. The grip should be such as to cause an even pull all over the area of the specimen, in order to obtain the true tensile strength of the iron. See page 450.

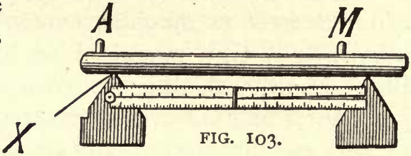

FIG. 103.

Another essential in operating testing machines is that of applying the weight as steadily as practicable. At Fig. 104 is shown the upper section of a type of testing machine now being largely used, in which the oscillation of the beam F, from the lower stop H up to the upper stop K, in some cases may mean a load of 100 pounds, which if brought up or down quickly results in a strain like an impact blow. A good plan to follow in using a machine of this design is to place one hand around the stop at K. By this plan, less room is allowed for the oscillation of the weighting beam and the hand readily informs the mind of any upper movement, so that the sliding poise can be made to balance the beam before a bar could break to make it questionable within one hundred pounds of just what is its true strength, by reason of the beam F rising suddenly to the stop K.

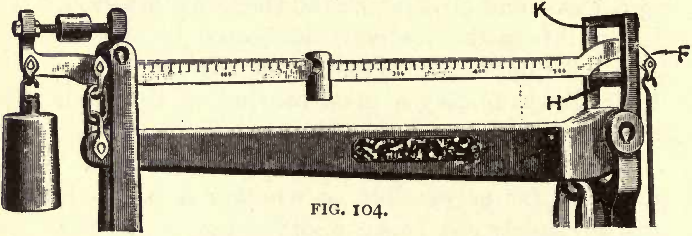

FIG. 104.

CHAPTER LXIV.

ROUND vs. SQUARE TEST BARS.*

The square test bar, cast flat, was, prior to 1890, almost solely employed. The author first advocated the use of a round test bar in an article in the *American Machinist*, June 6, 1889. He is aware that the square bar, cast flat, has been the basis of elaborate tables of transverse strength for use by engineers, etc., and for publication in our scientific text-books; yet, in spite of all this, the practice is wrong.

Metal, in cooling, arranges its crystals in lines perpendicular to the bounding planes of the mass, or, in other words, the crystals arrange themselves along the lines the waves of heat travel in passing outward from the casting as it cools off. To assist in illustrating this subject I have taken the following description and cuts (Figs. 105 and 106) from Spretson's work on founding. Speaking of the cuts, Mr. Spretson says:

> In the round bar the crystals are all radiating from the center. In the square bar they are arranged perpendicular to the four sides, and hence have four lines, in the diagonals of the square, in which terminal planes of the crystals abut or interlock, and about which the crystallization is always confused and irregular.

This is said to be very plainly exhibited by the effect

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* A revised extract of a paper read before the Western Foundrymen's Association, June, 1894.

of manganese in steel castings showing a contrast between round and square fractures.

A study of Figs. 105 and 106 impresses one with the importance of arranging for the greatest possible uniformity in providing for the radiation of heat from a test specimen, and also to afford it the most favorable condition to arrange its crystals uniformly throughout its body. It requires no great stretch of the imagination to conceive what a great influence the simple matter of slight differences in the "temper" of sand in a mould may have in causing non-uniformity in the even texture of a square bar compared to the even structure possible in a round bar. Mr. John E. Fry, in a paper before the Eastern Association, May 2, 1894, condemning one-half inch square test bars, clearly illustrates the effect of a little variation in the "temper" or dampness of sand, often making small bars wholly unreliable as a test for the relative strength of any kind of cast iron.

FIG. 105.

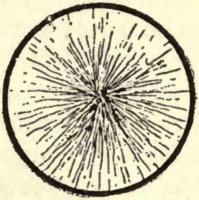

FIG. 106.

Before leaving Figs. 105 and 106, let me call attention to their clear exemplification of the necessity of casting test bars on end, in order to insure uniform cooling off. The heavy-work founder knows that metal first solidifies at the bottom of a mould, and if he is "feeding" a heavy casting, the metal, by solidifying at the bottom first, will gradually force his "feeding rod" upward, thus demonstrating that the greatest line for radiation or line for heat to escape is upward, or through the "cope" of a mould. For this reason, if we would break a casting a foot square into halves down the center of its vertical position, as when cast, we would find the last spot to solidify would generally be about three inches from the top, or one-fourth its height below the cope surface. It makes no difference how small a body of metal may be, the same principle is applicable to it as to the large body, and goes to fully demonstrate the irregularity for a central point of latest solidification which must exist in a test bar cast flat. Then again, uneven cooling is bound to cause more or less internal contraction strain in a test bar. It must be evident that a test bar cast on end will have an even radiation from all portions of its surface at any height, and thus give to the bar the best uniform grain throughout any section and also the best opportunity to lessen strains so far as cooling off has any effect. More information on the necessity of casting test bars on end will be found in the next Chapter, page 488.

The nature of all cast iron is such that any elements in a mould possessing heat-conducting powers, that will either chill or make closer the grain of the metal in the skin or surface, are very effective in changing results in the strength and contraction of iron, especially in light castings or small test bars. There is a great difference in iron in its susceptibility to elements tending to chill. Some iron, if poured into a dry sand mould, would show a gray fracture, but if poured into an iron or green sand mould, would show at the surface a white or chilled iron, the depth of which depends upon the character of the iron, the thickness of castings, etc. In Fig. 107, we see an irregular circle, outside of which we find the deepest close-grained sections at the corners A B. The lower the "grade" of the iron and the damper the sand the deeper will these corners chill or close up the grain of an iron. There is a limit to the extent to which combined carbon shown in the closing of the outer grain can cause strength in the test bar, where it is combined with a soft center or graphitic core as seen at D. A test bar can, by a radical difference in the grain of the core and outer body, embody such contraction strains within its own elements as to break with a lighter load compared with the true natural qualities of metal as exhibited by actual working results in castings or from a turned test bar. Degrees in "temper" or dampness of the sand comprising a mould have every influence in changing results in the corners of a test bar. A square bar is an erratic bar at its best; one cannot say what it will do in often showing different grades of iron to be partly the opposite of what a use of the castings would demonstrate. This is especially true where square test bars are cast flat.

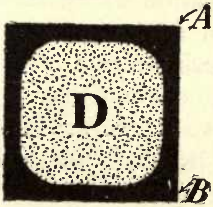

FIG. 107.

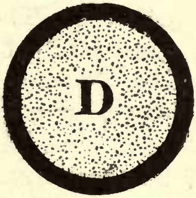

FIG. 108.

We will now turn our attention to the round bar, Fig. 108. It surely requires but little observation to impress one with the regularity of its outline comprising the surface or close-grained metal; and it appears like adding insult to injury to discuss the favorable conditions it presents over a square bar in permitting iron to show a uniform grain in a test specimen. No one need accept the illustration of this question as exhibited by the cuts (Figs. 107 and 108), as any founder can cast square and round test bars to ascertain the difference in the grain of two such fractures for himself.

For testing iron, by means of rough cast bars, I am at a loss to conceive how any one with the facts before him, as herein set forth, can scientifically support or argue for the adoption of a square test bar. When we consider the uniformity of radiation, crust, and grain, that a round bar cast on end makes practicable, and then look at a square bar cast flat, it does seem that we do not need any science but that a little use of fair reasoning is all-sufficient to guide us aright in deciding which of the two forms is the more liable to most closely approximate comparisons of the strength or contraction of iron mixtures, etc.

The Author's continued advocacy of the round bar, cast on end, since 1889 has been rewarded by the American Foundrymen's Association, at its annual convention in 1901, unanimously passing resolutions recommending the round bar cast on end as the most suitable for testing cast iron. This resolution also recommends that bars should not be smaller than one and one-half inches diameter. The sooner all come to recognize the advisability of adopting the above recommendations, though many may desire to use as small as 1⅛-inch diameter bars, which may often be permissible with soft grades, the better for all interested in or making use of test records. An account of the A. F. A.'s work in bringing about the above recommendations is found in Chapter LXX., pages 574 to 584.

CHAPTER LXV.

DISCOVERY OF EVILS IN CASTING TEST BARS FLAT.

At the meeting of the American Society of Mechanical Engineers held in New York City the week of December 3, 1894, the author, in a discussion on testing, briefly called attention to the series of tests seen on page 493. Before asking the reader to review the tests, the author wishes to comment on principles involved and what they demonstrate to us in emphatically proving that certain practices some follow are not correct. It is well known that the past practice in moulding test bars has been upon the principle of casting them flat, and also that the form generally used has been square or rectangular in preference to the round form cast on end which, the author is pleased to note, has attracted much attention and is now (1901) adopted by many as the only correct method to test the physical properties of cast iron. The author will now advance more proofs to show that the round test bar cast on end is the best method which we can adopt to reduce erratic results in testing to the minimum.

Early in 1894, the author discovered that in testing a bar cast flat for its transverse strength, by applying the load on the upper cast surface a much greater strength could be obtained than if the bar was turned the reverse side up. I have found in experimenting with a large number of bars one-half inch square, one inch square, and one and one-eighth inches diameter, with supports twelve inches apart, that I obtained on an average 30 pounds more strength for a one-half inch square bar, 100 pounds in the one-inch bar, and 150 pounds in the one and one-eighth inch round bar. I wish these figures to be accepted only as an average of many tests of bars of the respective sizes given, and with which, as a rule, the results have been very erratic.

I have found in a one-half-inch square bar as much as 50 pounds difference in testing the two sides and in the one-inch square and one and one-eighth inch round I have found a few bars which showed from 300 to 400 pounds difference, thereby presenting proof that casting flat any form of size of bar admits of errors and jugglery and is wholly wrong.

I would state that in experimenting with testing on the lower and upper sides of test bars, they should always be moulded in the same flask, poured from the same ladle and from the same gate. To prove my position on this question, I would first call attention to conditions which can be found by any who are sufficiently interested to experiment in this line. In Fig. 109, next page, is shown a side elevation of a bar resting on pointed supports A B, 12 inches apart, the distance which the author used in his experiments. The point of load is shown at D. The position of the bar is the same as when cast or lying in its mould. In examining such a bar it will be found that the metal at the lower side or shell E E is generally denser, or of a closer grain, than that composing the upper half of the bar. This is caused by the lower half being cooled more quickly than the upper half. This gives in the lower half of the bar, in a sense, more combined than graphite carbon, which results with iron not "white" in causing the "lower" half to be of greater strength than the upper half. But the degree to which this is affected in flat-poured bars is largely controlled by the difference in the "temper" of the sand, hardness of ramming, degree of fluidity, speed of pouring, and the quality of iron used. Since these conditions cannot be always the same, results in testing flat cast bars are erratic. That one side of a flat cast bar will always be in line of giving more strength than another, is understood when we take into consideration, with the above, the fact that in testing for transverse strength, we subject the under side of the bar to an extension or tensile strain, and the upper side to one of compression or crushing. If we have the densest or highest combined carbon side of a bar to resist the extension or tensile strain, it is reasonable to

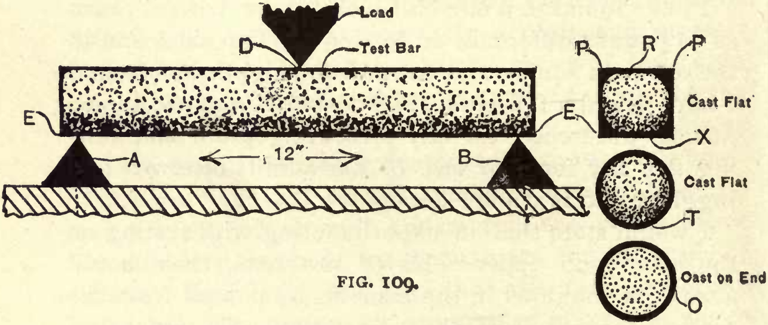

FIG. 109.

expect it to stand a greater load than if we placed the most open-grained or weakest side to the extension or tensile pull. Another point which proves that there is a difference in the cross sections of the grain of iron in a test bar poured flat is that if we drill into the end of such bars there will be found, as a general thing, a tendency for the drill to work itself more to the top or weak side of the test bar, as more clearly illustrated in Fig. 110. I cannot conceive why the adoption of the round bar cast on end should not greatly lessen the causes for the past erratic results in testing, as my experience with these bars so cast makes it manifest how closely two bars of like area, which have been properly cast on end, in the same flask, with the same gate and out of the same ladle, will come to each other. Table 103, page 493, is an example of how closely round bars cast on end can record like strength. I would call attention to the test of twelve bars, comprising four one-half inch square, four one inch square and four one and one-eighth inch diameter, which were all moulded in one flask, poured with the same ladle from the same gate and cast flat, as seen, page 493, and then compare the four one and one-eighth inch round bars, which are moulded two in a flask, upon the principle which the author advances for casting test bars on end. These were cast out of the same ladle after the above twelve bars were poured flat. The ladle for pouring the above sixteen bars held about 150 pounds of metal. It will be seen by the examination of Tables 100, 101, and 102 that all the

FIG. 110.

bars cast flat stood the greatest load, with their side which was down when cast being in extension when tested, and also that the greatest difference in this respect exists in the round bar. Again I would call attention to the fact that the results in all the flat cast bars were very erratic. This Table compares very closely in averages with a large number of tests which I have made on this point to satisfy myself as to the correctness of such results, and they always point in one direction.

A deceptive point which it might be well to notice in casting test bars flat is the chance it affords of making a test bar record too great a strength for an iron. Take a round bar cast flat and test it with its side cast down in extension, or as illustrated in Fig. 109, page 490, and one can record a greater strength than by any other method of casting; but where one desires to record the honest and natural strength of an iron, he should use the round bar cast on end. And by a comparison of the round bar cast on end with those cast flat, as seen by Tables 102 and 103, next page, the system which the author advocates is found to be one which will not permit a tester to obtain a greater strength than that which the iron truly possesses, nor admit of any jugglery in recording tests. When it is known that one side of a flat cast bar can often give 300 to 400 pounds more strength than its opposite side, there is surely an opening for deception and variable results. The mixture of iron charged for the test on next page was all pig metal of the analysis seen in Table 104. The analysis of the test bars shows the silicon to be reduced ten points and the sulphur doubled by re-melting the iron.

TABLE 100.—TRANSVERSE TESTS OF ½″ SQUARE BARS CAST FLAT.

No. of test.	Mode of testing.	Micrometer measurement.	Deflection.	Broke at in lbs.	State of fracture.	Strength per ½″ sq. in lbs.
1	Top up.	.504	.180	264	Sound.	260
2	"	.509	.170	260	"	251
3	Top down.	.493	.160	240	"	233
4	"	.526	.110	160	Small flaw.	145

Difference in strength extremes of sound bars, 27 lbs. or 11.59 per cent.

TABLE 101.—TRANSVERSE TEST OF 1″ SQUARE BARS CAST FLAT.

No. of test.	Mode of testing.	Micrometer measurement.	Deflection.	Broke at in lbs.	State of fracture.	Strength per sq. in. in lbs.
5	Top up.	1.022	.110	1,784	Sound.	1,709
6	"	1.052	.120	1,820	"	1,645
7	Top down.	1.044	.120	1,764	"	1,618
8	"	1.024	.100	1,600	"	1,526

Difference in strength extremes, 183 lbs. or 11.99 per cent.

TABLE 102.—TRANSVERSE STRENGTH OF 1⅛″ ROUND BARS CAST FLAT.

No. of test.	Mode of testing.	Micrometer measurement.	Deflection.	Broke at in lbs.	State of fracture.	Strength per sq. in. in lbs.
9	Top up.	1.161	.160	2,128	Sound.	2,010
10	"	1.140	.150	1,980	"	1,940
11	Top down.	1.171	.140	1,996	"	1,853
12	"	1.131	.100	1,682	"	1,674

Difference in strength extremes, 336 lbs. or 20 7-100 per cent.

TABLE 103.—TRANSVERSE TESTS OF 1⅛″ ROUND BARS CAST ON END.

No. of test.	Mode of testing.	Micrometer measurement.	Deflection.	Broke at in lbs.	State of fracture.	Strength per sq. in. in lbs.
	First flask.					
13	Cope side	1.111	.110	1,760	Sound.	1,815
14	Nowel side	1.116	.110	1,772	"	1,812
	Second flask.					
15	Nowel side	1.132	.111	1,772	"	1,761
16	Cope side	1.121	.110	1,720	"	1,743

Difference in strength extremes of two flasks, 72 lbs. or 4.13 per cent., but the greatest difference in one flask, tests Nos. 15 and 16, and which is the way Table 58 should be shown, is but 1.03 per cent.

Tested by Thos. D. West, October 23, 1894, assisted by C. B. Kantner, at Sharpsville, Pa.

TABLE 104.

Chemical analysis of pig iron charged.				Chemical analysis of test bars.			
Silicon.	Sulphur.	Mang.	Phos.	Silicon.	Sulphur.	Mang.	Phos.
1.48	.019	.35	.097	1.38	.038	.31	.099

A study of the tests on page 493 shows that the greatest difference in one flask of the strength extremes of the bars cast on end is but 1.03 per cent., compared with 11.59, 11.99 and 20.07 per cent. found in the bars cast flat. It may be well to mention again the fact that all the bars were poured out of the same ladle and that the flat cast bars were all moulded and cast together in one flask, giving them a much better chance to be uniform than the bars cast on end, as the latter were cast in separate flasks.

When a system is obtained, where with two bars cast together, there will only be three pounds of difference in their breaking loads per square inch, as is found with tests Nos. 13 and 14, Table 103, the author has a suspicion that it is about time some were making a study of the elements bringing about such close results.* The difference of 72 pounds between the two flasks poured on end, shown in Table 103, could be charged to the difference in the fluidity of the metal, which existed through lapse of time in pouring the two moulds, a quality affecting the strength, etc., of test bars more fully defined on pages 372 and 526. Additional information on casting test bars on end will be found on pages 508 and 512.

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* These two tests are given merely to show the close results that can be obtained, in a general practice, much better with round bars than with square ones.

CHAPTER LXVI.

PHYSICAL TESTS FOR THE BLAST-FURNACE, AND THEIR VALUE.*

Progress in the science of either making or mixing iron requires a study of the physical as well as the chemical properties. The importance of a correct system for such tests, to make comparison possible between different furnaces, or the same furnace at different times, or with founders, is self-evident.

The first point to mention is the value of re-melting samples of the furnace-casts. The occasional re-melting of samples of casts, in a small cupola, cannot but aid the advancement of research, and serve as a check on chemical analyses, and often as a protection to the furnaceman, by enabling him to learn what the founder can do in changing the character of iron after it has left the furnace yard. A little cupola will also often be convenient for casting small pieces for repairs that may be needed between the furnace-casts, or when a furnace is out of blast.

A furnaceman is often not informed of complaints concerning his iron until it has been all melted up; and then he has generally no remedy other than to inspect the castings claimed to have been made from

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* Extract of a revised paper read at American Institute of Mining Engineers' Meeting, Pittsburg, Feb., 1896.

the iron complained of. As a founder, I know there are ways in which the original character of pig metal can be so altered in mixtures as to place upon the furnaceman the blame for bad results for which he is not justly responsible. In such cases, the remelting of a sample by him might often exonerate him.* The expense of a small sample cupola need not alarm any furnaceman; he can erect one for twenty dollars. In fact, the author erected one at the Spearman Furnace, Sharpsville, Pa., January 17, 1896, which did not cost six dollars, and took but seven hours' labor of one man from the time ground was broken until the cupola was at work. A cast was made in ten minutes after the iron was charged. This cupola was made of an old shell, twelve inches in diameter and thirty inches long, which was lying around in our foundry yard. It had been used a few years previously in an industrial street parade, for casting horseshoes, which were thrown to the people as the wagon went along, the blast being furnished by means of an old pair of hand-bellows. If iron can be melted under such conditions, in such a baby cupola, no one need hesitate to believe that it can be conveniently done in a small cupola at a blast furnace, where all the blast required can be steadily supplied.

The following Tables 105, 106, and 107, seen on next page, give chemical and physical tests of a furnace-cast, taken January 18, 1896, at the Spearman furnace, Sharpsville, Pa., and is chiefly given to present one good form for such records:

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*If founders knew that furnacemen tested their own iron by remelting it in a cupola and kept a regular record of all their tests, it would have a great tendency to make many investigate thoroughly to find whether the fault was not their own before entering complaints to the furnacemen.

TABLE 105.—PHYSICAL TESTS OF FURNACE IRON TAKEN JANUARY 18, 1896.

No. of Test.	Contraction.	Deflection.	Strength	Fluidity.	Chill.	Diam'ter of Bar.	Strength per sq. in.
	Inch.	Inch.	Pounds.	Inches.	Not	Inch.	Pounds.
1	6-64	0.12	2,300	4½	taken.	1.194	2,054

TABLE 106.—PHYSICAL TESTS OF CUPOLA-IRON.

No. of Test.	Contraction.	Deflection.	Strength	Fluidity.	Chill.	Diam'ter of Bar.	Strength per sq. in.
	Inch.	Inch.	Pounds.	Inches,	Not	Inch.	Pounds.
2	8-64	0.08	2,220	5	taken.	1.242	1,907

TABLE 107.

ANALYSIS OF FURNACE-IRON.		ANALYSIS OF CUPOLA-IRON.	
Silicon.	Sulphur.	Silicon.	Sulphur.
Per cent.	Per cent.	Per cent.	Per cent.
1.02	0.034	0.81	0.056

NOTE.—The number of inches given under "fluidity" in this record is directly measured on the fluidity strip, seen at S, in Figs. 121 and 122, pages 509 and 514.

The day is past for tolerating the blind, ignorant practice which we foundrymen followed up to about 1890 in mixing iron. The wonder is that we ever "hit" what we wanted, when we consider how deceptive is the fracture of pig metal as a guide to its true "grade." I am aware that up to 1900 a little over half our founders kept up with the progress of utilizing chemistry in mixing their iron; nevertheless, I say, when the furnaceman has done his part, let the founder study to do his by calling chemistry to his aid, or else get out of the business and stop complaining about "bad iron." There is no "bad iron" in the sense some have inferred. All can be utilized in some class of work or other. All that is wanted is a knowledge of its chemical and physical properties; and when the furnaceman and founder understand these as they should, pig iron of any " grade " or quality need never be shipped to the wrong customer. It is simply a question of " carding the car " right, to have a furnaceman clean his yards, and have no complaint about his iron, however " bad " he may occasionally make it, if he will but give a correct analysis.

The foundry iron of the analysis in Table 107 is an excellent grade to make a machinable, strong casting for very heavy work, such as should not be under three inches thick in its lightest part, if all pig be used; but if the furnaceman gets the wrong shipping card on such a car of iron, and some unprogressive founder receives the iron, and because it may look " soft " or " open-grained " tries to mix one-third scrap with it, for light or medium castings, he abuses the furnaceman, because his castings crack and come out " white iron."

The cupola illustrated on page 501 is the smallest I know of now used for practical purposes. Before taking a " heat " out of this small cupola, there was but one point that I felt doubtful about, in practice with such a small size for the work I intended it to perform, and that was, whether it would increase the sulphur, by remelting, more or less than is done on an average in the large cupolas commonly used.

Owing to records of cupola mixtures kept at our foundry since 1892, or of the analyses of the pig metal that go to make exacting work (in which only shop-scrap can be utilized), and of the castings produced, we are enabled to judge fairly of the increase of sulphur by remelting, and found by comparison that the increase in sulphur caused by remelting in the small cupola cannot be regarded as any greater than would result from remelting in large cupolas. If anything, it is a little below what might be expected with fair usage. This is due to the iron not remaining in the baby cupola as long as in ordinary foundry cupolas.

I will now proceed to describe a system of testing which I installed at the Spearman furnace at Sharpsville, Pa., January 17, 1896, in which the managers took great interest and used, without a doubt, with much profit to themselves.

The outfit includes one Olsen transverse testing machine of standard make, one cupola, two flasks, and chill pig-moulds with a test bar pattern and mould-board. An excellent feature of the whole equipment is that it need not cost over one hundred dollars, including the testing machine. The price of such an outfit is no more than a furnace might have to pay for freight on one or two cars of condemned iron.

The cupola. Fig. 111 shows the cupola used. It may have a "drop bottom," as shown, or it may simply rest upon a plain plate, and be tipped by hand to clean it out, after the conclusion of heats. The figure itself explains all details necessary to the construction and plan of charging the cupola, as seen on next page.

The cold blast is used so as to be the same as in foundry practice. It may require a few trials to find out what pressure of blast will give the best results. It should not exceed eight ounces pressure at the cupola, and will generally be found to work best at about six ounces, where two one-inch tuyeres are used. Where a low pressure of about four ounces can be

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*If one is inexperienced in managing cupolas, I would advise the cupola being 14 inches inside diameter instead of 10 inches, as shown, and increasing the tuyere area 30 per cent.; that is, if a novice desires to use the smallest cupola practical for melting small samples.

well maintained, I would advise the two tuyeres being about two inches diameter, and give this plan the preference over one-inch tuyeres with higher blast pressures.

The cupola should have its bed of coke well on fire before the iron is charged, and the latter should be distributed evenly all over the surface of the bed, the largest pieces being placed in the middle. I have melted one-quarter of a common-sized pig all down in fifteen minutes from the time it was charged. This is mentioned merely to show that the baby-cupola can deal very rapidly with chunks of iron.

The melted iron should be held in the cupola until one charge is thought to have been all melted down, before it is tapped out. A charge of iron may range from 20 to 50 pounds; and several charges may follow, having a layer of coke between them, from four to five inches in thickness. For a heat over twenty minutes long, some good flux may be advantageously used to make a thin slag, which could be run off at the tap-hole or at a slag-hole, provided for the purpose, about two inches above the level of the tap-hole. To start the blast it is usually best to let the lowest pressure of blast found permissible with utility left on, up to the time that about two pounds of melted iron run out of the tap-hole. After this flowing of metal, plug up the hole and increase the blast pressure a few ounces, so as to bring down the iron quickly, and collect it in a good body, which will maintain its fluidity while it remains on the bottom bed before being tapped. In letting out the fluid metal, make a large hole and have a warm ladle to receive the liquid iron.

The lining used for the cupola is simply a coating of

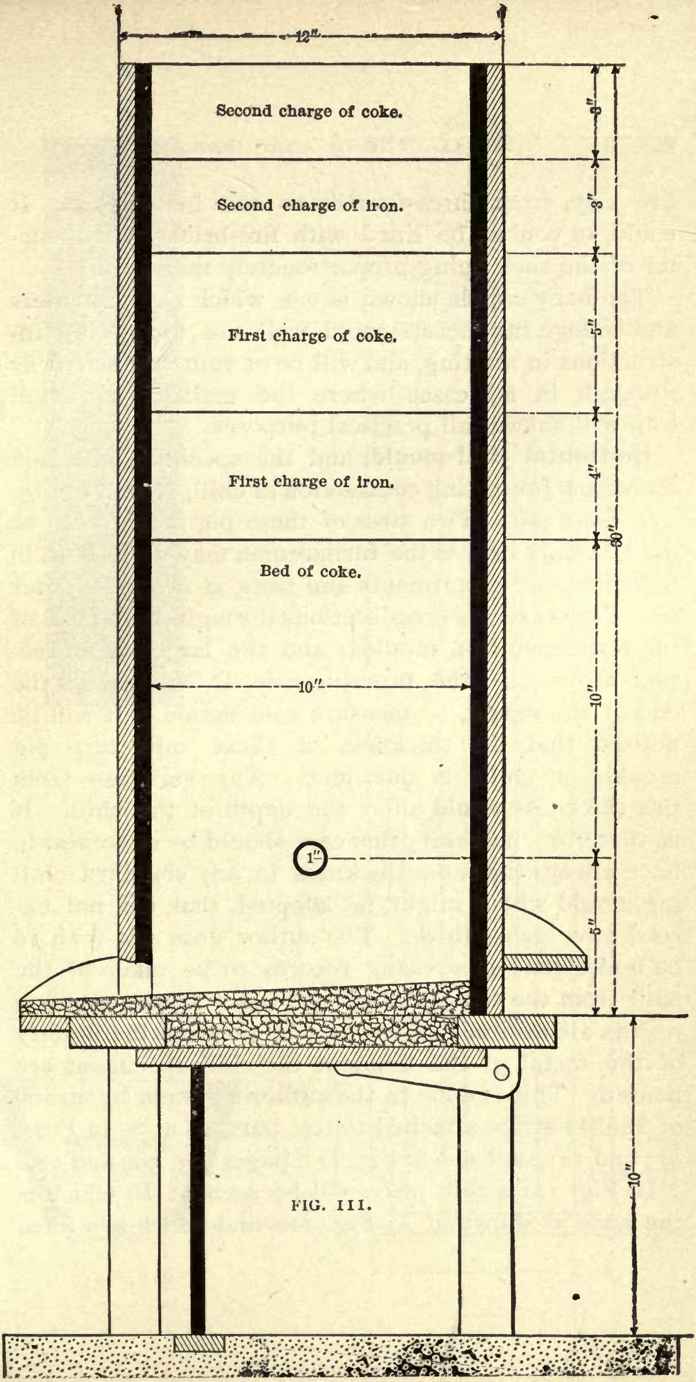

12"
Second charge of coke.
3"
Second charge of iron.
3"
First charge of coke.
5"
First charge of iron.
4"
30"
Bed of coke.
10"
10"
1"
5"
10"

FIG. III.

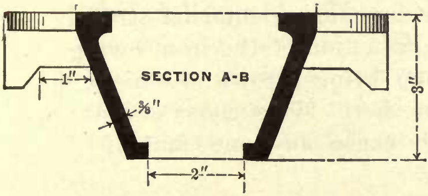
fire clay, from three-fourths to one inch thick. It could, of course, be lined with fire-brick; the diameter of the shell being proportionately increased.

The baby-cupola shown is one which experimenters and college instructors could well use for giving instructions in melting, and will be of value for scientific research in all cases where the melting of small iron will answer all practical purposes.

Horizontal chill-mould, and the specimen obtained therefrom for testing contraction or chill, is seen in Fig. 114, page 506. Two sizes of these pig-moulds can be used, or only one, as the furnaceman may deem best, in following out experiments and tests, as described later on. Fig. 115 shows cross-sections through the middle of the respective iron moulds; and the larger cross-section shows also the tapering-rule, D, applied at the end of the mould, to measure contraction. It will be noticed that the thickness of these miniature pig moulds or chills is one inch. Any variation from this thickness would affect the depth of the chill. It is, therefore, necessary that care should be exercised to have always the same thickness in any standard chill pig-mould which might be adopted, that did not exceed two inches thick. The author does not wish to be understood as advising records to be taken of the chill from the test-specimens, in cases where very fine results are desired, unless note be taken of the fluidity of the metal at the moment the chill specimens are poured. This is done in the author's system by means of fluidity strips attached to test bars, as at S, in Figs. 113 and 121, and also in Fig. 122, pages 503, 509 and 514.

In Fig. 121 a chill piece will be seen at B, which is the same as shown at A, Fig. 120, and which is a form

FIG. 113.



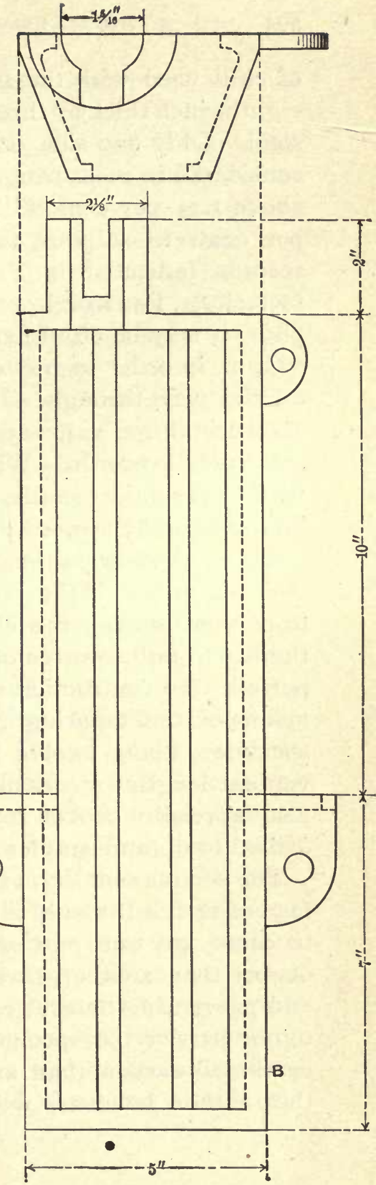


FIG. 112.

of chill used with the test bars shown, and is three-eighths inch thick by three inches long, and made of soft steel. Only one side or half of the test bar is here considered in measuring a chill for record. For iron above 1.25 per cent. silicon and no higher than 0.03 per cent. in sulphur, this system of obtaining chill-records indicated in Fig. 121, will work very satisfactorily. For iron lower in silicon or higher in sulphur, it may be often necessary to have a larger body of iron, in order to prevent a specimen being chilled all the way through. In such cases, chill-blocks, as shown in Figs. 114, 115, and 116, may be required to obtain chill records. Where best value is to be attributed to the chill records, the fluidity should be noted to be the same by eye or by the means shown in Fig. 121.

Fig. 116 shows a longitudinal section through the chill pig-mould of Fig. 114. The well at B is provided to prevent cutting the chill in pouring, and to cause the bar to pull towards one end in contracting, so as to permit the contraction to be readily measured by means of the tapering rule, shown at D. This test specimen, being twelve inches long, provides a convenient length for measuring the contraction, and can also be readily broken to note its fracture, or can be drilled to obtain samples for analysis.

The sections in Fig. 115 show that the bottom surface of the chill-mould is round, possessing no corners to cause any one part of the specimen to be chilled deeper than another, thereby causing internal strains and preventing natural contraction of the iron, owing to one part of the specimen being thrown into higher combined carbon than another. This consideration, the author believes, will cause any one making a study of the subject to agree with him in advocating the principle of the round chill.

The tapering rule D, Figs. 115 and 116, is graduated on one side, as shown, to measure the contraction in the sixty-fourths of an inch. The rule is cut off on the small end at a point where it is one-sixteenth of an inch in thickness. From this the taper runs up two inches, at which point it measures three-sixteenths of an inch. The distance between the one-sixteenth and three-sixteenths points is then equally divided by six lines, as shown, so as to read to the one-sixty-fourth part of an inch, according as the space of contraction will permit the rule to be inserted between the chill-mould and the pig specimen, as shown. The lines being one-quarter of an inch apart, the scale can be easily read; but the rule could, of course, be graduated finer if desired.

The study of the element of contraction, as it can be defined from any pig specimens, Figs. 114, 115 and 116, will prove very valuable, and, in time, may enable a tester to know at a glance, without further research, the true "grade" of an iron. It can aid the furnaceman to detect deception, which is now known to exist in the fracture of "direct metal," and also to learn the true effects of re-melting iron, and what metalloids cause the greatest contraction in the iron.

At E, in Figs. 114 and 116, will be seen a depression of about one-quarter of an inch below the top surface of the chill-mould. This is to provide means for a "flow-off," to insure the chill specimens being always of the same thickness and prevent any iron running over the edges of the mould to retard free contraction in any manner. The chill-mould, of course, is set level.

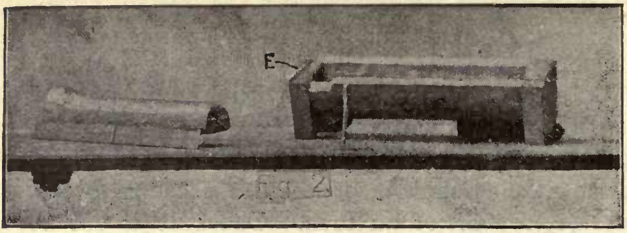


FIG. 114.—CHILL PIG MOULD AND CASTING.

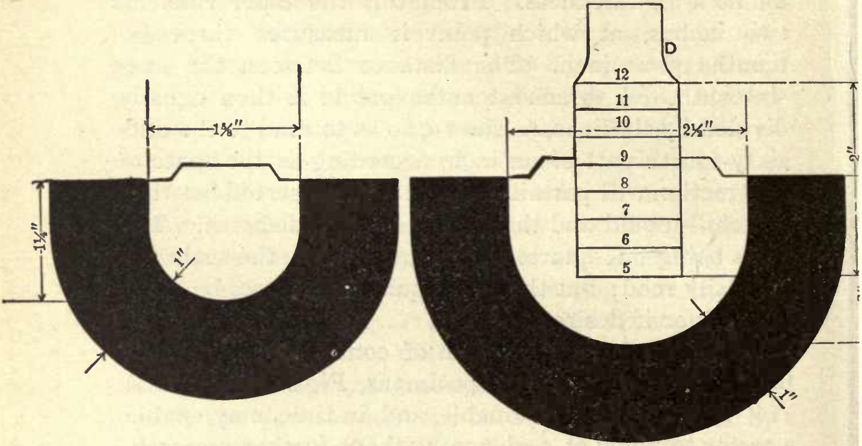


FIG. 115.—CROSS SECTION OF SMALL AND LARGE CHILL PIG MOULDS.

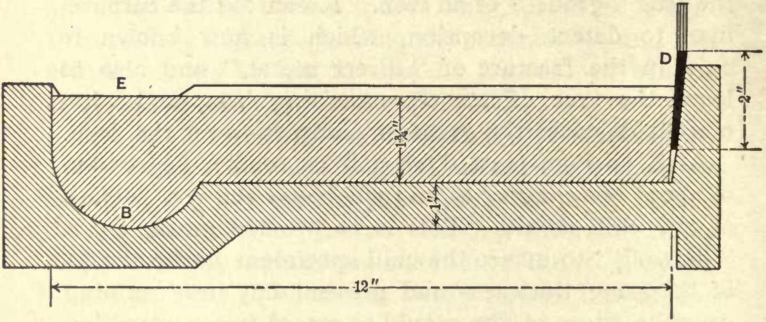


FIG. 116.—LONGITUDINAL SECTION OF CHILL PIG MOULD.

By using together the chill-moulds of both sizes, as shown in Fig. 115, an excellent illustration will be afforded of the reasons why many castings crack or pull apart, owing to the work being badly proportioned. The small pig test specimen will always show a greater contraction than the large one. Such ill results in cracks, etc., are often placed on the furnace-man's shoulders by claiming that he had sent "bad iron." Should a furnace-man not care to use these

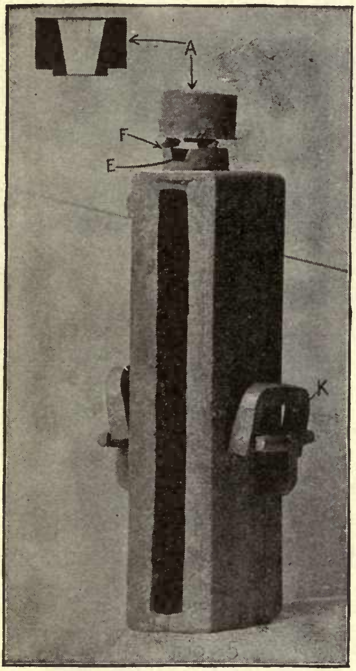


FIG. 117.—MOULD READY FOR CASTING.

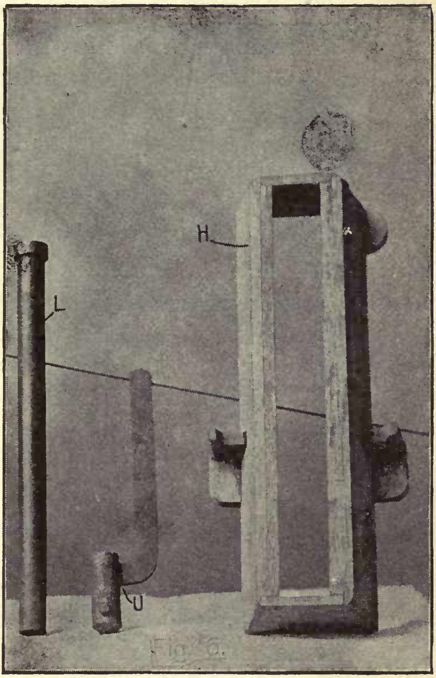


FIG. 118.—FLASK AND PATTERN.

two sizes of chill-moulds at one time, he may, under proper conditions, adopt either for constant use. In the case of very low grades of iron it might be necessary to adopt the larger chill-mould, since in the smaller one the iron might "go all white."

In moulding test-bars for determining transverse or tensile strength or the deflection or stretch of an iron, the author has advised a very simple design of a flask and one which would not require a $4-per-day moulder to make the mould. Any intelligent laborer can be taught in a very little while how to mould and cast such bars successfully; and this can be easily done in about two minutes.

In starting to mould a single test bar, the round test bar pattern, L, and the fluidity-strip pattern, U, Fig. 118, are laid in the recesses of the mould board, Fig. 119, which has previously been solidly placed. The half-flask, H, Fig. 118, is then laid on the mould board, rammed up and rolled over, and then the "cope" is put on; clamps, at K, Figs. 117 and 120, having been put on to hold the two parts close together while the cope is being rammed up. Before lifting the cope, the test bar pattern L is pulled out endwise. The cope is now lifted off; the fluidity-strip pattern, U, is drawn out; the cope is put on and clamped; and the mould is up-ended ready for casting, as seen in Fig. 117. The iron cup, A, Fig. 117, is used for the purpose of providing a wide funnel to pour into and keep the dirt from passing down with the iron. The slot cut in the iron end of the flask, as seen at E, Figs. 117 and 121, is to prevent the iron, as the mould fills up, from rising high enough to touch the under side of the cup. Should the metal in coming up quickly, as it does, strike the under part of this cup, an explosion could occur, making the iron fly in all directions. By the plan devised such accidents are prevented.

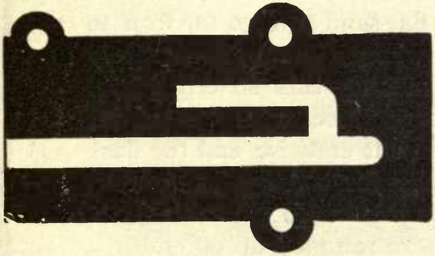


FIG. 119.—PLAN OF MOULD BOARD.

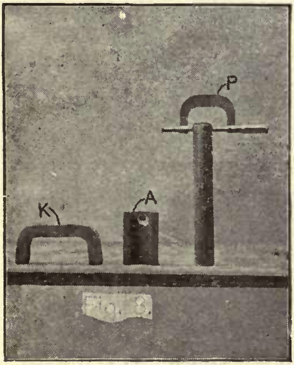


FIG. 120.—CLAMP, CHILL AND MICROMETER.

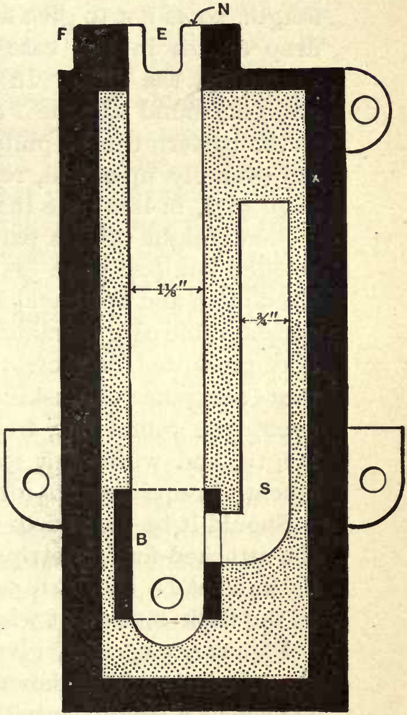


FIG. 121.—SECTION OF MOULD.

In cases where the fluidity and chill tests are not desired, and a plain round test bar only is wanted (which, for general purposes, will serve many ends), a plain round pattern, as at L, Fig. 118, page 507, which in the rough is one and one-eighth inches in diam., or, in fine figures, 1.1284 inches, is all that is required. (Plans for casting plain bars are seen on pages 521 and 527.) It is well to have the lower end of this pattern made a little pointed for about three-fourths of an inch of its length, so as not to give a flat sand surface for iron to drop on, as in the case where the bar is entirely square on the end. In making this strictly plain, straight, round bar, the "cope" need not be lifted off, as the pattern can be pulled out endwise and the flask immediately up-ended, ready for casting (as seen on page 507), in less time than it takes to tell it.

Some might think a pattern rammed up on end in a wooden box (see page 527) would answer just as well. To do this and not have any swells on the bar requires considerable care in ramming the mould. By the plan here presented, no more time is required, and there is more assurance of unskilled labor obtaining a perfect, even, true round bar, free of all swells for its entire length, and without a joint mark on it. These are essential requirements for a test bar.

Should it be desired to cast only plain bars, without the attached fluidity-strips, the hole in the end of the flask, as at N, Fig. 121, could be placed in the center of the flask instead of where it is shown in the figure.

Fig. 112, page 503, gives all the dimensions of the single test bar flask shown in Figs. 117 and 118. Fig. 113 shows a single bar with its fluidity-strip S, as taken from a mould. The two projections shown on the bar in this figure, also at A and M, Fig. 103, page 482, constitute plans to be utilized to measure the contraction of such bars when they are moulded in jointed flask.

The simultaneous casting of duplicate test bars, illustrated in the next Chapter, shows the design of flask, mould board and patterns, with the improved "whirl gate," which the author designed in the year 1895 for "running" round bars cast on end. The method complete is one which the testing committee of the Western Foundrymen's Association has used with the greatest success in obtaining perfectly solid bars. As furnacemen advance in the work of physical tests, many may desire to take up questions which the single cast bar will not permit of investigation, requiring bars cast double, plans for which are cited in the next Chapter. Whether the exact plans presented in this paper be adopted or not, the principles upon which they are based cannot be ignored in the attempt to secure true physical tests at the furnace or foundry.

As a supplement to this Chapter, the author desires to again call attention to the importance of the adoption by the engineering and foundry world of test bars of a size that can establish a fair relation to the chemical analysis of iron, or accord with the commercial value which usage has given to degrees in its strength. By a study of Chapter LXIX., page 528, it will be seen that we should not use a bar smaller than of one square inch area.* A few are still adhering to the use of one-half inch square bars, claiming that they have value in giving a "sensitive test." I would ask such, after having studied pages 454, 467 and 484, if they have not drawn the wrong conclusions, or if this does not truly mean that bars as small as one-half inch square or round are so "sensitive" to variations in the "temper" or dampness of sands and degrees in fluidity of metal, as to make them very erratic, and hence valueless to be used for a comparative test in any one single grade of iron, to say nothing about their inability to denote degrees of strength in the various grades used in general founding.

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*The American Foundrymen's Association recommends that bars should not be smaller than one and one-half inches diameter. See pages 487 to 573.

CHAPTER LXVII.

DESIGN OF APPLIANCES AND METHODS FOR CASTING ROUND TEST BARS ON END.

To successfully cast round test bars on end, when the contraction or fluidity is required in connection with the strength and chill of iron, it is essential to utilize a flask, etc., designed especially for such work. Figures 122, 123, and 124, pages 514 to 516, illustrate the design of flask, mould board and patterns with the "whirl-gate" which the author has designed for such a purpose. The test bar patterns and runner are illustrated at H, H, and F, Fig. 128, page 524. These patterns are also seen at D D and A, Fig. 122, page 514. The plan of drawing the patterns out endwise as shown avoids the necessity of any rapping of patterns; hence, if the mould is fairly rammed and the pins of the flasks fit true, it will be evident that few, if any, joints will be seen on the bars obtained.

Moulds cast on end from a parallel pattern will always be largest at the bottom, owing to the head pressure. In making the test bars patterns D D, Fig. 122, for the first standard mentioned in Chapter LXIX., as an illustration, have them 1.1284 inches in diameter, at one end and 1.0884 at the other. In common figures these would measure one and one-eighth inches diameter at the large end, and one and three-thirty-seconds of an inch at the small end, and of the same length seen in Fig. 122. By having a ring at the large end, as seen at H, Figs. 122 and 128, the smaller end will always be the down one in moulding, and in ramming the mould, do so to such a degree of hardness as to permit sufficient straining, due to head pressure, to have the castings come out closely alike as to size at the bottom and top.

It is well to mention at this point that should any desire to make their test bars in a "dry-sand" mould, they can readily do so, as there is no wood whatsoever connected with the flasks, thus making it practical to place the mould in an oven to be dried. For malleable and steel testing and some special purposes in iron, a "dry-sand" mould might often be found a very good method to adopt.

Referring to the question of "chilling," it cannot but be readily seen that as arranged by this system, the test bar and the chill must remain in close contact until removed by hand, hence truly recording the full chilling qualities of the iron. At V V, Fig. 126, page 522, can be seen the chill used in this system. It is simply two half-circles three inches long by three-eighths of an inch thick, having a hole drilled in them to fit over the pattern tips W W, Fig. 122, These chills are set on over the pattern before starting to fill the nowel with sand, and in shaking out, must, of course, be picked up and used as long as they last. They are made of a soft steel shaft, which, after being drilled or bored out, are then split as seen. See page 502.

In the case of very hard grades of iron, such as would go "white" in the one and one-eighth round test bar at the chill end, when a chill was placed on the pattern in ramming the mould which embraces such iron as is used in car wheel, chill roll, and gun metal—the author would advise the adoption of the second or third standard bars of one and five-eighths inches and one and fifteen-sixteenths inches in diameter described in Chapter LXIX. If the chill goes all "white" in the largest bar, he would use the largest chill block mould seen in Fig. 115, page 506, as a

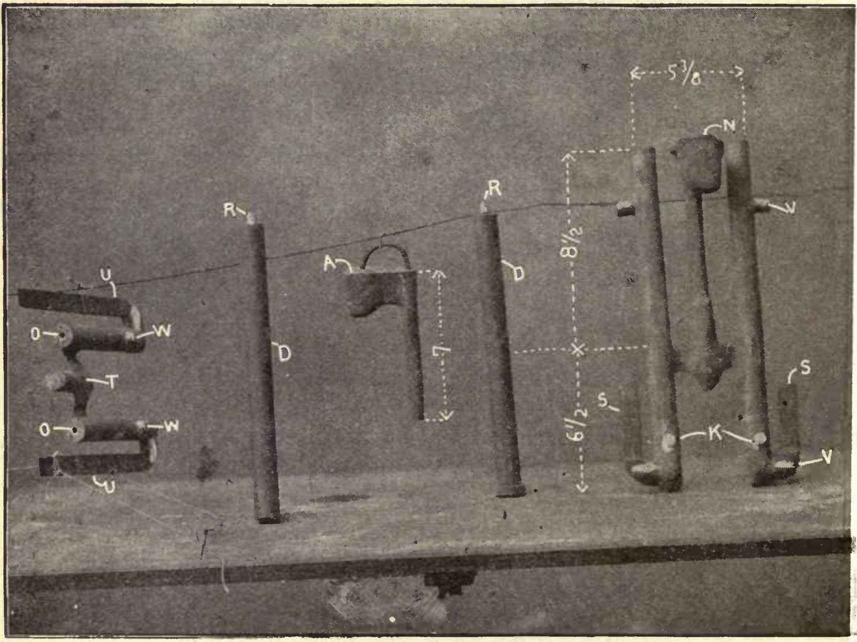

FIG. 122.—WHIRL-GATE, TEST BAR PATTERNS AND CASTING.

standard. To find the depth of a chill with either of these round test bars, hold the chill end (after a bar has been tested) over a solid piece of iron and strike it as seen in Fig. 125, page 522. A notch being cast in the chill end opposite the chill side, as seen at X, Fig. 103, page 482, permits the bar being readily broken when held as above described. To measure the depth of a "chill," consider only that portion turned "white" and the depth it has been chilled is to be defined by the eye.*

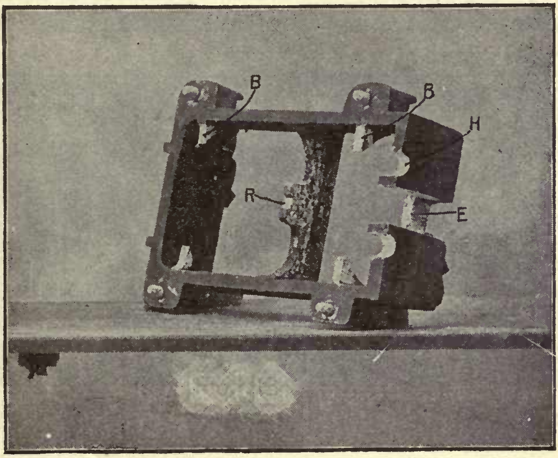

FIG. 123.—NOWEL HALF OF FLASK.

Knowing that the degree of fluidity has an effect and should, for close, fine work be recorded in order to make intelligent comparisons, the author has, in combination with other new features of this system, provided at U U and S S, Fig. 122, an arrangement made possible with this system, by which we can measure the

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* A plan to take blue prints, etc. of chills is seen on page 588.

height metal will rise in a long, thin wedge. These fluidity and life measuring strips are ten inches long by three-fourths of an inch wide, as at S, in Fig. 121, page 509. The base of these strips measures one-eighth of an inch thick, and they run up to a knife edge at the top. They are a very sensitive thermometer to denote both the fluidity and life of metal, as will be found by any one adopting the system. Having the fluidity strips poured in a vertical position, as arranged in this system in connection with the heavier bodies, prohibits any forced or unnatural pressure to be exerted, so as to have the strips falsely record the fluidity of metal when bars are poured. The metal cannot rise in the fluidity strips any faster than in the test bar, and hence the strips must have a gradual rise. Their measurement can be accepted as practical and representing the true fluidity and life of metal at the time it is poured. Take such fluidity strips and cast them flat (See Fig. 71, page 375); the length they "run" are largely determined by the way they are

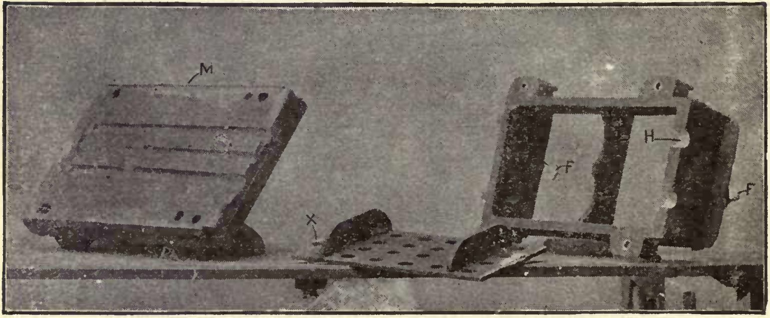

FIG. 124.—MOULD BOARD, BOTTOM PLATE AND COPE HALF OF FLASK.

poured. Unless great care is used, one may be able to make them "run" fully four inches farther than if they were poured steadily, whereas, when poured vertically, as in the author's system, if there is a quick dash at any time it cannot raise the metal in the fluidity strips any faster than in the test bar moulds, thereby causing a natural and equal rise to truly denote the metal's fluidity or life at the moment the bars are poured.

To obtain the contraction of a bar, the distance between the points or tips V V, Fig. 122, page 514, is measured. These contraction tips are accurately cast in the mould by means of four projections forming part of the flask, two of which are seen at B B, Fig. 123, These projections "chill" one face of the contraction tips V V, thereby giving a clean face to measure from. The lower tips are given form by reason of a swell being made at the base of the fluidity strips, as will be seen at the lower V in Fig. 122. The upper tips are formed by having loose tip patterns placed in the recesses of the mould board as seen, in such a manner that the uppermost projection B of the flask is on the top side of the tip V. By this arrangement full freedom for expansion at the moment of solidification is permitted, as when this takes place it can extend its length downward in the sand forming the bottom of the mould. These contraction tips are cast twelve inches apart and will be found as arranged to provide positive points for obtaining the contraction of any "grade" of iron.

At A, Fig. 122, is seen the pattern used for forming the pouring basin and runner which leads to the "whirl-gate." At N is shown how the pouring basin and runner look before being broken from the test bars. The reason for the recess seen in the end of the flask at E, Fig. 123, is to prevent the metal rising above that height at the close of pouring, and thus not give the metal a chance to form a "fin" between the top joint of the flask or over the top of its ends at H and thus still the more positively insure the casting's own weight pulling the contraction downward instead of the contraction pulling the whole body of the casting upward from the bottom of the mould, a factor which has been the cause of pulling the neck off from rolls or causing checks or total separation of parts in other kinds of castings. The cross bar in the flask is formed, as seen at R, Fig. 123, for the purpose of fitting over the runner where it connects with the whirl-gate's basin, to assist the same end just mentioned in compelling the contraction to follow a natural tendency, and not lifting the whole weight of a casting upward, as previously explained. At R R and O O, Fig. 122, are seen male and female pins and holes, which are arranged as shown so as to insure these two sections of the patterns coming together at true points, to make it impossible for the action of the rammer to distort them in any way.

In making the "whirl-gates" seen at T, Fig. 122, the operator must so proportion them that the runner joined to the basin A, Fig. 122, can carry the iron to the inlet of the "whirl-gates" as fast as they can deliver the metal to the mould, the idea being that as soon as the pouring is commenced, with either of the three standards, the upright runners are so proportioned that the pouring basin N can be kept full of iron, to prevent any dirt passing down the runner through the "whirl-gates" to the mould. Owing to the small diameter of the one and one-eighth inch test bar, when this size bar is used, care must be taken in getting a good form to the "whirl-gate." If that form shown in the cut at T, Fig. 122, is closely followed, it will be found to give an excellent whirl to the metal as it rises in the mould, so as to bring any dirt that may by chance flow with the metal into the mould up to the top of the casting, and thus cause all test bars to be of a sound fracture when broken. The "whirl-gate" portion of the pattern seen on the left of Fig. 122 is made of brass or babbitt metal. The fluidity strips UU are cast in the main patterns after they are finished to the proper size. These fluidity strips can be made of any thin piece of wrought iron or steel. To strengthen the union of the "whirl-gate" portion of the pattern with the body of the test bars, brass or copper wire is laid in the mould and "cast in." The size of the "whirl-gate" where it joins the one and one-eighth inch diameter bar is about one-eighth inch in thickness by one inch wide. For the one and five-eighths inch, one and fifteen-sixteenths inches diameter bars, make this part of the gate one and one-quarter inches and one and one-half inches wide respectively, maintaining the same thickness of one-eighth inch as above shown in the one and one-eighth inch diameter bar.

It will be noticed that iron-perforated bottom-plates are used instead of wooden bottom boards to give a backing to the "cope" and "nowel" when up-ended in order to prevent the pressure of the metal from bursting the mould when cast at such points. To secure these iron bottom plates in place rapidly, strips of iron are pivoted at F F, Fig. 124, on the main part of the flask as seen, then, by having a tapering projection cast on the bottom plates, as seen at X, Fig. 124, a few taps of a hammer on the binding strips F F are all that is necessary to secure the bottom plate in place.

Specifications often call for tests from turned bars. The author has arranged for such a test in a very simple manner, requiring but little machine work. At T, Fig. 127, page 522, is shown a bar having a swell cast on it. This can be made from six inches to eight inches long and of the diameter necessary to cause the "grade" of iron used to be readily machined to 1.128 inches, 1.596 inches or 1.955 inches diameter, so as to equal a one, two or three square inch area section and conform with the diameter of the rough bars given above for unfinished testing. The harder the grade of iron the larger diameter necessary at T to lessen the influence to chill or cause metal to be too hard for turning. But this should not exceed one and five-eighths inches diameter with the one and one-eighth inches diameter bar. Any iron that will be found too hard to be machined in this diameter of one and five-eighths inches of a swell, the second size or third size of a standard bar could then be utilized in having a swell cast on, half an inch larger in diameter than plain rough bars called for. Whatever size of a swell is used, the same should be constantly used, in order to always have the same amount of stock to be turned off a test specimen. There are very few grades of iron which can not be machined from a body one and five-eighths inches diameter. The author has had bars with a swell of one and five-eighths inches diameter, cast on one and one-eighth inch bars with grades of iron used in making chill rolls, car wheels and gun metal, and found no difficulty in having them machined, as shown by the turned bars given with the cuts seen on page 472. The plan adopted to form these swells is simply to place half sections of patterns, as seen at N N, Fig. 126, over the regular test bar pattern when moulding them; then when the cope is lifted off, they are drawn separately from the mould. Of course, bars can be cast plain their full length and then have a recess about three inches long turned into them, instead of following the swell plan, wherever this is preferable.

The flask's dimensions for casting 1⅛ inch round bars, as seen in Figs. 123 and 124, are to be made eight and one-half inches by 17 inches inside measurements and four inches deep. To cast two, one and five-eighths inches or one and fifteen-sixteenths inches test bars, for the second and third standard, mentioned page 533, the only change necessary in the whole system is to make the flask ten inches to eleven inches wide on the inside. If desirable, one flask could be made to answer for moulding either the one and one-eighth inch, one and five-eighths inch or one and fifteen-sixteenths inch diameter bars, simply by having a flask 11 inches wide and the holes in the end of the flask at H, Figs. 123 and 124, made one and fifteen-sixteenths inch diameter, also the one and one-eighth inch or one and five-eighths inch test bar patterns to have a swell of one and fifteen-sixteenths inches diameter at the point where it would rest, or fill the hole H when the bars are being moulded.

When the strength only is desired, then bars can be moulded in any common jointless flasks for the length of the bars or by "bedding" them in the floor simply by standing patterns on their end to ram them up on the plan illustrated on page 527. In gating and pouring such bars the metal is best dropped from the top through a cope, and not allow it to strike the sides of the mould, and when two or more bars are moulded in one flask, their top pouring "gates" should be all connected to one pouring basin, made deep enough so as to keep the "gates" full of metal when the bars are being poured. By careful work, plain bars can be cast on end by this plan that will prove sound when broken. Plans for single bars are described, page 509, and plans for two or more plain bars being cast together are seen in Fig. 129, page 527.

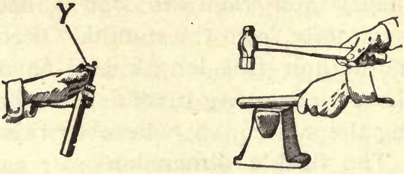

FIG. 125.

FIG. 126.

Let it ever be remembered that, at the best, a test bar can only be used to make relative comparisons in the physical qualities of mixtures, and to properly secure these a size and form of a bar must be used that is not sensitively affected by the dampness of a green sand mould, and degrees in fluidity of metal. This demands that a bar be of round form, not less than one and one-eighth inches in diameter, and that such is best cast on end, as is displayed by reading Chapters LVI., LIX. and LXV.

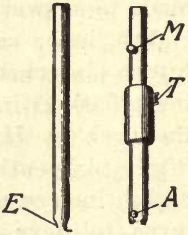

FIG. 127.

CHAPTER LXVIII.

MOULDING, SWABBING AND POURING TEST BARS.

In moulding test bars, every precaution should be taken to insure a uniform treatment at all times. The sand should always be of the same "temper," as far as practical, rammed regularly, and of the same degree of hardness. The best way to attain this is to select some one intelligent man, who will make it his business to do all the moulding and casting of test bars which shall be required for any one department. The end to be sought in obtaining test bars is that they should be as near as possible the size of the pattern from which they are moulded. There are two factors affecting these results. The first is in the ramming and "temper" of sand, the second, in drawing the patterns. Practice, with some, is such as to require more or less jarring or rapping of the patterns before they were removed from the mould, and while one moulder might not do so to a perceptible degree, another might go to the extremes. A system to be favored in making comparisons in one's own shop, or in the case of one firm with another, should be arranged so as to remove any semblance of the necessity of rapping or jarring patterns. For moulding test bars, some space as near the cupola as practical should be devoted for this special work and there should be a place for every tool and all kept as neat and clean as possible.

After a mould has been rammed up, by the author's system, the round portion of the test bar pattern is then pulled out endwise, before the cope is lifted off, as seen in Fig. 128, this page. For a handle to draw out the test bars endwise, two inches of the patterns project outside of the flask as shown at H. The cope is then lifted off and the balance of the pattern and gates drawn out. After all loose sand or dirt has been blown out lightly with a pair of bellows, the cope is closed on, flask clamped, and then up-ended ready for casting, as seen in Fig. 130, on page 527.

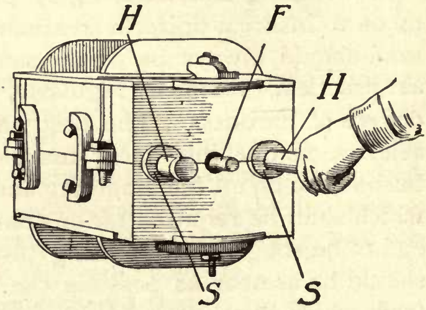

FIG. 128.

In drawing out the test bar patterns endwise, give them a half-twist around the mould before starting to pull the pattern straight out and they will come very easily, as it only requires a pull of from eight to twelve pounds at the moment of greatest power to draw them out. The pattern should be kept well varnished or bees-waxed, so as to prevent the friction of the sand wearing them away by a few years' use or cause them to become rough, making a " dirty mould." When the chills at A, Fig. 120, and V V, Fig. 126, pages 509 and 522, are used, care should always be taken that they are not rusty or wet from any cause, as this could cause an explosion when pouring a mould. It is well to rub the chills with a very slight coating of coal oil or good machinery oil, where they are not in constant daily use.

The "swab" is something that should not be used in moulding test bars, if possible to avoid it, for the reason that if sands are made wetter in some portions of a mould than others, it affects the grain of the iron at that place, making it different from the rest, and hence it may be an element likely to cause erratic results and deception in recording the iron's true strength. If the sand is such that a swab must be used, it should be done with the greatest caution, especially at that part of the mould where the bar will break in being tested. The plan of pulling the patterns out endwise before the cope is lifted off, as devised by the author in his system, makes it unnecessary, with sand at all fit to mould test bars in, to use any water on the joint of the round part of the bar. The swab might be used a little around the gates, but it is best to avoid it if at all possible to make a clean, firm mould without doing so. Construct a swab so that the flow of water can be under perfect control by the lightest squeeze. To insure the stream or drops striking just the part or spot desired to be dampened, a good plan is to insert a piece of one-eighth inch wire, or long, thin nail, through the body of the swab, to project below it about two inches, as a guide to direct the stream. By using this design of a swab, it will be found that only the exact parts desired to be dampened will be affected, and the water will not be scattered all over the mould, making parts like mud, as is often done by the kind of swabs sometimes used.

In pouring test bars, use only "clean iron." Never take iron having slag or dross floating on top of it. Not only should the iron be clean, but a "clean ladle" should be used and skimmed off before pouring. While being poured it should be skimmed so as to prevent the oxide, which often rapidly forms on the surface, from passing into the mould.

With the use of round test bars cast on end, an intelligent comparison of one class of metal with another will demonstrate that there is a dividing line between soft and hard grades as to which would be the strongest with "hot" or "dull" poured metal. At present, that chiefly concerning us here is, at what temperature are bars best to be poured. As the founder chiefly makes tests for comparison, either to test his own mixtures or to furnish tests to compare with those of competitors, at the request of a middle party, it seems but reasonable and best that a temperature be maintained that would best conform with that generally used. I would not advise a metal being too "hot" or too "dull," but something that would average about four and one-half inches up in the fluidity testing tips S and S, Figs. 121 and 122, pages 509 and 514.

Some founders might say their iron was hotter and would run up higher to a fine edge than that. I am not disputing these, but I do question whether they will always obtain the same high fluidity; and then again the iron may come out of the cupola all right, but owing to some "hitch" in the moulder getting to his "floor" ready to pour at some one time, could throw them off in their calculations. All elements and conditions considered, it is decidedly best to pour at a temperature while sure to run and make solid test bars, still not so high but the temperature of day in and day out can be utilized and all delays allowed for, so as to maintain a close uniformity. By endeavoring to maintain about the same temperature when pouring, it would go a great way in enabling the tester to attach more value to any comparison he might wish to make with his past record, or with others.

The cut Fig. 129 is a plan for casting plain test bars on end, so simple that any foundryman can find flasks, etc., to instantly change from casting flat to that of casting on end, should he desire to do so.* E, E is the test bar mould. B, B are the "gates" connecting the pouring basin and the moulds. M, pouring well. P, cope. R, nowel. For further description, see pages 510 and 521.

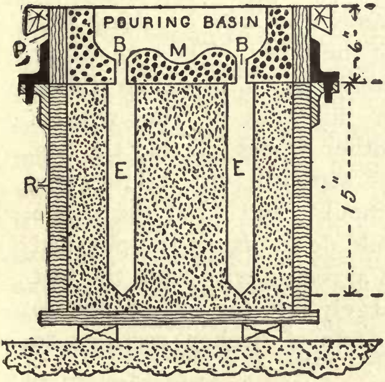

FIG. 129.

FIG. 130.

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*A few practice pouring bars on end without a cope, merely dropping the metal directly into the mould, but such a plan is more apt to give defective bars.

CHAPTER LXIX.

UTILITY OF THE TEST BAR AND STANDARD SYSTEMS FOR COMPARATIVE TESTS.*

Many lose sight of the real utility of test bars. They entertain the idea that they will give the actual strength, contraction or chill of single or unduplicated castings. The only way to obtain positive knowledge of these qualities is by making test bars of the same thickness and form, if possible, as those of the casting for which comparisons were to be drawn. In reality this would mean making two castings to be poured at the same time with the same iron, and breaking one to get the strength, etc., of the other. The true utility of the test bar is simply comparative, to define differences that may exist in mixtures of the various " grades " of iron, or, in other words, all that the test bar will do is to denote the strength, etc., of the iron which is poured into the mould; and what the shape and size of that mould would do to distort the physical qualities of the iron from agreeing with what the test bars have recorded, is largely left for experience to guess at or comparative tests of broken castings to define.

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* Revised paper presented by the author to the Foundrymen's Association, Philadelphia, Pa., December 2, 1896.

Where there are many duplicates, as in the manufacture of car wheels, pipes, etc., we can, by breaking a few castings, and test bars that have been cast out of the same ladle of iron, obtain a very fair base as a standard for future comparisons of what may be expected in the castings themselves from test bars from future mixtures. This is not saying that single castings made of the same pattern, cast at different times, could not have any comparative knowledge imparted of their strength, etc., by reason of using a proper test bar, cast with the same ladle of iron. If a single casting stands desired usage and the builder or buyer has a record of test bars that was poured of the same iron with the casting, he generally can rest fairly assured that, if at any other time he should get another casting made from the same pattern with test bars that would show a similar strength, he would have a casting that would be fairly equal in strength, etc., to the first one made. And again, the use of these can often prove protection to builders that have machines broken by claimants for unjust damages, as, for instance, in the case of punch and shear castings, which are often broken by reason of carelessness on the part of workmen or attempts being made by the proprietors to utilize a machine above the strains guaranteed. For if the builder can prove that previous castings, which had tests recorded from test bars, had stood the guaranteed strains to compare closely with the casting that broke, he cannot be far out of the way in maintaining the position that the close comparison of all his test bar records justified him in assuming that all castings made from that one pattern should be closely alike, for the reason that they can be classed under the head of duplicates similarly as cited above for car wheels, etc., the only difference being that these single castings are not cast in large numbers and may have months intervening between their production, so that in a practical sense castings can, when they are occasionally duplicated, have the test bar records accepted to denote their physical qualities in a comparative manner, as where any number of castings are steadily or daily made from the same pattern.

The utility of the test bar is being more and more recognized and made use of. The author believes that within ten years almost all founders and engineers will recognize standards for physical tests.* How are we going to be able to make intelligent comparisons with our own records or those of others, where we find bars as small as one-half inch square to two inches square being used, and some of rectangular form and again, it can be said, in all kinds of lengths, from a foot up to four feet long, so that we practically find hardly two founders using the same form or length of a bar, or builders and engineers exacting the same character of tests? Some will say that the difference in both the length and area of such a variety of bars could be computed to strength per square inch, in making comparisons. It can be shown (see Chapter LXI., page 476) that there is about as much difference to be found in formulas for computing such variations as is found above in test bars, and also that so eminent and able an authority as Prof. C. H.

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* Many consider that the distribution of the first two editions of this work, in connection with the author's advocacy of round bars cast on end in trade papers, is largely responsible for the conditions leading up to the recommendation by the American Foundrymen's Association of the proposed standards seen in the next chapter.

Benjamin, of the Case School of Applied Science, has shown that formulas used prior to 1901 are unsuited and incorrect for figuring the strength of cast beams, etc.

The prevailing practice of recording tests to-day may, in some cases, where test bars not less than of one inch area are used, be accepted as an approximation in so far as relates to a firm's own practice in making comparisons for mixture, with permanent hands, but should a firm desire to bring in a new manager or tester, who has been guided in rulings or records obtained from other shop practice or systems, his past experience will prove of very little value to him; hence the firm must lose in many ways before the new man is enabled to be rightly guided by information which he can deduce from his new system. Then, again, a manager or tester in making any changes from one work to another is also a loser and is subjected to the same inconveniences, etc., just mentioned. This shows us that both sides can lose some, saying nothing as to what is lost by their not being able to make intelligent comparisons with the outside foundry and engineering world, or with blast furnaces from which large quantities of pig metal must and should be intelligently purchased. Present practice shuts us up like a clam, and makes us dead to all the benefits which a standard of physical tests could insure. Progression demands something broader and of more correct utility than the practice of 1901 insures.

In reviewing tests recorded of test bars or castings in our engineering text-books of the past, we find the practical utility of the same to be largely lost, for the reason that there is no base presented upon which to formulate mixtures, to duplicate fairly the "grade" of the iron comprising the casting or test bar whose strength, etc., has been recorded. If for each test of all such castings or test bars we had a standard system, we could then by referring to the tests of any mixtures in our own practice which had recorded similar physical qualities in a test bar, be at once in a very favorable position to obtain or produce a similar casting, having like physical qualities. Some might suggest chemical analyses of the castings being recorded in order to give a base for making comparisons and duplication of like castings. This would work admirably in all cases, but of the two methods the physical test is often more economical and practical for adoption by some founders, for the reason, that there are some who can generally conduct physical tests, but who cannot maintain a laboratory with its chemist, or engage outsiders. Even where founders are equipped with laboratories, the physical tests are necessary as a "hand-maid," to tell what is being achieved, and still further argue for the advisability of a standard system of physical tests.

If there were no difference in the "grade" of an iron to make a difference in the hardness, strength, contraction, etc., of mixtures or castings, then we would not require any physical tests, but when we consider mixtures of iron can be made ranging all the way from 600 to 4,000 pounds, with one square inch area bars twelve inches between supports, it plainly illustrates the benefits to be derived by accompanying a casting with tests obtained from the same ladle or iron by means of suitable test bars, whether the strength is obtained by means of transverse or tensile tests to make comparisons.

Because the 1⅛-inch round bar is large enough not to have its carbon severely distorted to make tests erratic or belie the ruling power of the percentage of iron, etc., in the metal, by the chilling influence of a green sand mould, and also because it is not so small but that strong grades can often, for rough estimates, be used for comparison with weak grades on low-priced testing machines, are reasons why the author used a bar as small as 1⅛-inch diameter as one standard for making comparative tests. Having shown in many tests, (page 468) that the 1⅛-inch round bar will fairly record degrees in the strength of cast iron to fairly agree in a comparative way with the commercial value attached to the strengths of the various mixtures ranging from stove plate up through light machinery, heavy machinery, car wheel, chill roll and gun metal, the author would now refer to two other sizes, 1⅝-inch and 1$\frac{15}{16}$-inches diameter as being also well fitted for recognition as standard bars. The two latter sizes of bars are best utilized by founders who may make mixtures containing less than 1.50 in silicon and above .04 in sulphur. For those above 1.75 in silicon and below .07 in sulphur in the test bar or casting, the 1⅛-inch diameter bar will be found to generally record fair comparisons in degrees of strength.*

It is to be understood that while either size of the above three proposed standard bars would not err much in recording true degrees in the strength, deflection, and contraction where comparisons are to be made in any one "grade" or in

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* While the 1⅛-inch round bar will answer fairly well for making general comparisons in all irons having over 1.75 silicon and under .07 sulphur, still the author approves the recommendations found on page 573, which show that test bars should not be smaller than 1½ inches in diameter, and cast on end, as such will give truer results than the 1⅛-inch round bar in general practice, especially in making comparison of the widest ranges in grades.

all of them, the same size bar must be used. One size bar cannot be used for one per cent. silicon iron and then dropped and another taken up to test percentages above or below this. (See Chapter LXVII., page 520.) Whatever size of a common sense bar the testers use, in making comparison through any range of work, they must stick to that one, and then, if they desire to make comparison with outside records that have been obtained with standard bars other than the one size they use, they would then be compelled to make tests with the same size of bars which was used to obtain the outside test. Of course, if a firm desired, they could cast the three sizes of bars together, mentioned on page 533, with the same ladle of iron, and thus always have at hand records by which they could make comparisons on a moment's notice, with any outside tests that had been obtained with either of the three standard sizes of bars mentioned herein.*

The following Tables, 108 to 113, pages 536 and 537, display tests of the author's proposed three sizes of standard bars, accompanied with a chemical analysis of the various mixtures shown to still increase their value. A study of these Tables (combined with those of Chapter LX., page 460), the author believes, will sustain him in his advocacy of the 1⅛-inch, 1⅝-inch and 1$\frac{15}{16}$-inch round test bars as well fitted for and to maintain a standard of comparative physical tests.

The tests presented are obtained from the actual mixtures used for pouring castings in the various specialties mentioned, and, as seen, are arranged in the order of their strength. Double the amount of tests were made, but those shown illustrate the relation of the different areas in strength per square inch as

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* For three other standards, see pages 573, 577 and 579.

well as large numbers could, and make study an easy task to readily demonstrate their utility as being suitable for standard comparative tests.

The tests shown are all of solid bars cast on end, and they illustrate among other valuable features the fact that the two and three square inch area round bars record a greater strength per square inch than the one square inch area round bars. This series of tests also shows conclusively that no one should use a test bar smaller than of one square inch area with the expectation of making any fair comparisons of degrees in the strength, etc., of his irons.* While the one square inch area round bar shown does not record the high strength for strong metals that the larger bars do, it is made very evident that they do record degrees of strength fairly accurate for use in a comparative test for soft irons or those above 1.50 in silicon for ordinary testing, a fact also demonstrated by the specialty tests as seen in Table 96, page 466, showing a gradual rise, in denoting degrees of strength in different grades of iron ranging from 1,480 to 3,686 pounds per square inch.

The test bars shown in this chapter were cast during the month of May, 1896, and were kindly supplied by the foundries of the Lloyd-Booth Co., Youngstown, O., Philadelphia Roll & Machine Co., A. Whitney & Sons, both of Philadelphia, Pa., the Shenango Machine Co., and Graff Stove Foundry Co., both of Sharon, Pa. The test of "Bessemer," Table 113, was cast by the author.

Tables 108, 110, 111, 112, and 113 were tested by Prof. C. H. Benjamin at the Case School of Applied Science,

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*This is in keeping with the recommendations of the A. F. A., not to use bars smaller than 1½ inches in diameter. (See next chapter.)

and those of Table 109 by the Riehle Bros., of Philadelphia, Pa. The relative strength per square inch is obtained by dividing the actual breaking load by the area of the bar, at its point of fracture. (For rule, see page 476.)

TRANSVERSE TESTS OF SPECIALTY IRONS WITH ONE, TWO AND THREE SQUARE INCH AREA TEST BARS.

TABLE 108.—CHILL ROLL IRON.

No of test.	Diam. of bar. Common rule.	Microm-eter.	Breaking load.	Area of bar.	Stre'gth per sq. in. in lbs.	De-flection.
1	1 ⅛″	1.140″	3,250	1.021	3,183	0.105
2	1 ⅝″	1.655″	9,500	2.151	4,417	0.090
3	1 15-16″	1.968″	15,250	3.042	5,013	0.085

TABLE 109.—GUN CARRIAGE METAL.

No. of test.	Diam. of bar. Common rule.	Microm-eter.	Breaking load.	Area of bar.	Stre'gth per sq. in. in lbs.	De-flection.
4	1 ⅛″	1.122″	2,780	.988	2,812	0.100
5	1 ⅝″	1.664′	9,250	2.174	4,254	0.110
6	1 15-16″	1.859″	11,820	2.714	4,355	0.100

TABLE 110.—CAR WHEEL IRON.

No. of test.	Diam. of bar. Common rule.	Microm-eter.	Breaking load.	Area of bar.	Stre'gth per sq. in. in lbs.	De-flection.
7	1 ⅛″	1.174″	2,200	1.082	2,033	0.053
8	1 ⅝″	1.690″	8,100	2.244	3,610	0.070
9	1 15-16″	2.008″	13,500	3.167	4,263	0.072

TABLE 111.—HEAVY MACHINERY IRON.

No. of test.	Diam. of bar. Common rule.	Microm-eter.	Breaking load.	Area of bar.	Stre'gth per sq. in. in lbs.	De-flection.
10	1 ⅛″	1.187″	2,800	1.1066	2,530	0.092
11	1 ⅝″	1.705″	7,100	2.282	3 111	0,072
12	1 15-16″	2 001″	11,900	3.143	3.786	0.079

The chemical analyses seen in Table 114 were kindly furnished by Dickman & Mackenzie, of Chicago, and Dickman & Crowell, of Cleveland.

Aside from the attention which has been called by this paper to various points in the following tests, there are two factors which some may be at a loss to understand. The first is the break in the gradual in-

TABLE 112.—STOVE PLATE IRON.

No. of test.	Diam. of bar. Common rule.	Microm-eter.	Breaking load.	Area of bar.	Stre'gth per sq. in. in lbs.	De-flection.
13	1 1/8″	1.182″	2,500	1.097	2,288	0.117
14	1 5/8″	1.745″	6,030	2.391	2,530	0.078
15	1 15-16″	2.047″	9,900	3.288	3,011	0.081

TABLE 113.—BESSEMER IRON.

No. of test.	Diam. of bar. Common rule.	Microm-eter.	Breaking load.	Area of bar.	Stre'gth per sq. in. in lbs	De-flection.
16	1 1/8″	1.175″	2,150	1.084	1,983	0.100
17	1 5/8″	1.698″	5,500	2.263	2,430	0.100
18	1 15-16″	1.991″	8,900	3.112	2,860	0.085

TABLE 114.—CHEMICAL ANALYSIS.

Specialty.	Silicon	Sulphur.	Mang.	Phos.	Comb. Carbon.	Graph. Carbon.	Total.
Chill Roll..........	.84	.071	.285	.547	.61	2.45	3.06
Gun Metal..........	.73	.059	.408	.453	.76	2.47	3.23
Car Wheel..........	.78	.132	.306	.364	1.07	2.36	3.43
General Machinery	1.30	.053	.224	.433	.58	3.31	3.89
Stove Plate.........	2.47	.094	.265	.508	.19	4.00	4.19
Bessemer Iron.................	1.52	.059	.326	.083	.49	3.73	4.22

crease of strength of the 1⅛ bars, which is displayed by test No. 7 being weaker than tests Nos. 4 and 10. This is due to the high sulphur in the iron when in a small body as of 1⅛ inches diameter, causing the combined carbon to overreach its limit for gradually increasing the strength of the 1⅛-inch bars, as shown by the break in tests Nos. 1, 4, 10, 13, and 16. Test No. 7 is one which strongly emphasizes the wisdom of not using bars smaller than 1½ inches in diameter where the best comparative records are desired, and strongly endorses the A. F. A. recommendations, seen on page 577. The second factor is that shown by the low strength displayed by the "Bessemer" iron shown in Table 113. Had the "iron" in the Bessemer Table 113 been near the percentage seen in Table 111, for heavy machinery, the strength of the test bars in Table 113 should have nearly equalled that of Table 111. To note the influence of "iron" on the strength of grades, see Table 37, page 250.

CHAPTER LXX.

METHODS OF CASTING TEST BARS FOR THE A. F. A. TESTS, COMPILATION AND SUMMARY OF RESULTS.

Prior to about 1890, there had been felt for many years the need of tests on cast iron, to give those interested in its use reliable data of its physical qualities. Some work had been done in an effort to obtain records that could be used, but before the appointment of the American Foundrymen Association's committee, in the spring of 1898, little of practical value had been obtained aside from that presented in the first two editions of this work. This was due in part to the want of a broad experience in founding by experimentors, and their inability to originate practical methods for moulding and casting test specimens in the right manner. Some, for one example, started off with an elaborate series of tests on one grade of iron only, thinking that such would suffice, when in reality there are about a dozen grades that should be considered. Aside from this error the bars were all cast flat, and at different pouring temperatures.

The unreliability of records and systems for testing that were pressed on the trade from 1890 to 1899 caused the author to labor in every way he could to show wherein they erred, and to get others interested sufficiently to help bring about a series of tests that would result in giving the engineering and foundry world elaborate records of tests, secured through means that recognized the different grades, and the importance of having all tests in any one grade poured at the same temperature. The many tests and papers which the author presented demonstrating the errors of past methods of testing cast iron, finally resulted in awakening foundrymen and others to the necessity of taking some action in the matter; and by the valuable assistance and efforts of Dr. Richard Moldenke, the author had the pleasure of seeing the A. F. A. appoint a committee, at its annual convention in 1898, to obtain such tests as were thought necessary. This committee consisted of Dr. Richard Moldenke, Messrs. James S. Sterling, Joseph S. Seamen, Joseph S. McDonald, and the author. The first work of the committee was to outline the kind, sizes, and number of test bars, and the method of moulding and casting. The latter was left wholly to the author, as he had stated that he could devise a method whereby a large number of different sized test bars, comprising green sand and dry sand moulds as desired, could all be cast on end, from one ladle of iron inside of thirty seconds, thus insuring all bars of any one set being poured with metal of practically the same temperature. Some doubted the practicability of such an achievement, and not until after the first set of 192 bars were cast on end from one ladle, within twenty seconds and no bars lost, was such recognized as being feasible. This was an achievement that should place all the tests of the A. F. A. on a plane far above all others ever made; at least, all who have noted to any degree the variations

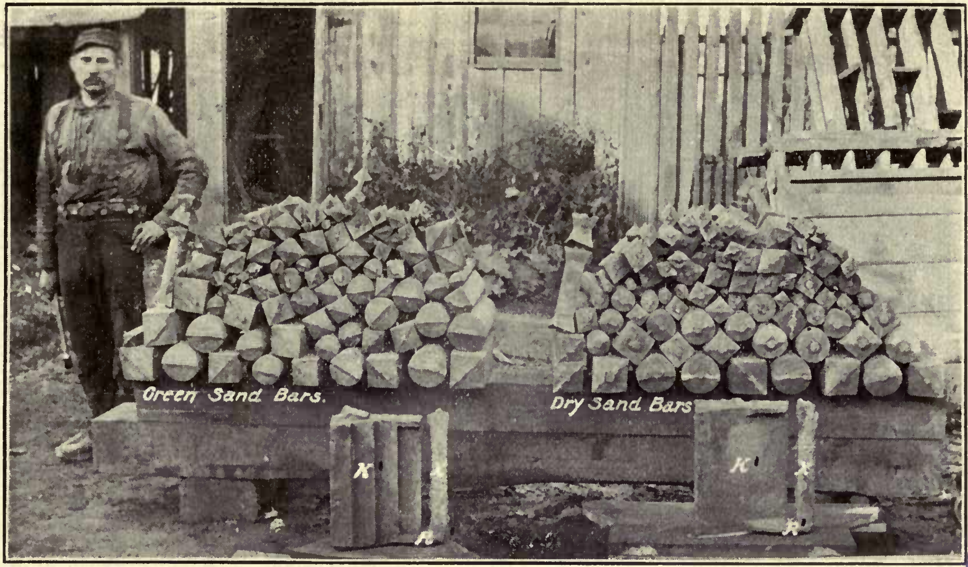

FIG. 131.

A Set of the A. F. A. Test Bars all Poured at same Temperature.

that can exist in the physical qualities of cast iron due to variations in the pouring temperatures, must perceive its importance.

The first cast of the test bars, also the chill and fluidity test pieces, are seen at Fig. 131, page 541. The patterns and core boxes used are shown in Figs. 132 to 136. At Fig. 137 is seen one of the malleable iron flasks used for making the green sand bars from the mould boards seen in Figs. 133 and 134, pages 544 and 546. The flask, as shown, is clamped and upended ready for lowering into the casting pit, to be placed as seen at K, Fig. 138, page 550. The making of all these patterns, core boxes, and flasks was under the supervision of Dr. R. Moldenke while engaged as metallurgist with McConway & Torley of Pittsburg, and who donated them to the committee in the interest of the trade. Doctor Moldenke is to be credited with having done most of the work in making the patterns and fitting up the flasks.

The floor space required for casting a full set of these bars was eight feet wide by eighteen feet long, dug out to make a pit about three feet deep. The time required to mould and cast a full set as shown in Fig. 131 involved about thirty days' labor. The first set was made under the author's close supervision; in fact, he did considerable of the work. After the pit was dug out a level floor was made in the bottom and all the green sand moulds and cores were set in place after the manner shown in Fig. 138. These set, sand was rammed around all the flasks and cores up to the level of K and W, Fig. 140, page 552, after which a double row of vents was made down each side of the cores and flasks. A bed of fine cinders was next

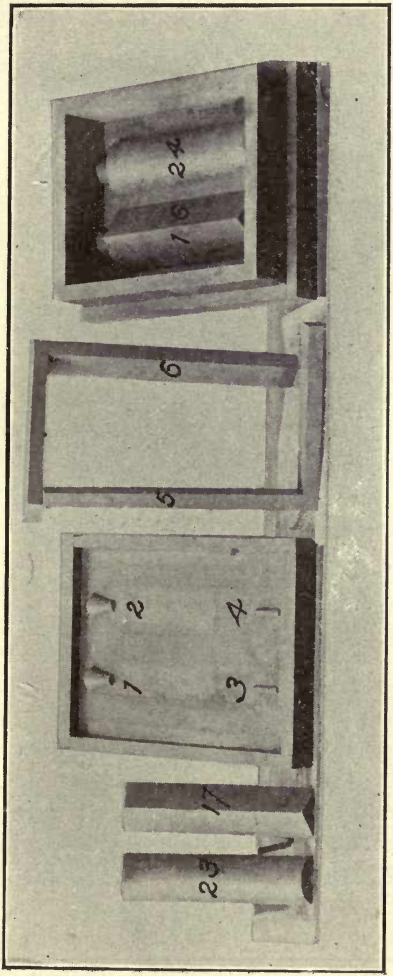

FIG. 132.

Core Box for Moulding Dry Sand, Square and Round Test Bars. Cores are seen at W, page 550.

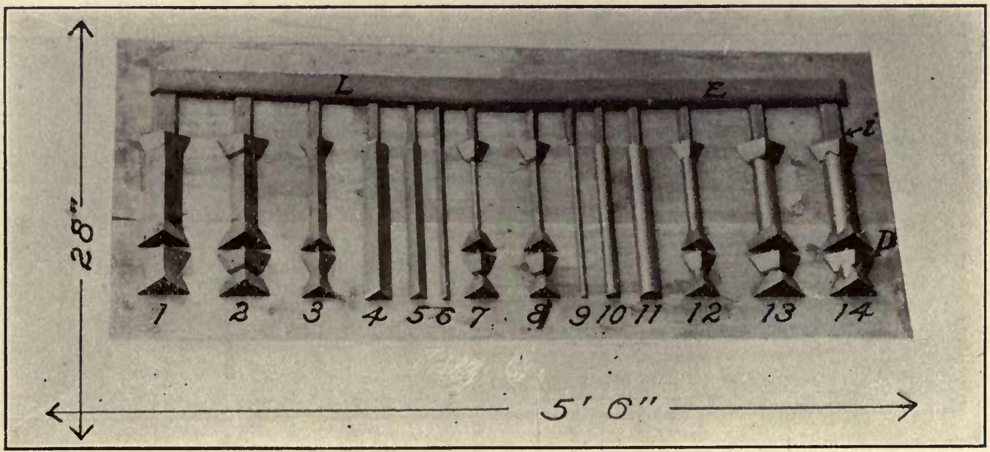

FIG. 133.

Mould Boards, Gates and Nowel Half of Patterns for Moulding Tensile and Transverse Green Sand Test Bars, seen on left of Fig. 131, page 541.

laid at the level of K and W, as shown by the black dots in Fig. 140. The cinders were also brought out to come under the pouring basin A, Figs. 139 and 142, pages 552 and 554, after which cores to form the gate connection G and risers E, seen in Figs. 138 and 139, were placed in position as shown, and sand was then rammed up to a level of the top of the cores and moulds. To keep the dirt from dropping into the mould through the gate holes seen at W, Fig. 138; while ramming up the pit, boards, to cover the gate holes (not shown), were used. After the pit was rammed up to a level of the top of the cores and flasks, these boards were removed and runner patterns of the form seen at Fig. 136, page 548, were then placed over the cores to form runners in connection with the main basin A, as seen at Fig. 140. This done, plates were set on edge as at M, S, and X, after which the inlet plate H was set up against the plates S, and plates as at B set against its ends after the manner shown. This completed, a board 12 inches deep by 15 feet long was braced 11 inches away from the face of H and the whole bed was then rammed up and finished to appear as seen at Fig. 142. This cut also shows men in position to test lifting the inlet plate H by means of levers Y, resting on the plate M, to come under lugs N. Stops, as at P, prevented the inlet plate being lifted to any greater height than 2½ inches, which insured clean metal only passing to the moulds, as when the basin A was filled by the ladle U, as seen on page 556, all dirt was confined and remained upon the surface of the metal in the basin A. Two risers were carried from the two outside flasks, as at E, and left uncovered when casting, so that when the moulds were filled all surplus metal

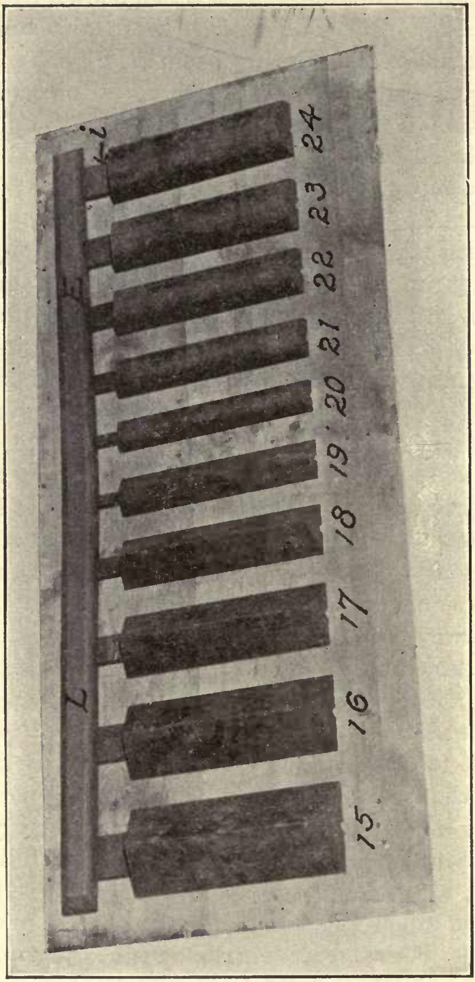

FIG. 134.

Mould Board, Gates and Nowel Half of Patterns for Moulding large Transverse Green Sand Test Bars, seen on left of Fig. 131, page 541.

remaining in the basin and runners flowed out readily to pig beds having a lower level than the pouring basin and runners as seen at C, Figs. 142 and 143, thus leaving the moulds disconnected to be removed singly from their casting pits after the gate connections between the flasks at G were broken. The basin A being, as shown, one foot wide and deep, gives a body of fluid iron weighing about three tons, uniform in temperature. And when it is said that from the moment the inlet plate H was lifted to the time the 192 test bars and two chill blocks, all weighing when cleaned 3,780 pounds, were all poured scarcely twenty seconds passed and no bars were lost, all will realize the success achieved.

Casting half the bars in dry sand cores was done for the purpose of making a comparison between the effects of a green and dry sand mould and to give greater completeness to the results. The dry sand bars were made in cores instead of iron flasks, for the reason that it was thought that some of the shops the work was assigned to might not be in a position to dry the dry sand moulds, but could handle the cores.

In making the cores it was very desirable to have them of a character that would crush easily when the bars commenced to contract, as anything preventing this might strain the bars internally so as not to give a true test. The author adopted the following mixture for making the cores:

1 part lake, river, or bank sand,
3 parts fine silica or crushed sand,
1 part rosin to 25 parts of sand,
1 part of flour to 25 parts of sand
1 part glutrose to 30 parts sand.
Wet balance with water.

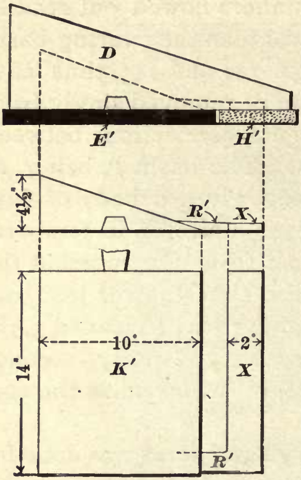

FIG. 135.

The core mixture mentioned possesses very little body to stand up in a green state; so little that, in making the larger cores, rodding was very necessary, in order to hold the cores together. When this mixture is dry the cores are exceptionally strong to handle, but crush very easily when the castings commence to contract. To form the small neck in the green sand tensile test bars as at D, Fig. 133, cores made of the above mixture were used as at F above, Fig. 136. This division in the tensile test bars was made for the purpose of giving a long and very short test specimen.

To obtain the contraction, a device, Fig. 144, page 557, was arranged so as to punch ⅜-inch holes in the cores and green sand molds. These formed pins in the mould that were exactly 12 inches apart, so that when the castings were cold the contraction could be accurately

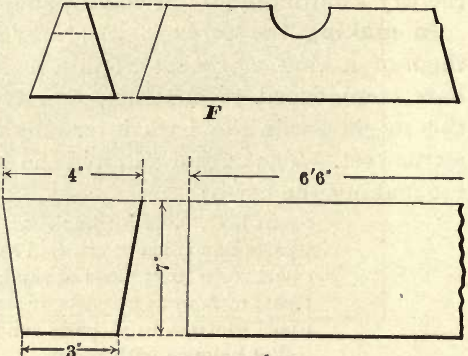

FIG. 136.

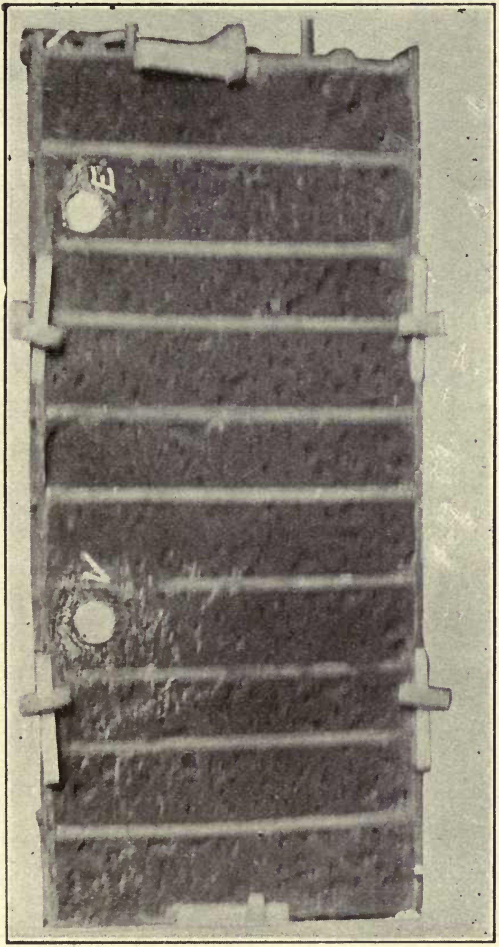

FIG. 137.

A Flask of Green Sand Test Bars up-ended, ready for placing in Casting Pit and set as at K, pages 550 and 552.

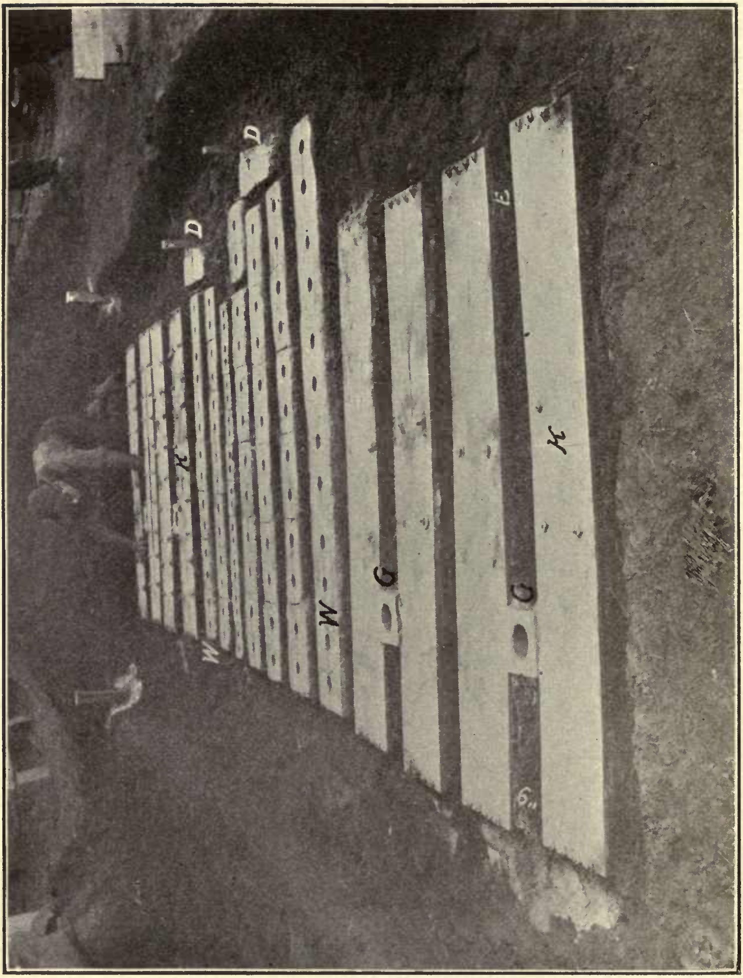

FIG. 138.

Perspective Plan View of Green and Dry Sand Moulds to be Poured at one Time, when Runners, etc., are measured. The few records shown will give a fair idea of the ratio of contraction in the large and small bars.

To obtain the chill, the author devised the form of test block seen in Figs. 135 and 145, pages 548 and 559. It was made of the wedge form seen, so that the block could be used throughout all the different grades. These chilled tests were cast in a core having one face part chill and part core, as seen at E′ and H′, Fig. 135. The chill E′ was 1½ inches thick. The chill tests, Figs. 145 to 147, pages 559 and 563, chilled but slightly at the top points and face, while the chill for chilled rolls (not shown) are all chilled, showing the hard nature of iron used for chilled rolls, etc.

The fluidity of the metal was tested by means of two fluidity strips ⅛ inch thick at their base, running up to a knife-edge 14 inches long, as seen at X, Figs. 131 and 135, pages 541 and 548. The principle involved in these fluidity strip tests is the same as described for those shown on pages 515 to 517, and they serve to show the difference that might exist between the fluidity of the various sets of test bars that were made and noticed in connection with the tests recorded from pages 558 to 570.

The different kinds of physical tests consisted of transverse, deflection, tensile, compression, contraction, and chill tests. The bars varied in size from ½ inch, square and round, increasing ½ inch in size in each class up to 4 inches square and 4½ inches round for transverse tests, and from ½ inch square and round to about 2 inches square and 2¼ inches round for tensile tests. There were four bars of each kind and size made in green sand and four bars of each

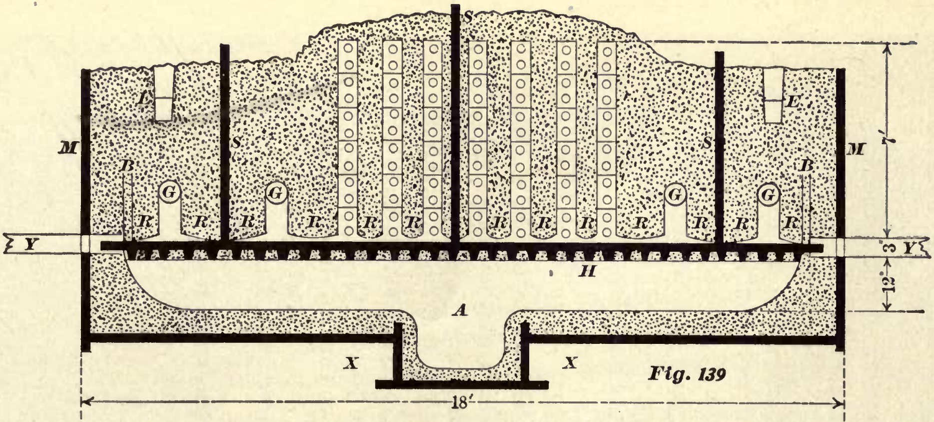

Fig. 139

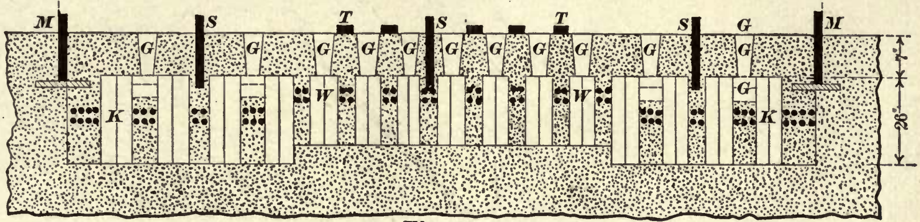

Fig. 140

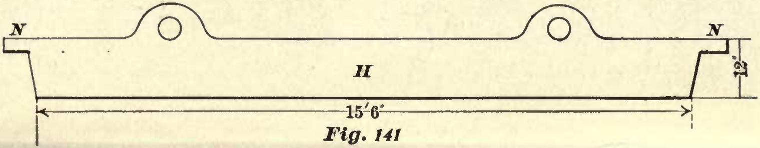

Fig. 141

Elevation View of Green and Dry Sand Moulds, ready for Pouring, as seen on pages 554 and 556.

made in dry sand, making a total of eight bars of each kind. Nearly one-half of the total number was finished by being planed if square, and turned if round bars, so as to make a comparison between the rough cast bars and those which had a trifle more than ¼ inch of stock removed from their surface. This was done by finishing down the rough bars to correspond in size to those of next smaller dimensions as, for example, a 4½-inch rough bar was turned down to a 4-inch bar, and a 4-inch bar down to a 3½-inch bar, and so on until a 1-inch rough bar was finished to a ½-inch bar. This finishing work was chiefly done by Dr. R. Moldenke.

There were 1,601 tests made on 1,229 test bars, not counting the chilled pieces and fluidity strips, making, roughly, 15 tons of test specimens that were handled. To tabulate all the tests as they originally appeared in the American Foundrymen's Association Journals, and which were originally designated from A to L, making a total of 12 different grades or specialties that were tested, would require more space than could be justly given here. In an effort to condense the results of the A. F. A. tests, and at the same time present a fair summary of the whole, the author has omitted, excepting in one or two instances, all tests of square bars and those of round bars cast in dry sand, which reduces the records to 282 tests as shown in Tables 115 to 126, pages 558 to 570. However, a study of what tests are presented in connection with the summary at the close of the tables will, the author believes, better serve the end for many than were all the original tables published, without reduction or comment at his hands. The work involved in obtaining these tests can only be known by those who have followed up such testing, and

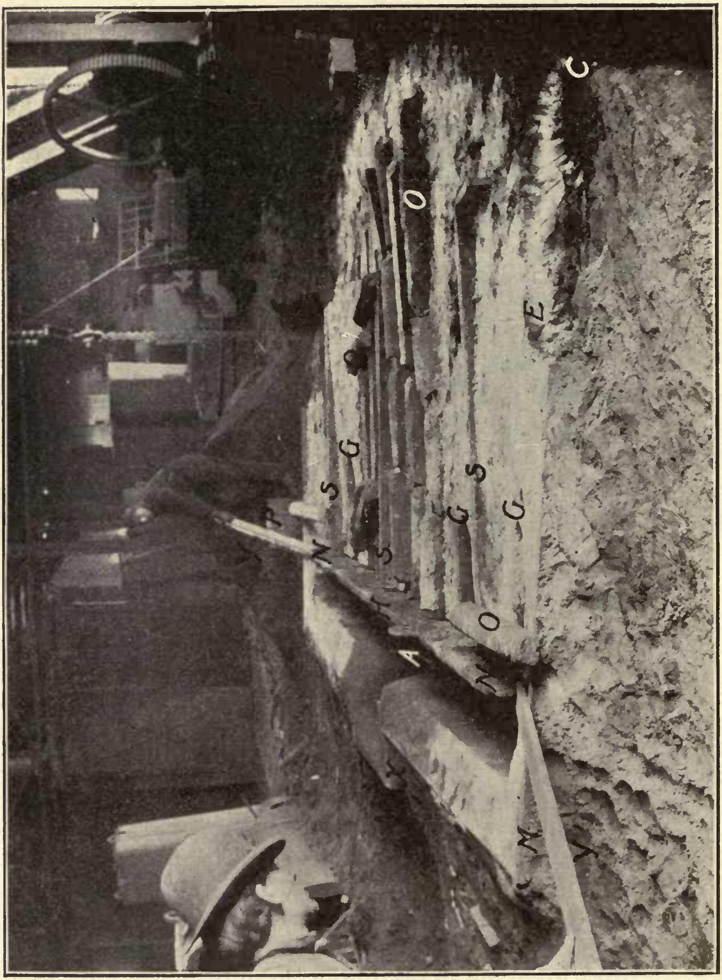

FIG. 142.

Perspective Plan View of Top Runners and Pouring Basin of the Illustrations seen on pages 550 and 552.

too much praise cannot be accorded Dr. Richard Moldenke, as chairman, for the great zeal, time, and much money he has expended in supervising and assisting in the accomplishment of this work. We have also to mention as entitled to credit Mr. H. E. Diller and Mr. A. Pechstein, who assisted Dr. Moldenke in making physical tests and chemical analyses. Credit is also due to the respective persons and firms mentioned in connection with each table of series A to L, for their valuable assistance and kindness in donating the castings required for the test bars.

The transverse bars were made about 15 inches long and tested 12 inches between supports. Any depressions that the knives might make in the surfaces of the round or square bars were noted in recording the deflection. Two tests were made, on an average, of each kind in all the different sizes of bars. The averages of the two tests in the original tables of the selected bars are recorded in Tables 115 to 126, so as to condense the results. The round bars are selected in preference to the square bars in compiling Tables 115 to 126, for the reason that they are better than square bars, as is explained in Chapter LXIV.

The tensile tests in original tables, all of which were compiled by Dr. R. Moldenke, were reduced to strength per square inch and shown in connection with their actual breaking load, but the author has separated these so as to give the strength per square inch of the tensile tests in the independent Table 126, to be above the chemical analyses of the different specialties shown in Table 127, both seen on page 570. The actual load at which tensile bars broke is shown in the last column of casts A, B, C and G to L. The form of bars as turned for the tensile tests is seen in Fig. 148, page 583.

The bars cast in dry sand and green sand showed

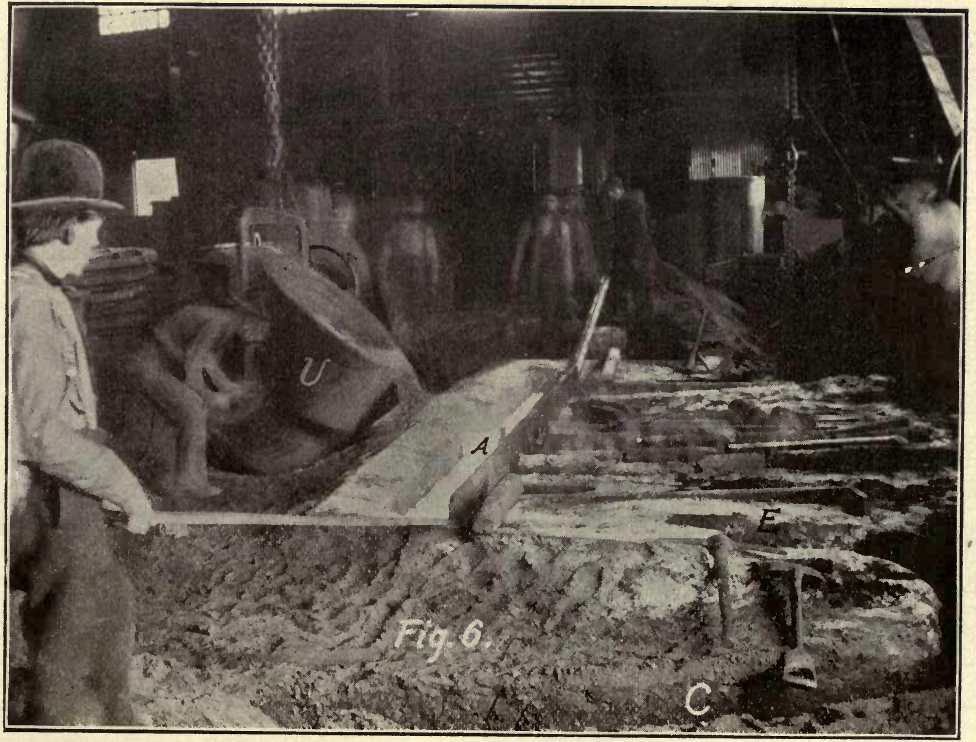

FIG. 143.

Perspective View of Pouring a Set of the A. F. A. Test Bars.

that, as a rule, those cast in the former moulds were weaker than in the latter. One hundred tests of different green sand bars, averaging closely alike in size, gave an average strength of 33,700 pounds, whereas 100 tests in dry sand bars gave an average strength of 31,751 pounds, showing a difference of 1,949 pounds or 6 per cent. greater strength for the bars in green sand than those in dry sand. The gray iron showed the greatest and most uniform difference. There were a few casts, in both the chilled and gray iron, in which the dry sand bars averaged the greatest strength. One of these varieties is shown in the unfinished dry sand bars of Table K 124, page 568. It is natural to expect the green sand bars to show the greatest strength on account of the chilling influence of a damp mould. The results of the original tables shown in the A. F. A. Journal also show that tests of green sand bars are more erratic than those of dry sand, although, as a rule, the difference is not sufficient to cause the dry sand bar to be given the preference in general practice; but where the greatest delicacy in testing is desired, by the use of unfinished bars, then the dry sand bar would be preferable. The author selected the bars from green sand for the Tables 115 to 126 for the reason that such are almost entirely used in general practice, and hence will permit of a better

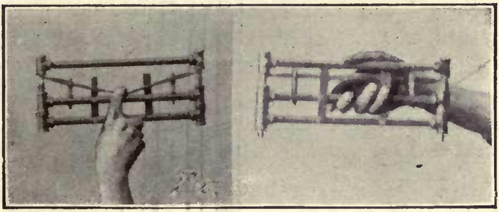

FIG. 144.

comparison. Further summary of results, especially those illustrated by Tables 115 to 126, are given by the author on pages 571 and 574.

TABLE A–115.—TESTS OF BESSEMER IRON CAST AT THE THOS. D. WEST FOUNDRY CO., SHARPSVILLE, PA.

Transverse tests of unfinished green sand bars.				Transverse tests of finished green sand bars.*				Tensile tests of unfinished and finished green sand bars.		
No. of test.	Diameter.	Break'g load.	Deflection.	No. of test.	Diameter.	Break'g load.	Deflection.	No. of test.	Diameter.	Break'g load.
1	.59	445	.173	9	.56	150	.305	16	.57	40,440
2	1.20	2,440	.130	10	1.13	1,880	.234	17	1.13	13,630
3	1.78	6,425	.126	11	1.69	5,430	.160	18	1.71	28,860
4	2.30	13,965	.110	12	2.15	10,025	.114	19	2.27	44,830
5	2.92	24,320	.101	13	2.82	19,150	.086	*Finished bars.		
6	3.44	36,875	.100	14	3.38	29,340	.072	20	.56	3,440
7	4.02	58,435	.090	15	3.95	51,985	.079	21	1.13	13,490
8	4.65	77,335	.082					22	1.69	27,520

***All the finished bars** shown in tests Nos. 9 to 15, as well as in all the finished bars in Tables 116 to 126, designated by stars, were made of rough bars cast in green sand that had a trifle over ¼-inch of stock turned off their surfaces. As an illustration, the tensile bars 20, 21, and 22 of the above Table 115 were of the diameter seen in transverse tests Nos. 10, 11, and 12 before they were turned

Compression tests from bars cast in dry sand of Table 115 showed a ½-inch cube cut from a rough ½-inch bar to stand 29,570 pounds, and a ½-inch cube taken from the center of a 1-inch square bar 20,010 pounds; from the center of a 2-inch square bar, 13,180 pounds; 3-inch square, 9,830; and 4-inch square, 9,100 pounds.

The iron used for Table 115 or cast A was an all-coke pig iron mixture having about 5 per cent. scrap melted in a cupola, and is a class of iron used for castings that

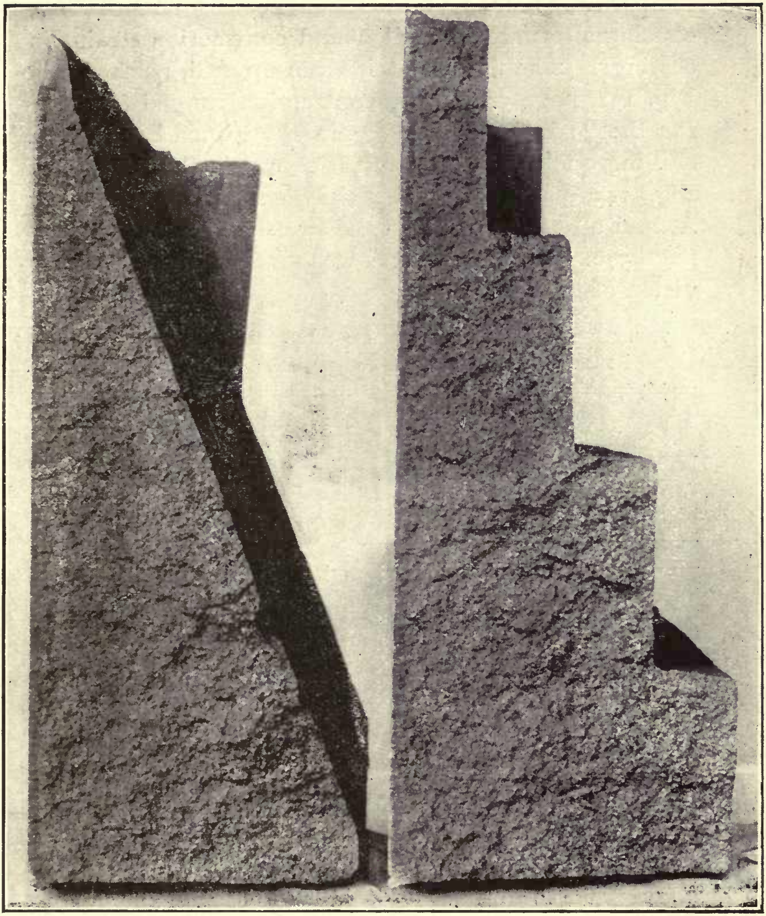

FIG. 145.—FRACTURE OF CHILL TEST PIECE IN SERIES A.

are required to show exceptional service under high temperatures or severe sudden heating and cooling, causing alternate expansion and contraction strains in castings. The fluidity strips ran up full, as shown in Fig. 131, page 541. The contraction ranged from .17 for the ½-inch bars to .03 in the 4-inch bars. The chilling qualities of the iron is shown in the test piece, Fig. 145, page 559. The chemical analyses of Cast A, and all others to Cast L, are shown in Table 127, page 570. This first cast A was made under the supervision of the author

TABLE B–116.—TESTS OF DYNAMO IRON CAST AT WESTINGHOUSE ELECTRIC AND MANUFACTURING CO., PITTSBURG, PA.

Transverse tests of unfinished green sand bars.				Transverse tests of finished green sand bars.*				Tensile tests of unfinished and finished green sand bars.		
No. of test.	Diameter.	Break'g load.	Deflection.	No. of test.	Diameter.	Break'g load.	Deflection.	No. of test.	Diameter.	Break'g load.
23	.58	210	.106	31	.56	230	.306	38	.58	4,440
24	1.17	2,300	.125	32	1.13	2,115	.160	39	1.12	15,540
25	1.74	7,070	.079	33	1.69	6,120	.115	40	1.70	29,140
26	2.26	15,780	.086	34	2.15	11,065	.080	41	2.27	46,580
27	2.86	31,470	.101	35	2.82	24,180	.095	*Finished bars.		
28	3.47	48,200	.095	36	3.38	41,485	.073	42	.56	4,750
29	4.01	73,550	.093	37	3.95	65,150	.065	43	1.13	15,370
30	4.62	100,120	.061					44	1.70	27,200

*For references to meaning of the star in Tables 116, 117, 120, 121, 122, 123 and 125, see paragraph following Table 115, page 558.

Compression tests of Table 116 from bars cast in dry sand showed a ½-inch cube cut from a rough ½-inch square bar to stand 38,360 pounds, and a ½-inch cube taken from the center of a 1-inch square bar 23,000 pounds; from the center of a 2-inch square bar, 18,130 pounds; 3-inch square, 13,790; and 4-inch square, 12,430 pounds.

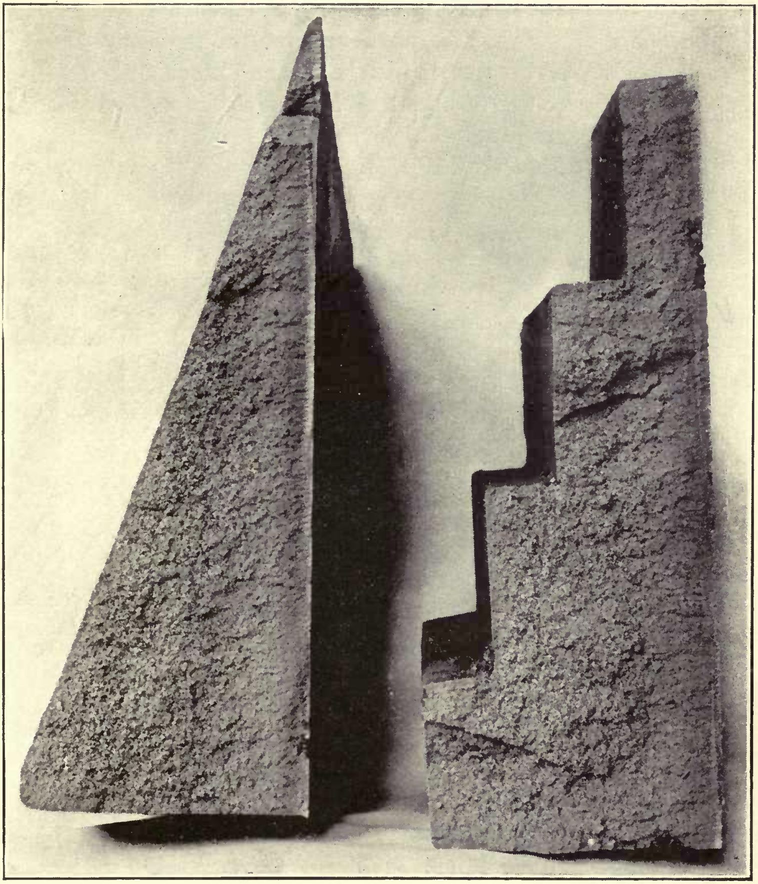

FIG. 146.—FRACTURE OF CHILL TEST PIECES IN SERIES B.

The iron used for cast B was soft enough to machine readily in sections little more than ½ inch thick. A mixture of coke and charcoal pig iron, with about 40 per cent. of scrap, was used and melted in a cupola. The fluidity strips ran up nearly full. The chilled test pieces gave a chill of about 1-16 inch thick, as seen in Fig. 146, page 561. This cast was made under the supervision of Mr. Jos. McDonald.

TABLE C–117.—TESTS OF LIGHT MACHINERY IRON CAST AT WESTINGHOUSE ELECTRIC & MFG. CO., PITTSBURG, PA.

Transverse tests of unfinished green sand bars.				Transverse tests of finished green sand bars.*				Tensile tests of unfinished and finished green sand bars.		
No. of test.	Diameter.	Break'g load.	Deflection.	No. of test.	Diameter.	Break'g load.	Deflection.	No. of test.	Diameter.	Break'g load.
45	.56	345	.155	53	.56	320	.305	60	.57	4,740
46	1.14	2,320	.119	54	1.13	2,235	.130	61	1.13	15,860
47	1.75	6,940	.085	55	1.69	6,780	.112	62	1.70	32,020
48	2.27	16,330	.079	56	2.15	12,495	.096	63	2.27	48,230
49	2.84	31,030	.088	57	2.82	26,965	.085	*Finished bars.		
50	3.43	50,200	.074	58	3.38	43,150	.086	64	.56	4,340
51	3.98	72,180	.067	59	3.95	72,695	.075	65	1.13	14,990
52	4.63	104,470	.044					66	1.69	26,030

Compression tests from bars in the above Table 117, cast in dry sand, showed a ½-inch cube cut from a rough ½-inch square bar to crush at 38,500 pounds, and a ½-inch cube from the center of a 1-inch square bar at 24,890 pounds; from the center of a 2-inch square bar, 18,010 pounds; 3-inch square, 15,950, and a 4-inch square, 14,220 pounds.

The iron used for cast C was of a character to run into very thin sections, and yet be soft enough to machine readily. About 40 per cent. scrap was used in a mixture of coke and charcoal pig iron, melted in a cupola. The fluidity strips ran up full. The chill

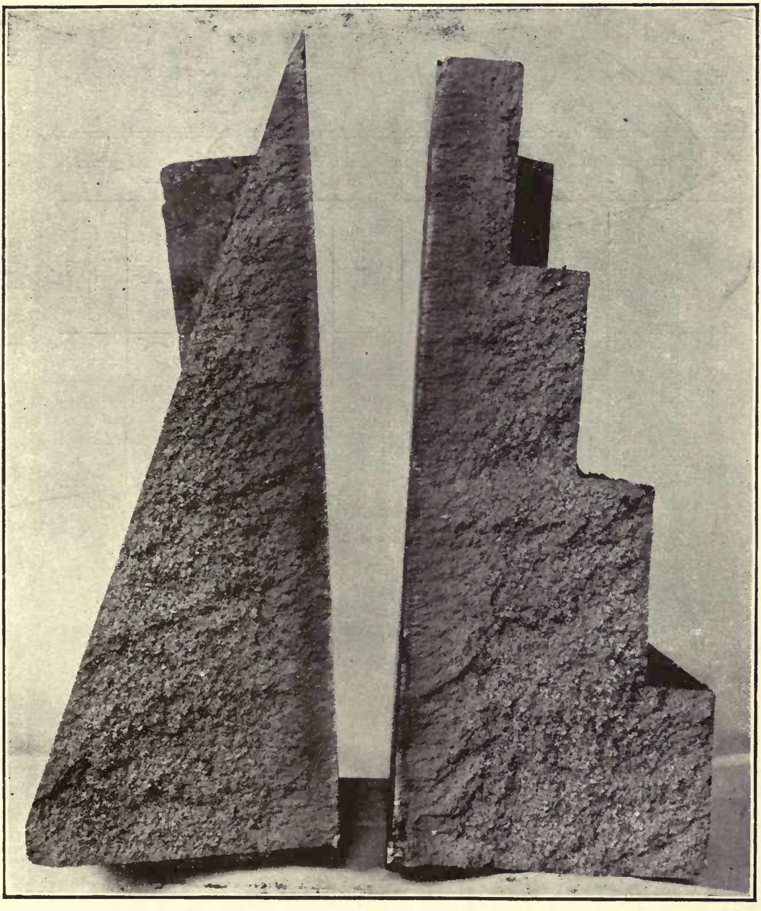

FIG. 147.—FRACTURE OF CHILL TEST PIECES IN SERIES C.

was merely perceptible, as shown in Fig. 147, page 563. This cast was made under the supervision of Mr. Benj. D. Fuller.

TABLES D & E–118.—TESTS OF CHILLED AND SAND ROLL IRON CAST AT SEAMEN, SLEETH ROLL CO., PITTSBURG, PA.

Transverse test of unfinished green sand bars in cast D.					Transverse tests of unfinished green sand bars in cast E.				
No. of test.	Diameter.	Breaking load.	Deflection.	Contraction.	No. of test.	Diameter.	Breaking load.	Deflection.	Contraction.
67	.54	280	.225	.....	75	.57	480	.280	......
68	1.14	2,460	.280		76	1.12	2,310	.215	.17
69	1.74	11,880	.270		77	1.73	7,100	.180	..
70	2.27	25,130	.248	.15	78	2.23	20,650	.190	.16
71	2.79	48,650	.220	.14	79	2.93	44,200	.180	.15
72	3.39	84,200	.200	.12	80	3.26	61,800	.190	.14
73	3.94	126,360	.170	.12	81	3.92	99,280	.180	.13
74	4.50	201,020	.160	.11	82	4.33	128,980	.150	.12

The iron for cast D was used for heavy chilled rolls, made from a mixture of cold blast charcoal pig iron melted in an air furnace. Transverse bars were cast only, for the D and E casts, as no data of commercial value could be obtained from tensile tests owing to the metal being all white in the sections falling within the scope of ordinary testing machines; in fact, the fractures of the chill test pieces of the pattern shown in Figs. 145 to 147 were white all the way through. The fluidity strips ran up full, showing good hot iron. The contraction ranged from .28 in the ½-inch bar down to .11 in the 4-inch bar. The smaller bars of the D and E cast were tested by the Pittsburg Testing Laboratory, and the heavy ones by the Riehle Brothers Testing Machine Co., Philadelphia, Pa.

The iron for cast E was used for making sand rolls and is of a class similar to Cast D, and must resist great bending strains and sudden heating of their surfaces. The iron used was warm blast charcoal, melted in an air furnace. Though the fluidity strips ran up full, some of the small bars were lost owing to the fact that such iron chilled quickly in a molten state. The chilled test pieces were white throughout the body, the same as with Cast D. The contraction ranged from .18 in 1-inch bars to .11 in 4-inch bars. This cast was made under the supervision of Mr. J. S. Seamen.

The iron used for cast F consisted of shop scrap mixed with old grate bars, rusty thin malleable scrap, and a white weak pig iron, melted in a cupola. The mixture gave a perfectly white fracture up to the 2½-inch sections, and slightly mottled in the center of the large bars. It was impracticable to machine this iron, and hence no such tests are shown. The fluidity strips did not run up full, showing the effect of oxidized iron, the chill extending throughout the whole casting of the test pieces. The contraction ranged from .28 in the ½-inch bars down to .11 in the 4-inch bars.

TABLE F–119.—TESTS OF SASH WEIGHT IRON.*

Transverse tests of unfinished green sand bars.*

No. of test.	Diameter.	Breaking load.	Deflection.	Contraction.
83	.55	170	.085	.29
84	1.13	2,760	.085	.26
85	1.69	6,270	.062	.20
86	2.15	15,480	.060	.....
87	2.81	35,900	.035	.16
88	3.40	54,420	.027	.14
89	3.98	72,870	.025	.12
90	4.51	86.420	.020	.11

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* This cast and those seen at G, H, I, J, K, and L, pages 566 to 569, were made under the supervision of Dr. Richard Moldenke, at the Pennsylvania Malleable Co.'s foundry, Pittsburg, Pa.

TABLE G–120.—TESTS OF CAR WHEEL IRON.

Transverse tests of unfinished green sand bars.				Transverse tests of finished green sand bars.*				Tensile tests of unfinished and finished green sand bars.		
No. of test.	Diameter.	Breaking load.	Deflection.	No. of test.	Diameter.	Breaking load.	Deflection.	No. of test.	Diameter.	Breaking load.
91	.54	420	.130	99	.56	370	.200	106	.55	7,440
92	1.13	2,450	.125	100	1.13	2,040	.205	107	1.13	26,830
93	1.69	7,290	.110	101	1.69	6,570	.170	108	1.71	44,100
94	2.14	14,880	.100	102	2.15	12,440	.140	109	2.27	62,760
95	2.84	27,020	.097	103	2.82	24,900	.150	*Finished bars.		
96	3.38	47,810	.080	104	3.38	44,130	.130	110	.56	6,770
97	3.97	70,550	.080	105	3.95	60,050	.120	111	1.13	24,480
98	4.50	86,100	.070					112	1.70	40,060

The iron used for cast G is such as was intended to resist abrasion and sudden increase of temperature on its surface, and also to be a good chilling iron. The mixture contained cold and warm blast charcoal pig iron, some coke pig iron, steel scrap, and old car wheels, melted in a cupola. Fluidity strips ran up full, and the chill was about ⅝-inch deep in the face of the chill test pieces.

TABLE H–121.—TESTS OF STOVE PLATE IRON.

Transverse tests of unfinished green sand bars.				Transverse tests of finished green sand bars.*				Tensile tests of unfinished and finished green sand bars.		
No. of test.	Diameter.	Breaking load.	Deflection.	No. of test.	Diameter.	Breaking load.	Deflection.	No. of test.	Diameter.	Breaking load.
113	.58	545	.130	121	.56	450	.240	128	.56	5,440
114	1.15	2,100	.120	122	1.13	1,570	.200	129	1.13	14,400
115	1.71	6,900	.120	123	1.69	5,100	.180	130	1.71	34,930
116	2.14	12,880	.105	124	2.15	10,660	.175	131	2.27	42,770
117	2.83	20,520	.100	125	2.82	18,740	.160	*Finished bars.		
118	3.39	42,360	.090	126	3.38	39,500	.140	132	.56	5,400
119	3.98	64,740	.090	127	3.95	55,000	.130	133	1.12	14,920
120	4.55	79,450	.080					134	1.69	30,110

The iron for cast H was intended for stove plate and very light ornamental or plain castings. The fluidity strips ran up full and showed the finest impression of mould. The mixture contained high phosphorus, coke pig iron, and stove plate scrap. No chill was seen in the test piece

TABLE I–122.—TESTS OF HEAVY MACHINERY IRON.

Transverse tests of unfinished green sand bars.				Transverse tests of finished green sand bars.*				Tensile tests of unfinished and finished green sand bars.		
No. of test.	Diameter.	Breaking load.	Deflection.	No. of test.	Diameter.	Breaking load.	Deflection.	No. of test.	Diameter.	Breaking load.
135	.58	390	.220	143	.56	300	.300	150	.64	7,560
136	1.13	2,490	.180	144	1.13	2,120	.270	151	1.20	24,210
137	1.70	7,010	.140	145	1.69	6,570	.240	152	1.71	25,740
138	2.17	14,140	.110	146	2.15	13,200	.200	153	2.28	39,660
139	2.84	28,110	.105	147	2.82	26,440	.165	*Finished bars.		
140	3.38	42,000	.095	148	3.38	40,000	.125	154	.56	4,510
141	3.97	58,770	.095	149	3.95	59,190	.130	155	1.13	14,120
142	4.52	73,400	.080					156	1.69	24,990

TABLE J–123.—TESTS OF CYLINDER IRON.

Transverse tests of unfinished green sand bars.				Transverse tests of finished green sand bars.*				Tensile tests of unfinished and finished green sand bars.		
No. of test.	Diameter.	Breaking load.	Deflection.	No. of test.	Diameter.	Breaking load.	Deflection.	No. of test.	Diameter.	Breaking load.
157	.55	420	.19	165	.56	300	.19	172	.57	5,970
158	1.15	2,550	.18	166	1.13	2,410	.16	173	1.14	18,580
159	1.72	5,544	.16	167	1.69	6,020	.14	174	1.70	38,300
160	2.16	14,340	.12	168	2.15	12,880	.11	175	2.27	62,440
161	2.84	27,770	.13	169	2.82	25,300	.12	*Finished bars.		
162	3.38	50,660	.11	170	3.38	42,420	.07	176	.56	5,860
163	3.93	66,240	.08	171	3.95	64,590	.06	177	1.13	20,070
164	4.51	78,970	.07					178	1.69	41,920

The iron used for cast I was made of all-coke pig, mixed with machinery scrap, and a little scrap steel, melted in a cupola. The mixture was intended for heavy machinery castings. Fluidity and chill not reported.

The iron used for cast J contained some steel scrap and high sulphur pig, mixed with a No. 1 foundry coke pig iron, melted in a cupola. The mixture was such as was desired to give a dense, even-grained iron having high wearing qualities, impervious to steam, air, and ammonia gases. The iron was quite fluid, and gave a chill about 1-16 inch deep in the face of the test pieces.

TABLE K-124.—TESTS OF NOVELTY IRON.

Transverse tests of unfinished green sand bars.				Transverse tests of unfinished dry sand bars.**				Tensile tests of unfinished bars in green and dry sand.		
No. of test.	Diameter.	Breaking load.	Deflection.	No. of test.	Diameter.	Breaking load.	Deflection.	No. of test.	Diameter.	Breaking load.
179	.57	200	.14	**187	.56	240	.17	195	.57	5,630
180	1.13	1,860	.11	**188	1.15	2,080	.13	196	1.15	17,860
181	1.69	6,000	.10	**189	1.68	5,810	.11	197	1.70	36,820
182	2.15	10,910	.07	**190	2.17	11,450	.10	198	2.27	51,180
183	2.85	21,030	.06	**191	2.84	21,950	.10	**199	.60	6,850
184	3.40	39,500	.07	**192	3.40	41,570	.07	**200	1.13	17,430
185	3.96	54,660	.04	**193	3.97	56,770	.05	**201	1.70	33,990
186	4.53	70,020	.03	**194	4.54	73,500	.04	**202	2.26	45,040

** As there were no tests of finished bars in green sand in this cast, we supplemented them with tests of unfinished bars cast in dry sand, designated by the two stars, as above.

The iron used for cast K was soft in very thin sections and also very fluid, and ran well. The mixture contained high silicon and phosphorus pig iron, stove plate scrap, and odds and ends of light junk scrap, melted in a cupola. The iron was intended for such work as locks, light hardware, and novelty castings, which includes light electrical supplies. The fluidity strips ran up full, and the chill test pieces showed only a slight evidence of a chilling effect beyond the closing up of the grain.

TABLE L–125.—TESTS OF GUN IRON.

Transverse tests of unfinished green sand bars.				Transverse tests of finished green sand bars.*				Tensile tests of unfinished and finished green sand bars.		
No. of test.	Diameter.	Breaking load.	Deflection.	No. of test.	Diameter.	Breaking load.	Deflection.	No. of test.	Diameter.	Breaking load.
203	.57	520	.24	209	.56	460	.35	216	.57	8,740
204	1.14	3,470	.17	210	1.13	3,260	.31	217	1.15	30,460
205	1.69	10,530	.15	211	1.69	9,710	.27	218	1.70	51,490
206	2.18	22,550	.14	212	2.15	20,480	.20	219	2.27	69,950
207	2.84	43,730	.12	213	2.82	41,190	.19	*Finished bars.		
208	3.40	75,460	.11	214	3.38	70,770	.14	220	.56	8,220
Two additional tests beyond range of machine.				215	3.95	98,640	.10	221	1.13	31,330
								222	1.69	47,000

The iron used for cast L was a mixture of the best grades of charcoal iron, and some steel and furnace scrap iron, melted in an open-hearth steel furnace. It is a class of iron that was intended for cannon and mortars, special dies, and heavy machinery castings requiring good strength and toughness, with uniformity of texture and dense granular structure. The iron was very hot and gave a chill of about 1-16 inch thick in the face of the chill test pieces.

Table 126, next page, gives the strength per square inch and table 127 gives the analyses, both of which are fully explained on page 555.

TABLE 126.—TENSILE STRENGTH PER SQUARE INCH OF UNFINISHED AND FINISHED BARS IN TABLES 115 TO 125.

Ap'rox. Orig. Diam.	A	B	C	G	H	I	J	K	L
.57	16,000	16,205	18,265	31,000	21,760	23,620	22,960	21,650	33,610
1.14	13,700	15,865	15,865	26,560	14,260	21,850	18,210	17,340	29,570
1.70	12,520	13,115	14,170	19,340	15,320	11,290	16,940	16,220	22,680
2.27	11,015	11,405	12,060	15,530	10,610	9,780	15,490	12,700	17,400
Fin. Diam.									
.56	13,762	19,000	17,386	27,080	21,600	18,040	23,440		32,880
1.13	13,490	15,375	14,994	24,480	14,920	14,120	20,070	....	31,330
1.69	12,230	12,525	11,570	17,810	13,380	11,100	18,630	....	20,890

TABLE 127.—CHEMICAL ANALYSES OF MIXTURES A TO L, TABLES 115 TO 125.***

Series.	Class of Iron.	Silicon.	Sulphur.	Manganese.	Phosphorus.	G. Carbon.	C. Carbon.	T. Carbon.
A†	Ingot mold............	1.67	.032	.29	.095	3.44	.43	3.87
B	Dynamo frame......	1.95	.042	.39	.405	3.23	.59	3.82
C	Light machinery...	2.04	.044	.39	.578	3.52	.32	3.84
D	Chilled roll............	.85	.070	.15	.482	.06	2.30	2.36
E	Sand roll.........	.72	.070	.17	.454	None.	3.04	3.04
F‡	Sash weight..........	.91	.218	.24	.441	.20	2.51	2.71
G	Car wheel.....	.97	.060	.40	.301	3.43	.74	4.17
H	Stove plate...	3.19	.084	.38	1.160	3.08	.33	3.41
I	Heavy machinery..	1.96	.081	.48	.522	2.99	.33	3.32
J	Cylinder.........	2.49	.084	.47	.839	2.99	.40	3.39
K	Novelty	4.19	.080	.67	1.236	2.85	.03	2.88
L	Gun metal............	1.32	.044	.43	.676	2.62	.50	3.12

† All pig iron. ‡ Nearly all burnt scrap.

*** The above analyses of Table 127 were determined from drillings obtained from 1″ square dry sand bars, taken from the respective casts.

SUMMARY OF RESULTS OF THE A. F. A. SERIES OF TESTS.

A peculiarity between transverse and tensile tests which the A. F. A. series of tests displays, lies in an increase of transverse strength per square inch, and a decrease of tensile strength, in opposite directions, according as areas of cross sections are enlarged. For illustration, take the unfinished bar, test No. 2, Table 115, page 558, which is 1.20 diameter, giving an area of 1.13 inches, and compare its strength per square inch in an approximate way with test No. 8, which has an area of 16.90 inches, and we find that the larger body has 52.7 per cent. greater strength per square inch of cross section or area than the smaller body. In the case of tensile tests, we find, by an examination of Table 126, opposite page, that an average of all the 1.14 diameter unfinished bars gave 57,250 pounds greater strength per approximate square inch than an average of the 2.27 diameter unfinished bars. Were the bars larger than 2.27 diameter, we would find the same principle to hold good.

The results show that in the construction of machinery, etc., we may expect greater strength per square inch in transverse strains and less in tensile, as areas of cross sections are enlarged, and further demonstrate that cast iron castings are best constructed to stand transverse strains. Why it is that the reverse of results should be obtained between transverse and tensile tests as shown is largely due to the principle "in union there is strength," being applicable to transverse and not to tensile strains.

However, if any one should cut a 4½-inch square bar of gray iron into 1-inch square sections, they would find that any one of the sections would then stand a much less transverse or tensile load than bars of the same area that had been cast 1 inch square of the same iron.

It was a current impression that a large body of cast iron is weaker in strength per square inch than small ones of the same grade or cast. We find by a study of Tables 115 to 126 that this is true only in the case of tensile strains. This is the first time that the author knows of attention being called to this fact, and now that such is publicly done herein it will result, no doubt, in changing many practices that have been followed, based on the supposition that in the same iron large bodies were weaker in strength per square inch than small ones.

The difference between the strength of finished and unfinished bars, as shown by the A. F. A. tests, demonstrates that where the same thickness of iron is removed in finishing test bars, finished bars are less erratic in recording strength tests than unfinished bars, and that as a rule finished bars are weaker than unfinished ones of the same iron. A finished bar that will prove stronger than an unfinished one would generally be due to the outer surface body holding the combined carbon higher than was best for strength in that grade of iron. This generally occurs only in bars that give a great strength in an unfinished as well as finished state. To show the difference between unfinished and finished bars, to make an approximate comparison, seven tests, A, B, C, G, H, I, and J of the 1.70 diameter unfinished bars and seven tests of the

1.69 diameter finished bars (Table 126, page 570), some casts having a difference of only .01 diameter, show 5,380 pounds or 5.25 per cent. less tensile strength than the unfinished bars. Carrying this to transverse tests, in calculating the difference of fifty tests of each class in similar sizes of bars, we find that the finished bars were 212,000 pounds or 16.2 per cent. weaker than the unfinished bars. The hard grades show a greater difference than the soft grades in this respect. Of all the transverse tests in Tables 115 to 126 there are only about six finished bars that show a greater strength than their mates in the unfinished bars. The ½-inch bars are ignored in all the computations because of their unreliability, as proven by the series of A. F. A. and other tests.

The adaptability of different size bars for comparative testing is well demonstrated by the A. F. A. series of tests. They strongly endorse the author's contention against the use of bars as small as ½ inch square or round, and also show that bars can be too large as well as too small. The committee's report recommends bars to be no smaller than 1½ inches diameter and not larger than 2½ inches, and all bars to be cast on end, which is another point originally and strongly advocated by the author. These recommendations are seen on pages 575 and 583. For several years the author has realized from experience in testing that a 1½-inch diameter bar was about as small as should be used where the best records are desired in gray irons, but he accepted the 1⅛-inch diameter bar shown in other parts of this work for testing, on account of its being of an area the most used in the past to meet the general conditions of founders who possess small testing machines, and are not that far from the best but that they can in some cases be utilized in giving enough approximate comparative data of cast iron, as is shown in Chapters XLIV., LX. and LXIX.

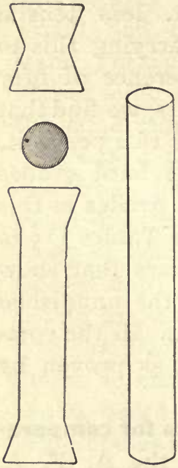

FIG. 148.

The utility of the A. F. A. tests is not confined to the summary given in this chapter. There are other qualities which their wide range of tests offer for study in obtaining valuable knowledge that can be utilized, in some special instances, to assist any in the best practice of making mixtures of iron, grading castings, and testing which they set forth. As the tests were originally obtained chiefly to derive knowledge of what is best to suggest for standardizing the testing of cast iron, we will now present an extract of the A. F. A. committee's final report as tendered by the chairman, Dr. Richard Moldenke, who is also secretary of the association.

AN EXTRACT OF THE A. F. A. COMMITTEE'S REPORT ON STANDARDIZING THE TESTING OF CAST IRON.

Your committee desires to state that during the past year (1900) sufficient work has been done to warrant a final report, based upon the results obtained and the conclusions derived therefrom. The magnitude of the operations was fully realized at the inception of the plan (in 1897), but it was held that the necessities of our industry on the one side, and the constantly growing demands from buyers on the other, fully warranted every effort of time and trouble given to this important subject so vital to our existence. All of the members of your committee are active foundrymen, heavily burdened with responsibilities which leave little leisure for the more interesting pursuits of industrial science, yet as little time as possible was lost, and only those investigations postponed which were not actually required for the purposes of this report.

We must therefore beg that our report be received, and our committee on standardizing the testing of cast iron be discharged. And we further beg that permission be granted to the individual members of our committee to utilize the mass of material collected, for further investigations of interest to the foundry trade, and the publication of such results as part of the proceedings of this association.

Throughout the whole line of operations only regularly constituted mixtures were used, the balance of the heats from which these test bars were cast going directly into commercial castings of the classes designated. The results are therefore entirely comparable with daily practice, and are not exceptional cases prepared specially for a good showing. For purposes of comparison green sand and dry sand bars were made side by side, even though the iron, in practice, goes into only one of these classes of moulds. It was felt that comparison records were wanted just as much as specifications for the separate lines of product. For this reason also we recommend one standard size of test bar for comparative purposes only, each class of iron being given its special treatment for the information wanted in daily practice, in addition.

Our studies on the shape of the test bar have resulted in the selection of the round form of cross section, and this mainly on the score of greatest uniformity in physical structure, the corners of the square bar introducing elements which become troublesome. It is fully realized that the work of testing bars, especially transversely, is made more difficult by the adoption of the round bar; but, after all, this should only mean the taking of proper precautions in measuring the actual net deflection — that is, deducting the upper and lower indentations in the bar by the knife edges, as ascertained by micrometer measurement, from the deflection record.

There is still a further point of interest in the preparation of test bars, and that is the making of coupons from which the quality of the casting to which they are attached is to be judged. This method is used extensively in government work and in the making of cylinder castings. The idea of obtaining material from the same pour in the same mould as part of the casting itself is good enough in theory. Unfortunately, however, this direct connection introduces elements of segregation and temperature changes in the cast iron which make this test less valuable than is generally supposed. At best, the iron which has passed through the different parts of a mould before entering the space for the coupon will not be representative of the whole body, but rather one portion of it only. We therefore recommend the method shown later on in Fig. 149. The metal can be poured from crane or hand ladle clean and speedy, and possesses the temperature of the average iron in the casting more nearly than the coupon method now practiced.

Your committee, while giving specifications for the tensile test of cast iron, is of the opinion that the transverse test is the more desirable, and certainly within reach of even the smallest foundry. We further would suggest to the mechanical engineers of this country the desirability of standardizing the speed at which the various tests should be performed, and also the urgent necessity of studying the impact test in its various phases. We deem these questions outside of the province of this association, our work being the selection of methods for getting at the true value of the material we sell, without prejudice or favor.

In selecting the test bars for the purpose of specification, we have followed the cardinal principle of selecting the largest cross section for the iron consistent with a sound physical structure, and within the range and structural limits of an ordinary testing machine. The following are the sizes of bars selected for tests as a result of our investigations:

For all tensile tests a bar turned to .8 inch in diameter, corresponding to a cross section of ½ square inch. Results, therefore, multiplied by two, give the tensible strength per square inch.

For transverse test of all classes of iron for general comparison, a bar 1½ inches diameter, on supports 12 inches apart, pressure applied in middle, and deflection noted. Similarly for light machinery, stove plate, and novelty iron a 1½-inch diameter bar; that is to say, for irons running from 2 per cent. in silicon upward, or from 1.75 per cent. silicon upward where but little scrap is in the mixture.

For dynamo frame, cylinder, heavy machinery, and gun metal irons, similarly a 2-inch diameter bar is recommended; that is, for irons running from 1.50 to

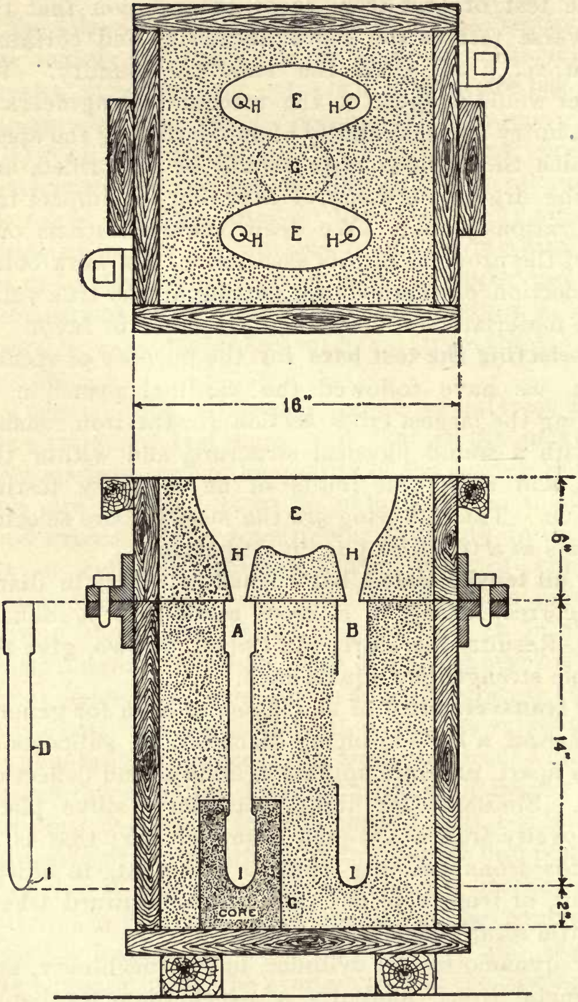

FIG. 149.

Plan and Elevation View of Casting a few Tensile and Transverse Test Bars on end, at one pouring.

2 per cent. in silicon, or where the silicon is lower and the proportion of scrap is rather large.

For roll irons, whether chilled or sand, and car wheel metals, a 2½-inch diameter bar is recommended; that is, for all irons below 1 per cent. silicon, and which may therefore be classed as the chilling irons. This would include also all white irons.

The method of moulding the test bars we would recommend is given herewith, and is such as will be readily understood by every practical foundryman. Both tensile and transverse bars are shown in the same flask. The elevation shows the tensile bar at A and the transverse one at B. The core C is used with the tensile bar in order to ram it on end. The core box is seen at Fig. 150. In starting to mould up the bars the dried core is set on the bottom board, and then the pattern as seen at D placed into the hole in the top of the core and let rest on its bottom. Now ram up the bar with green sand in the usual manner. The plan shows four bars. This can be modified as desired. If no tensile bars are wanted, the core is avoided altogether. Two bars may be poured at a time, or four, or more, by simply connecting the pouring basin E E as shown by the dotted line around G, in which case, however, the basin E E should be made much smaller. At least three bars of a kind should be made for a given test. The accompanying sketches give all

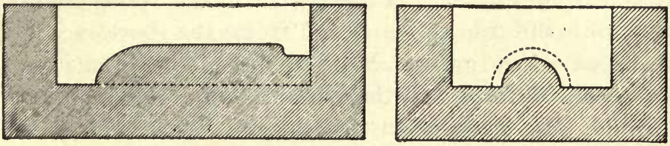

FIG. 150.—CORE BOX, TENSILE TEST PATTERN.

the necessary dimensions. It will be noted that the bottom of the mould is conical, as seen at I. This is to present a sloping surface to the dropping iron and help to avoid its cutting the bottom of the mould.

These bars could be moulded flat and poured on their ends by arranging the flask in such a manner that pouring gates and basins can be provided on top. The extra labor of carrying out this method, in a measure counterbalances the making of the core C. The only advantage of moulding flat lies in the greater certainty of obtaining bars free from swells when made by inexperienced moulders.

The sand should not be any damper than to mould well and stand the wash of the iron without cutting, blowing, or scabbing. It should be rammed evenly to avoid swells, and poured by dropping the metal from the top through gates or from the ladle direct into the open mould. If the sand will not stand pouring from the top, then pour from the bottom by means of whirl gates. If there are more than four bars to be poured from the same ladle of iron, where it would take more than two minutes' time in pouring, they should be gated so that the one pouring basin can fill all the gates at about the same time, thus insuring all bars in a set having the same temperature of pouring. After the bars are cast they should remain in their moulds undisturbed until cool.

PROPOSED STANDARD SPECIFICATIONS FOR GRAY IRON CASTINGS AND TEST BARS, AS ADOPTED BY A. F. A.

1. Unless furnace iron or subsequent annealing is specified, all gray iron castings are understood to be of

cupola metal; mixtures, moulds, and methods of preparation to be fixed by the founder to secure the results by purchaser.

2. All castings shall be clean, free from flaws, cracks, and excessive shrinkage. They shall conform in other respects to whatever points may be specially agreed upon.

3. When the castings themselves are to be tested to destruction, the number selected from a given lot and the tests they shall be subjected to are made a matter of special agreement between founder and purchaser.

4. Castings made under these specifications, the iron in which is to be tested for its quality, shall be represented by at least three test bars cast from the same heat.

5. These test bars shall be subjected to a transverse breaking test, the load applied at the middle with supports 12 inches apart. The breaking load and deflection shall be agreed upon specially on placing the contract, and two of these bars shall meet the requirements.*

6. A tensile strength test may be added, in which case at least three bars for this purpose shall be cast with the others in the same moulds respectively. The ultimate strength shall also be agreed upon specially before placing the contract, and two of the bars shall meet the requirements.

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* NOTE.— The remarkably wide range oi values for the ultimate strength and modules of rupture which are really good for the various classes of iron, precludes the giving of definite upper limits in the specifications. It will therefore remain a matter of mutual agreement in each case, the requirements of service and price per pound paid regulating the mixtures which can be used.

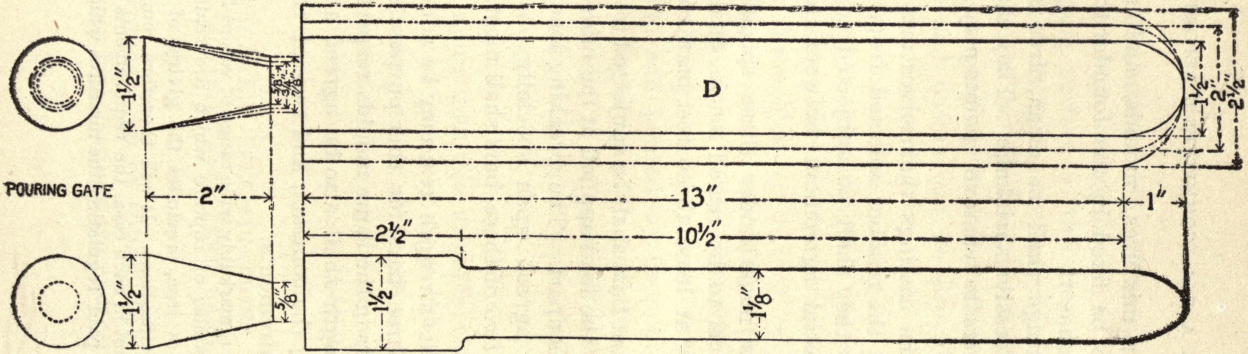

FIG. 151.—PATTERNS FOR TEST BARS FOR CAST IRON.

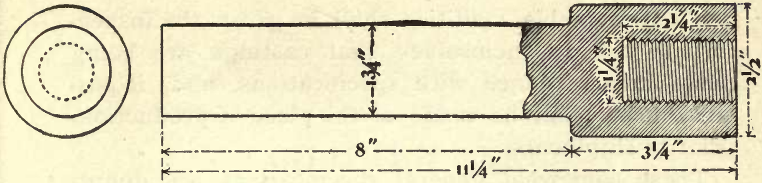

FIG. 152.—STEEL SOCKET FOR TENSILE TEST OF CAST IRON.

Two required. Test pieces should fit in loosely.

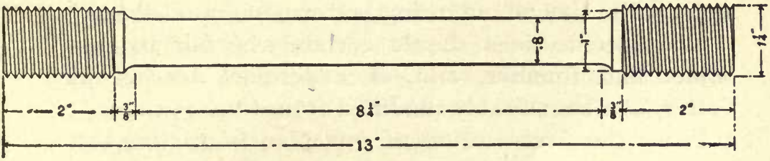

FIG. 153.—STANDARD TEST BAR FOR CAST IRON.

Cross Section equals ½ square inch.

7. The dimensions of the test bars shall be as given herewith. There is only one size for the tensile bar and three for the transverse. For the light and medium weight of gray iron castings the 1½-inch D bar is to be used, for heavy gray iron castings the 2-inch D, and for chilling irons the 2½-inch D test bar. These bars are seen in Figs. 151, 152, and 153.

8. Where the chemical composition of the castings is a matter of specification in addition to the physical tests, borings shall be taken from all the test bars made, well mixed, and any required determination, combined carbon and graphite alone excepted, made therefrom.*

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* NOTE.—There should really be no necessity for this test, for the requirements of the physical tests presuppose a given chemical composition. It may, however, sometimes be expedient to know the total carbon, silicon, sulphur, manganese, and phosphorus of a casting to insure good service conditions.

9. Reasonable facilities shall be given the inspectors to satisfy themselves that castings are being made in accordance with specifications, and, if possible, tests shall be made at the place of production, prior to shipments.

These somewhat general specifications are doubtless capable of being modified, but are presented by us to this Association for discussion and possible approval in lieu of anything better now in existence.*

The specifications should certainly be fair to consumer and founder, and, if experience teaches us better, can be suitably modified from time to time.

From the first outline of our plan of casting test bars, now known so generally, to the final completion of this report we have endeavored to obtain information valuable to our industry, and sincerely hope that much good may result from this, we think, impartial series of conclusions. Respectfully,

DR. RICHARD MOLDENKE,
THOS. D. WEST,
JAS. S. STIRLING,
JOS. S. SEAMAN,
JOS. S. MCDONALD.

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* This report and specifications were received and unanimously adopted by the A. F. A. Convention at Buffalo, June, 1901. The committee was tendered a vote of thanks and was discharged.

CHAPTER LXXI.

NEW PROCESS FOR BRAZING CAST IRON.

In the "American Machinist" of March 14, 1901, an editorial appears on this subject in which it says: "If the reports of the extreme ease with which this process is applied and of its successful results are well founded, its discovery marks an important epoch in metal working. It was invented by an engineer named Poech, and has been thoroughly tested at the Mechanical Technical Testing Institute at Charlottenburg, near Berlin. Professor Martens, of this institute, testifies that the iron thus brazed stands the strain like new and has not deteriorated under the process. The discovery has already been applied by a number of prominent engineering firms in Great Britain.

"**This method of brazing is explained as follows:** After the surfaces have been cleaned, they are treated with a moistened mixture of 'ferrofix' (which is the term applied by the inventor to a metallic oxide, preferably of copper) and a flux such as borax, soluble glass, or, better, 'borifix,' a mixture recently invented and patented by the same inventor. The surfaces are well covered with borax or borifix, then with strong solder such as is used for wrought iron, and then the metal is brought to a red heat. A chemical decomposition takes place in which the oxygen of the metallic oxide combines with the carbon of the iron to form volatile carbonic acid or carbonic oxide, setting free pure metal. This metal covers the surfaces of the iron intimately, filling the smallest pores, and facilitates the direct and intimate union of the solder with the iron. The flux that has been added covers the place of the brazing with a vitreous skin, which prevents the oxidation of the iron and the soldering metal.

"**The avenues of utility suggested** for the new process are three: First, repairing cast iron; second, putting together large castings (which may be made in sections to facilitate moulding and transportation); third, brazing cast iron to other metals. In this way cast iron can be used in places where wrought iron or steel is now employed, by making only that part out of the stronger metal which is exposed to special strain. While it is hardly to be expected that all pieces can be brazed with equal success, it is stated that a gear wheel 40 inches in diameter and weighing about 220 pounds has been satisfactorily repaired in six places in hub, spokes, and crown. Moreover, bars 4 inches in diameter which have been thus brazed and then broken at the same place with a chisel, showed a new line of rupture. It is not known that 'ferrofix' has yet reached America, but it can be obtained in Germany from Rodolphe Winnike of Berlin. It is also being introduced to the trade in England from H. Bertram & Co., 28 Queen street, London, E. C., who offer to supply full particulars."

ETCHING.*

Those who have much to do with chilled irons will find the etching test a valuable one. While the practised eye alone can arrive at the true valuation of what the etched surface shows, yet the test is so simple that the operation should be understood generally. The greatest development has naturally been in the line of the steels. First, to distinguish between these and wrought iron and thus readily detect fraud and substitution. Second and later, to get at the actual crystalline structure in order to judge the quality as affected by the heat and mechanical treatment the specimens had received.

For cast iron, the polished and etched surface shows up the nature of the crystalline structure in the chilled portion, and the gradation into gray iron. Where experiments are made with additions of steel or wrought scrap, the appearance of the etchings is a guide to the probable wearing qualities. The samples must be first prepared by filing or grinding to get a flat surface. Then this is smoothed with successive grades of emery cloth until a bright surface is obtained which is not too deeply scratched. This polished surface must not be touched with the fingers, as anything of a greasy nature prevents the acid from attacking the iron. Now the piece is immersed face up in nitric acid diluted with ten parts of water. It is best to use this mixture cold. A few seconds will suffice to bring out the structure. The test piece is then taken out and washed thoroughly in running water.

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* This article on etching was contributed to this work by the kindness of Dr. Richard Moldenke.

If it is desired to print from the etching, more care must be taken. The specimen should be perfectly flat, — if possible, with two parallel surfaces. The etching solution used is weaker — say one nitric acid, and fifty or even one hundred water. A small brush can be used to advantage to run over the top of the specimen to remove the spent acid and keep a good circulation. This makes the etching process slow but uniformly even. The result, however, is really fine, and the novice will do well to practice on wrought iron, which gives beautiful etchings. In printing from these etched specimens an ordinary printer's roller, not too heavily charged with ink, is used, and the paper must be a superfine calendered variety which is perfectly smooth.

TABLES OF UTILITY FOR FOUNDING.

TABLE 128.—NET WEIGHT OF SAND PIG IRON PER TON OF 2,268 LBS.

Net.	Gross.	Net.	Gross.	Net.	Gross.
1	2,268	35	79,380	69	156,492
2	4,536	36	81,648	70	158,760
3	6,804	37	83,916	71	161,028
4	9,072	38	86,184	72	163,296
5	11,340	39	88,452	73	165,564
6	13,608	40	90,720	74	167,832
7	15,876	41	92,988	75	170,100
8	18,144	42	95,256	76	172,368
9	20,412	43	97,524	77	174,636
10	22,680	44	99,792	78	176,904
11	24,948	45	102,060	79	179,172
12	27,216	46	104,328	80	181,440
13	29,484	47	106,596	81	183,708
14	31,752	48	108,864	82	185,976
15	34,020	49	111,132	83	188,244
16	36,288	50	113,400	84	190,512
17	38,556	51	115,668	85	192,780
18	40,824	52	117,936	86	195,048
19	43,092	53	120,204	87	197,316
20	45,360	54	122,472	88	199,584
21	47,628	55	124,740	89	201,852
22	49,896	55	127,008	90	204,120
23	52,164	57	129,276	91	206,388
24	54,432	58	131,544	92	208,656
25	56,700	59	133,812	93	210,924
26	58,968	60	136,080	94	213,192
27	61,236	61	138,348	95	215,460
28	63,504	62	140,616	96	217,728
29	65,772	63	142,884	97	219,996
30	68,040	64	145,152	98	222,264
31	70,308	65	147,420	99	224,532
32	72,576	66	149,668	100	226,800
33	74,844	67	151,956		
34	77,112	68	154,224		

TABLE 129.—NET WEIGHT OF CHILLED PIG IRON PER TON OF 2240 LBS.

Net.	Gross.	Net.	Gross.	Net.	Gross.	Net.	Gross.
1	2,240	26	58,240	51	114,240	76	170,240
2	4,480	27	60,480	52	116,480	77	172,480
3	6,720	28	62,720	53	118,720	78	174,720
4	8,960	29	64,960	54	120,960	79	176,960
5	11,200	30	67,200	55	123,200	80	179,200
6	13,440	31	69,440	56	125,440	81	181,440
7	15,680	32	71,680	57	127,680	82	183,680
8	17,920	33	73,920	58	129,920	83	185,920
9	20,160	34	76,160	59	132,160	84	188,160
10	22,400	35	78,400	60	134,400	85	190,400
11	24,640	36	80,640	61	136,640	86	192,640
12	26,880	37	82,880	62	138,880	87	194,880
13	29,120	38	85,120	63	141,120	88	197,120
14	31,360	39	87,360	64	143,360	89	199,360
15	33,600	40	89,600	65	145,600	90	201,600
16	35,840	41	91,840	66	147,840	91	203,840
17	38,080	42	94,080	67	150.080	92	206,080
18	40,320	43	96,320	68	152,320	93	208,320
19	42,560	44	98,560	69	154,560	94	210,560
20	44,800	45	100,800	70	156,800	95	212,800
21	47,040	46	103,040	71	159,040	96	215,040
22	49,280	47	105,280	72	161,280	97	217,280
23	51,520	48	107,520	73	163,520	98	219,520
24	53,760	49	109,760	74	165,760	99	221,760
25	56,000	50	112,000	75	168,000	100	224,000

TABLE 130.—TABLE OF CHEMICAL SYMBOLS AND ATOMIC WEIGHTS.

(MEYER & SEUBERT.)

Aluminum, Al.	27.04	Lead, Pb.	206.39
Antimony, Sb.	119.6	Litharge, PbO.	
Arsenic, As.	74.9	Magnesium, Mg.	23.94
Bismuth, Bi.	207.5	Manganese, Mn.	54.8
Bromine, Br.	79.76	Mercury, Hg.	199.8
Cadmium, Cd.	111.7	Nickel, Ni.	58.6
Calcium, Ca.	39.91	Nitrogen, N.	14.01
Carbon, C.	11.97	Oxygen, O.	15.96
Carbon Graphitic, C (Graph.)		Palladium, Pd.	106.2
Carbon Combined, C (Comb.)		Phosphorus, P.	30.96
Carbonic Acid, CO_2.		Phosphoric Acid, P_2O_5.	
Carbonic Oxide, CO.		Platinum, Pt.	194.3
Chlorine, Cl.	35.37	Potassium, K.	39.03
Chromium, Cr.	52.45	Silicon, Si.	28.0
Cobalt, Co.	58.6	Silver, Ag.	107.66
Copper, Cu.	63.18	Sodium, Na.	22.995
Fluorine, F.	19.06	Sulphur, S.	31.98
Ferric Oxide, Fe_2O_3.		Tin, Sn.	117.35
Ferrous Oxide, Fe. O.		Tungsten, Wo.	183.6
Gallium, Ga.	69.9	Uranium, Ur.	239.8
Gold, Au.	196.2	Vanadium, V.	51.1
Hydrogen, H.	1.	Yttrium, Y.	89.6
Iodine, I.	126.54	Zinc, Zn.	64.88
Iridium, Ir.	192.5	Zirconium, Zr.	90.4
Iron, Fe.	55.88		

TABLE 131.—VALUE IN DEGREES CENTIGRADE FOR EACH 100 DEGREES FAHRENHEIT.

Fahr.	Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.	Cent.
100	55.56	1000	555.56	2000	1111.11	3000	1666.67
200	111.11	1100	611.11	2100	1166.67	3100	1722 22
300	166.67	1200	666.67	2200	1222.22	3200	1777.78
400	222.22	1300	722.22	2300	1277.78	3300	1833.33
500	277.78	1400	777.78	2400	1333 33	3400	1888.89
600	333.33	1500	833.33	2500	1388 89	3500	1944.44
700	388.89	1600	888.89	2600	1444.44	3600	2000 00
800	444.44	1700	944.44	2700	1500.00		
900	500.00	1800	1000.00	2800	1555 55		
		1900	1055.55	2900	1611.11		

"*Absolute Zero*" of the Air Thermometer is equal—460° Fahrenheit.
" " " " " —273.5° Centigrade.

HEAT UNITS.

There are three units in use for measuring the quantity of heat contained in matter.

The first is the *British thermal unit*, and which is the amount of heat required to raise 1 pound of water 1° Fahrenheit.

The second is the *thermal unit*, and which is the amount of heat required to raise 1 pound of water 1° centigrade.

The third is the *calorie*, and which is the amount of heat necessary to raise 1 kilogram of water 1° centigrade.

The calorie is used in Germany, France and other countries using the metric system of weights and measures.

TABLE 132.—HEAT OF COMBUSTION.

Heat developed by combustion of one pound of the following substances:

Substance.	Calories.	Substance.	Calories.
Anthracite	7,200 to 8,200	**Lignite**	4,500 to 6,000
Alcohol	7,185	**Manganese to MnO**	1,723
Carbon to CO	2,404	**Marsh Gas**	13,063
Carbon to CO_2	8,080	**Olifient Gas**	11,858
Coal—bituminous	6,500 to 9,000	**Olive Oil**	9,860
Coke	6,400 to 8,000	**Petroleum**	10,600 to 11,000
Diamond	7,879	**Phosphorus—P_2O_5**	5,747
Ether	9,028	**Silicon**	7,830
Hydrogen	34,462	**Sulphur to SO_2**	2,162
Iron to FeO	1,351	**Sulphur SO_3**	2,868
Iron to Fe_2O_3	1,887	**Wood**	2,500 to 4,000

TABLE 133.—SCALE OF TEMPERATURES BY COLOR OF IRON.

Dark red, hardly visible	970° F.	Orange	2000° F.
Dull red	1300° "	Yellow	2150° "
Cherry, dark	1450° "	White heat	2350° "
" red	1650° "	" welding	2600° "
" light	1800° "	" dazzling	2800° "

TABLE 134.—MELTING POINTS OF METALS.

	Cent.	Fahr.		Cent.	Fahr.
Aluminum	850	1,562	Iron	1,590	2,894
Antimony	441	826	Lead	330	626
Bismuth	266	511	Manganese	1,550	2,822
Cadmium	321	610	Nickel	1,450	2 642
Cromium	1,700	3,092	Palladium	1,500	2,732
Cobalt	1,500	2,732	Platinum	1,775	3,227
Copper	1,054	1,929	Silver	954	1,749
Gold	1,147	2,097	Tin	230	446
Iridium	1,950	3,542	Zinc	427	801

TABLE 135.—RELATIVE CONDUCTIVITY OF METALS FOR HEAT AND ELECTRICITY.

Metal (in vacuo).	Heat.	Electricity.	Metal (in vacuo).	Heat.	Electricity.
Silver	100.	100.	Iron	11.9	14.44
Copper	74.	77.43	Steel	10.3	
Gold	54 8	55.19	Lead	7.9	7.77
Zinc	28.1	27 39	Platinum	9.4	10.53
Brass	24 0	22.0	German Silver	6.3	6.
Tin	15.4	11.45	Bismuth	1.8	1.8

Specific Gravity of a substance is the ratio of the weight of unit volume of the substance to the weight of the same volume of water at 4°C.

Density of the substance is measured by the number of units of mass in a unit volume of the substance.

TABLE 136.—SPECIFIC GRAVITY AND WEIGHT PER CUBIC INCH—METALS.

Metal.	Sp. Grav.	Weight per cu. in. lbs.	Metals.	Sp. Grav.	Weight per cu. in. lbs.
Aluminum	2.56-2.67	.094	Manganese	8 01	.200
Antimony	6.71	.242	Magnesium	1.74	.062
Bismuth	9 9	.357	Mercury	13.59	.491
Brass	7.8-8 8	.281-.310	Nickel	8.7	.314
Bronze	8.7	.314	Palladium	11.4	.411
Copper, cast	8.79	.317	Platinum, rolled	22.07	.798
Copper, wire	8 89	.322	Platinum, cast	20.33	.735
German Silver			Silver	10.5	.380
Gold, hammered	19.40	.701	Sodium	.97	.035
Gold, cast	19 26	.697	Steel	7.82	.283
Iron, cast	7.20	.260	Tin	7.29	.263
Iron, bar	7.79	.282	Zinc	6.86	.248
Lead	11.37	.411			

TABLE 137.—ULTIMATE RESISTANCE TO TENSION IN POUNDS PER SQUARE INCH.

Metals.

	Average.
Brass—cast	17,000
wire	48,000
Copper—cast	19,000
sheet	32,000
wire	61,000
Iron—cast	10,000 to 40,000
wrought	48,000 to 54,000
wire	70,000 to 90,000
Lead—cast	1,200
sheet	3,000
Platinum—wire	53,000
Steel	60,000 to 120,000
Tin—cast	5,000
Zinc	7,000 to 8,000

TABLE 138.—TIMBER (SEASONED).

Wood.

	Average.
Ash	16,000
Beech	12,000 to 18,000
Hickory	11,000
Oak—American	11,000 to 18,000
Pine— “ white and red	10,000
Poplar	7,000

139.—TABLE OF DECIMAL EQUIVALENTS OF 8THS, 16THS, 32DS, AND 64THS OF AN INCH.

8ths.	**32ds.**	**64ths.**	31-64 = .484375
1-8 = .125	1-32 = .03125	1-64 = .015625	33-64 = .515625
1-4 = .250	3-32 = .09375	3-64 = .046875	35-64 = .546875
3-8 = .375	5-32 = .15625	5-64 = .078125	37-64 = .578125
1-2 = .500	7-32 = .21875	7-64 = .109375	39-64 = .609375
5-8 = .625	9 32 = .28125	9-64 = .140625	41-64 = .640625
3-4 = .750	11-32 = .34375	11-64 = .171875	43-64 = .671875
7-8 = .875	13-32 = .40625	13-64 = .203125	45-64 = .703125
	15-32 = .46875	15-64 = .234375	47-64 = .734375
16ths.	17-32 = .53125	17-64 = .265625	49-64 = .765625
1-16 = .0625	19-32 = .59375	19-64 = .296875	51-64 = .796875
3-16 — .1875	21-32 = .65625	21-64 = .328125	53-64 = .828125
5-16 = .3125	23-32 = .71825	23-64 = .359375	55-64 = .859375
7-16 = .4375	25-32 = .79125	25-64 = .390625	57-64 = .890625
9-16 = .5625	27-32 = .84375	27-64 = .421875	59-64 = .921875
11·16 = .6875	29-32 = .90625	29-64 = .453125	61-64 = .953125
13-16 = .8125	31-32 = .96875		63-64 = .984375
15-16 = .9375			

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*This work contains 153 illustrations.

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