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Open Hearth Steel Castings

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OPEN HEARTH STEEL CASTINGS

BY W. M. CARR

A complete exposition of the methods involved in the manufacture of open-hearth steel castings by the basic and acid processes. This work is compiled from a series of articles by the author, written for and published by *The Iron Trade Review* and *The Foundry*.



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CHAPTER I

MELTING STOCK FOR ACID AND BASIC PRACTICE—REFRACTORIES—FUELS—ALLOYS—MOLDING MATERIALS FLUXES

In view of the growing interest manifested by both producers and consumers of cast sections in the production of steel castings and their increasing utility, the salient points of their manufacture by the acid basic and open-hearth processes will be presented in this series of articles which cover :

First—The selection and representative composition of melting stocks, alloys, refractories, fuels, melting materials and fluxes.

Second—Furnace construction and the melting and manipulation of heats.

Third—The conditions of melting as effecting the physical properties of products.

Fourth—The analyses and physical tests of different grades of products.

Fifth—The effect of the constituent materials and metalloids usually present in open-hearth steel castings.

Sixth—Heat treatment or annealing, with notes on microscopic examinations.

Seventh—Discussion of the causes of blow holes and shrinkage cracks.

Eighth—The repair of defects by thermit welding.

Ninth—Approximate cost of open-hearth installations.

MATERIALS FOR ACID PRACTICE

MELTING STOCK.—The composition of materials for acid castings comes within well defined limits, for the main reason that the process is nearer a melting, rather than a refining one, owing to the fact that the metalloids, sulphur and phosphorus, are not removed during the conversion of the charge. As their presence in the finished product must be subject to specification, it follows that the melting stock must be bought with a limit to the contents of the elements named. Only in regard to quantities of sulphur and phosphorus exists the distinction between acid and basic melting stock. Pig iron for ordinary practice analyzes as follows:

Total Carbon	2-3.5 per cent
Silicon	0.50-1.5 per cent
Sulphur	0.04 or less
Phosphorus	0.04 or less
Manganese	0.50-0.75

In addition to pig iron, steel scrap known as “basic scrap” is also bought on analysis or chemical specifications. Being the product of rolling mills, etc., following basic practice, the contents of sulphur and phosphorus are usually low, and they are the only elements of composition taken into account. A representative analysis of steel scrap for acid practice is as follows:

Sulphur	0.015-0.03 per cent
Phosphorus	0.010-0.03 per cent

Since the physical character is usually represented by billets, crop ends, blooms, plate-shearings, defective castings and waste metal from steel foundries, the nature of them necessarily predetermines the composition in regard to the presence of carbon, silicon and manganese. With a charge of pig iron and steel scrap it is comparatively easy to keep

the composition of finished product within acid specifications.

REFRACTORIES

Silica sand forming the hearth of the furnace, known chemically as an acid, lends its classification to distinguish between the two processes. It does not present a condition wherein certain elements are removed during melting of stock, namely, sulphur and phosphorus. The amounts of those elements charged will be found in the finished product. The function of silica sand is mainly a refractory one. That is, it must have heat resisting qualities, but not to the extent that it will not set or sinter slightly to satisfactorily preserve the contour of the shallow dish-like formation of the hearth. It must not be too fusible, otherwise there would be excessive scorification or cutting of the hearth. It must set or sinter sufficiently to resist abrasion due to the charging of stock. It is difficult to lay down strict chemical specifications for silica sand. There are certain conditions of composition not expressed by an analysis of the total constituents. The combinations of them with their neighbors cannot be ascertained. However, a silica sand of the following analysis gave excellent results in practice:

Water	0.24 per cent
Silica	97.25 per cent
Alumina and Iron Oxide.....	0.16 per cent
Lime	0.08 per cent
Magnesia	0.39 per cent
Alkalies	0.36 per cent
Loss on Ignition	0.36 per cent

There are several deposits of silica sand in the west and middle west that are supplied to steel foundries and no difficulty will be found in getting the best quality for the purpose. As a general rule a silica sand for hearth lining must be low in lime, manganese and the alkalies (potash

and soda); an excess of any tends to lower the fusion point of the sand, destroying its required sintering or refractoriness. Usually a silica sand with less than 95 per cent silica will not answer for a refractory.

FUEL

It is a question of local conditions as to whether the fuel may be natural gas, oil, tar, or producer gas. Natural gas is by far the most satisfactory, owing to its high calorific value and its non-contamination of the bath or molten charge. It is fed directly into the working body of the furnace without any preheating or a passing through the regenerator chambers. Oil, next in efficiency, may be crude petroleum or a grade known as residuum; a by-product of petroleum distillation. The heating values are high, and in certain grades the composition will answer for acid work. Some grades are rather high in sulphur, which is absorbed by the stock in melting.

Tar has been satisfactorily used when available as a by-product in the manufacture of coke by Otto-Hoffman retort ovens. The construction of burners permitted a simultaneous burning of the gas resulting from the coke retorts.

Producer gas is used extensively and when near a reliable supply of coal, is considered cheaper than the aforementioned fuels. A description of gas producers and liquid fuel burners will be given in subsequent chapters. Gas distilled in a producer does not have as high a heating value as liquid fuels, nor is the efficiency so great, because many of the total heat units are lost in the process of distillation of the coal (soft or anthracite). With liquid fuels or natural gas the total thermal efficiency is available within the working body of the furnace, there being no intermediate losses before delivery at the point of combustion. Natural gas or liquid fuels are easy of control in flame regulation; furnace construction and repairs are simplified and lessened; regularity of product and longer cam-

paigns are assured. Producer gas is irregular, and owing to heavy deposits of tarry and sooty matter, regular weekly stoppages must be made to clean out mains and flues. Liquid fuels or natural gas eliminate such losses of working time.

HEATING VALUE OF FUELS

B. T. U.

Natural Gas	300-600 per cubic foot
Oil	14000-17000 per pound
Tar	15000 per pound
Producer Gas	100-150 per cubic foot
Bituminous Coal	10000-12500 per pound

One ton of bituminous coal yields in a modern producer, 160,000 cubic feet of gas with 65 per cent efficiency in heating value of the coal.

ALLOYS

FERRO-MANGANESE.—The standard quality contains 80 per cent manganese. A representative analysis will be as follows:

Iron	12.14 per cent
Manganese	80.00 per cent
Carbon	5.6 per cent
Silicon	0.5 -1.00 per cent
Sulphur	0.010-0.03 per cent
Phosphorus	0.100-0.75 per cent

FERRO-SILICON.—The standard grade carries 13 per cent silicon and is usually sold on a guarantee of 11 per cent of that element. The following is a usual analysis:

Silicon	9 13 per cent
Carbon	1 2 per cent
Sulphur	0.04-0.08 per cent
Phosphorus	0.10-0.50 per cent

In recent years there have been put on the market several grades of electrolytic silicons that are very satisfactory. The most economical grade is the one carrying 50 per cent silicon, and considered on the basis of the unit cost of silicon, is cheaper than the commoner alloy. The following is a typical composition of an electric furnace ferro-silicon:

Silicon	50 52 per cent
Iron	44 46 per cent
Carbon	0.15 -0.25 per cent
Sulphur	0.003-0.010 per cent
Phosphorus	0.04 -0.06 per cent

The purpose of the aforementioned alloys will be considered farther on.

IRON ORE.—The purpose of iron ore is two-fold. One is to increase the fluidity of plastic slags, the other as a carrier of oxygen to assist in the removal of the carbon from the bath of molten metal. The total iron liberated in the interchange between its oxygen and the carbon of the bath adds to the yield of metal. The most satisfactory ores for open-hearth practice are the magnetites or hard hematites. The soft ores are apt to dissipate their combined usefulness in the slag instead of oxidizing carbon. No particular limits are placed on their compositions, excepting that they be high in iron and moderately low in phosphorus. A fair analysis is as follows:

Iron	60 68 per cent
Silica	1 5 per cent
Sulphur	0.05-0.100 per cent
Phosphorus	0.03-0.500 per cent

MOLDING MATERIALS.—Since all steel castings are poured at higher ranges of temperature than gray iron or malleable castings, it is essential that the sands and clays (binders) be as refractory as possible. Pure silica is the most desirable—the purer the better. The following is an analysis of a typical steel molding sand:

Silica	98.5 per cent
Alumina	1.40 per cent
Iron Oxide	0.06 per cent
Lime	0.20 per cent
Magnesia	0.16 per cent
Combined Water	0.14 per cent
Alkalies	0.25 per cent

It must be of such a nature or structure physically that the heated gases in the mold when displaced by liquid steel will have a free passage outwardly. It is preferable that the grains be sharp and irregular rather than rounded as would be the case with sand subjected at some time to the action of water. The color is often white or slightly tinged with yellow. Its color is not necessarily a guide to its qualities, but it is often an indication.

FIRE CLAY.—Pure Silica sand having no binding properties, varying amounts of clay are mixed with it to give the sand a needed bond and substantiality to the mold prepared for the reception of the hot steel. The clay must also be refractory and possess a maximum degree of plasticity. Low grade sands and clays would fuse at the temperature of liquid steel and cause the castings to be of an irregular rough surface. An attempt to economize in the sand pile is apt to spoil one's reputation for clean-looking castings.

It is not always reliable to have recourse to chemical tests on refractories or molding materials, since actual practice will affirm the desirable qualities in them. The following is a typical composition of fire clay:

Silica	60 66	per cent
Alumina	25 20	per cent
Iron Oxide	nil- 2.00	per cent
Lime	nil- 1.00	per cent
Magnesia	nil- 1.00	per cent
Alakalies	nil- 2.00	per cent
Combined Water	7.50-10.50	per cent

The value of a fire clay depends largely upon a low content of alkalies and a freedom from carbonates of lime. Oxide of iron has a strong fluxing effect, but its presence below 3 per cent is harmless.

CORE COMPOUNDS.—Any reliable proprietary article will answer and the list will include molasses water, rosin, flour, linseed oil, etc., all of which are too well known to need any description.

MATERIALS FOR BASIC PRACTICE

MELTING STOCK.—Basic melting possesses a marred flexibility in the selection of stock over acid melting. It is by some considered a sort of metallurgical scavenger. While it is true that there are greater latitudes in quality of pig iron and scrap yet it must not be overlooked that the promiscuous dumping of any kind of stock into a basic furnace cannot yield a reliable product. If good castings are the object sought, discretion must be observed in the selection of materials entering into their manufacture. In regard to quantity basic pig iron greatly exceeds acid pig so far as availability is concerned. The ores of the southern and south-western states are plentifully endowed by nature for the yield of unlimited supplies of basic pig. As to scrap, the situation is somewhat of an uncertainty, owing to the inroads made by the larger interests engaged in the production of ingots in basic bottoms. In consequence prices for scrap have a tendency to gradually rise. The factors controlling the choice between basic and acid practice for castings are ones of location and contingency to the sources of

supply of raw materials. So far as the relative value of the product of either process is concerned, it is true that basic castings are fully as satisfactory, from the view point of quality, as those made by the acid process. It must be remembered, one is a melting method and the other a refining one. The basic process to get good results needs intelligent handling and a higher development of melting skill. The pig iron necessary is known as "standard basic" and the following analysis represents the ulterior limits in composition:

Silicon	1.00 per cent
Sulphur	0.05 per cent
Phosphorus	1.00 per cent

"Off-basic" can carry as high as 1.50 silicon and again as high as 0.07 sulphur. Shipments of these grades on standard contracts can be accepted at a concession in price and it is permissible to use a moderate amount of "off-basic" in charges with no harm to follow. As was mentioned under "Acid Melting Stock" the sulphur and phosphorus charged in that process would equal that of the finished product. In basic melting it is possible to eliminate 50 to 75 per cent of the sulphur and 95 per cent of the phosphorus, thanks to the character of the lining of the furnace and slags formed by the liberal additions of limestone with the charge. For castings it is desirable to have on hand several brands of basic pig; some with low phosphorus and some with high manganese. Certain brands can be obtained with phosphorus as low as 0.200 while standard in other particulars and at ruling prices. Brands with high manganese ranging from 1.5 to 3.00 per cent command a higher price. It is not good practice to make the entire pig iron charge high phosphorus stock. The reasons for mixing brands in regard to phosphorus and manganese will be considered under furnace manipulation.

STEEL SCRAP.—The character of this material is not con-

sidered chemically because the physical nature of it brings it well within working limits as to composition. It is usually designated "heavy railroad melting scrap," but liberties are sometimes taken and unless the consumer exercises circumspection almost anything may be found in it from shop sweepings to tomato cans. *Heavy* scrap is the desideratum, and may consist of, as an illustration, steel rails, knuckles, draw bars, wheel centers, car-springs, fish-plates, defective castings (steel), ingots, etc. Gray iron castings should be religiously excluded when sold as steel scrap. It is allowable to use limited quantities of defective malleable castings although draw bars of such materials are sold as steel. Five per cent of the scrap charge in malleable scrap will not upset the melter's calculations. The scrap charge will be augmented by daily waste from the foundry.

REFRACTORIES

The hearth of basic furnaces in American practice is made with magnesite, a substance classified chemically as a base and possessing the quality, in addition to resisting high temperatures, of being but slightly affected by a slag highly charged with lime which would be fatal to a hearth lined with silica sand. To lengthen the life and efficiency of a basic hearth the first consideration is to keep out of the charge as much silicious matter as possible. Magnesite, the carbonate of magnesia, is an importation from Austria, where it is calcined converting it into magnesia, the oxide of the metal magnesium, by the removal of the major portion of carbon dioxide. It is still considered commercially as a magnesite. Its composition ranges as follows:

RAW

Magnesium Carbonate	93.19 per cent
Calcium Carbonate	1.43 per cent
Iron Carbonate	2.61 per cent
Silica	2.75 per cent

CALCINED

Magnesia	90 95	per cent
Lime	1 2	per cent
Iron Oxide	0.5-3.50	per cent
Silica	0.5-2.75	per cent
Volatile Matter	0.5-1.00	per cent

DOLOMITE.—This material is extensively deposited in the United States. It is a double carbonate of lime and magnesia. It is used either calcined or raw. Principally it is used for patching slag lines, where scorification of the hearth is the heaviest. It is not recommended for points below the slag line. A typical analysis is as follows:

RAW

Silica	0.5	2.00	per cent
Iron Oxide	0.5	2.00	per cent
Alumina	0.5	2.00	per cent
Calcium Carbonate	50	55	per cent
Magnesium	40	44	per cent

CALCINED

Silica	0.5	2.00	per cent
Iron Oxide	0.5	2.00	per cent
Alumina	0.5	2.00	per cent
Lime	50	55	per cent
Magnesia	37	45	per cent

CHROME ORE.—A substance highly refractory to heat and neutral to the action of acid and basic slags. Unfortunately it has no bond and for that reason its uses are somewhat limited. It is used for patching parts of the hearth where cutting above the slag line is severe upon the brick work, usually in gas ports and door jambs. (In European practice it is stated that entire hearths are lined with lump

chrome ore.) Aside from patching it is used as a neutral lining between magnesite and silica bricks. Its composition is as follows:

Chromic Oxide	40-60 per cent
Iron	15-18 per cent
Alumina	5-30 per cent
Silica	1-5 per cent

FLUXES

The most efficient in basic melting is ordinary limestone. Its function is to form a slag that will readily absorb the sulphur and phosphorus of the charge and act as a vehicle for the oxidizable silicon, iron and manganese. The purer the grade the better, that is, a richness in carbonate of lime and a freedom from silica.

A fair analysis is as follows:

Silica	0.25- 1.00 per cent
Oxide of Iron and Alumina	0.50- 2.00 per cent
Carbonate of Lime	95. -99. per cent
Carbonate of Magnesia	0.5 - 1.00 per cent

FLUORSPAR.—The function of this material is to thin a limey slag when in the judgment of the melter it seems thick or sluggish. A moderate addition of fluorspar will liven it and its action may be likened to certain fluxes used in brazing metals—the property of dissolving at higher temperatures metallic oxides. It is plentifully deposited in the United States. A good grade will analyze as follows:

Calcium Fluoride	90-98 per cent
Oxide of Iron and Alumina	0.5-1.00 per cent
Silica	nil-1.00 per cent

IRON ORE.—See “Acid Melting Materials.”

ALLOYS.—See “Acid Melting Materials.”

FUELS.—See “Acid Melting Materials.”

As a guide to purchasing stock the following tabulations will be of assistance in furnishing approximate amounts for regular consumption. The figures are based on the different kinds of stock necessary to produce 1 net ton of castings:

	Acid.	Basic.
Pig Iron	620 pounds	1227 pounds
Steel Scrap	1880 pounds	1227 pounds
Ferro-Silicon	54 pounds	57 pounds
Ferro-Manganese	28 pounds	35 pounds
Iron Ore	26 pounds	30 pounds
Aluminum	3-10 pounds	3-10 pounds
Limestone		300 pounds
Magnesite		34 pounds
Silica Sand	1800 pounds	1600 pounds
Fire Clay	300 pounds	350 pounds
Gas Coal	950 pounds	1250 pounds
Fuel Oil	55 gallons	80 pounds
Boiler Coal (power)	900 pounds	900 pounds

CHAPTER II

FURNACE CONSTRUCTION—AREAS AND VOLUME—DRAFT REGENERATION

In American practice, when larger tonnages in output are sought, the general capacity of an open-hearth furnace working on castings is about 20 tons per heat. This capacity approaches the maximum that can be economically handled in jobbing shops and will amply represent a general rule. Larger tonnages may be occasionally needed if the class of product is in the shape of heavy work requiring but a few molds to receive a heat of steel and consuming but a moderate interval of time to pour them, but in cases of a heat of steel to be put into a large number of molds the pouring time may be so extended that the metal will lose its temperature. Therefore, charges exceeding 20 tons for miscellaneous castings are apt to result in losses due to cold steel. The illustrations, Figs. 1, 2 and 3, given herewith, show the usual lines of a modern stationary furnace of 20 tons capacity. The lines are the ultimate of experience in various plants and embody the best that is obtainable for that type of furnace at the present time. As they are only representative they may be subject to some minor changes which may be dictated by necessities arising from local conditions in erecting. The principles of construction are the same in both acid and basic furnaces, the differences occurring in the character of the materials forming the

torily accomplished. The patching may become loosened in a succeeding melt. Such difficulties are more liable to happen in basic bottoms than on acid. Another argument in favor of the movable furnaces is that the tapping hole troubles are eliminated. In stationary furnaces difficulties and annoying delays are encountered through "hard-taps" as a result of the materials used to temporarily close the tapping hole becoming fused or hardened and offering great resistance to tools necessary to open it at the proper time. In well ordered plants such difficulties are a rare occurrence, but still the risk exists. With a movable furnace the tapping hole is never tamped or closed so that there is

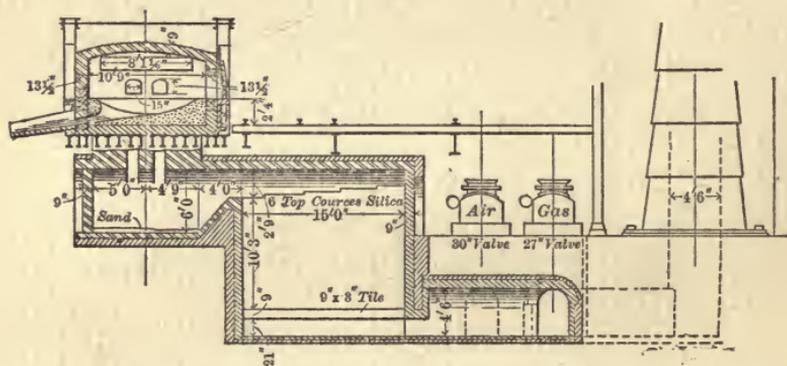


FIG. 2.—SECTIONAL, STATIONARY TYPE OPEN-HEARTH STEEL MELTING FURNACE

always the assurance that the metal can be drawn off when desired. Against these favorable considerations is the comparatively heavier first cost of the movable furnaces over the stationary, so that the question as to which type is to be approved will remain a debatable one. However, the relative volumes in regard to hearth area, regenerator chambers, etc., on the basis of the capacity of output per heat will be the same in any style of open-hearth furnace. The

next in order will be some general rules as to points of construction and volumes for a 20-ton unit.

CONSTRUCTION.—The metal work such as buckstays, tie-rods, hearth pan, doors, etc., should be of rigid construction to withstand the heavy duty due to brick work expansion when the furnace is at full working heat. All walls should be bound at the ends. Rolled shapes should be used whenever possible. Skew-backs of all arches

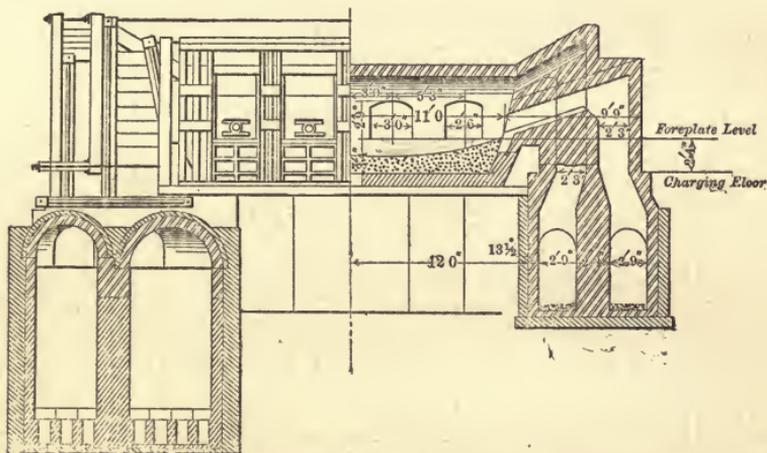


FIG. 3.—CROSS SECTION, STATIONARY TYPE OPEN-HEARTH STEEL MELTING FURNACE.

should be braced by the binding, particularly those of the roof. In the regenerator chambers the ends of all outside or partition walls should be bound, as should the ports, because the brick expansion may cause leaks and permit ignition of the gas before it reaches the working body of the furnace. The conditions of the subsoil at the selected site should be well studied before putting in the foundation. Foundations should be of rigid and first-class masonry to guard against irregular settling. They should be of hard red brick laid in cement or concrete. No part of the fur-

nace structure should extend below the lowest point at which water may be found. Water is an enemy to smooth furnace operation, if it finds its way into flues or chambers. All underground flues not protected by clay should have an outside course of red brick.

The reversing valves should be of such construction that leakages and loss of gas will not occur when operated. There are two distinct types, one known as the "butterfly-valves" and another as the "turtle-back." The latter is water sealed, which is an advantage. The stack should be of such construction as will induce a good draught, depending upon the damper for regulation.

Whenever possible the doors, door frames and furnace fronts should be water cooled, features which add to the operator's comfort in watching his furnace. The cost of installation and maintenance may be heavy but will result in a longer life for the parts and a consequent lessening of their repairs offsetting the first cost. This arrangement is only possible on stationary furnaces. On movable ones the piping connections, etc., would be too complicated.

All flues, excepting those leading from the uptakes to the furnace body, should be roomy to prevent choking and cutting by the deposit and heat of waste gases. Roominess is an essential in flues or conduits connecting the gas producers with the regulating and reversing valves and it is good practice to have such conductors above ground the entire distance to allow ready access for the purpose of cleaning out unavoidable accumulations of soot and tar. Gas flues or uptakes leading to the furnace body should be built with fake arches in their back walls, so that they can be readily repaired when badly cut without disturbing the rest of the furnace. They should also slope towards the hearth so that the incoming gas will be directed downwardly and impinge upon the stock or charge. The air port will also have the same direction, and with the gas and air inlets and outlets working properly the sheet of flame will

be kept away from the roof which will be guarded against burning or cutting.

AREAS AND VOLUMES.—The hearth length of an open-hearth furnace should be as great as possible in order that the greatest possible benefit be derived from the calorific value of the fuel. An undue shortening would be wasteful because the heat of combustion would be spent in the outgoing gas and at the sacrifice of fuel consumption and excessive cutting of outlets leading to the chambers, meaning an increased cost in furnace repairs.

Practical experience has taught that a 20-ton furnace can be safely operated with a hearth length of 20-25 feet and a width of 9-11 feet. The total area of hearth surface will work out to very close to nine square feet per ton of capacity. The width is limited to a maximum of 15 feet because furnace operatives cannot throw a shovelful of refractory material much over that distance to reach the back-wall. Generally the length will be $2-2\frac{1}{2}$ times the width.

The depth of the fully lined hearth will depend upon the dimensions of length and width. A shallow bath will give rapid working but at the sacrifice of much burnt metal or a yield which is only a small percentage of the metal charged. A deep bath will retard the melting and present difficulties in maintaining desirable thermal conditions. The medium will be learned by the individuality of the furnace and conditions of practice, but to put the problem in figures the ranges for the choice will be between 15 inches to 20 inches of depth.

An important consideration in furnace practice is re-generator chamber volumes. The fuel efficiency will be controlled largely by the length of the furnace as mentioned and also upon the proper construction of the chambers. The purposes of them will be subsequently considered. At present attention will be given to their volumes. In that particular there will be conditions to take into account as to how much room can be allowed by the space in the build-

ing where the furnace or furnaces may be located both above and below the charging floor and the depth to which the foundations and flues can be safely carried. The efficiency of a regenerator chamber depends upon the number of "checkers" it can carry and the direction of incoming and outgoing gaseous bodies. Direction is meant by the flow of gases whether they be nearly horizontal or nearly vertical in travel.

In American practice the longest dimension of the chambers is horizontal, while in European practice some are built with greater depth than length. It would seem, in view of the natural tendency of heated gases to rise, that the latter plan is the better, but as stated how they shall be built depends upon variable conditions; however, with a given chamber volume the efficiency varies with the depth. There is quite a range of figures as to volumes of regenerators per ton of capacity with different plants varying from 65 cubic feet to 140. A good figure to work by is 90 cubic feet per ton, allowing 1-3 for gas and 2-3 for air chambers.

If the fuel should be oil or liquid or natural gas the volume can be decreased materially because such varieties of fuel are led directly in the body of the furnace instead of passing through the regenerators, thus offering a possibility of dispensing with the space occupied by regenerators, commonly used as ducts for producer gas, but it is better that a furnace be built with an eye to suitability for producer fuel because the supply of liquid fuel or natural gas is subject to possibilities of irregular deliveries and a furnace built only for the latter fuels would cause some annoyances were they to be short. By the same token, producers should always be installed as a safeguard no matter what fuel may be regularly used. Thus there would be but little delay to put the producers for gas into service were liquid fuel or natural gas to fail.

The uses of regenerator chambers will next be considered. The purpose is to store in them heat carried over by

waste gases produced by the fuel combustion in the furnace body, the heat being absorbed by a large number of No. 1 fire brick, piled in such a manner that the gases in their travel from the body of the furnace to the stack will have to pass through innumerable ducts or passages. Bricks piled in such a manner are called "checkers." The plan is to pile the bricks so that they will form rectangular passages of about 3 to $3\frac{1}{2}$ inches in width. The passages will run horizontally and also vertically. Sometimes they will be in a direct line in both directions, the length and width of the chambers or the bricks may be piled in such a way that the passages are zig-zag or "staggered." Generally they are staggered in a vertical direction with straight passages horizontally.

DRAFT

The question of draft has to be considered and with as many bricks as it may be possible to checker and with the greatest possible depth of chamber the free working of the furnace will be augmented by straight passages in both directions. Indications as to heat absorption by checkers can be gauged by the temperature of the waste gases entering the stack with the furnace at full working heat.

Pyrometrical observations by the writer show the normal working conditions of the stack gases to be an average of 500 degrees Cent. with gases entering the outgoing down-takes at 1,400 degrees Cent. and with air at atmospheric temperatures entering chambers and passing through them in the up-takes at 1,000 degrees Cent. will suggest the heat absorption and radiation of the checkers.

The temperature of combustion is not sufficiently high to maintain a continued liquation of a bath of molten metal as its carbon decreases, because the air necessary to support combustion, even with a forced draft, carries away or absorbs the calorific energy of the flame playing upon the

bath of metal. In other words cold air lessens the full heating value of combustion that should otherwise be spent in work. If, then, the temperature of the necessary air for complete combustion be raised, to that extent will the flame efficiency be increased. On that rests the principle of regeneration.

Let the course of the air be followed in the chambers of an open-hearth furnace passing from left to right. The reversing valves are in position to direct the inflow of gas and air in their respective chambers on the left side of the furnace. Passing through the checkers and innumerable ducts, they enter the up-takes. The gas upon reaching the furnace body immediately ignites and draws upon the accompanying air for complete combustion, the respective volumes of each being under control by the operator. The flame energy being dissipated in work, the waste gases are now drawn by the draft and pushed along by a rear expansion towards the stack but, before reaching it, nearly all their heat units are absorbed by the checkers in the right-hand set of chambers. After an interval of 15 to 20 minutes the reversing valves are thrown and the gases are reversed in direction. The air and gas now passing into the already heated right-hand chambers carry back by radiation to the furnace body some of the waste heat previously deposited there to add to the heat units produced by combustion. The efficiency of the flame will be greater from the right-hand chambers work, assuming both sets to be of an equal temperature at the beginning of the operation, and after the second reversal the left-hand chamber will bring a still greater increment of heat value than its neighbor. That is to say, the heat units radiated to the incoming air and increasing the flame value necessarily permits more heat for the outgoing checkers to absorb. Thus it will be seen that with the increase in the number of reversals there will also be a gain in heat for work.

It would be possible to melt the best refractories by reaching high ranges of temperature by the principle of re-

generation but by careful watching on the part of the operator, flame and air volumes are properly regulated to prevent burning of the furnace. At the same time, enough heat must be maintained during the progress of a melt to preserve the fluidity and proper temperature of a bath of steel at proper intervals. Without the system of regeneration it would not be possible to successfully handle 200 tons or less of liquid steel at a time in a single operation of an open-hearth furnace.

The speed at which the gases travel through the furnace when working is due to both draft and expansion. As soon as the cold incoming air comes in contact with the heated checkers it immediately expands and produces a slight pressure which forces the body of air before it upwardly, and entering the furnace body it not only assists the combustion of the fuel, but washes and protects, so to speak, the roof of the furnace with a film of air and at the same time depresses the flame upon the bath of metal. With free passages in the down-takes and checkers, the stack will readily take care of the waste gases. Obstructions in either would make a slow working furnace and disagreeable waste of flame out of the furnace doors.

Another important feature about regenerative chambers is that they should never be under the furnace body or have their up-takes directly below the ports. In the first instance there would be danger of irregular settling causing cracks in the partition walls between the air and gas chambers, which would allow gas leakages and ignition of same before entering the furnace. In the second place there is always more or less dust and slag carried along by the draft which would be deposited in the checkers with chambers located as just mentioned, thus choking them and, of course, crippling their life. Good practice requires that the chambers be placed at the furnace ends and extend at right angles to them under the charging floor. There should also be spacious receptacles at the lowest point of each down-take to retain accumulations of dust and slag

before they could reach the chambers. Such are known as slag pockets and with proper construction they can readily be cleaned out without disturbing the checkers.

ACID FURNACE BRICK WORK

The furnace body wherever subjected to uniform, high temperature is lined by first grade silica bricks. Piers and outside walls of the structure below the charging floor can be red brick; linings of flues and chambers including checkers are No. 1 fire brick. Silica brick will not answer for checkers because they will crumble under the varying ranges of heat.

The hearth pan is lined with fire brick to the depth of nine inches or more, but above metal line of a fully lined hearth, the sides, walls and roof are silica. With the brick work complete the furnace is first dried moderately and carefully with a wood or soft coal fire kept going for a few days.

The gas or oil can then be turned on slightly at first and then gradually raised to nearly full working temperature. Layers of silica sand of the quality described in chapter I are then spread over the bottom. They are put in in succession and between each interval the flame is allowed to set or sinter the sand until hard. This operation is repeated until the hearth lining will have reached a depth of 18 to 20 inches including the fire bricks. A hearth so lined with a suitable refractory ought to last almost indefinitely under favorable conditions.

There will be occasional patching of the slag line and bottom with sand, at the end of each heat, the extent of which will be controlled by the conditions and character of stock used in melting. A hearth properly lined must be set hard enough to resist attrition by the charging of melting stock. Under skillful handling an acid furnace ought

to turn out normally 950 heats or more in a campaign at the rate of at least 3 heats per working day.

BASIC FURNACE BRICK WORK

The designation basic is rather a misnomer. The nature of the basic process requires a lining of such materials that will resist the fluxing action of limey slags and vapors necessary to purify and refine phosphoric melting stock. Unfortunately no materials are commercially available to completely line a furnace body, so recourse can only be had to a hearth lined with basic materials, with roofs, sides and walls of furnace body above the slag line consisting of silica or acid bricks, the reasons being that bricks of basic or neutral material, such as magnesite or chrome, while being refractory, do not give as good results as silica bricks, owing to a liability to crumble if placed in the walls or roof. Therefore a basic furnace is part acid and part basic lining.

With the exception of the furnace body in regard to brick work, the construction is the same as an acid furnace. The hearth pan is first lined with fire brick followed with magnesite bricks. Usually the bottom is lined with ground magnesite. It may be mixed with about 5 per cent of anhydrous tar and rammed in to form the hearth and then slowly and carefully brought to full temperature; or the magnesite may be put in loosely in layers and gradually sintered. A small percentage of ground basic slag is sometimes mixed with it to insure a partial fusing or sinter.

A magnesite hearth while costly gives the best results in service and will sinter hard enough to withstand rough usage by charging of the stock. Where the magnesite bricks meet the silica bricks of the walls, a parting of chrome ore is placed as a neutral separation of the two to prevent a fluxing liable to ensue between them at full working temperature.

There will always be some scorification of the hearth at

the slag line and an occasional formation of holes in the bottom, due to the action of silicious matter carried in with the stock. The repairs to the hearth are made with raw dolomite on the slag line, and with ground magnesite on the bottom. Dolomite being so much cheaper it is fully as effective as magnesite at the slag line. In the raw state it is not recommended for bottom repairs, because at a high temperature it is calcined, contracting greatly in bulk and for that reason holes in the bottom cannot be satisfactorily filled with it. Under the heat of fused stock it would loosen, float upwards, and leave the condition as bad as before the patch.

Undue hearth scorification can be controlled by proper care in the character of stock. Hence the consumption of refractories for hearth patching can be kept at the minimum figure. With proper care a basic hearth of magnesite should last indefinitely, and the life of the brick work of the roof and walls ought to yield 400 or more heats at 3 heats per day.

CHAPTER III

FUELS AND ACCESSORIES—DISCUSSION OF THE USES OF COAL AND OIL

As the choice of fuel may rest between producer gas or oil, a description of the operation of either will be briefly considered. Referring to the illustration of a gas producer, Fig. 4, a general idea will be formed of its construction. The one shown is of the simpler kind and entirely hand fed and poked. In some of the large rolling mills coal is fed in continuously by a mechanical device, and the bed of the fuel is poked by a mechanical contrivance. The principle of operation is the same in either case so far as making gas goes.

For a continuous supply of gas, air and steam are forced through an incandescent bed of bituminous coal on top of which is fed at regular intervals fresh coal. Frequently the mass is poked with long bars to break up the decomposing coal and to prevent holes or passages being formed which might allow air to pass through them and dilute the gas. In the vicinity of the grate, which is water sealed, the fuel is completely burned, while near the top the fuel gives off its volatile matter, forming copious volumes of smoke with some tarry matter. As the fuel descends towards the grate it is gradually burned to ash.

For proper working conditions the bed of coal should be kept at a constant height, and vigorous poking should be frequently and persistently followed.

The object of water-sealing the grate is to permit the amount of air necessary to gasify the coal, to be under control at all times.

The use of steam lessens the temperature of combustion

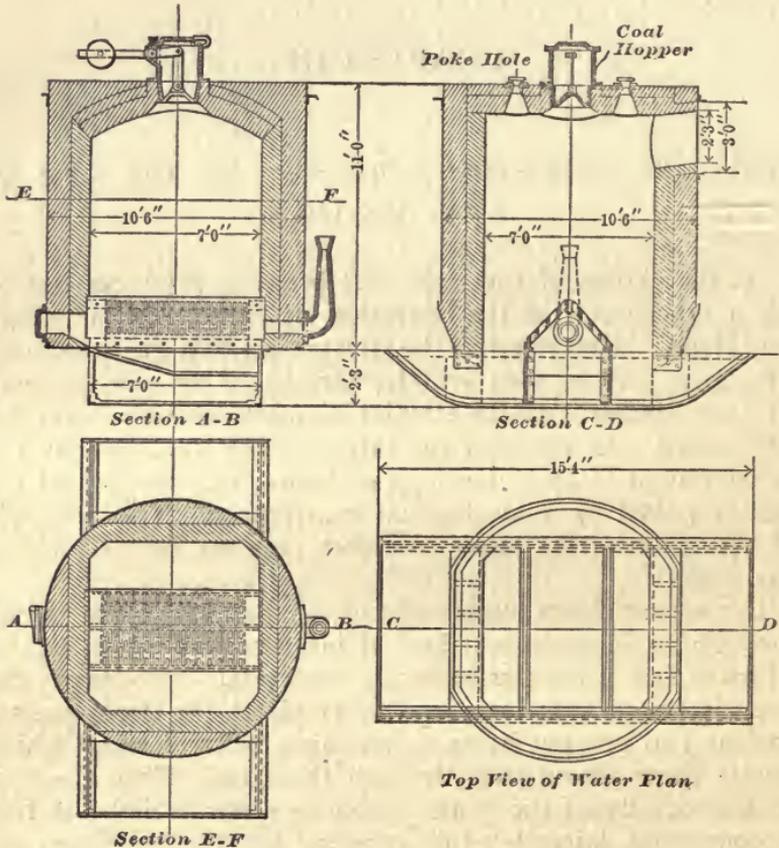


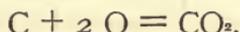
FIG. 4.—GAS PRODUCER.

at the grate and so lengthens the life of the grate bars. At the same time the steam chemically combines with the fuel to form water gas as will be shown. It also prevents the

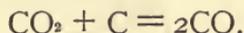
formation of clinkers, making it easier to keep the fires clean.

To make good gas the fuel must be hot, and close attention must be given to the admixture of air and steam forced into the producer. Too much steam tends to cool the fires and pass into the flues, undecomposed, causing an extravagant loss of fuel efficiency. A deep, hot bed of coal will yield the richest gas.

It will not be amiss to consider some of the chemical changes that take place in a producer. Roughly the bed of fuel in it can be divided into two zones. The lower one, nearest the grate, can be called the CO_2 zone and the upper one the CO zone. The air coming into union with the fuel near the grate forms



CO_2 is of course, non-combustible, but as it passes upwards it combines with the glowing carbon of the CO zone and absorbing some becomes



the latter constituent forming the larger volume and chief calorific agent of producer gas. By the action of steam we have



The calorific value of this last product is greater in equal volume than the CO formed in second equation but at the expense of the heat in the bed of fuel. The following is an analysis of producer gas by volume:

C O	27.00 per cent
C O ₂	5.00 per cent
H	10.00 per cent
C H ₄ + C ₂ H ₄	1.50 per cent
O + N by difference	56.50 per cent
	100.00 per cent

The amount of oxygen in the gas will be about 1 per cent,

and represents the air that passes through the producer uncombined. The index to the proper working of the producer is the amount of CO_2 present. Under the most advantageous conditions it will rarely fall below 2.5 per cent and with bad conditions it will exceed the average of 5 per cent. The causes of an excess are due to insufficient poking, a shallow fire and faulty brick work allowing air leakage to ignite the gas before it can be delivered to the furnace.

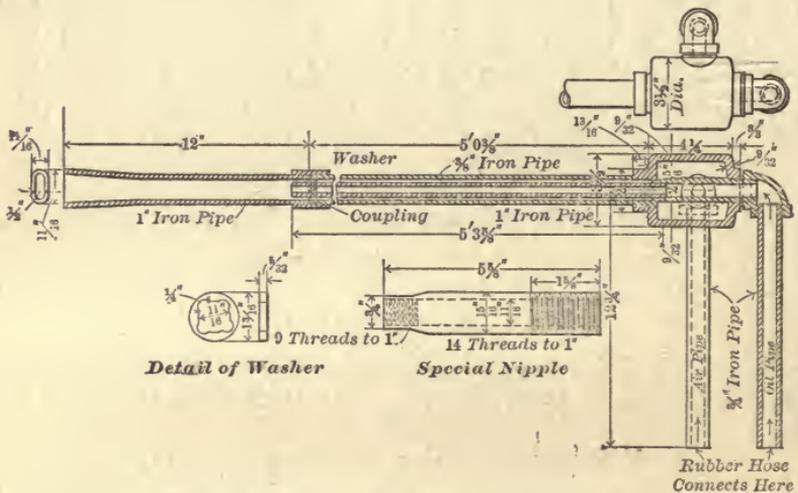


FIG. 5.—OIL BURNER FOR OPEN-HEARTH FURNACE

At the best, producer gas is unsatisfactory, and the steel melter is always at the mercy of the vigilance or lack of it of the gas man.

One ton of bituminous coal yields 160,000 to 170,000 cubic feet of gas with a calorific value, at the producer, of about 137 B. T. U. per cubic foot. The gas in traveling to the furnace loses heat units at a variable rate. The actual amount of gas delivered to the furnace is hard to determine, owing to leakage and the consumption in drying ladles.

Liquid fuels, such as crude petroleum or residuum, possess a high calorific value, usually expressed at 14,000 to 17,000 B. T. U. per pound of oil. Because the oil being delivered directly to the furnace (see oil burning device and furnace construction for same, Figs. 5 and 6), and igniting, when atomized by steam or compressed air, yields its entire thermal efficiency to work with no intermediate losses as is the case with gas, the value of oil over the latter is marked.

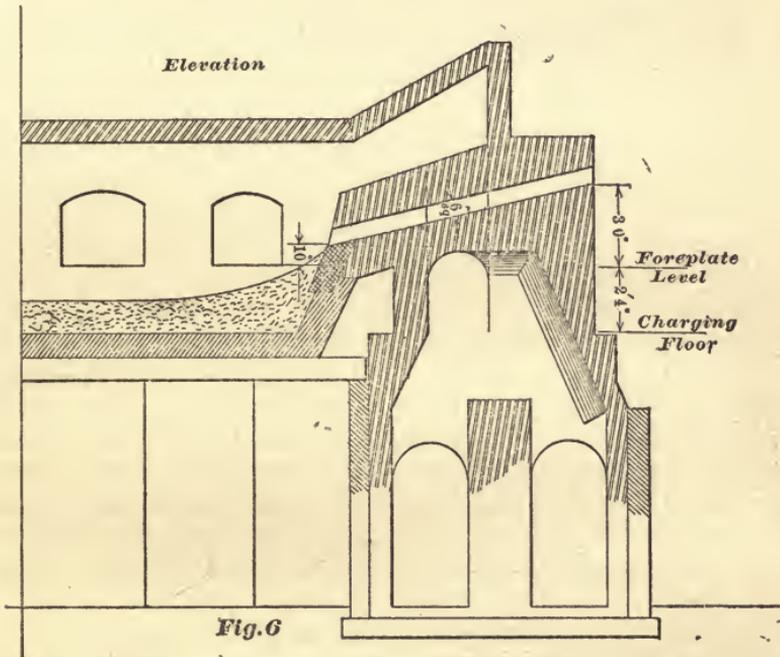


FIG. 6.—FURNACE ARRANGED FOR BURNING OIL

It is difficult to make an actual comparison between oil and coal for steel melting on the basis of the cost of a ton of metal produced. The figures may be in favor of coal in certain localities, and in favor of oil in others. Yet the advantages of oil over coal in working results are so pro-

nounced that discrepancies in cost against oil are offset by its usefulness.

Ignoring the relative costs, the principal points in favor of oil against gas will be considered.

First, the higher thermal value: A cubic foot of gas will yield 137 B. T. U. Taking 16,000 B. T. U. as an average of one pound of oil and allowing a cubic foot of oil at 57.11 pounds then $57.11 \times 16,000 = 913,760$ B. T. U. a substantial gain in favor of oil against an equal volume of gas.

Second, the simplicity of installation. One furnace will require a storage tank with a capacity of about 17,000 gallons. From this the oil is pumped to the burner which essentially is the producer in the sense that the arrangement of the burner permits a necessary atomization of the oil by steam or compressed air before ignition. It is superfluous to make a further comparison on this point, in view of the crudity of the gas producer.

Third. The use of oil lessens furnace repair costs and allows longer campaigns before shutting down for general repairs. This point alone, is perhaps the strongest one in favor of oil. Conditions of brick work in regenerator chambers do not require the same attention with liquid fuel as they would with gas. That is to say, should there be leakages in the partition wall between air and gas chambers, they can be ignored, using oil; but with gas they would necessitate a shut-down of the furnace to repair them. The same applies to ports and down-takes.

Fourth. The character of the oil not being subject to the same latitudes of irregularity as the composition of the gas, there results a decided gain in the certainty of the furnace's work. The temperature of the bath is under control, and regularity of output can be expected—a feature not so dependable with gas.

Fifth. The labor cost is greatly lowered. One man per working day attends the pumps. In the gas house there will be a foreman and several laborers to feed and poke the

fires, and to wheel away the ashes. The labor in unloading and stocking coal is also eliminated. With these features can be mentioned the removal of the attendant dirt and smoke with gas producers; the loss of time in cleaning gas mains and other conditions that would occupy too much space to mention.

Oil fuel will also be useful for drying ladles, firing annealers, core ovens, etc.

CHAPTER IV

MANIPULATION OF HEATS IN ACID PRACTICE—COMPOSITION OF CHARGES—DETAILS OF RECARBONIZING—

Given an acid lined hearth and stock for melting purposes, the next step will be to consider some of the changes that take place in the conversion of the materials charged into steel. As has been mentioned the only elements, that are confined within stated limits, are the sulphur and phosphorus. Considerable latitude remains in making up the charge in regard to the available silicon, carbon and manganese carried in by the stock. Assuming the stock to be made up of pig iron, billets, blooms, plate-clippings, axle-butts, defective steel-castings, shop scrap or wasters in varying proportions, a charge of 24,000 pounds will be studied because the diagram herewith shown (Fig. 7) was plotted on a heat of that size. The proportions and changes would be relatively the same in a 20-ton heat.

The charge will be as follows:—

Acid pig iron	= 3,600	15 per cent
Mixed scrap	= 20,400	85 per cent
Lbs.	24,000	100 per cent

AVERAGE COMPOSITION

C	.....	0.90 per cent
Mn	.....	0.47 per cent
Si	.....	0.40 per cent
S	.....	0.024 per cent
P	.....	0.028 per cent

The order of charging will be as follows:—

First.—Two-thirds of the pig iron.

Second.—Lightest sections of scrap.

Third.—Heaviest sections of scrap.

Fourth.—One-third or remainder of pig iron.

The object in charging the pig iron in two portions with the larger amount on the bottom is to protect it from scori-fication caused by the oxide of iron always formed in the melting of the scrap which oxidizes at a faster rate than the pig iron. The portion of pig iron on top is the first to melt and in dripping over the scrap lowers the melting point of the latter and in a measure protects it from undue burn-ing or oxidation until the whole mass sinks below the slag formed during the exposure of the stock to the flame action.

The length of time occupied in charging varies as to the size of the pieces of scrap charged and the room it offers to follow with the rest of the stock.

Occasionally there may be some little time elapse before the bulky stock may have partly melted and subsided before the charge can be completed. Usually the length of time consumed in charging is about one to one and one-half hours.

The charging of stock being completed the history of the heat is divided into two stages: First, the melting; second, the complete fusion and conversion of the materials. Dur-ing the first period little or no change takes place in the composition, the main action being the transmission of the solid stock to the liquid form and with it the formation of the slag which is to play an important part in the subsequent conversion of the stock to steel.

The length of time required to liquify the stock is normal-ly from 2 to 2½ hours, and during that time the tempera-ture of the furnace is gradually increasing owing to the method of regeneration already explained.

It is certain that some changes occur as soon as the stock begins to melt and the slag begins to form. Perhaps the most pronounced change takes place by flame action on the

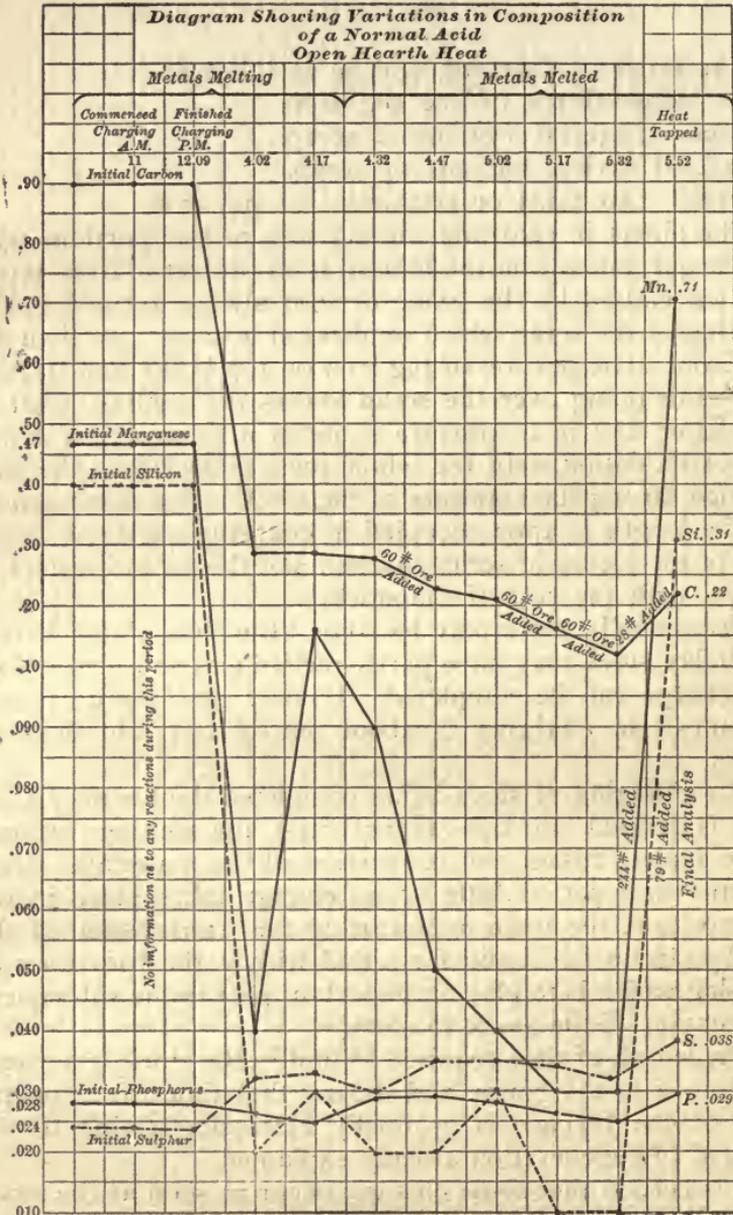


FIG. 7—SHOWS VARIATION IN COMPOSITION OF A NORMAL ACID OPEN-HEARTH HEAT

exposed stock, it being strongly oxidizing; but not until the charge becomes entirely fused or liquid does the active part of conversion begin.

With complete liquation of the charge the flame simply becomes a vehicle of heat and, under the practiced eye of the melter, the thermal conditions are so maintained that the temperature of the bath is gradually increased as the conversion progresses. It is necessary that the temperature of bath be gradually increased because of the influence of carbon. In general terms the fusing point of iron or steel depends upon the amount of that element, the higher percentage fusing at a lower point thermometrically than the lower amounts.

Glancing at the diagram the carbon will be seen as gradually increasing as the conversion progresses. Without a corresponding increase in temperature, the bath of metal would become pasty; and with the bath in that condition there would be losses.

In order to induce liquation at the first stage of conversion it is necessary to introduce carbon in addition to that being furnished by the pig iron of the charge. Fluidity and proper thermal conditions succeeding are then easily attained.

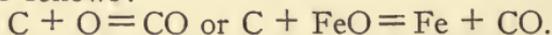
Assuming the stock to be melted and having passed from direct flame action below a covering of slag the functions of that will next be considered. The existence of the slag is derived from sand carried in mechanically by the stock, the oxidation of the silicon contained in the pig-iron and scrap to silica, the oxidation of the manganese brought in by them to manganous oxide, some scorification of the hearth and the oxidation of iron to ferrous oxide.

Normally the slag is automatically formed, in regard to composition, throughout the progress of the heat.

Should there be an excess of FeO due to low silicon pig-iron, there would be an excessive cutting of the hearth and it might be necessary to add sand to furnish the needed SiO_2 to form the adjustment of proper slag composition.

Approximately a normal slag in an acid heat consists of nearly equal parts SiO_2 acid and $\text{FeO} + \text{MnO}$ (bases) and this composition will exist throughout the heat with a gradual increase in volume resulting from the continued oxidation of silicon and manganese and by the addition of iron-ore.

The oxidation of the carbon causes a lively bubbling in the bath by the liberation of carbon monoxide (CO) as a result of the exchange between the FeO of the slag and the oxygen furnished by iron-ore additions, which may be expressed as follows:



The metallic iron reduced from the FeO of the slag and that brought in by the iron ore (Fe_2O_3) is immediately absorbed by the bath. Were there no additions of ore the slag would become thick and pasty owing to the decrease of the base FeO .

Test samples should be taken regularly after melting, the fractions of which indicate the amount of carbon in them, giving guidance to the melter as to the necessary additions of ore.

In acid practice, only the carbon is considered in preliminary tests, but for detailed information they may be examined for the usual elements. When in the judgment of the melter the bath needs no more iron ore and the decreasing carbon has reached a predetermined point (which can be accurately estimated by the practiced eye) preparations are then made to finish the heat.

The thermal conditions being satisfactory and the slag normal, deoxidizers and recarburizers in the shape of ferro-silicon and ferro-manganese are then added and the heat of finished steel is ready to tap or draw off into a hot ladle.

DETAILS OF RE-CARBONIZING

Assuming that the chemical composition of the metal going into castings shall be as follows:

C	0.25 per cent
Si	0.300 per cent
S	0.040 per cent or less
P	0.040 per cent or less
Mn	0.75 per cent or less

which may be considered as representative of regular practice on medium hard cast-steel. Taking as a basis 24,000 pounds of metal charged and the weights of ferro-silicon and ferro-manganese 792 and 305 pounds respectively, from them there will be furnished silicon, manganese and carbon plus those several elements contained in the bath at the time of final additions. According to these analyses the available elements will be first, silicon from the FeSi with 10 per cent silicon,

$$792 \times 0.10 = 79.2 \text{ pounds Si;}$$

second, manganese from the FeMn with 80 per cent manganese,

$$305 \times 0.80 = 244 \text{ pounds Mn;}$$

third, carbon from both the FeSi and FeMn.

$$\begin{array}{r} 792 \times 0.015 = 11.88 \\ 305 \times 0.055 = 16.77 \\ \hline 28.65 \text{ lbs. C} \end{array}$$

Taking into account the residual silicon, manganese and carbon of the bath, and adding to them those furnished by the FeSi and FeMn there will be,

$$\begin{array}{l} \text{Si} = 0.0001 \times 24,000 + 79.2 = 81.6 \text{ total available} \\ \text{Mn} = 0.0003 \times 24,000 + 244.0 = 251.2 \text{ total available} \\ \text{C} = 0.0012 \times 24,000 + 28.7 = 57.5 \text{ total available} \end{array}$$

With the number of pounds of the several elements divided by the weight of the charge there will be found the approximate analysis of the finished product,

$$\begin{aligned}
 100 \times 81.6 \div 24,000 &= 0.34 \text{ per cent Si} \\
 100 \times 251.2 \div 24,000 &= 1.05 \text{ per cent Mn} \\
 100 \times 57.5 \div 24,000 &= 0.24 \text{ per cent C}
 \end{aligned}$$

or calculating another way the approximate composition can be determined in finished product using the same quantities of values in terms of available silicon, manganese and carbon:—

$$\begin{array}{r}
 100 \times 79.2 \\
 \hline
 24,000 \\
 100 \times 244 \\
 \hline
 24,000 \\
 100 \times 28.65 \\
 \hline
 24,000
 \end{array}
 \begin{array}{l}
 \text{Residual} \\
 + 0.01 = 0.34 \text{ per cent Si} \\
 + 0.03 = 1.05 \text{ per cent Mn} \\
 + 0.12 = 0.24 \text{ per cent C}
 \end{array}$$

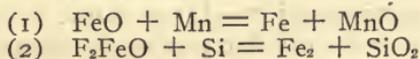
In making the foregoing computations the amounts of sulphur and phosphorus have been ignored. With a slag highly charged with silica no absorption of these takes place, and the amount of either carried in by the melting stock nearly equals the finished product in regard to their content. Usually there are slight gains. The sulphur increases because of flame contamination and a loss of metallic iron by oxidation. Phosphorus also increases slightly through the latter cause. Both may be slightly augmented by movements from the deoxidizers.

The chemical composition as shown in the foregoing figures will differ from that shown by the ultimate analysis of a sample taken when the steel is going into the molds. Comparing the approximate and ultimate figures we find:

	Approximate Analysis.	Ultimate Analysis.
C	0.24 per cent	0.22 per cent
Mn	1.05 per cent	0.71 per cent
Si	0.34 per cent	0.31 per cent

The main difference is between the manganese added and that found, the cause of which will be understood in the explanation of the purpose in using the deoxidizing agents FeSi and FeMn. During the second stage of the conversion, the bath of molten metal carries variable quantities of dissolved ferrous oxide (FeO) and with that substance there is a vigorous chemical action between the carbon and the oxygen of the FeO producing throughout the bath copious bubbles of the gas CO. So long as the bath remains liquid this chemical action will go on, charging it with that gaseous body. Were the metal in that condition to be poured into castings they would be found to be unsound or honey-combed with blow holes.

Since solidity of product is one of the objects sought in the physical properties, recourse must be had to some agent or agents that will remove the cause of the gas-forming action in the bath of metal before it can be drawn off. The agents must possess greater affinity for the oxygen of the dissolved FeO than the carbon in intimate association with it. Practical experience has shown that manganese and silicon accomplish the purpose and these elements are commercially available in the alloys, FeMn and FeSi. Hence their designation as deoxidizers. The functions may be expressed as follows:



In the interchange between the C and the FeO we have a gas impregnating the bath. In the interchange, as shown in the above equations, we have a solid or an easily fusible slag formed by the SiO₂ and the MnO, which being lighter than the molten metal quickly floats to the surface of the bath. Thus with normal conditions the metal will cease bubbling and pour quiet or "dead" and tend to make solid castings.

The amounts of silicon and manganese in the finished metal will in the main depend upon the condition of the bath

at the time the deoxidizers are added, and the difference in analyses between the approximate and ultimate figures may be taken to represent the amount consumed in "washing" the bath of metal.

The usual practice in adding the deoxidizers is as follows: The carbon having dropped to, say, 0.10 to 0.12 per cent, the dose of FeSi, broken into short pigs, is placed on the breast of the furnace in order to heat it up before pushing it into the bath. After a lapse of about eight minutes the whole is pushed into the bath, allowing a little time to pass during which the FeSi is melting and dissolving. To insure a complete distribution the bath is agitated with bars of iron. Ten minutes after the FeSi is added the metal is ready to tap, but before doing so, the dose of FeMn is thrown in and then the tapping may take place. It is sometimes the practice to put part of the FeMn into the furnace and part into the ladle, the latter being done while the steel is flowing into it.

In an acid heat the losses of silicon in the act of deoxidizing are not great, but of the manganese used for the same purpose, considerable is consumed, being greater when entirely added to the furnace than when divided between the furnace and ladle. For this reason it is necessary to make allowances for such losses when calculating the necessary dose. Further, the losses are greater when using oil for fuel than when gas is used, the latter flame being "soft" and the former sharp. An oil flame may be likened to a blow-pipe and its effect always strongly oxidizing.

As already shown, silicon will reduce the FeO, but the reduction is not always complete, and what may escape the silicon may further unite with the manganese. Hence the reason for simultaneously using two powerful and active reducing agents. The influence of the two agents remaining in the finished steel after their reducing function will be considered later.

The yield of metal after conversion against the weight charged is a variable one and depends upon the character of the stock and manipulation. If the stock, other than the pig

iron, should be of light, thin sections, there will be a heavy melting loss due to excessive burning or oxidizing. If the flame should be very sharp during the melting period, the same condition will arise. The melting losses are also heavier on oil fuel than on gas for the reason stated. Not only will the conditions (when abnormal) result in heavy melting losses, but the effect will be seen in certain physical properties of the product. That is to say "over-oxidation" from any cause is bad practice; yet even with a greater tendency towards "over-oxidation" following the use of oil, the condition is still subject to control. To express the losses in figures to represent the difference between metal charged and that yielded is not so easy, but it may be found to be about 5 per cent.

The principal points about the manipulation of an acid heat may be given as follows:

First—To charge enough pig iron so that there will be a high enough initial carbon to ensure an easily maintained fluidity of bath. A low percentage of pig iron will mean a rapid heat, but at the sacrifice of quality and a very high flame temperature. The less carbon charged the greater the chances of over-oxidation.

Second—Charge as heavy sections of scrap as possible and protect it as far as possible from burning with a covering of pig iron.

Third—Watch the flame conditions, to guard against undue burning of stock. This point calls for a high degree of skill to maintain flame conditions and yet reach the thermal ranges necessary to melt the stock.

Fourth—Be judicious in oreing heats. Too much ore is harmful.

Fifth—Aim for uniformity of product in a given class of work.

Sixth—Over-anxiety for tonnage will make the scrap pile grow.

CHAPTER V

BASIC PRACTICE—SLAG—SILICON—SULPHUR—PHOSPHORUS—MANGANESE—CARBON—SLAG COMPOSITION—ORDER OF CHARGING—MELTING—CHARGING COLD STEEL

The problem of charging into a basic open-hearth furnace, phosphoric and otherwise impure materials, converting the same into good castings, offers many interesting features. To get satisfactory and uniform results, certain conditions require close attention and niceties of adjustment. When with a suitably lined basic hearth and the proper melting stock it is possible to begin with a high initial phosphorus and sulphur content and end with an almost complete removal of them, it is clear that the chemical history of the manipulations in conversion is more varied than that of an acid heat. As already stated, 95 per cent of the phosphorus and 60 per cent to 75 per cent of the sulphur can be eliminated in a basic bottom. Concerning the other constituents the conditions in regard to their removal during conversion and their presence in the finished product are practically the same as in acid castings.

SLAG

Given, then, a basic bottom and melting stock, the changes in a heat will be considered. The function of the basic bot-

tom is only a refractory one and the material entering into it plays no part in the direct purification and conversion of the stock. The calcereous slag is the active agent and the bottom must be of such material that the action of such a slag will have the least possible cutting effect. To minimize that effect, the best results will be obtained with a magnesite lining prepared as previously described. Limestone or calcium carbonate forming the slag and classified as a "base" will not flux with magnesite, also a "base." That is, an admixture of two or more bases will successfully resist high temperature or those common to steel melting; but a combination of an acid (silica, etc.) and a base (lime or magnesite, etc.) will at similar ranges of temperature readily fuse. Hence the metallurgical necessity of the hearth lining being of a similar character chemically to that of the slag which may be formed in open-hearth melting.

Silica being greedy for any base and always ready to fuse in the presence of a base, the life of a basic hearth will be subject to its influence, therefore it is important that the substance be allowed to enter the charge only in the smallest amounts possible. Through the charge it will be carried in as silicon (subsequently changed to silica) and sand adhering to the stock. With pig iron cast in chills, the amount of sand from that source will be practically nil. Defective castings charged directly from the molding floor may have more or less sand on them and unless they are carefully cleaned to free them from burnt cores, etc., there will be danger of undue hearth scorification both on the slag line and bottom, causing an increased use of refractories for patching.

SILICON

Theoretically silica or silicon should be absent in basic stock. Practically it is not free from either, but the condition is none the less subject to control. Therefore in selecting pig iron for basic melting the maximum percentage

of silicon is given as one per cent. The amounts of that element in the various kinds of steel scrap are so low that the figures are negligible. Assuming the total charge to be equal parts of pig iron and steel scrap the initial silicon carried in by stock will average about 0.5 per cent. It is good practice to keep in the neighborhood of that figure, but a slight variation or increase will not be a serious objection. If there should be on hand some "off basic pig iron" that is high in silicon (over one per cent), or high in sulphur (over 0.05 per cent), a small quantity can be charged at the rate of about one per cent of the charge and will have but a very slight effect upon the desired initial composition.

SULPHUR

In regard to sulphur and its position in the composition of the charge, it does not seem necessary to be very rigid as to how much can be considered dangerous. Actually standard basic pig iron, while rated at 0.05 per cent maximum carries more than that because of the generally accepted method of analysis giving uniformly low results. Were a more tedious method and a more accurate one employed, the figures on sulphur would generally be nearer 0.07 per cent than the standard stock requirements; hence the amount of sulphur actually going into a charge is really higher than shown by the individual analyses of the pig irons forming part of it. The same differences between the apparent analyses and actual content of sulphur holds true on various grades of pig iron until very low amounts are reached. In the light of recent practice, the influence of sulphur in the finished product is not regarded as harmful as it once was. There is therefore no good reason to place a strict limit on how much shall go into a charge. On an average the total amount will rarely go above 0.04 per cent. Rail scrap frequently carries 0.07 per cent and over. The pig iron will range from 0.01 to 0.05 per cent, and

with many kinds of steel scrap to select from, ranging from 0.02 per cent and higher, it will not be difficult to keep the initial sulphur at or about the average stated if so desired. In the writer's experience there was a time when it was considered bad practice to have the initial sulphur exceed 0.03 per cent, and the aim was to get lower. (At this point the question as to the influence of sulphur will not be considered, but will be deferred to a subsequent chapter). With a normal basic slag and proper conditions, much higher ranges of initial sulphur can be safely handled. There will be almost complete elimination in conversion, so that specification for finished product can be kept within easy reach even with an initial sulphur of 0.07 per cent.

PHOSPHORUS

Concerning phosphorus and keeping in mind the ulterior limit in the analysis of the finished product, it is as well not to make the entire pig iron charge all high phosphorus material. While the figure on standard basic pig iron is one per cent and was drawn for ingot practice for castings it is better to have at least two kinds of basic pig of which one may be low and one other standard. A brand carrying about 0.25 per cent of phosphorus or less is not difficult to procure. With a charge of mixed brands of pig iron, and the usual varieties of scrap, it will be possible to keep the initial phosphorus of the charge low. During the progress of conversion and with a strongly basic slag, there will be practically a total absorption of phosphorus by it from the bath. At the end of the heat in recarburizing with ferro-silicon, etc., there will be a tendency on the part of the phosphorus to re-enter the metal, depending in a great measure upon the amount of that element charged, and the basicity of the slag. There is always some re-absorption, and it is greater with all high phosphorus pig than when it may be diluted with low phosphorus pig iron. Hence the need of mixing the pig iron in regard to phos-

phorus content. Average practice will give a negligible reabsorption if the initial phosphorus is about 0.1 to 0.3 per cent.

MANGANESE

In addition to the elements enumerated, there is always more or less manganese carried in with the stock. In basic melting it is useful in several ways. One function is to assist in maintaining a necessary fluidity of the slag, and it will exist in that body principally as an oxide, resulting from the metal in the charge. It also aids in the removal of sulphur in the bath, and at some period during the melting unites with it, forming a readily fusible sulphide of manganese which floats upwards, and either dissolves in the slag or upon reaching the surface and becoming exposed to the flame action, may be oxidized or volatilized. The action of manganese, however, is not quite clear, but from actual results there is no doubt that its influence in de-sulphurizing is quite potent. In that respect it operates in conjunction with the Ca O (lime) furnished by the limestone, which is also an active de-sulphurizer. It has been observed that a moderately high initial manganese assists in washing the bath of dissolved oxides always present in metal which has been subject to the impinging action of the flame before the period of liquation has been reached and the mass disappears below the slag. The deoxidizing effect will not begin until the mass has partially or entirely fused and is covered with a layer of slag. Deoxidizing will take place by the union of silicon and carbon with the oxygen, and whatever manganese may be present in excess of that which may unite with the sulphur will considerably augment the effect. The joint operation of the three elements will give cleaned metal. With ordinary melting stock the average or initial manganese will be about 0.5 per cent, but if it is possible by the use of a high manganese pig iron to

raise it nearer one per cent, the results or deoxidizing effect will be more satisfactory. Or in the absence of that kind of melting stock, the deficiency can be made up with spiegeleisen, an alloy carrying 20 per cent of manganese or a certain amount of manganese ore will be useful for the same purpose, if charged at the proper time,—before the first portion of metal. It is recommended, however, that the needed manganese be carried in by high manganese pig iron, because it is possible to get a better distribution of that element than by adding a small quantity of the alloy mentioned to make up any deficiency. For that reason it is good practice when purchasing melting stock, to have on hand pig iron carrying between 1.5 to 2.5 per cent manganese.

CARBON

Since pig iron generally contains 2.5 to 3.5 per cent total carbon and with 50 per cent pig and 50 per cent steel scrap the initial carbon of a charge will be from 1.5 to 2 per cent. Whether the carbon may be in the combined or graphitic form is not considered, because when the pig iron is liquid, it is all in the former condition irrespective of the constitution before melting. It will be observed that there is a difference between acid and basic melting in regard to the percentage of pig iron in the charge. In the former there will be 15 per cent, but in the latter 50 per cent. The reason for the difference is due to the larger volume of slag formed in basic melting, which requires a considerable portion of the heat units to penetrate it, to promote the necessary fluidity of the bath of metal below. As has been pointed out, the amount of carbon present largely controls the melting point of iron and steel and with a high initial percentage of it in a charge of cold stock, it is possible to acquire liquation at a relatively low temperature. Were there a low initial carbon as in acid melting, there would be much trouble with viscosity of the bath, because of heat

absorption in the heavy body of basic slag. With the bath melted at a high range of carbon, the necessary thermal conditions are comparatively easy to attain. A high carbon at melting, between 0.5 to 0.8 per cent, is considered good practice; further, it means a prolongation of that period in which deoxidization or clarifying of the bath occurs. A lower carbon at melting would shorten that period, and at the same time there would be undesirable conditions likely to arise, such as low temperature of the bath, and overoxidized metal, both tending to give bad results in the product. Should a heat melt soft (low carbon) it can be "doctored" by adding cold pig iron, and the temperature raised by flame adjustments, but recourse to such treatment is always dubious as to the outcome.

SLAG COMPOSITION

The foregoing elements of the charge being adjusted in accordance with general practice, the next step will be to consider the slag composition, which is to play an important role in the conversion and purification of the bath. In contrast to acid melting, the slag will be one highly charged with lime, a substance already shown to be objectionable in an acid hearth, but desirable in treating basic stock. The normal composition of a basic slag will not be reached until the stock has melted and the slag attained its maximum fluidity, which period occurs during the second stage of a heat that for convenience may be designated "Metals Melted." Taking as an average the analyses of twenty samples of slag selected from various normal heats in the second stage, the following can be considered the usual composition of a basic open-hearth slag:

Silica	16.00 per cent
Ferrous oxide	22.00 per cent
Lime	40.00 per cent
Magnesia	8.50 per cent
Manganous oxide	8.50 per cent

The foregoing analysis can only be regarded as applying to the conditions of practice existing when they were made, and not as a rule to follow in all cases, but under general conditions they may serve as a guide. In order to form a basic slag there are several important conditions to take into account. First—Enough lime must be added to combine with or neutralize the silica, which will result from the oxidation of the silicon carried in by the metals, and that carried in mechanically as sand; otherwise, there would be a thin slag and an undue cutting of the hearth by the silica. Second—Too much lime must be avoided, as it tends to form a thick, pasty slag that causes trouble in tapping the furnace or brings about a heavy consumption of fluorspar to flux it.

There is a medium to be sought between basicity and fluidity and at the same time the function of the slag in absorbing and retaining phosphorus must not be overlooked. The measure of the latter action mainly depends upon the amount of lime in excess of that united with the silica, lime in a basic slag being the active de-phosphorizing agent. As to fluidity, that condition in addition to the influence of silica will depend upon the varying amounts of manganese in the stock which enters the slag as an oxide. Oxide of iron operates in the same manner and is always present independently of that added as iron ore. The iron oxide of the slag will result from the rusty coating on the stock and the impinging action of the flame during the first stages of a heat. In general terms the higher the content of silica the greater the fluidity, but at the expense of de-phosphorization and hearth. Fortunately the medium can be found because of the presence of iron and manganous oxide, since a law seems to exist in slag formations that fluidity or fusibility is controlled by the number of bases present. So, assisted by manganous oxide and iron oxide in the presence of lime and silica, desirable slag conditions in basic melting can be attained without much difficulty.

In addition to the elements given in the slag analysis

there may be small negligible quantities of alumina and alkalis. The amount of magnesia results mainly from hearth cutting. To forecast the exact amount of lime to be added solely on theoretical grounds is not easy, because the total available silica cannot be accurately determined owing to the uncertain quantity of sand adhering to the stock. Whatever silica may be available in the stock will require at least enough lime in the ratio of 1 to 3 to satisfy it. Also the purity of the limestone, generally used as a carrier for the necessary lime of the slag, must be taken into account and any silica this may have will depreciate the available lime in the same degree. Therefore, the nearer a limestone approaches a pure carbonate of lime the greater its efficiency. In actual practice the amount of limestone required to form a normal slag will vary between 7 and 15 per cent of the weight of the charge. With standard melting stock and a pure limestone it will be comparatively easy to get satisfactory adjustments. In the hands of a skillful operator assisted by the chemist the behavior of a heat can be followed at any desired stage, so that untoward conditions of purification will be within control. Agencies are constantly at work in slag formations following the laws of attractions and affinities which present problems of scientific interest. To solve their complexities would be a difficult task.

If an open-hearth furnace be regarded as a chemist's laboratory experiment on a large scale, and viewed from a chemist's standpoint, the delicacies of definite chemical reactions are not obliterated because of the very hugeness of a furnace. Whether the operation be conducted on a minute scale or on a larger one, definite laws are omnipresent. Could the operator bear in mind that he is handling tons of material with forces equally potent as in the chemist's ounces, he would stand in awe of them. Careful, intelligent work combined with practical experience makes it possible to put basic practice in the same plane of effi-

ciency as acid melting notwithstanding prejudice to the contrary existing in some minds.

ORDER OF CHARGING

Having determined upon the amount of limestone necessary to form the basic slag, the next step will be to consider the order of charging. With a basic hearth prepared as outlined in previous chapters the method of charging may be conducted as follows: First the stone is spread over the bottom in as regular layers as possible, followed by the lighter sections of scrap, which should be more or less rusted. If not rusty, some iron ore may be added with the scrap to make up the lack of oxide to assist in subsequent slag fusibility. Then two-thirds of the pig iron should be distributed as evenly as possible, which may be followed by the remainder of the scrap. By this time the furnace will be well filled with bulky stock, and it may be necessary to allow the flame to partly melt it, thus forming room for the final addition of pig iron.

The serious part of melting now begins and at this stage the finished product in regard to quality will be greatly influenced by the manner in which the exposed stock may be subjected to flame action. There will be a desire on the part of the operator to get the heat out of the furnace in record time and with speed in mind the temptation to use a sharp, hot flame will be strong. On the other hand, a soft, mellow flame will not melt as quickly as a sharp one, yet the character of the product will be better than under the first named conditions. In one instance the bath will be highly charged, when melted, with dissolved oxides and in the other instance less so. It is not possible under any conditions to melt a mass of pig iron and steel scrap without some formation of oxides, and their subsequent solution in the bath, so long as it remains uncovered by a protective layer of slag. Good practice requires that there be a dividing line between speed and slowness, a sharp flame and a

soft one, and that object is a difficult one to reach. The quantitative expression of dissolved oxides cannot be stated, but their influence can be detected in varying degrees. That such conditions do exist is a fact, and the conclusion is based upon careful observations and research, the results pointing undoubtedly to the influence of the flame action, whether gas or liquid fuel may be used and also to the amount of initial carbon present in the stock. Oreing during the second stage or "Metals Melted" also may aggravate the evil. That it is an evil, will be pointed out, and one not fully appreciated or understood. To it can be traced the non-success and consequent prejudice against basic melting, because, in some instances, it has been found in certain physical requirements that basic steel was not as good as acid steel for castings. In other words, expressing the difference between basic and acid steel in regard to certain physical properties, basic steel is more likely to carry dissolved oxides than acid steel, provided care has been taken to guard against their introduction or formation. Differences in chemical composition can only exist in the amount of sulphur and phosphorus for a given grade of product and the said differences being too small to exert any great influence, no cause can be assigned other than the one mentioned in studying the contrasting physical properties of both classes of steel. The condition of over-oxidation is not so liable to present itself with a gas flame, but even such a flame can be so adjusted as to abuse the stock. With an oil flame the danger is greater, because of the intense blow pipe effect of the oil burner. In experienced hands, however, quality duly regarded, normally, the oxidizing effect with any kind of fuel need not be excessive.

MELTING

Under flame action in a fully charged furnace the stock will soon begin to melt and it will be observed that the melt-

ing of the pig iron goes on quite rapidly, dripping to the hearth in small streams, while the steel scrap melts at a slower rate, and in melting, the liquid steel frequently scintillates or burns forming either vapors or solid oxide. The dripping pig iron lessens that action, more or less, by protecting the lower carbon steel stock. The melting proceeds gradually, and the mass decreases in bulk and passes below a layer of rapidly forming slag. At this time, however, the slag formation is not entirely complete, but will be found to consist mostly of silica and iron oxide with comparatively little lime, the temperature of the furnace at this point not being sufficiently high to thoroughly dissolve the lime still resting on the bottom of the furnace. The composition of the slag at this period is practically an acid one and results from the sand of the stock and the silicon of the metals, since it is one of the first elements to submit to oxidation. Samples taken from the first portions of melted metal have shown a high sulphur content, much higher than that carried in by the stock. The cause can be attributed to the absorption of sulphur from the flame. During the first stage but little information can be ascertained as to the changes which may take place in the composition, because the mass is a conglomeration of pasty semi-liquid pig iron, steel and slag.

CHARGING COLD STOCK

In charging cold stock about one half of the time required to work a fifteen to a twenty-ton heat is taken up in melting. As that interval advances the slag is increasing in volume and some changes in composition will take place in the first portions of the metals melted. The slag is more or less viscous with lumps of lime coming to the surface as it becomes loosened from the bottom. There is a foaming or bubbling in the slag caused by CO_2 being liberated from the limestone and also by the action between the oxides of the slag and the carbon of the bath. As the lime

continues coming to the surface it increases the basicity of the slag and with that condition there will be a rapid absorption of phosphorus from the bath.

The operator feels over the bottom of the furnace with a long bar to determine whether the bath is entirely melted or not. If no pasty masses are touched the bath is completely molten. A sample of metal is then poured into a small oblong mold, quenched and broken to study the fracture, the appearance of which indicates the carbon present and also whether there may be any phosphorus remaining. An experienced eye can readily read the carbon of the test quite closely. If the grain is small and the fracture of rather a dull color, the heat is said to have melted "hard." If the grains are large and bright the heat has melted "soft." Other indications confirm this in the way the first test piece may break under the blows of a sledge, the "hard" or high carbon steel snapping easily, while the "soft" or low carbon steel bends or flattens before fracture.

To confirm the melter's judgment, as a rule, the first test piece is sent to the laboratory for a quick test on carbon and phosphorus. When the test piece indicates a high carbon, the melter does not wait for the analysis, which only occupies about ten minutes, but may throw into the bath a few shovels of iron ore to assist in the lowering of the carbon, and, at the same time, thin the slag. In a few moments the chemist reports carbon usually 0.50 to 0.70 with only a trace of phosphorus. The melter is now satisfied that his conditions are normal. Should the phosphorus have shown incomplete removal in the first test, a second one would be taken after an interval of about fifteen minutes and submitted to another chemical analysis. The addition of the iron ore immediately after the first test would have increased the slag's basicity and fluidity and no doubt would have eliminated what phosphorus might have remained in the bath at the time of the first sample. Usually the second test shows phosphorus out of harm's way.

If the phosphorus resists removal, it is necessary to add lime to the slag. This would have a tendency to cool the bath and also raise the lime content of the slag and of course intensify the de-phosphorizing action. If the temperature of the bath at melting be very high, there may be a tendency to retard the removal of phosphorus, since there seem to be certain ranges of temperature wherein de-phosphorizing does not depend entirely upon slag conditions. It has been observed that in cases where a normal slag refused to completely de-phosphorize, an addition of a few hundred pounds of pig iron caused a quick and perfect absorption of the phosphorus by the slag. The action could only be explained on the basis that the pig iron so added could exert no other influence regarding the phosphorus than that of cooling the bath. This fact gives plausibility to the theory of the thermal ranges where they may be a change or reversal of affinities, or, in other words the oxidizing action is more inclined to give its attention to the carbon in preference to the phosphorus.

The activity in de-carbonizing is one that varies with the temperature and this fact also seems to apply with equal force inversely to phosphorus. The term "very hot" may seem indefinite in reference to the bath when melted, but in the absence of figures stating temperatures at the several stages of an open-hearth heat, the use of vague expressions concerning them cannot be avoided. It is doubtful if the slight ranges of temperature covering the periods affecting the removal of phosphorus can be observed by the eye even with experienced operators. It is certain that the ranges of temperature in question come within apparently normal conditions and are therefore narrow. But, if the ranges were wider, they would be readily detected without the seeming need of pyrometry to fix them.

Assuming that the second test sample shows a low phosphorus, usually 0.005—0.015, further manipulation proceeds smoothly. The slag will have nearly reached its full share of lime; in other words, the lime will have come to the

surface from the hearth bottom where it was charged. If the dose of iron ore has not given the desired fluidity to the slag, an addition of two or three shovels of fluor-spar will bring it about quite rapidly. Fluor-spar should be used but sparingly because excessive doses tend to aggravate the cutting action on the slag line around the hearth.

If the first or second preliminary test samples show low phosphorus the examination for that element is not carried out in subsequent tests. Only the carbon is carefully watched and after it has reached about 0.25 no further ore should be given to a bath. The carbon reduction can go on without any assistance from that source because the slag will, at that period, carry its full quota of iron oxide to actively promote decarburizing. Excessive additions of iron ore will surcharge the bath with oxide which causes blow holes and red shortness in the finished product. A liberal use of iron ore will shorten the time of making a heat and in a measure, increase the yield of metal because the reaction between the carbon of the bath and the oxide of iron furnished by the ore sets free an equivalent of metallic iron which enters the bath. But good practice demands discretion in the treatment of the bath with ore.

It generally follows that when a heat melts "hard," temperature conditions at the end of the heat will be normal because the initial amount of carbon will be high enough to produce perfect liquation and the interval of time occupied in its removal will be great enough to preserve proper thermal adjustments by regular reversals of flame action, inflowing air and outgoing gases. Should a heat melt "soft," the temperature of the bath is apt to be low and without a gain in the carbon much difficulty would be encountered with pasty steel. An attempt to raise the flame temperature to get the fluidity of the bath would harm the roof and brick work of furnace by scorching. But recourse is had to extra doses of cold pig iron to furnish the necessary carbon and thus promote fusion and other desirable conditions. Such practice is called "doctoring" but the outcome is

never so satisfactory as when the heat is worked naturally. It is a safe rule that when a heat melts "soft" and consequently dull or cold, that the first preliminary test will show thorough slag absorption of phosphorus. This fact gives plausibility to the theory of the temperature ranges affecting the removal of that element.

When the carbon reaches a point where the test samples are very tough, difficult to break and showing, upon fracture, a fibrous structure, and chemical tests show them to be between 0.10 to 0.14 carbon, preparations are made to finish the heat. If a test spoon of liquid steel be taken from the bath and poured over the lip, running freely and leaving the spoon clean and free from skull or chilled steel, the temperature of the bath is considered good. The next step will be to quiet the bath by adding one-third of a weighed portion of ferro-manganese. This material as shown in previous chapters takes precedence over the remaining carbon in de-oxidizing and so lessens the ebullition of gaseous carbon. After an interval of a few minutes the heat of metal is tapped into a pre-heated ladle, and before the slag comes, the final doses of ferro-manganese and ferro-silicon are thrown in with the stream of steel and the heat is said to be finished. The furnace bottom is now drained of slag and some remaining pools of steel. The slag line is patched with raw dolomite and whatever holes there may be in the bottom are filled with ground magnesite. The furnace is then ready for a succeeding charge.

DETAILS OF RE-CARBURIZING

It will be noted that in basic melting no ferro-silicon is added to the bath to deoxidize as in acid practice. To do so would be to invite irregularities, such as a release of phosphorus from the slag, a re-absorption of it in the bath, a cutting of the hearth, a great loss in available silicon and uncertainty as to quality of product. The measure of the

power of the slag to take up phosphorus from the bath is its basicity and any addition of silicon decreases that property. The better practice is to make the silicon additions

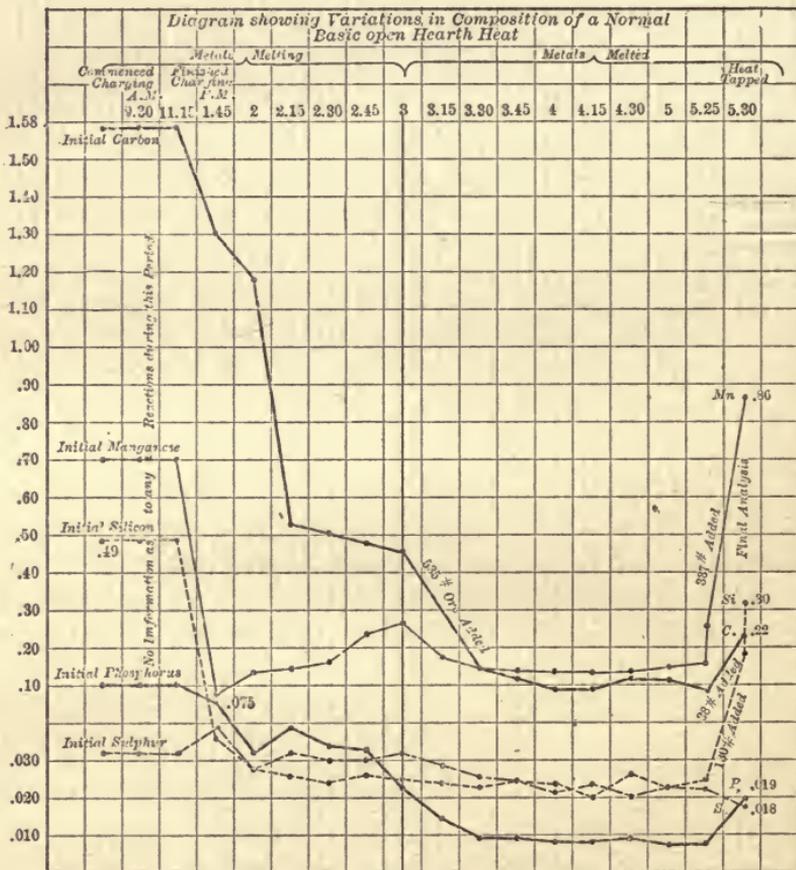


FIG. 8.—COMPOSITION OF A NORMAL BASIC OPEN-HEARTH HEAT

entirely in the ladle. If the ordinary grade of ferro-silicon (9 per cent to 13 per cent Si) is used, it must be melted before it can be added to the ladle.

The melting may be done in a small cupola, or a reverberatory furnace fired with coal, or in a suitable oil furnace. In any case, there are certain annoyances, such as hitches in getting the ferro-silicon melted at the proper interval and in condition to transfer the desired quantity to the steel ladle when the heat has been tapped from the open-hearth furnace. There are also losses in available silicon due to oxidation when melting the charge of ferro-silicon by any method. These losses are variable and cannot be avoided. In making calculations allowances must be made for such losses. It would not be practical to add the dose of ferro-silicon, using the common grade, cold. The drawbacks just mentioned can be avoided by the higher grade electrolytic ferro-silicon which usually carries about 50 per cent of silicon. The quantity of this latter grade for a dose is only about one-fifth of the commoner kind, so that there is no need to melt it before using, thus eliminating the difficulties arising in handling the ordinary grade. The heat units evolved in the reaction between the oxide of iron contained in the molten steel and the silicon available in the high grade ferro-silicon, more than offset any chilling effect set up by the addition of a cold charge of that material. There is always some consumption of silicon in de-oxidizing and it is greater in basic melting than in acid. The loss varies between 20 per cent to 30 per cent of the total available, particularly in using the common grade of ferro-silicon.

The greater part of the ferro-manganese addition can be made in the ladle with but a slight loss in de-oxidizing and with no chilling effect upon the liquid steel.

If the finished product is to show a final analysis as follows:

C	0.20 to 0.25 per cent
Si	0.30 to 0.35 per cent
Mn	0.65 to 0.85 per cent

the calculations for the recarburizers, as an illustration, will

be made on the basis of molten FeSi with 9 to 13 per cent Si and also on FeSi carrying 50 per cent Si, the weight of the charge being 36,000 pounds. Taking the lower limit of silicon, in the final analysis there will be required

$$36,000 \times 0.003 = 108 \text{ pounds Si.}$$

With the ferro-silicon averaging 11 per cent silicon the charge of that material to furnish 108 pounds silicon is

$$\frac{108 \times 100}{11} = 982 \text{ pounds,}$$

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but there may be a combined loss of the synthetical silicon in melting and in de-oxidizing of about 20 per cent; it will be necessary to increase the charge of ferro-silicon accordingly to $982 \times 1.2 = 1,178\frac{1}{2}$ pounds. The carbon carried in by that quantity will be

$$1,178\frac{1}{2} \times 0.015 = 17.67 \text{ or } 18 \text{ pounds}$$

divided by the weight of the charge

$$\frac{18}{36,000} \times 100 = 0.04,$$

the percentage of available carbon.

To get the manganese in the final analysis to, say, 0.75 per cent it will be necessary to add:

$$36,000 \times 0.0075 = 270 \text{ pounds Mn.}$$

Standard ferro-manganese carries 80 per cent, then to have the synthetical manganese it will require

$$\frac{270 \times 100}{80} = 337\frac{1}{2} \text{ pounds FeMn.}$$

The residual manganese in the bath at the time of the additions will be an increment and it will nearly equal the loss mentioned in available manganese. From the ferro-manganese there will be carbon furnished to the extent of

$$\frac{337\frac{1}{2} \times 0.06}{21} = 20\frac{1}{4} \text{ pounds.}$$

$$\frac{20\frac{1}{4}}{36,000} \times 100 = 0.05 \text{ per cent C.}$$

The addition of ferro-manganese is divided into two portions, 1-3 in furnace and 2-3 in the ladle.

Summarizing the recarburizers there will be available in total elements.

C	0.12 +	0.04	0.05	0.21
Mn	0.15 +	—	0.75	0.90
Si	0.02 +	0.36	—	0.38

The foregoing available composition in regard to the carbon will be very close to the required analysis and the complete analysis compared with the total available elements will depend in a great measure upon the condition of the bath in regard to the quantity of oxide formed during the conversion and refining of the charge.

If the electrolytic ferro-silicon be preferred to the common grade, it will not change the details in regard to the dose of ferro-manganese, which will remain the same as shown in the preceding paragraphs. The figures for silicon can be taken as follows:

$$\frac{36,000 \times 0.003 = 108 \text{ pounds Si.}}{108 \times 100} = 216 \text{ pounds Fe-Si.}$$

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Since the electrolytic silicon being in a condensed form the de-oxidizing effect is more pronounced and efficient. The losses are much less than in the ordinary grade. There arises no particular need to take into account the losses or differences between the synthetical analysis and the final. It is not necessary in adding silicon as a deoxidizer to work extremely close to figures for finished analysis, if enough is added in the first place to accomplish the purpose. The amount of carbon furnished by the electrolytic silicon is

quite small $216 \times 0.0025 = 0.54$ pounds and $\frac{0.54}{36,000} \times 100 = 0.001$ per cent or practically nothing at all. From the

ferro-manganese there will be 0.05 per cent which added to the residual, assumed to be 0.12 per cent, would make the available carbon 0.17 per cent, a figure rather low for ordinary castings where the tensile strength required may be 60,000 to 70,000 pounds per square inch.

Two methods may be followed to raise the carbon to 0.20—0.25 per cent. One is to finish the heat at a correspondingly higher residual carbon. The other is to make up the difference between 0.17 and 0.20—0.25 by an addition of solid carbon in the form of coke or anthracite at the time of dosing in the ladle.

Concerning sulphur, there is no great effect upon it at the time of recarburizing. The figures for the residual and the final analyses are practically the same excepting occasionally a small decrease coming within the common errors of chemical tests. If any differences occur outside of them, the lessening of the sulphur can be assigned to the influence of manganese in combining with some sulphur and passing off into the slag as a manganese sulphide. No gain in sulphur at this stage has been observed in the writer's experience.

If the initial phosphorus is kept low in the charge, about 0.10 to 0.15 per cent and with only 0.005—0.015 per cent remaining at the time of finishing the heat, the synthetic silicon in the action of de-oxidizing in the ladle changing to silica passes into the super-natent slag, combines with the lime, liberates or releases some phosphorus held there, which immediately reverts to the molten metal and raises the analysis of that element. Under such conditions, taking a sample when about one-half of the metal from the ladle has been poured, there will be found a marked increase of the phosphorus over the residual so that the finished steel will show 0.02—0.03 phosphorus. The rephosphorizing in the ladle goes on continually so long as the metal remains liquid and if a sample were taken from the last portion of metal in contact with the slag, there would be found a still further gain in phosphorus. If a much

higher initial phosphorus were charged there would be a still greater revision, and castings poured at the end of a heat might be found with a content of phosphorus near the point of being objectionable. This feature of re-absorption is peculiar to the basic process and is more noticeable in the steel castings practice than in the production of ingots for rolling purposes, because in the latter product the silicon added at the end of a heat is much less than in the former. Hence the importance of not charging large quantities of highly phosphoric stock in the manufacture of basic steel castings.

The melting losses depend upon the character of the stock and the conditions of practice and may vary from 6 per cent to 12 per cent of metal charged. In representative plants with established and extensive experience a yield of 93 per cent in the ladle can be considered a fair average.

CHAPTER VI

CHEMICAL ANALYSES AND PHYSICAL TESTS.—DETERMINATIONS OF SILICON, PHOSPHORUS, MANGANESE, SULPHUR AND CARBON IN STEEL AND PIG IRON.—PRELIMINARY TESTS.—PHYSICAL TESTS.—SOLUTIONS

The appended methods of chemical analyses are the result of several years' experience and have proven to be accurate and reliable. In several instances, the methods may be considered as standard, and are in daily use in many leading establishments.

In the manufacture of basic steel castings, where it is highly important to know the extent of dephosphorization as quickly as possible in preliminary tests taken during the progress of a heat, a suitable centrifugal machine is necessary, which can be purchased through any house dealing with chemical supplies.

DETERMINATION OF SILICON IN STEEL

Five times the factor weight (2.3510 grams) of the drillings are weighed off, placed into a $5\frac{1}{4}$ -inch porcelain dish, and a watch glass placed concave side down. Thirty cc.

of silicon mixture are added. The dish is heated until the solution is evaporated, and fumes of sulphuric acid are given off. After cooling, 45 cc. hydrochloric acid, (1 part hydrochloric, 2 parts water) are added. Heat until all is dissolved, except the separated silica. Filter, wash alternately with hot hydrochloric acid (1-1) and hot water, until free from iron and acid. Burn and weigh. One fifth the weight represents the silicon percentage. Time required, fifty minutes.

DETERMINATION OF PHOSPHORUS IN STEEL

Two grams of the drillings are weighed off, placed into a 250 cc. Erlenmyer flask, and 35 cc. nitric acid (specific gravity 1.2) added. The flask is heated until the drillings are in solution, and no brown fumes are given off. Ten cc. of a five per cent solution of potassium permanganate are added, and the heating continued until the solution is colored brown, when a few drops of saturated cane sugar solution are added. The solution is cleared, and after heating a few minutes the flask is removed from the heat, and cooled in water. Neutralize with concentrated ammonia, and acidify with concentrated nitric acid until the solution assumes an amber color. To this solution at a temperature of 70-80 degrees Cent., add 50 cc. of ammonium molybdate solution, and a few drops of ammonia to hasten the precipitation. Shake well, and allow to settle in a warm place for ten minutes. Filter, wash with cold water until free from acid. Remove paper to original flask, add from 3 to 5 cc. or more if necessary, of potassium hydroxide solution. Add a few drops of a one per cent alcoholic solution of phenolphthalein. Shake thoroughly, allow to stand for five minutes, and titrate excess of alkali with nitric acid solution. The number of cubic centimeters of potassium hydroxide solution, neutralized by the phosphomolybdates represents hundredths per cent of phosphorus in the drillings. Time required, forty minutes.

DETERMINATION OF MANGANESE IN STEEL

One-tenth dram of the drillings is weighed off and placed into a test tube (1 x 8 inches), and 15 cc. nitric acid (specific gravity 1.2) are added. The test tube is heated over a sand bath until the drillings are in solution, and the nitrous oxide fumes are expelled. About 0.7 grams lead peroxide (PbO_2) is added to the test tube taken from the sand bath, after which it is replaced and heated for one minute, then filled two-thirds with hot water. Boil a few minutes and settle by means of a centrifugal machine. Pour the clear solution into a flask, and titrate with sodium arsenite solution. The number of cubic centimeters of arsenite solution required, represents tenths per cent of manganese in drillings.

Time required, twenty-five minutes.

DETERMINATION OF SULPHUR IN STEEL

Fifty times the factor weight (6.88 grams) are weighed off, and placed into a 500 cc. Erlenmyer flask: The delivery tube is attached leading into a 100 cc. Erlenmyer flask, which contains 10 cc. hydrogen peroxide, 10 cc. concentrated ammonia, and 20 cc. water. Eighty cc. of hot hydrochloric acid (1-1) are added, and heat applied. When solution is complete, disconnect the apparatus, make the solution slightly acid with hydrochloric acid, bring to a boil, and add 10 cc. of a ten per cent solution of hot barium chloride. Boil five minutes, filter, using ashless pulp, burn and weigh barium sulphate, and make correction for sulphur in hydrogen peroxide. The weight of barium sulphate, divided by 50, represents thousandths per cent sulphur. Time required, fifty minutes.

DETERMINATION OF CARBON IN STEEL

Weigh 0.3 grams of drillings, and 0.3 grams of stand-

ard into separate test tube. Add 5 cc. nitric acid (specific gravity 1.2). Heat in a water bath until solution is complete. Cool in water and compare. Time required, thirty minutes.

DETERMINATION OF SILICON IN PIG IRON

One gram of the sample is washed off into a $3\frac{3}{4}$ -inch casserole, and a watch glass placed concave side down. A few drops of concentrated hydrochloric acid are added, then 15 cc. of silicon mixture. The casserole is heated until sulphuric acid fumes are given off. After cooling, add 30 cc. hydrochloric acid (I-2), and boil until all is dissolved except the carbon and silica. Filter, wash alternately with hot hydrochloric acid (I-1), and add hot water until free from iron and acid; burn and weigh. If high in silicon, treat with hydrofluoric acid. The weight multiplied by 0.47 represents the percentage of silicon. Time required, one hour.

DETERMINATION OF PHOSPHORUS IN PIG IRON

From high phosphorus pig weigh off 0.2 gram and from low phosphorus pig as much as is best suited for the determination. To the 0.2 gram add 25 cc. of nitric acid (specific gravity 1.13). Boil until the drillings are in solution, adding more acid if necessary. Filter off graphite, add potassium permanganate, and proceed as in the determination of phosphorus in steel. Time required, fifty minutes.

DETERMINATION OF MANGANESE IN PIG IRON

Proceed as in the determination of manganese in steel.

DETERMINATION OF SULPHUR IN PIG IRON

Five grams of the drillings are weighed off into a 500

cc. Erlenmyer flask, and a delivery tube connected which leads into a glass containing 10 cc. cadmium chloride solution, and 50 cc. water; 70 cc. hot hydrochloric acid (1-1) are added through the thistle tube, and heat is applied until the drillings are in solution, and steam has driven off all other gases. Disconnect, add a few cubic centimeters of starch solution, 40 cc. hydrochloric acid (1-1), and titrate immediately with iodine solution. The number of cubic centimeters of iodine solution represents hundredths per cent of sulphur. Time required, thirty-five minutes.

PRELIMINARY TESTS

CARBON.—Weigh off 0.2 gram of the drillings, and 0.2 gram of the standard into separate test tubes. Heat until solution is complete and compare colors. Time required: Four minutes.

MANGANESE.—Proceed as in the final test. Do not boil after adding water. Time required, six minutes.

PHOSPHORUS.—One and one-half grams of the steel are weighed off into a 300 cc. Erlenmyer flask, and 35 cc. nitric acid (specific gravity 1.2) are added. When violent action ceases, place flask on heat, boil until drillings are in solution and no brown fumes are given off. For every eight points carbon, add one cubic centimeter of concentrated solution of chromic acid. Boil one minute. Transfer to a graduated bulb containing 50 cc. molybdic acid solution, shake violently, and allow to settle in centrifugal machine. Each small division on bulb represents hundredths per cent phosphorus. Time required, five minutes.

SOLUTIONS

SILICON MIXTURE:

Water	1,300 cubic centimeters
Nitric acid	435 cubic centimeters
Sulphuric acid	275 cubic centimeters
Add sulphuric acid slowly.	

STANDARD ACID AND ALKALI FOR PHOSPHORUS DETERMINATION:

1 per cent solution potassium hydroxide.

1 per cent solution nitric acid.

100 milligrams oxalic acid crystals equals 10 cc. potassium hydroxide.

Standardize with steel of known phosphorus contents.

MOLYBDATE SOLUTION:

Stock Solution.

Molybdic acid250 grams

Ammonia1,000 cubic centimeters

To use, 90 cc. stock solution in 338 cc. nitric acid 1.20 specific gravity.

Keep acid cool, and stir while adding molybdic acid.

SODIUM ARSENITE SOLUTION:

STOCK SOLUTION.

Sodium Carbonate15 grams

Arsenous Oxide 5 grams

Water500 cubic centimeters

Boil and filter.

To use, take 68 cc. stock solution to 2,000 cc. water, standardize against steel of known manganese contents.

CADMIUM CHLORIDE SOLUTION:

Cadmium chloride35 grams

Water1,200 cubic centimeters

Ammonia 800 cubic centimeters

IODINE SOLUTION:

Iodine 9 grams

Potassium Iodide18 grams

Dissolve in a few cc. of water and dilute to two liters.

Standardize against American Foundrymen's Association pig iron standards.

STARCH SOLUTION :

Mix a tablespoon full of starch with a little cold water, and pour into 100 cc. of boiling water, and continue the boiling for some time. Shake before using.

NITRIC ACID, SPECIFIC GRAVITY, 1.2 :

Nitric acid	1,250 cc.
Water	185 cc.

NITRIC ACID, SPECIFIC GRAVITY, 1.13 :

Nitric acid	645 cc.
Water	1,800 cc.

PHYSICAL TESTS

The specifications prepared by the American Society for Testing Materials, and shown in the following table, are

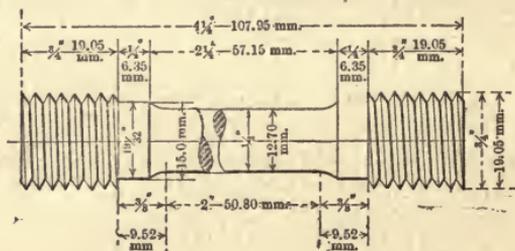


FIG. 9.—STANDARD TEST BAR

quite generally recognized as being fair to both producer and customer. An objection to be raised is the costly style of the test bars recommended (Fig. 9).

When a large number of tests are to be made in the machine, cutting the threads greatly increases the cost.

When no specifications for physical tests are imposed the type of the bar shown in Fig. 10, will answer for works

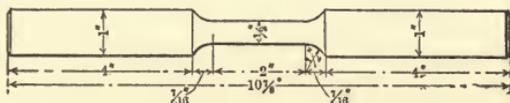


FIG. 10.—TEST BAR FOR WORKS' TEST

tests, solely as a guide to the quality of product, and where the customer does not insist upon the test-bar with the threaded ends as illustrated.

The specifications, mainly, are drawn to cover the physical properties and they alone should be considered, for the reason that there is no distinct relation between the chemical composition and the physical behavior.

The method of the treatment of castings is the prime consideration, and with a given chemical composition, it is possible to get a wide variation in physical tests with different heat treatments. From the standpoint of the manufacturer, specifications should only be applied to physical tests, leaving to him the adjustments of the processes of manufacture to harmonize with the expected physical requirements.

Test bars can only at best, show the condition their metal may be in, both in regard to the composition and the treatment to which they may have been subjected.

It would not follow that, because a test bar representing a given heat of steel, gives poor results in tensile or bending stress, the entire heat was poor also in that. A test-bar can only show what might be expected of a finished casting of equal composition if it were to receive the same treatment as did the bar.

Tensile and bending tests serve useful purposes, but still

leave something lacking. If a test-bar under such stress gives excellent results or if a finished casting be subjected to the drop test, and possibly bends without fracture, proving great ductility, the evidence is not necessarily a positive guide as to life in service. Quite generally a steel casting is set up in service in such a manner that it may be constantly under alternating stresses or rapid and repeated shocks. Practical results from service data do not confirm the theory that ductile steel should resist such strains. Failures under such stresses frequently fall short of explanation in the light of recognized tests projected to prevent such failures. There then arises another want to be filled, a gap vacant because chemical analyses, physical tests and microscopical examinations do not enable the metallurgist to throw around the fruit of his labors the fullest possible precautions intended within the scope of such tests. Possibly fuller information is to be found by supplementing already established tests with other tests to approach as near as possible the conditions to which steel castings are subjected in service, namely—vibratory stresses. A study of such stresses will no doubt give much valuable information and change certain conditions now thought to be essential.

CHAPTER VII

RELATION BETWEEN COMPOSITION AND PHYSICAL PROPERTIES—CARBON—CAST STEEL—TENSILE STRENGTH— DUCTILITY—ELASTICITY—ELASTIC LIMIT— HARDNESS

CARBON—In order to understand the matter under consideration it would be well to study the definition of steel. Principally it is a combination of iron and carbon, and certain other ingredients to be regarded further, without any sharply defined limits as to the amount of carbon alloy. On the basis of composition alone the lower amounts may equal those found in wrought iron, and going to the other extreme it is difficult to say where steel ends and cast iron or pig iron begins. The composition of wrought iron in regard to carbon may range from traces to such amounts as 0.07 per cent, yet the softer steels can be produced with as low a carbon as 0.07 per cent, but the physical condition may be quite different as compared with wrought iron. As the carbon increases until a point is reached at or about 2.5 per cent the combination is then regarded as cast iron, the latter being the crudest form from which by various processes of purification and decarbonization many kinds of steel are produced. The process of manufacturing wrought iron is also a purifying and decarbonizing one with an essential difference whereby, in a sense, the former is a product of

a "dry" method, while steel with any range of carbon is the result of a "wet" one. In other words, the temperature of the puddling furnace in which wrought iron is made is not sufficiently high to maintain fusion or fluidity completely during the full interval of the progress in conversion and purification. The initial charge is composed mainly of pig iron with a total carbon of between $2\frac{1}{2}$ and 4 per cent, which readily melts and because of certain active influences gradually loses its carbon but gains in plasticity because of temperature limitations and the type of furnace used, so that at the end of the operation there will be a mass of almost carbonless iron which can be divided into several bulky, spongy balls and worked into shapes. On the other hand, steel making is the result of a process conducted under temperature conditions wherein fusion or liquation is maintained from the time of melting cold stock until such time when decarbonization has proceeded to almost any desired extent, so that with a proper type of furnace and necessary thermal ranges it is possible to equal in composition the commoner analyses of wrought iron. Thus, it will be understood that the content of carbon in the lower ranges will not suffice to mark the division between iron and steel. Another difference presents itself in, perhaps, a mechanical way. That is, wrought iron may contain slag or cinder enveloping its fibres varying in quality between 0.2 per cent and 2.0 per cent, and which will play an important part upon its physical properties. The presence of cinder is due to the sponge-like formation of plastic wrought iron in its last stage of manufacture enclosing slag or cinder. Steel being produced by liquation permitting a separation of the slag and liquid metal by gravity, the finished product will be practically free from mechanically contained cinder, thus securing a greater continuity or intimacy within itself and therefore more strength than wrought iron containing an equal amount of carbon.

The metallurgy of steel is based principally upon the influence of carbon which controls the familiar properties of strength, ductility, malleability, weldability and most of all, the property of being hardened and tempered. The presence of carbon in iron is purely accidental, due to the use of carbonaceous fuel as a source of heat in smelting iron ores. Had the primitive iron makers stumbled upon some other substance that had a similar power of separating iron from its earthy matters, we might today be working with steel, the most important and useful of all metals, founded upon another basal element. Nature, in her bounteousness, has given us coal in abundance. It seems the simplest fundamental fuel for smelting iron ores; but owing to the affinity that exists between carbon and iron for each other there results a product highly carbonized, yielding a metal limited in its capacity for strength and ductility.

Carbon is recognized as existing in iron or steel in several forms with a variety of subdivisions; generally it is regarded as two constitutional divisions, one as combined carbon and another as free or graphitic carbon, the former being a definite chemical compound of iron and carbon, expressed by the symbol Fe_3C , and the latter (graphite) nearly pure carbon. It is stated by authorities that iron can carry theoretically, about two per cent of combined carbon and still be regarded as high carbon steel. Should the carbon be carried beyond that point and if heated and cooled slowly the pure or free form of carbon would appear in a small degree and the alloy would then be on the borderland of cast iron. As is well known, wrought iron and the very softest steels are both malleable, ductile and weldable, but as the content of carbon increases, those properties gradually diminish and the skill to work them becomes of a higher order than that required in the softer or milder grades. Cast iron is practically unforgable or weldable merely because of the excess of carbon present either in the combined or free state. Summarizing the

general explanations, steel may be regarded as a matrix of iron in which is dissolved or alloyed varying amounts of combined carbon, with an absence of it in the free or graphitic form; a freedom from slag or cinder, the product of a process of liquation or complete fusion throughout the operation of refining and conversion.

CAST STEEL is a substance distinguished from wrought iron, in that during certain stages of manufacture it is sufficiently liquid to pour into such receptacles as metal or sand molds. The composition of the product may cover wide ranges. Wrought iron as already stated is worked up from plastic masses of partially or completely decarbonized cast iron. Open-hearth castings are the product of liquid steel with limited composition poured into molds composed chiefly of silica sand. The physical properties must conform to certain requirements of strength, toughness, ductility and soundness. The attainment of such objects is brought about by adjustments of chemical compositions during the process of refining the raw material and also by certain methods of heat treatment applied to the finished product. Steel castings are divided into three grades: "soft," "medium," and "hard." Standard specifications do not define the chemical composition of each grade but give attention mainly to the physical properties as cited in the preceding pages. Generally stated the following figures will cover the composition of each class of castings:

	Carbon.	Silicon.	Sulphur.	Phosphorus.	Manganese.
Soft	0.17-0.20	0.25-0.35	0.015-0.050	0.020-0.04	0.50-0.75
Medium	0.20-0.30	0.25-0.35	0.015-0.050	0.020-0.04	0.50-0.75
Hard	0.30-0.40	2	0.015-0.050	0.020-0.04	0.75-1.00

TENSILE STRENGTH is understood as the resistance of a body to a stretching force steadily applied. The force necessary to produce a rupture is expressed in pounds per square inch of section.



DUCTILITY is that property which yields to a tensile stress and produces a permanent deformation or elongation with or without rupture. It is expressed in "percentage of elongation" and is measured between two pre-determined points. It may also be indicated by the contraction of area when a specimen is measured, before and after the feature, in cross section. Not only will a specimen increase in length under a certain stress but at one point it will decrease in area so that upon fracture there may be a distinct "necking" and the rate of decrease in sectional area is expressed in "percentage of contraction," which, together with the measured elongation, can be regarded as indices of ductility.

ELASTICITY is that point where a permanent deformation under a load begins or where a specimen fails to assume its original length or sectional area when the load is released. This definition can also be applied to describe the arrival of a "permanent set." The determination of elastic limit is a delicate one and in engineering problems is very important, representing the practical value of a casting. In making calculations for service loads the elastic limit of the metal entering into castings is taken as a basis, not the tensile strength. For general purposes 50 per cent of the ultimate or tensile strength is taken as the value of the elastic limit. An increasing ratio between elastic limit and tensile strength is a prime object to reach in high grade products.

HARDNESS is understood as the property of a body to resist the static penetration of another harder body, or it may mean the ability to resist attrition caused by the movement of another harder body.

Unfortunately there are not known any precise data as to the influence of carbon in steel castings upon the tensile strength and ductility of the metal in them. The influence can only be stated in general terms in the light of practice. To get exact values would entail difficult researches; it would be necessary to have conditions fixed in order to

study the influence of successive increments of the element. The furnace practice, casting temperatures and heat treatment would have to be constant in each case for strict comparisons. The contents of silicon, sulphur, phosphorus and manganese would have to be subject to definite control with only variations permissible in the carbon of each specimen before reliable information could be deducted. Experience has proven as a recognized fact that carbon is both a hardening and strength giving agent. Reference to the physical requirements of the three grades of castings and their corresponding chemical analyses will bear out the general assertion, but owing to other disturbing influences, more or less potent, the ranges of analyses are not concordant with the tensile strength and ductility for each class. That is, it is indefinite that a 0.17 to 0.20 carbon may show about 60,000 pounds per square inch, and a given elongation and contraction. As the carbon increases there are gains in strength but decreases in ductility in the remaining grades. Campbell in his admirable work on the "Manufacture and Properties of Structural Steel," gives formulas for the calculation of the physical properties on the basis of chemical composition and in a later treatise¹ revises them, giving values for several elements common to steel, making a distinction between acid and basic practice. His figures apply to *rolled* material produced under fairly regular conditions, but it would seem inconsistent to apply the same formulas to steel castings manufactured under totally dissimilar methods. Kent² quotes Webster giving values of carbon in rolled stock in conjunction with three other elements, sulphur, phosphorus and manganese, as a constant of 800 pounds per square inch with each 0.01 per cent of that element with a base value of 34,750 pounds per square inch for carbonless

¹Journal British Iron and Steel Institute, No. 2, 1904, pp. 21 to 62.

²Mechanical Engineers' Pocketbook, 1904, p. 389.

³Iron and Steel and Other Alloys, 1903, pp. 192 to 162.

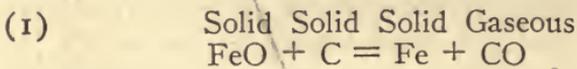
⁴Manufacture and Properties of Structural Steel, 1896, p. 329.

wrought iron. Prof. H. M. Howe³ shows that the hardening power increases with the carbon content and also roughly plots a curve giving a direct increase in strength varying with the carbon until a point is reached near 1.20 per cent when the strength or tenacity rapidly decreases, with a further gain in carbon up to three per cent, where the strength then remains fairly constant up to 4.50 per cent of that element. The maximum strength at 1.20 per cent being about 140,000 pounds per square inch falling to about 25,000 pounds at three per cent and at 4.50 per cent to about 18,000 pounds. Campbell⁴ assumes a base value of wrought iron as 38,000 to 39,000 pounds per square inch and constructs formulas for both acid and basic steel compositions with 0.01 per cent carbon giving 1,210 pounds per square inch for each point gained in the first named grade and 950 pounds per square inch for each point of carbon in the latter grade, but which, as already stated, apply only to rolled material. In steel castings the distributing factors are so numerous that it seems impossible to formulate precise mathematical computations covering the physical properties, while taking into account the composition and values of each element. The furnace practice, perhaps, the greatest factor entering into the equation and since no two heats are handled exactly alike in all particulars the problem becomes more and more abstruse. Character of stock, flame action, oreing, casting temperature, recarbonizing and the methods of doing the same, rate of cooling in the sand, either in dry or green sand molds, all need consideration as do methods of heat treatment, leading one into a maze of speculation. General terms, therefore, cannot be avoided. Certain authorities have been cited and the reader is at liberty to form his own conclusions as to which can or may be followed in attempting to give a value to carbon and its influence upon open-hearth steel castings.

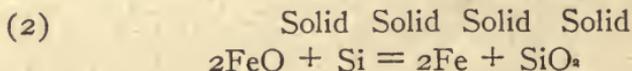
◀ SILICON.—To the gray iron founder silicon conveys a different impression than to the steel founder. In one case

it is regarded as a softening agent because of its property in releasing graphitic carbon in the cooling of gray iron when liquid and thus lowering the combined carbon which tends to make iron castings hard. In the other case, the carbon being low and entirely in the combined state with no graphitic carbon liberated, the function of silicon becomes a different one. To a slight extent, about one-tenth that of carbon, the effect is to harden steel castings. Primarily the purpose of adding silicon to open-hearth steel is to promote solidity, but an anomalous condition sometimes arises in unsoundness coupled with an amount of silicon in the finished product usually considered enough to produce the opposite and desired effect—soundness. In general practice 0.30 per cent is enough to give freedom from blow holes, but if unsoundness still presents itself another condition is operating which will be explained later. To greatly exceed that figure is wasteful and would tend to induce brittleness in the castings which, however, may be more or less modified by heat treatment.

Silicon in steel casting practice is depended upon mainly as a deoxidizer and the action may be understood by the following equations:



As already explained the foregoing reaction always occurs in a bath of molten steel until some agent is introduced that possesses a greater affinity for the oxygen combined with iron as ferrous-oxide. Silicon being available for the purpose reacts as follows:



and under normal conditions stops the gaseous formation assisting the production of sound castings. The SiO_2 (silica) being lighter than iron floats upwards to the surface and becomes part of the slag.)

If a test-spoon of liquid steel be taken from the bath when the action is most lively, the metal, as soon as it begins to solidify, will emit volumes of minute sparks giving evidence of some gas-forming action or release of some gases in conformity with equation (1). If the specimen when cold is separated by fracture, a sponge-like texture will be noticed as the result of the afore-mentioned escaping gases; and which will suggest what might be expected were such metal poured into castings without a deoxidizing or solidifying treatment. Just what the composition of the gases are is not clearly known, but it is certain that the reaction in equation (1) is largely responsible for the greater quantity of them. Some authorities anticipate the presence of such gases as hydrogen and nitrogen. Their presence may be possible in pneumatic processes, but scarcely in open-hearth steel wherein fluidity of the bath is maintained by the heat of a flame action radiated through a protective layer of slag and entirely away from the possible contamination of such gases subject to introduction with the atmospheric air necessary for flame combustion and which do not come in direct contact with the metal below the slag. Proof is ample that perfectly sound castings can be made, depending solely upon deoxidizers which possess no attraction for hydrogen or nitrogen; therefore if they should be present they are not sensibly indicated by porosity. Silicon is accredited with the additional property of increasing the power of steel to dissolve or occlude gases. The question is largely conjectural because from practical observations the evidence in support of such a theory is wanting. It is difficult to conceive of a solution of a gas in a solid without some intimation of pores; if such pores do exist they can only at best be minutely microscopic. The writer, in his experience, has not observed any condition attributable to the occlusion of either free hydrogen or nitrogen in open-hearth steel castings.

The question of the influence of silicon beyond solidity

has no bearing on weldability or forgability, such properties not being considered in steel castings.

SULPHUR.—Perhaps there is no element which is so strongly stigmatized as an enemy in steel casting practice. No one as yet has claimed that it is harmful in the finished casting, yet specifications usually state that it shall not exceed 0.05 per cent, and for what reason is yet not understood. The manufacturer may be more concerned in seeing the sulphur excessive rather than the customer. Whether a casting may carry 0.05 per cent or more cannot affect its value in service. Whatever harm may follow an excess of sulphur ought to manifest itself before the casting is stripped from the mold and thus prevent it reaching the customer. Authorities state that sulphur tends to make metal "red-short," a condition existing in iron and steel exhibiting itself by the metal crumbling or cracking when being worked, rolled, forged or welded at temperatures suitable for such operations. The effect is not always due to the presence of sulphur, which may be masked or modified by other constituents. In steel castings it is said to produce "red-shortness" also and which may be described as property of the metal to separate or crack at points where the contractive force is greatest during a period when the metal is passing from a liquid to a viscous semi-plastic state. The condition may or may not occur in concordance with the amount of sulphur present. "Red-shortness" may appear with a very low sulphur content or it may be absent when the sulphur is considered high, so that it is not possible to scan a chemical analysis and reconcile the varying degrees of "red-short" effects with them. It is possible to have castings of a given design molded repeatedly under as near as possible like conditions yet have some "red-short" and others absolutely free from any such flaw with identically the same steel in composition in each case. Similar designs may be cast in acid and basic steel separately. The acid casting may not be "red-short," but the basic badly so, or vice versa, yet in the first instance

the sulphur will be nearly 0.05 per cent and in the other 0.25 per cent or less. The repetition of such evidences all tend to discredit the belief that sulphur is the main cause of castings being "red-short" in the mold. The presence of manganese exerts an effect to neutralize sulphur's "red-shortness" without changing the ultimate analysis of sulphur. An excess of the last named element beyond 0.07 per cent in steel castings may give some trouble, but generally the ranges are between 0.015 to 0.05 per cent, and within them it is practically inert. The common practice is to carry the manganese at or about 0.75 per cent and with that quantity the usual content of sulphur will exist entirely as a harmless sulphide of manganese. Were the manganese much lower the sulphur then might exist as an iron sulphide, the latter combination being more active as a "red-shortner" than the former. If "red-shortness" persistently appears in steel castings with normal analyses another condition is active, a remedy for which is beyond any effort to change the composition to control it. The conditions under which the metal is treated in the melting and the design of the pattern or details of molding often play a more important role in producing "red-short" castings than sulphur.

PHOSPHORUS. <—This element, like carbon, is a hardening agent, but unlike it, its hardening influence is not subject to any great modification by heat treatment. An excess of the element produces the effect of "cold-shortness," the opposite of "red-shortness," a property of weakness under shock or impact; a condition of brittleness. > Where castings are subjected to severe strains the phosphorus should be kept below 0.05 per cent, particularly with the higher ranges of carbon. Ordinary castings with no special requirements can carry as high as 0.08 per cent. Phosphorus can replace carbon as a hardener and when the carbon is American Standard Specifications For Steel Castings.

	Hard	Medium	Soft
Tensile strength, pounds per square inch	85,000	70,000	60,000
Yield point, pounds per square inch	38,250	31,500	27,000
Elongation, per cent in two inches	15	18	22
Construction, per cent	20	25	30

high the phosphorus should be kept low because an excess of two or more hardeners will produce disagreeable brittleness, so to preserve toughness it is a good practice to keep all hardeners as low as possible, depending upon one element only for the necessary strengthening effect. The value of phosphorus as a strengthening agent is about 900 pounds per square inch for each 0.01 per cent.

No effect is known traceable to phosphorus upon the condition of "red-shortness."

MANGANESE.—This element is one of the most useful in steel casting practice and in all steel making. It works in conjunction with silicon as a deoxidizer and assists in the removal of gases in a very similar action by forming a fusible slag with the oxygen combined with the ferrous-oxide. When found in castings it is the result, usually, of an addition of ferro-manganese used at the end of the refining operation and with it will be carried in a certain amount of carbon. Roughly stated five-eightieths of the manganese in excess of the residual amount of that element in the bath at the finishing period represents the quantity of carbon furnished by the ferro-manganese addition. So that as the manganese increases there will also be a gain in strength until a point is reached at or about 1.50 per cent when a disagreeable weakness and brittleness result. If the manganese is kept about 0.75 per cent, other elements being low, brittleness is absent, but if it be carried above that to about 1 per cent it is necessary to carefully anneal the castings because without that they will be more or less brittle. Heat treatment, however, improves them, conferring toughness, elasticity, ductility, and strength, provided other conditions are normal. In the higher ranges manganese has a peculiar and contradictory

action. When a content is reached at or about 1.50 per cent the metal is hard and brittle, that condition remaining until about 7 per cent is reached; the metal then becomes both tough and hard. Between 7 and 14 per cent a peculiar alloy is obtained, known as Hadfield steel, which possesses the striking property of unusual toughness and hardness combined. If manganese is kept between 0.70 to 0.75 per cent in finished castings good results ought to follow. An excess complicates conditions, while falling below might cause blow-holes, "red-shortness," and other weakness in products.

CHAPTER VIII

BLOW HOLES IN STEEL CASTINGS—DISCUSSION OF CAUSES

A common source of annoyance in steel castings is found in porosity or in unsoundness. The ingot manufacturer finds it comparatively easy to get around such drawbacks by liberal discards or end cropping of ingots usually more or less spongy or blow-holed at the upper end. Not so with the production of castings. The problem of pouring liquid steel into the green or dry sand molds has a distinctive complexity in comparison with casting into ingot molds made of iron or dry sand with simple lines or shapes.

Blow holes in a steel casting may be due to a variety of causes. They must not be confounded with "shrink holes" or cavities due to a difference in the rate of cooling of parts contrasting in dimensions. A light section in conjunction with a heavier one will cool faster and in doing so will draw upon the heavier and more liquid section, thus depleting it of steel, with the result that in the heavier section there will be some voids. Hence the important reason for forming larger headers or reservoirs to hold a supply of steel from which the casting below can make drafts to offset the contraction in cooling. Frequently in separating such headers rough irregular cavities will be found at the joint of the header and the castings which are known as "shrink holes," (see Fig. 11) and may be formed even in cases of the casting being free from "blow holes." The

position of cavities or pores, due to either gases or shrinkage, will determine their identification.

Blow holes may be found in any part of a machined or fractured casting. Shrink holes occur only at certain points. They are irregular in shape, with rough surfaces, but upon close examination will be found covered with delicate, minute crystals. The walls of a shrink hole are usually the same color as the metal itself, provided no air was present while the casting was hot. Blow holes are always the result of air, vapor or gas. Their shape as a rule is oblong, lenticular or spherical. If oblong in shape they are due to metal being imperfectly deoxidized or "killed"

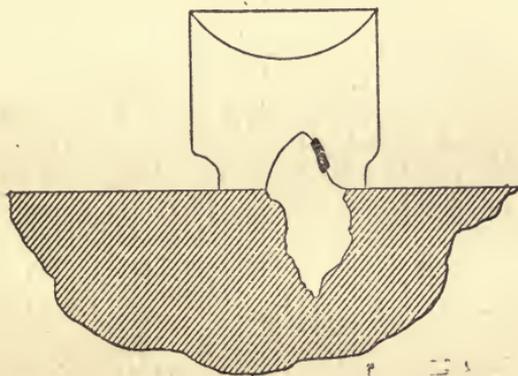


FIG. 11.—SHRINK HOLE. DOTTED OUTLINE SHOWS POSITION OF RISER

and they will always be found with their axes or longest dimensions at right angles to the cooling surface of the body of metal (see Fig. 12). If they are globular or spherical they are caused by vapor or air and not by gas or gases, the result of chemical action within the metal, but by damp sand, imperfect venting—details of molding. While it is perfectly possible (and is regularly done) to get sound, solid steel machinery castings from green sand

molds, accidental causes may make the sand too damp. In that case there may be blow holes because of an excess of steam or aqueous vapor formed by the hot steel.

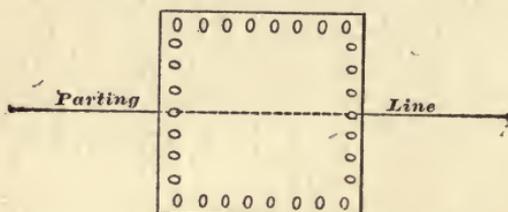


FIG. 12.—BLOW HOLES CAUSED BY GASEOUS STEEL IMPERFECTLY DEOXIDIZED.

If the green sand mold should possess the right "temper" and globular, spherical holes still be found, there may be two causes effective. One may be that the sand, green or dry, is too close or too strong, preventing a free escape of the gases as they are formed by the heat of the inflowing steel upon such binders as may be used to give body to the

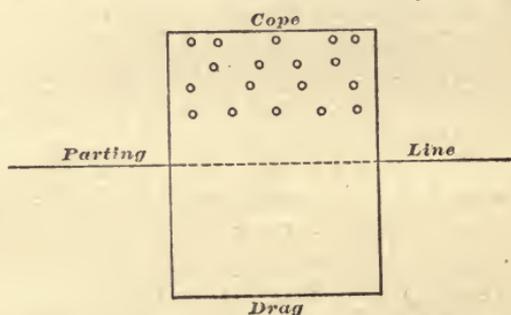


FIG. 13.—BLOW HOLES CAUSED BY DAMP SAND, VAPORS FROM CORE—RENDERS IMPERFECT VENTING

sand and cores. Evidence of that may be seen in fractured castings, which will have a solid drag side, but a more or less porous cope side (see Fig. 13). A casting blown be-

cause of gaseous or improperly "killed" metal will be more or less spongy at all points of both drag and cope. Porosity is often caused by failure to freely vent the highest points of the cope which will cause air pockets to be formed which the liquid steel may not be able to displace and such conditions as described can occur in spite of dry and good green sand molding or properly deoxidized steel. Thus it will be understood that in spite of the highest skill manifested in the melting department, it may be nullified by conditions on the molding floor. A study of the daily discard in the scrap pile as it is broken up will be a good guide, as to what errors are being made in practice, and with a slight knowledge of the causes of porosity one can greatly modify faults.

If the chemical analyses are normal, that is, the figures on manganese and silicon, are within usual limits, but blow holes of the oblong character are persistent, the cause can be traced to the furnace platform. There may be too sharp a melting flame, too much air admitted for flame combustion, or a too liberal use of ore in refining. Any one of these conditions will surcharge the metal with oxide beyond the influence of the usual addition of the deoxidizers, manganese or silicon. Such practice may be covered up or lessened by an increase of deoxidizers, but always at the sacrifice of the physical requisite in steel castings, toughness. The writer knows from his experience in advanced steel casting practice in either green or dry sand, acid or basic steel, that it is possible to produce sound castings free from pin holes or blow holes which will satisfy the most exacting demands. Still there is no royal way to the production of sound castings. It is fraught with patience, skill, study and industry.

CHAPTER IX

DISCUSSION OF THE CAUSES OF CRACKS IN STEEL CASTINGS

One of the most common sources of weakness in steel castings is the liability to crack in the mold. The condition is the result of "red-shortness." It is an annoyance and a continual point of contention between the melter and the molder, each blaming the other for his share in the cause, the molder claiming the steel as it leaves the furnace is not just what it should be and the melter saying that the metal is faultily cast in the desired forms without any consideration as to the proper distribution of metal in the light and heavy sections of a casting. From the standpoint of the metallurgist the melter is at times to blame and at other times the molder, or, going further, the engineer who submits the designs to be cast.

The condition of "red-shortness" or cracks is far from obliging and may present itself at the most unexpected and inopportune times. If in a given heat of steel there should be found a number of discards among various designs because of cracks and the trouble continues for a long period, it is safe to say that the metal is not receiving the proper treatment in the furnace. If cracks appear only in one design in a given heat of steel among other and different designs, the trouble is due to some fault either in a molding detail or the lines of the casting. In other words a few discards in keeping with an average loss of bad castings cannot be blamed upon the metal.

As discussed in previous sections, if "red-shortness" is troublesome attempts are frequently made to reach a lower sulphur analysis, but not with success. It has been thought that in doing so the trouble might abate, because the element sulphur is given the credit for "red-short" effects and that a correction could only be found in the composition. If cracks are numerous the cause is mainly due to the flame character in melting and the way the refining is conducted. Through such conditions the metal becomes contaminated with an oxide of iron that acts in a measure precisely the same as sulphur is said to do, and what may seem strange, also, is that it is possible to deoxidize the metal to the extent that blow-holes caused by gaseous steel are practically absent, yet "red-shortness" will still be causing trouble. Numerous instances have been observed in practice which point to the fact that there must be an indefinable form of oxide (iron) that does not submit to the cleansing action of silicon and manganese as final additions. In such a case as soon as the furnace manipulation could be brought under control a very serious campaign of cracked castings was stopped without any change in design of castings, methods of molding or analysis of finished product. There could be noticed also a change in the fracture of the metal in regard to the appearance of the crystals, another evidence which could be traced back to furnace manipulation, which is in a great measure responsible for "red-shortness" in castings, independently of the amount of sulphur initially or finally.

In regard to molding conditions and their influence upon cracks the trouble often lies in several directions. Steel in cooling contracts much more than gray iron cast from a similar temperature. There is a point where the steel has lost its fluidity and is more or less viscous, but is without stability and will crumble under pressure. When the steel passes to a lower temperature it seems to increase in density and becomes more or less malleable. At the viscous point should there be any resistance offered to the metal

while cooling and contracting, because of improper distribution of metal or absence of fillets at angles, or of a flask bar, hard core, core arbor or hard molding sand, there is danger of a separation or a crack (a crumbling of the metal) at that point where the contractive force could not overcome the resistance of the obstacles mentioned. Should the metal be "over-oxidized" at the range of temperature where viscosity is manifest, the liability to crumble is aggravated and the castings will crack with very slight resistance from the causes mentioned.

It is not to be supposed that should the metal be absolutely free from oxide it will not crack even under extreme resistance of mold parts. The conditions of crumbling under slight pressure at a high heat, near the melting point, are peculiar to all carbon steels. Therefore, if the steel were ever so pure it would crack if held rigidly while cooling and contracting.

Let the metal be poorly handled in the furnace and many cracks will appear in spite of care on the part of the molder. If, however, due care is observed in the position of the gate to allow a uniform cooling of the metal in the mold, cores are made of such a mixture that under the heat of the liquid metal they will crumble to dust or non-resisting masses, ample sand space between flasks, bars and projections on castings provided, and molding sand used of such a texture that when subjected to a high temperature it will become non-resistant, then, with good metal, cracked castings need not cause much worry by a low yield of salable product.

CHAPTER X

HEAT TREATMENT AND ANNEALING—CONSIDERATION OF THE RELATION BETWEEN STRUCTURE, HEAT TREAT- MENT AND PHYSICAL CONDITION

Under heading of heat treatment and annealing it is not proposed to advance arguments as to whether or not steel castings should be annealed since some opinions are held that it is not necessary with certain compositions chemically. Rather the remarks herein will be an explanation of what occurs when cast steel is given various heat treatments.

From a theoretical standpoint all steel castings should be annealed. Practically it is difficult to properly undertake the operation, particularly when the tonnage may be large, as then the process presents commercial considerations. If specifications are rigid it is important to carefully anneal, and it is at this point that the nub of the question arises. To keep the output parallel with deliveries would involve an extensive array of annealing furnaces, and since most foundries are without capacity to anneal their entire output, an attempt to treat all castings produced would result in a slighting of the necessary care to get the best out of the process. It is better not to anneal at all than carry it out without each casting getting a proper treatment under skillful conditions. Annealing is a waste of time and money without this proper and skillful care in the work.

In general most metallurgists view heat treatment as

primarily a method to equalize or lessen strains and stresses set up in a casting during cooling in the mold, especially when the shape may be complicated by intricate parts or light and heavy sections combined. True a re-heating will tend to adjust these strains but really heat-treatment is a method to procure in a casting the best possible conditions in the internal structure consistent with the physical properties.

To understand what is involved in the more advanced practice necessitates a consideration of the relation between structure, heat-treatment and physical conditions.

The internal structure or crystalline formation depends mainly upon the casting temperature and the rate of cooling from that temperature. It is known that the physical properties reflect in a large degree the size, shape and character of the crystals formed in steel castings. If a freshly fractured surface of a steel casting cooled normally from casting temperature be examined, to the eye the grain will be coarse and large. If the same casting be reheated to a much lower temperature than that at which it was cast, say a bright red, cooled and again fractured it will be noticed that grains or crystals are much smaller and closer than in the original piece. It will also be noticed that after the re-heating it was more difficult to produce fracture than in the first instance, that the metal seemed tougher. These facts give but a hint of the potent changes set up.

The refinement of the crystals when subjected to varying ranges of temperature and rates of cooling offer interesting features which to fully appreciate, requires a delving into their details by means of a microscope. The microscopic examination of metals has developed a comparatively new science known as "Metallography" and with it a number of terms which apply to crystalline formations in metals not visible to the unaided eye.

Before going into a recounting of the constituents visible through the microscope and formed in cast steel, the

changes produced by heat treatment upon the physical properties will be considered.

If a piece of cast steel be allowed to cool freely from a casting temperature there will be a grain or crystal growth proceeding to a certain point when the growth ceases. The metal in that condition will not possess its maximum ductility expressed as elongation and contraction of area. It will be more or less brittle, depending upon the carbon content. If that same piece of steel be re-heated to or about the point at which the grain growth stopped and allowed to cool slowly, the coarse grain developed during the first cooling will be greatly modified, broken up or obliterated and replaced by a finer grain than it had originally. In this new condition the ductility will be greatly improved; the metal will be tougher and better fitted for service conditions in any case than without a re-heating. Such a re-heating is properly speaking "annealing." The object then in annealing is to so affect the grains or crystals as to develop the maximum degree of toughness that a casting of a given composition is capable of developing.

By referring to Fig. 14, an idea will be suggested as to

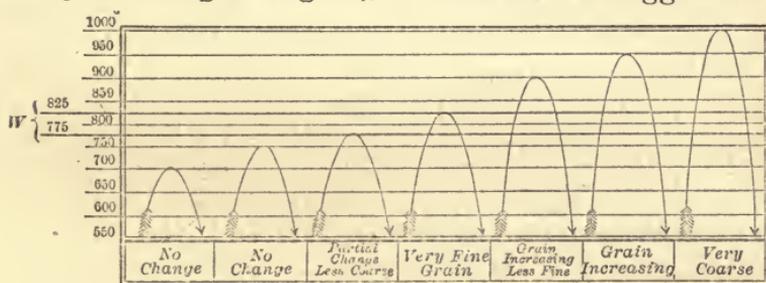


FIG. 14.—SHOWING STRUCTURAL CHANGES

the changes taking place in structure by heating. The examination was made on a piece of 0.25 carbon steel possessing a coarse structure common to steel of that composition cooled normally from casting temperature. The arrows indicate the temperature to which the specimens were

heated and immediately allowed to cool. The heat was obtained in an electrical muffle furnace and the temperature measured by a Le Chatelier pyrometer. The structures were noted microscopically. The range "W" refers to recalcence or refining temperature. It is that range thermometrically at which all coarse crystallization acquired in cooling from temperatures above "W" and near the melting point is changed and replaced with a finer structure or as fine as it is possible to get in an ordinary piece of cast steel. A re-heating below "W" does not accomplish anything in cast steel. A re-heating greatly above "W" causes the grain to again grow after it had been refined while the piece was passing through the recalcence period.

To grain-refine a piece of cast steel it is necessary to pass through and slightly above "W," and after that point has been reached nothing is to be gained by a prolonged or higher heating. That is to say, if the piece is heated throughout at the needful refining temperature the fire may be drawn or if the shape will permit it, it can be air-cooled immediately. In doing so all stresses will be minimized and no matter what the previous structure may have been, the irregularities of original stress and grain will be removed by heating the mass to a uniform color (slightly above "W") and then allowing it to cool uniformly.

The equation of time for grain refinement depends largely upon the size and shape of the piece; a wire may be brought to the right heat in a few moments. Then it should be withdrawn because a longer heating is needless. A cube 8 inches or more in section might take several hours to refine it and heat it through, but as soon as uniformly heated and refined there is absolutely nothing to be gained by heating further. Longer heating would result in grain enlargement, a decrease in ductility, toughness, a heavy scaling of the piece and a superficial de-carbonization as in malleableizing if "W" is greatly exceeded. To sum up the question of temperature and its effect upon grain size Prof. Sauveur says:

(1) "When a piece of steel, hardened or unhardened, is heated to the temperature 'W,' all previous crystallization however coarse or however distorted by cold working, is obliterated and replaced by the finest structure which the metal is capable of assuming."

(2) "The higher the temperature above 'W' from which the steel is allowed to cool undisturbedly the larger the grains."

(3) "The slower the cooling from a temperature above 'W' the larger the grains." "*The Metallographist*," Vol. 2, pp. 265 and 266.

So much for temperature and corresponding grain growths. The matter in the following table is selected from averages obtained in researches conducted some four years ago by the writer upon the effect of grain size as affecting the physical properties of cast-steel:

Tensile strength, pounds, sq. in.	Elongation per cent.	Contraction per cent.	Treatment.
			Series I.
80,385	13.26	16.2	Metal as cast.
78,767	27.20	40.4	Heated to "W."
79,422	14.80	15.3	Greatly above "W."
			Series II.
77,779	26.5	28.5	Metal as cast.
74,504	25.0	48.8	Heated to 830 degrees Fahr., quenched, reheated to 750 and air cooled.
78,792	25.0	34.3	Heated to 815 degrees Fahr., one hour and air cooled.
74,058	25.7	31.	Heated 24 hours at 850 degrees Fahr. Cooled in furnace. Four hours in heating. Eleven hours cooling.
73,376	24.2	26.7	Heated 36 hours between 850 to 900 degrees Fahr. Heating up 3 hours 15 min. Cooling down 9:45.
90,400	2.5	3.	Heated to 1,200 degrees Fahr., and quenched.

In the foregoing Series I are the averages of a number of bars from one heat of steel and Series II from another heat. A study of the figures will readily show what can be done in arriving at different physical properties by varying the heat-treatment. Reference to diagram Fig. 15, which is a record of some extreme tests carried out by the United States government at Watertown arsenal, will

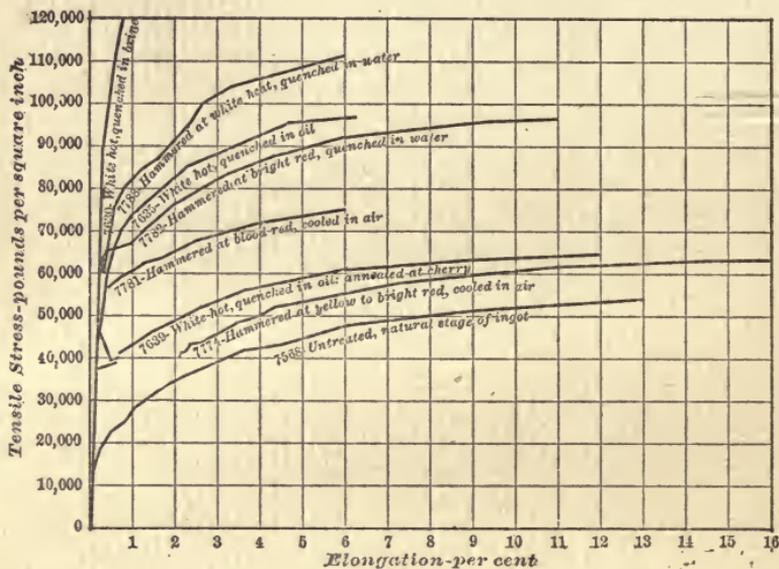


FIG. 15.—RECORD OF GOVERNMENT TESTS

still further enlighten one as to the contrasting behavior physically affected by heat treatment. These experiments in conjunction with others on record show, that, unless the heat-treatment is a constant and other conditions normal in steel casting practice, it is not possible to readily forecast, by means of formulas, the physical properties taking into account the chemical composition.

The ranges of ductility and tensile strength seemingly vary with temperature and rate of cooling. The treatment

that will give the maximum degree of elasticity combined with the maximum degree of ductility is the one that should be aimed at in high grade product.

The strength or elasticity depends upon the amount of carbon present and the form that it assumes as a result of the heat treatment it may receive.

Ductility depends upon the smallest possible degree of refinement or non-crystalline formation structurally that the carbon-iron alloy is capable of assuming. These refinements control the annealing or heat-treatment methods and satisfactory results cannot be obtained in practice without an observance of the laws governing them. The process can best be studied with the aid of a microscope. Photomicrograph Fig. 16 is a view showing the structure of 0.25 carbon cast steel magnified 190 times. Fig. 17 shows the same steel heated to 1,200 degrees Fahr. and cooled slowly in the furnace. Fig. 18 is the same steel heated to 1,200 degrees Fahr. and air cooled. In Fig. 19 it was heated to 825 degrees Fahr. and air cooled. All photomicrographs are magnified the same, and a study of the various formations in conjunction with the physical properties as tabulated will show plainly what is accomplished in cast steel by heating and cooling differently. Figs. 16, 17 and 18 are all coarse and more or less brittle. Fig. 19 shows the refinement obtained at "W" and with it will be found physically a great improvement in ductility. In each case the composition is precisely the same since each specimen was cut from one bar of steel.

Some attention will now be given to the constituents recognized microscopically in steel.

First in order comes "Ferrite" which may be seen in the submitted photomicrographs by the white areas. It is nearly pure iron, that is, carbonless (plus Si, S, P, and Mn). It is soft, weak and ductile.

Next in importance is "Cementite," and which is not free or visible separately in ordinary cast steel. It is the carbon-iron alloy and is expressed definitely as Fe_3C . It is

that constituent which confers hardness, elasticity and strength upon steel.

Finally, there is "Pearlite," which is distinguished from "Ferrite" by the dark areas shown in the photographs. It is a mixture or combination of "Cementite" and "Ferrite" in the proportion of 1 to 6. The constituents as named are the only ones that enter in the problems of annealing cast steel. (There are others, such as martensite, troosite, etc., which are only found in steels that may be hardened and tempered.) Cementite is not structurally free until the carbon exceeds 0.9 per cent. Pearlite is recognized as existing in three forms. In photomicrograph Fig. 16 it is called "lamellar" and is always found in steel slowly cooled from a high temperature (in this case from a casting temperature of nearly 1,600 degrees Fahr.). Fig. 17 indicates also cooling but from a lower temperature. The structure is still "lamellar" but not distinctly so. Fig. 18, cooled at a quicker rate (air quenching) but from the same temperature as Fig. 17 is called "sorbitic" pearlite. The physical properties accompanying such a structure would be slightly stiffer than in Fig. 17 with about the same ductility. In Fig. 16 the ductility is low but with a higher



FIG. 16.—SPECIMEN OF CAST STEEL IN CONDITION AS CAST (AIR COOLED)



FIG. 17.—SAME STEEL HEATED TO 1,200° CENT. (2,192° FAHR.) AND COOLED SLOWLY IN THE FOUNDRY

tensile strength than Figs. 17 and 18. Fig. 19 gives a view of "granular" pearlite and is one sought when ductility and resistance to shock are necessary. The tensile strength with such a structure is slightly lower than those of the preceding. In the last structure we have a view of the marked change that has occurred by a heating to "W" when the previous structure was as shown in Fig. 16 and also in the other photographs what occurs in grain growth when the temperature is carried far above "W." Were the temperature increased to or about 1,500 degrees Fahr. there would have been in Figs. 17, 18 and 19 about the same formation as in Fig. 16.

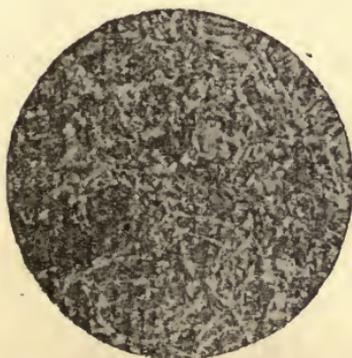


FIG. 18.—SAME STEEL HEATED TO 1,200° CENT. (1,192° FAHR.) AND AIR QUENCHED

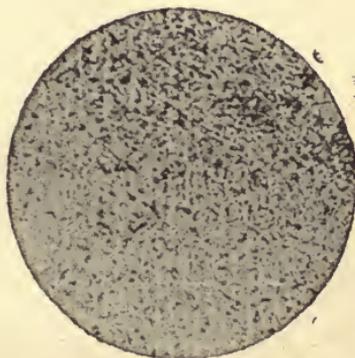


FIG. 19.—SAME STEEL HEATED TO 800° CENT. (1,472° FAHR.) AND COOLED IN AIR. AN IDEAL STRUCTURE FOR STEEL CASTINGS

A study of Fig. 16 reveals a reason why cast steel unannealed is more or less brittle and snaps or fails suddenly on shock or impact. The dark areas or the carbon compound is comparatively hard, while the light or carbonless areas are weak and there is an uneven distribution of the strong and weak parts so that the ferrite areas offer planes of cleavage under stress.

When the structure is broken up as in Fig. 19, the crystals are very small with an even intermingling of the several constituents with cleavage planes practically reduced to nil. A fracture occurring in cast-steel with a coarse structure always follows the ferrite areas and it is not known that the line of separation passes through the pearlite. A coarse microstructure usually accompanies a coarse fracture while a fine microstructure will show a fine, silky fracture.

CHAPTER XI

REPAIR OF STEEL CASTINGS WITH THERMIT—"BURNING-ON" OF METAL

Since the advent of chemistry in foundry practice there is no metallurgical invention that has proved so useful as the thermit process as perfected by Dr. Hans Goldschmidt. Its flexibility and simplicity appeal strongly to the steel foundrymen for supplying liquid steel in almost any quantity quickly and at any time. The process has been too well promulgated in the technical press to need any explanation here as to its composition and action. Rather the remarks herein will relate to the methods of applying it in the practice of making repairs of the defects common to steel castings. The consideration from the foundry standpoint is mainly appearance and in this regard thermit is superior to all means, in the writer's knowledge and experience, of remedying unsightly flaws which can cause rejection without depreciating the strength.

Whether a casting should or should not be repaired with thermit will depend upon the cost of the operation. If the repair cost should exceed the molding cost, it will be cheaper to re-melt it, because the casting will always have a credit value on the basis of the market price of scrap and the loss because of the flaw will only represent the labor in molding and handling. The question of delivery frequently offsets other considerations.

Many castings are of such a size that they can be readily

repaired in blacksmith's fire at a nominal cost for fuel and labor. Thermit is extremely useful in heavy, valuable castings. The commonest flaws in them are shrink-holes, under-headers, sand-holes, miss-runs and cracks.

If the defect is a shrink-hole or sand-hole and where there is no machined surface, the method of filling is quite simple. There may be some grease or oil in the hole which must be removed before it can be welded. It is not always possible to pre-heat or burn out, because the operation is slow and tedious, particularly in the case of large castings, and there may not be a large torch or oil burner convenient. The simplest way to remove the grease is to pour into the hole some loose thermit, ignite it and allow the heat of the reaction to burn out the oil, grease and dirt which it will do most effectively. There will be a violent sputtering in the hole and a mass of slag and spongy metal. The slag can be chipped out readily. The hole is then ready for the final treatment. A gate-pin can be secured which must be larger in diameter by at least 1 inch than the hole. It should be placed over it in an upright position, and some green molding sand packed around it. Withdrawing the pin leaves a mold into which the thermit can be placed. The depth of the mold should be at least $2\frac{1}{2}$ inches. When the thermit is ignited, and while burning, some loose thermit should be poured upon it for the reason that the mold will not hold in the first instance enough thermit to completely fill the hole. As soon as the action has ceased and the slag solidified the mold can be broken away together with the mass of slag. The button of metal will be white hot and as soon as it reaches a yellow or bright red it can be forged by a hand hammer. This treatment will effectively and cheaply fill any hole of the character described on surfaces that will not require machining. The button of metal will protrude more or less, but it can be ground down or chipped, preferably ground.

In case such defects as just mentioned are on surfaces that may require machining, a different procedure is neces-

sary because blow-holes must be absent from such surfaces. The same method of removing grease and dirt can be followed as in the foregoing paragraph and a charcoal or coke fire can be built over the flaw. Sand must be removed by chipping to expose clean metal. The mold must be dry sand. It can be made from a slab-core by cutting a recess or hole in it with a file. The mold must be as large in diameter inside in excess of diameter of the flaw, as in the previously described method, and must be carefully placed over the flaw, weighed down and the joints daubed with moist clay or dough and backed by green sand. A thermit crucible is then placed directly over the mold, charged, ignited and tapped in the usual manner. It is not recommended in this case to attempt to forge or hammer the button while hot. Let the parts cool down normally. Afterwards grind the button down flush. Grinding is better than tooling because the button, if the proper quantity of thermit has been used, will stand up some distance when the casting is placed upon a planer, and if the leverage of the tool is too great and there is danger of taking too heavy a cut, thus tearing the soft thermit metal out. Because of its softness it gathers under or crowds the tool and also prevents or interferes with free cutting, increasing the resistance and danger of tearing. A light cut can be taken and when the button decreases in size, of course the leverage decreases, too. Should the metal be porous from any cause, or should the weld be imperfect because of an insufficiency of thermit in the first instance for welding, the operation can be repeated since thermit metal welds beautifully to the same metal and a second treatment usually satisfactorily finishes the job.

In case of shrinkage cracks, the metal must be cut away along the line of the opening to the extent of at least $\frac{1}{2}$ inch or more. A mold of core material must be rammed on the casting to get the contour of the parts, allowing a mold space to form a band overlapping the edges of the opening at least $\frac{1}{2}$ inch on each side of it and from $\frac{3}{4}$ to

1 inch in thickness. In welding such flaws the incoming thermit metal must enter the mold at the lowest point and overflow at the highest, using enough to get a good circulation. When cool the band of metal can be removed to the finished surface.

No fixed rule can be laid down as to the quantity of thermit to use. Usually there are no scales in the cleaning room of a steel foundry, and the operator must use his own judgment how much to use for a given operation. Practice alone will govern and there is always the satisfaction of knowing that if a weld be imperfect from any cause it can be repeated.

All foundrymen are familiar with the well known "burning-on" of metal. Thermit practice is essentially in many details the same operation with the advantage that a "burn" can be made at any convenient time if the compound is available. The same rules will apply as in "burning-on" excepting that allowance must be made for a voluminous slag which always accompanies an action of thermit.

The operation of "burning-on" by ordinary liquid steel can be augmented by adding thermit to the ladle of steel taken for the purpose. An addition of 5 per cent by weight will greatly increase the temperature of the steel and of course make the operation sure because of the gain in heat.

CHAPTER XII

COST OF EQUIPPING FOUNDRIES FOR THE MANUFACTURE OF OPEN-HEARTH STEEL CASTINGS—STEEL DEPART- MENT FOR GRAY IRON FOUNDRIES—ESTIMATED PROFITS

Owing to the widespread interest manifested in the erection of steel casting plants there has been considerable speculation as to the cost of their equipment. The following estimate is made on the basis of daily output of sound and salable castings, per ton of capacity:

Furnaces only	\$1,200
Gas producers and gas mains, or oil storage tanks and accessories	600
Buildings, 800 square feet of floor space per ton, at \$1.25 per foot	1,000
Power, machinery, cranes, hoists, molding machines, tools, drying ovens, etc.....	2,300
Total cost per ton	<u>\$5,100</u>

These figures are based on a plant having an estimated capacity of 150 to 160 tons per day, or 4,000 tons monthly, with an equipment of 5 open-hearth furnaces costing approximately \$750,000. A single open-hearth furnace lined for acid melting costs very nearly \$1,000 per ton capacity. One for basic melting costs \$1,200 per ton capacity. These figures cover excavation, brick work, castings

and structural material, including stack, but do not cover the platform or facilities for charging.

STEEL DEPARTMENT FOR GRAY IRON FOUNDRIES

The average capacity of a furnace for open-hearth steel casting work is 20 tons. The number of furnaces in operation in a given shop with two or more furnaces will vary according to the demand. When castings are the only product, at least one furnace should be kept in reserve, pending repairs or a shut-down in the active furnaces. This will equalize deliveries and production. Gray iron foundries using steel castings will undoubtedly find it profitable to install an open-hearth furnace which should be of a size that can conveniently fit in with the existing equipment for handling ladles of hot metal. Would recommend a basic lining, since it permits the purchase of cheap iron and almost any kind of steel scrap. The basic process has reached such a stage of development that any foundryman with intelligence can successfully acquire the skill for its profitable operation. Modern foundry chemistry is fatal to mysterious information. There are no secrets or esoteric systems known only to the few. The principles of basic practice are an open book.

With a basic furnace in an active gray iron foundry of anything like a modern character it would be perfectly feasible to manufacture steel castings in moderate, profitable quantities in conjunction with the regular product. About the only change necessary in the molding end of the practice would be a supply of silica sand and a sand mill to prepare the molding mixtures. A furnace of convenient size would have a capacity of 5 tons per heat. Such a furnace could easily produce four heats in 24 hours and could be depended upon to regularly make at least three, and if desired, only one heat per day. In the meantime, however, there would be a steady consumption of fuel to keep the furnace hot. The fuel should be either natural gas or fuel

oil. Producer gas is often uncertain, irregular in composition, and requires additional labor for attendance and maintenance.

COST OF A FIVE-TON FURNACE

A 5-ton basic open-hearth furnace would cost approximately \$6,000 if erected in a modern active iron foundry. As an additional outlay to cover bottom pour ladles, furnace platform, oil storage tanks, pumps, oil piping, burners, etc., a liberal figure would be \$4,000, making a total expenditure of \$10,000, not including, however, the buildings.

Charging 5 tons per heat, consisting of 50 per cent pig iron and 50 per cent scrap, there should be produced under normal practice, $1\frac{3}{4}$ tons daily at the rate of three heats in 24 hours. The loss or shrinkage is estimated at 15 per cent which includes the melting loss, gates, risers, sculls and defective castings. The melting loss in the furnace is, on the average, 7 per cent. This low loss is an important economical factor.

PROFITABLE INVESTMENT

With a normal demand for castings an average profit of $\frac{1}{2}$ per cent per pound could be expected, or \$10 per net ton of product, which would be equivalent to \$127.50 per day. There would be times when the furnace would be out of commission for repairs, periods which should not exceed one month at the most, but under ordinary conditions two weeks should cover general overhauling. With proper care a basic furnace is capable of producing 400 heats before undergoing general repairs, or a campaign of 133 working days, in round numbers four months. Assuming the active period for production would only be nine months in the year at the rate of 25 working days per

month, there would be a productive period of 225 working days. At the rate of $12\frac{3}{4}$ tons per day or a yearly total of $2,868\frac{3}{4}$ tons at \$10 per ton, would yield a profit of \$28,687.50, figures which look attractive from a promoter's view point, and might be vivid to embody in a prospectus. But, there would be times when the yield would shrink considerably, owing to errors in practice, break-downs, delays and other detractive conditions, which would seriously decrease the difference between manufacturing costs and selling prices. As an extreme case, it will be assumed that the yield over metal charged was only 50 per cent good castings for the entire productive period as estimated; that the average profit was decreased to $\frac{1}{8}$ cent per pound and that the tonnage was only $7\frac{1}{2}$ tons daily or $1,687\frac{1}{2}$ tons yearly. The profit then would be \$4,218.75, and charging off 25 per cent for interest, replacements, depreciation, etc., there would be a net return of \$3,164.07 on an investment of \$10,000 for a five-ton furnace in an active iron foundry. This would be equivalent to a profit of 31 6-10 per cent on the outlay, which, in view of the extremely unfavorable conditions considered in the estimating, makes a steel foundry as profitable as any foundry enterprise.

An open-hearth steel foundry, with intelligent practice and normal times or demand, offers an attractive venture to the investor and no doubt will receive the attention of gray iron founders who are interested in steel casting manufacture.



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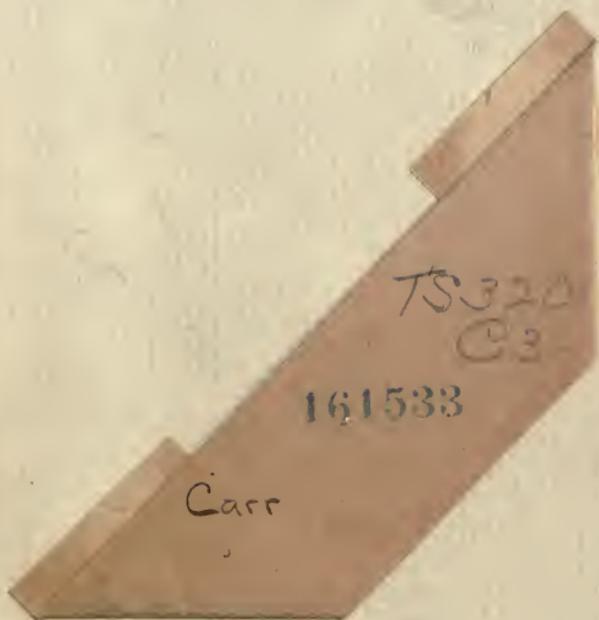
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