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COMPOSITION AND HEAT TREATMENT OF STEEL

CHAPTER I

THE MAKING OF PIG IRON

THE iron that forms the base for all steel, as well as iron, products is first obtained from its ores, as a commercial product, from a blast furnace similar to that shown in Fig. 1. It is then in the form of an iron that contains a large amount of carbon, both in the graphitic and combined state. This makes it too weak and brittle for most engineering purposes, but about one-third of the total product is run out of the blast furnace into pigs of iron that is used only for castings that are to be subjected to compressive, transverse or very slight tensile strains, such as bed plates or supporting parts for machinery, stove plates, car wheels, etc.

The various kinds of steels are relatively increasing in proportion to the amount of pig iron used. To-day about two-thirds of this product is being turned into steel through purification by either the Bessemer, open-hearth, puddling, crucible, or electric methods. The carbon content is reduced to any desired point, the graphitic carbon being eliminated by any of these processes, and the silicon and manganese are oxidized out by the accompanying reactions, or as a condition precedent to the reduction of the carbon. The two impurities of the metal which are the greatest bane to engineers and steel makers alike are phosphorus and sulphur. These are reduced by either the basic open-hearth, puddling, or electric processes.

In making steel, the operation begins by making pig iron from the iron ore, which is a natural iron rust or a combination of iron and oxygen. The oxygen is removed by combining iron ore, coke, and limestone in a furnace, as shown in Fig. 2, and heating them to a high temperature by injecting superheated air into the bottom of the furnace. The coke is burned by the oxygen in the air; a part of it aids in maintaining this high temperature while the rest is useful in removing the oxygen.

This superheated air is usually produced by passing the blast through a hot blast stove. This has been previously heated by means of the combustible gases which have been conducted from the top of the furnace to the bottom through the pipe shown to the left of the furnace in Fig. 2.

Four of these stoves are shown grouped in pairs, to the left of the blast furnace, in Fig. 1. They are about the same height as the furnace,

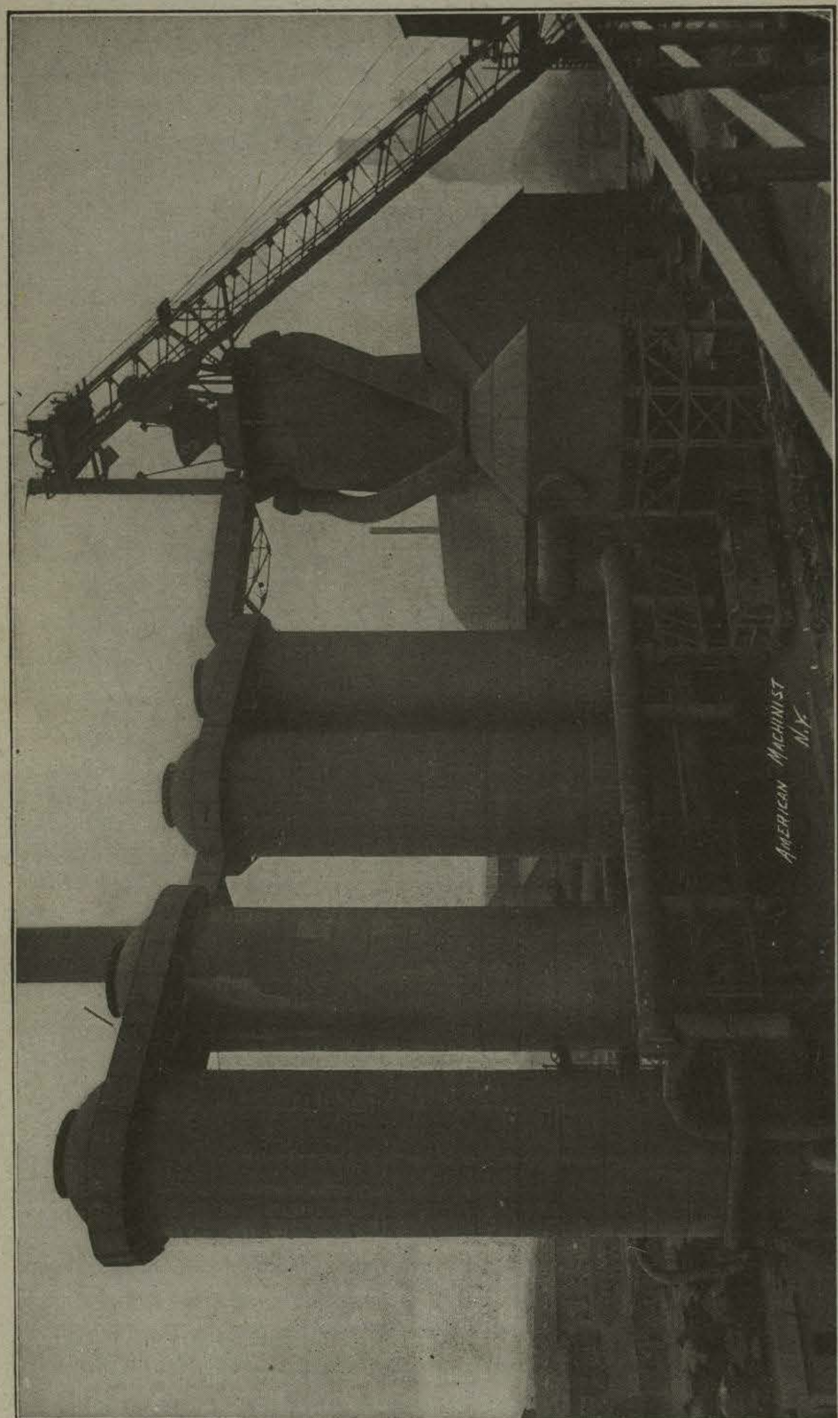

Fig. 1. — Blast furnace and its hot stoves.

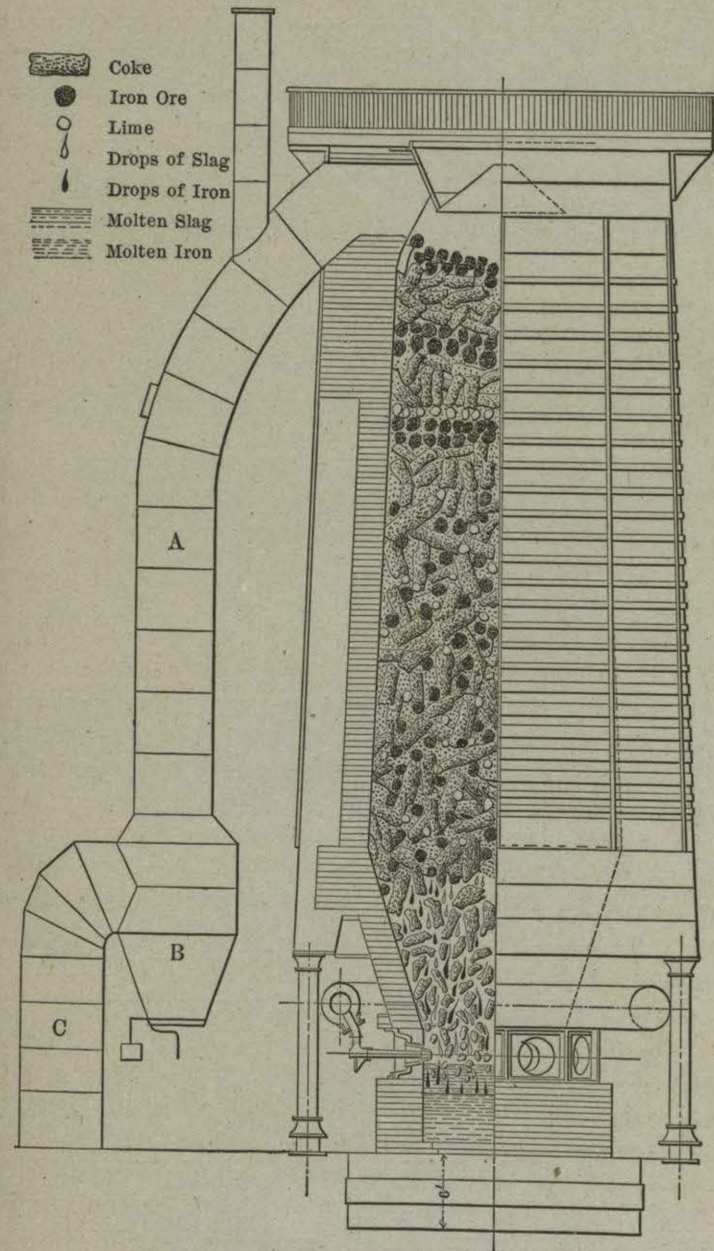

Fig. 2. — Details of blast furnace. Condition of charge at different levels.

which may be from 60 to 100 feet, and are round steel tanks that have a comparatively small annular fire-brick chamber in the center for nearly the height of the tank. This chamber is surrounded with brick work that is filled with flues. The gas from the furnace comes in at the bottom of the central annular chamber; burns on its passage up this; comes down through the flues in a heated condition, thus heating up the brick work, and then passes out the chimney as waste product.

When the brick work is heated properly, the gas from the furnace is shut off and the air blast from the blowing engines passed through the stove on its way to the furnace.

This heats the air in its passage up through the central chamber and down through the flues, and makes it a hot blast when it enters the tuyeres of the furnace. Thus it increases the temperature of combustion in the blast furnace. Four hot blast stoves are used with each furnace, so that three can be burning gas and warming up, while the fourth is having the air blast sent through it into the furnace.

The gas, which is a product of combustion of the materials in the blast furnace, comes down through the pipe *A* (Fig. 2), which is called the downcomer, leaves most all of its accumulated dirt at *B*, and then passes out of the pipe *C*.

From one-third to one-half of this gas is all that is needed to keep the stoves hot and the balance is generally burnt under the boilers where it generates the steam for the blowing engines. In some cases it is used directly in gas blowing engines. Often there is more than enough gas for the heat and power requirements of the blast furnace and the excess is used to generate a part of the power used by the steel mills.

The blast furnace is usually charged by means of a skip car running on an inclined track. The charge is dumped from the car into the top of the furnace through a hopper and bell, and consists of coke, iron ore and limestone. The change that takes place in these as they pass down through the furnace is plainly shown in Fig. 2.

The coke serves as a fuel for generating the heat that melts the iron ore, and the limestone unites with the earthy material as the ore is being reduced to a molten state. The resultant slag is run off from the top of the iron through a hole in the side of the furnace below the tuyeres. The metallic iron melts and collects in the hearth below this slag, and is tapped out of another hole, close to the bottom. From this it is run through channels into molds that form it into "sows" and "pigs," or the molten metal is tapped from the furnace into ladle cars as shown in Fig. 3, in which it is taken to furnaces for conversion into steel.

While the metal is in contact with the white-hot coke in the furnace it absorbs a certain amount of carbon, some of which is chemically combined with the iron and another part is held in suspension as graphite.

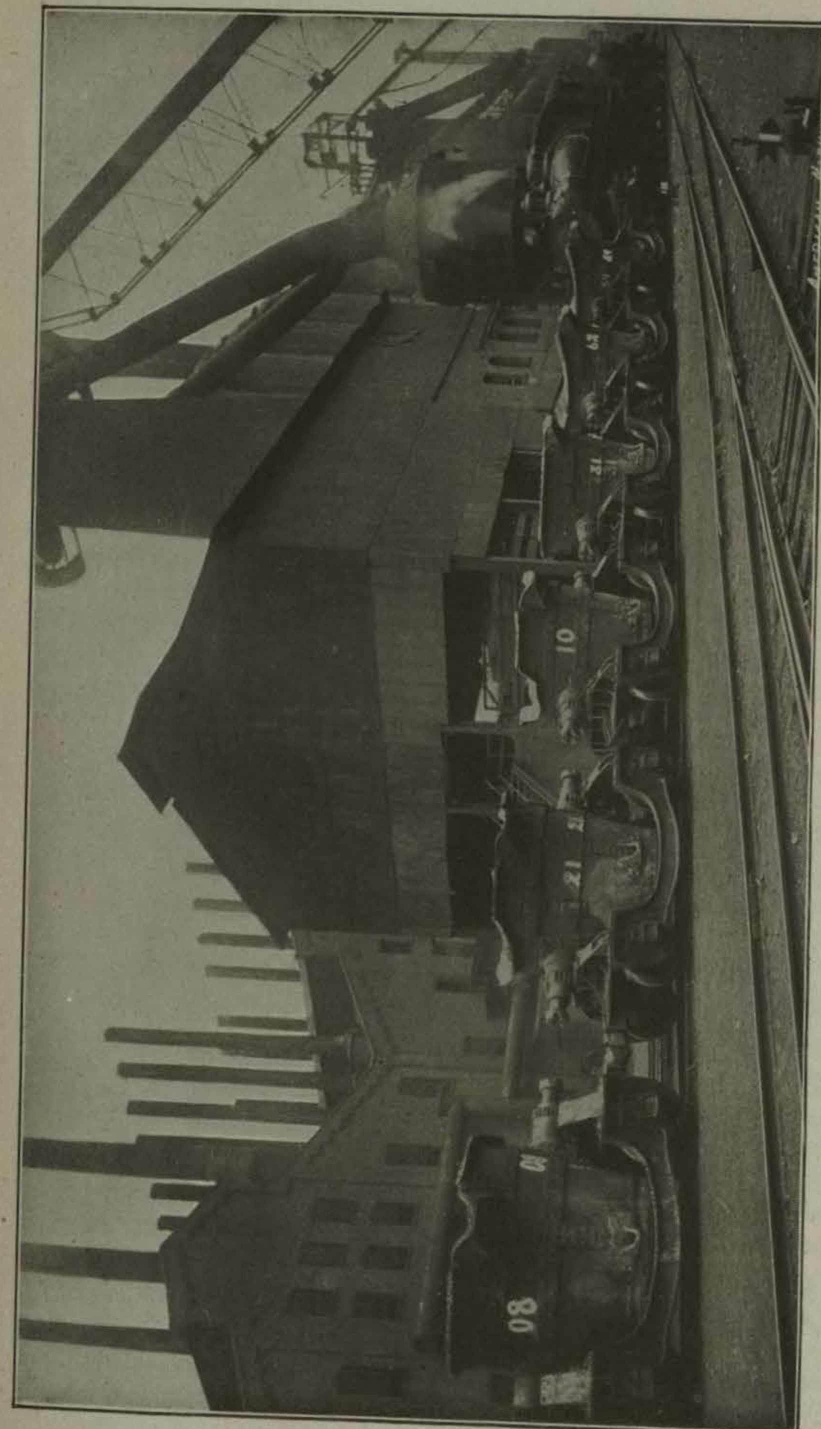

Fig. 3. — "Hot metal" ladle cars carrying molten cast iron to steel converters.

If the "sows" and "pigs" are cooled slowly it tends to make the carbon take the form of graphite. When such iron is broken it has a gray or black appearance showing loose scales of graphite, and the iron is soft and tough.

If the metal is cooled quickly, or chilled as soon as it comes from the furnace, the carbon has a tendency to be kept in the combined state. When fractured such metal will be white and hard.

Of this product about 20% is made into gray-iron castings, 3% into malleable-iron castings, 3% is purified in puddling furnaces to make wrought iron, and the balance, or 74%, is converted into steel by the various

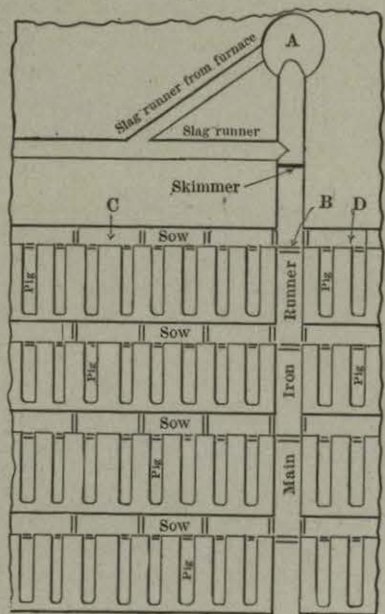

FIG. 4.—Section of sand bed for casting pig iron.

processes. Of the latter about 40% is converted by the Bessemer process, 31% in the basic open-hearth furnace, and 3% in the acid open-hearth furnace.

About 6% of the production of wrought iron goes into the manufacture of crucible steel. Recently the electric furnace has been brought into use, and this promises to take a certain percentage for conversion into the finer grades of steel.

The older method of casting the blast into pigs, and which is still used now by many is to have a casting floor in front of the blast furnace that is composed of silica sand. In this sand, impressions or molds are made for the pigs and these connected with runners called "sows," which in turn are connected to a main runner from the furnace. Fig. 4 shows how

the floor is laid out. In front of and under the tap hole of the furnace a trough is laid into which the iron is run. From this the main runner for the iron goes down the center of the cast-house. Branching off on either side of this are the sows with the pigs leading off from the sows.

Removable dams are formed at the junction of each sow with the main runner. The iron is first allowed to flow into the sow and pigs at the lower end of the runner, *i.e.*, at that end farthest from the furnace. When these are filled the iron is dammed off by thrusting a "cutter" into the runner just below its junction with the next higher sow, the dam at the entrance of the sow being at the same time broken so that the iron can enter. This is continued with successively higher sows and rows of pig beds until all of the iron has run out of the furnace. After solidifying and cooling the pigs, sows and runner are broke up, loaded on cars and the floor remolded, ready for the next tapping. At the entrace to each pig and at stated intervals in the sows and runner, as shown by the double lines, a dam is formed that about half filled these, so as to make the metal thinner at this point and thus allow it to be broken more easily into nearly standard sizes and weights.

Automatic machines into which the pigs are cast, cooled, and then dumped into cars are now used at some blast furnaces, as the saving in labor is a big item; the pigs are more uniform in size, thus facilitating handling, piling, and storing, and they are free from the adhering silicious sand that is especially objectionable in the basic open-hearth furnace.

The pig molding machines are made in several styles, the most common forms of which are a revolving frame with the pig molds in a continuous series around its annular outer edge, as shown in Fig. 5, and a series of molds attached to an endless chain which carries them in a straight line from where they are poured to the cars into which they are dumped, as shown in Fig 5. In the latter, the empty molds travel back to the ladle underneath the filled ones, and in both the molds are sprayed with thick lime water, long enough before they are filled to allow the water to be dried out by the heat of the mold, and leave it covered with a coating of lime so the molten metal will not stick to the steel molds.

ELECTRIC SMELTING FURNACE

The experiments that have for some time been carried on for the electric production of pig iron seem to be fast approaching a successful culmination, and we may in the near future see this method used commercially, especially where an adequate water power is available.

The Noble Steel Company in California have built several furnaces in this country. Their first attempt was a 1500 kilowatt, three-phase, resistance type of furnace that was completed in July, 1907, but after running it a short time the mechanical difficulties which presented them-

Fig. 5. — Revolving pig casting machine at Bethlehem Steel Co.

selves made this type of furnace impractical commercially, and it was abandoned.

A 160 kilowatt furnace of a different type was then constructed and run for 40 days. From this run data were gathered that were used in the construction of the present 1500 kilowatt furnace, shown in Fig. 7. The data obtained would indicate that with one ton of charcoal, costing about $9, three tons of pig iron could be produced with about 0.25 electric horse-power-year per ton.

The quantity of carbon used for the electric smelting of iron ores is only about one-third of that required for the ordinary blast furnace.

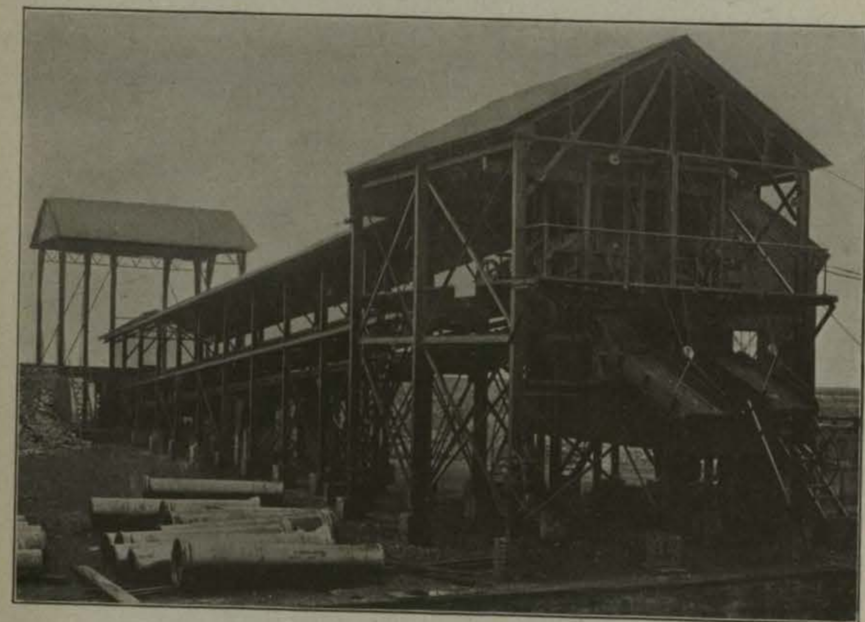

Fig. 6. — Double strand, endless chain, pig casting machine.

Thus charcoal can be used and the product will be charcoal pig iron, which, owing to its comparative purity, would demand a higher price than the ordinary product.

In the furnace shown in Fig. 7, the ore with its proper fluxing materials is brought in, in cars, and fed into the preheater, *A*, where it is dried and heated by the products of combustion piped from the combustion chamber of the furnace, *B*, through the flue, *C*. After drying it is dumped in the scale car, *D*, which runs around the top of the stack, on a circular track, so it can alternately take a charge of ore and flux from *A*, and carbon from the hopper, *E*, weigh them and charge them into the furnace in the proper proportions through the usual hopper and bell in the top of the stack.

Six electrodes (*G*) are arranged equidistantly around the furnace, and the electric current passing through between them melts the charge, the metal and slag collecting in the crucible at the bottom of the furnace, from which they are drawn as in ordinary practice. All the necessary heat is supplied by electrical energy, and thus no blast is blown in. This causes all of the solid carbon to be used for reduction, excepting of course the small amount that is dissolved into the pig iron. Above the level of the charge, however, are small openings at *F*, for admitting the correct

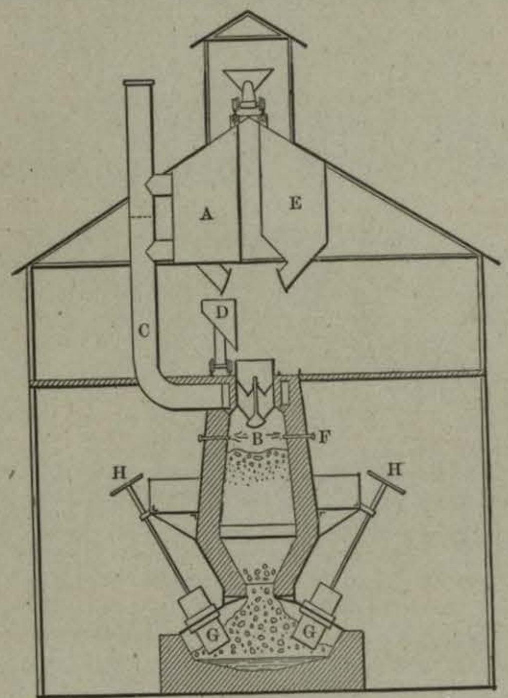

Fig. 7. — Electric pig-iron furnace at Noble Steel Co., Heroult, Cal.

amount of air, through valves, to burn the gases that result from the reduction of the ores in the lower part of the furnace.

In Fig. 8 is shown the combination of electric and blast furnace that has resulted from several years of study and experiments conducted by three Swedish engineers at the Domnarfvet Iron Works in Sweden. In this a large crucible with an arched roof is formed at *I*. An opening is left in the center of the roof, and over it is constructed a stack (*J*) very similar to the ordinary blast furnace; in fact, the only difference being that the bosh is contracted more at *K*, where the charge enters the crucible. This was made necessary by the fact that too large an opening would not retain the required heat in the crucible part of the furnace without

increasing the power to generate the electrical energy to too high a point. It was feared that this contraction would result in the furnace clogging

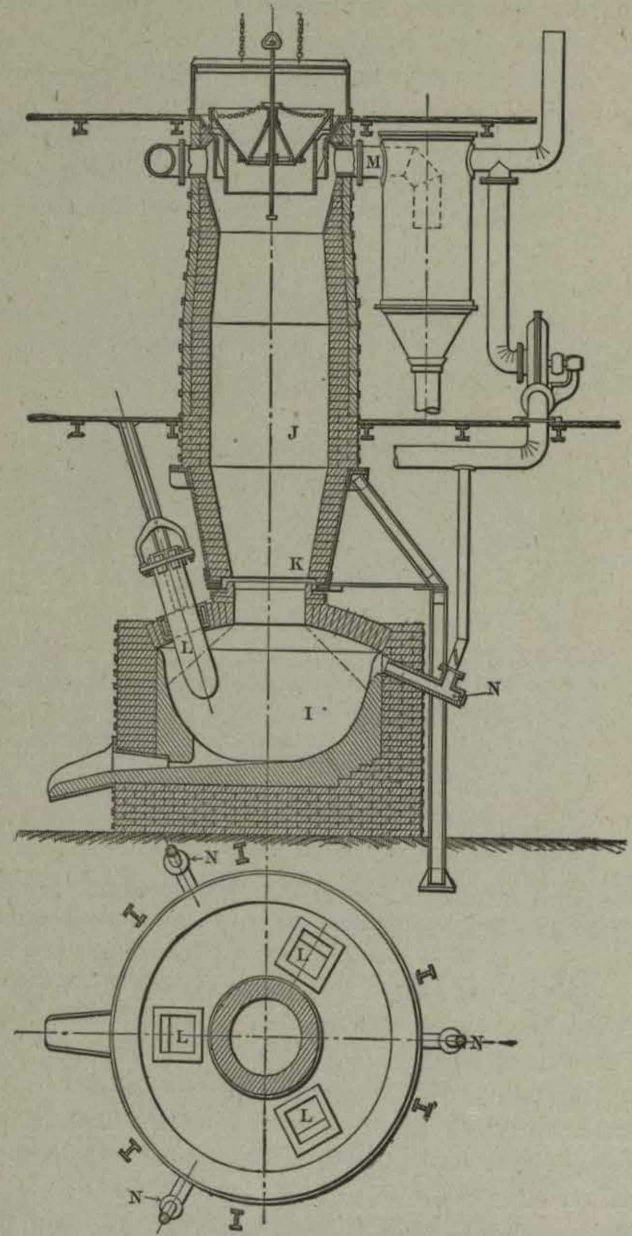

Fig. 8. — Electric furnace at Domnarfvet Iron Works, Sweden.

and an overhang form in the bosh, but with a continuous run of three months no such condition was apparent.

Three electrodes (*L*) that project into the crucible through a water-jacketed stuffing-box in the arched roof conduct a three-phase alternating current of 40 volts to the charge. The current is from 8000 to 9500 amperes, and the load 480 to 500 kilowatts. The arched roof over the crucible gave considerable trouble in the earlier experiments by being overheated, but this is now preserved by taking the gaseous products of combustion from the top of the furnace at *M*, and blowing them back through tuyeres at *N*, which are provided with peep-holes so the roof can be examined and the volume of gas increased or diminished as desired.

In the three months' run, that was terminated July 3, 1909, by the general strike in Sweden, it was demonstrated that the electrodes did not need readjusting oftener than once a day, and in one case an electrode was not touched for five days; that the consumption of energy was remarkably uniform even though the short run did not enable the furnace to approach its working condition until near the end; that the charge moved with regularity into the melting chamber; free spaces were maintained underneath the arched roof next to the outer wall, and the gases kept the roof effectively cooled.

This furnace was first constructed as an induction, but was later changed to a resistance furnace. It is started and worked the same as the ordinary blast furnace, and in the experiments so far only coke has been used, but charcoal can be used as well as the "prime ore briquettes" and "slig" which they get in Sweden. It has produced 2 tons of iron per electrical horse-power-year, but conditions would indicate that this could be increased to 3 tons. It being easy to make a pig iron in this furnace with a low carbon content, if the molten iron was transferred directly to electric refining furnaces, it would greatly reduce the time consumed in converting it into steel. It now takes a comparatively long time to reduce the carbon to the percentage required in the electric converting furnace when ordinary blast-furnace iron is used.

The carbon in the experiments with the Swedish furnace averaged about 1.80% in the three months' run, while in some previous experiments it ran as high as 3.20%, and in one tapping it was as low as 1%. The silicon varied between 0.20 and 0.07%, but in one case was 4.40%. The sulphur content has been as low as 0.005%, with 0.50% of sulphur in the coke that was used.

The ability of the electric furnace to reduce the impurities to a minimum may result in its becoming a prominent factor in the reduction of the ore, and the conversion of this into steel as soon as experience teaches the operators to control the carbon and silicon, and it is demonstrated that it is practical commercially. In Denmark there will soon be started another ore furnace, and in Canada negotiations are well advanced for an electric iron-ore reduction and steel plant with a capacity of 5000 horse-power.

CHAPTER II

Bessemer Process of Converting Iron into Steel

In converting the blast-furnace iron into steel the Bessemer process has formerly been the one most used, but the improvements in the open-hearth method have been such that it is replacing the Bessemer, in many places, for the cheap production of steel, and the product which it turns out is much better.

In the Bessemer process a converter similar to that shown in Figs. 9 and 10 is shown, it being pear-shaped and open at the small end. It is hung on trunnions so the metal can be easily poured in and out. Into this is poured the melted pig iron, which is usually taken direct from the furnace, although it is sometimes remelted, and through this is blown cold air in fine sprays in the proportions of about 25,000 cubic feet of cold air per minute to every 10 tons of molten metal, which is the usual charge for a converter.

Curious as this may seem to the uninitiated, the cold air raises the temperature of the molten metal to such a high degree that it is often necessary to inject steam or add scrap to cool off the metal. This rise in temperature is due principally to the combustion of the silicon, manganese and carbon of the iron when they come in contact with the oxygen of the air. The silicon and manganese are oxidized and pass into the slag chiefly during the first four minutes of the blow, after which the carbon begins to oxidize to carbon monoxide (CO), which boils up through the metal and is forced out of the mouth of the converter in a long bright flame that gradually diminishes, until at the end of six minutes more the carbon has been reduced to about 0.04% and the flame dies away.

Except for the impurities which poison the metal, namely phosphorus, sulphur, oxygen and possibly nitrogen, it has become for all practical purposes a pure metal that is very brittle. This makes it necessary to add certain ingredients that will toughen, strengthen, and harden it so as to make it useful and workable.

Carbon is added in different percentages while it is in the molten state to give it the proper degree of hardness and strength.

Manganese is added for the purpose of removing the oxygen which the metal has absorbed during the process of conversion, and which renders it unfit for use. It also combines with the sulphur and partly neutralizes the bad effects of this element.

Silicon is also added for the purpose of freeing the metal from blow-holes, which it does partly by removing chemically the gases and partly

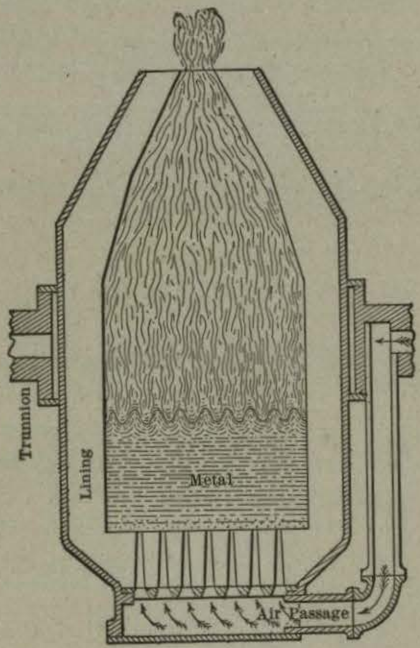

FIG. 9. — Bessemer converter purifying the metal.

through increasing their solubility in the molten steel. Of these last two elements but one-half to two-thirds of the percentages added will be

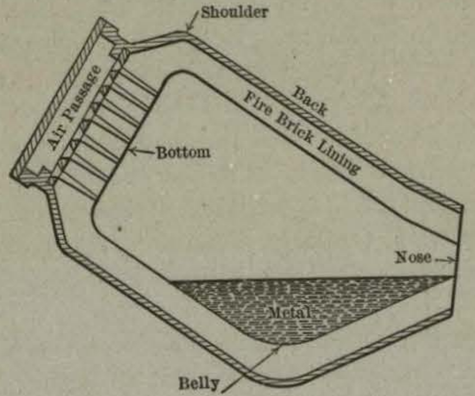

FIG. 10. — Bessemer converter tilted to pour finished metal into ladle.

found in the finished product, owing to their being partially oxidized and passing out into the slag.

These ingredients are added to the charge in the converter by first melting iron containing them in the proper amounts in a small cupola in the converter house, called the spiegel cupola. Pig iron high in manganese and carbon, called spiegeleisen, is mixed with other iron high in silicon until the right percentages of all three are obtained to give the 10 tons of metal in the converter its desired composition. The addition of this

Bessemer converters at Lackawana Steel Co.

mixture is called recarburizing. After this the converter is tilted, as shown in Fig. 10, and the steel poured into ladles. These are bottom-pour ladles, as shown in Fig. 12. In these, as the name signifies, the metal is poured from the ladle through a hole in the bottom. This saves turning the ladle over and also draws the molten metal away from the slag. From the ladles the metal is run into cast-iron ingot molds placed on cars, which are moved beneath the pouring ladle. After the metal has solidified in the molds the ingots are removed and placed in soaking pits, where they become of an equal temperature throughout, and are then ready for rolling. The ingot molds usually are kept going through the

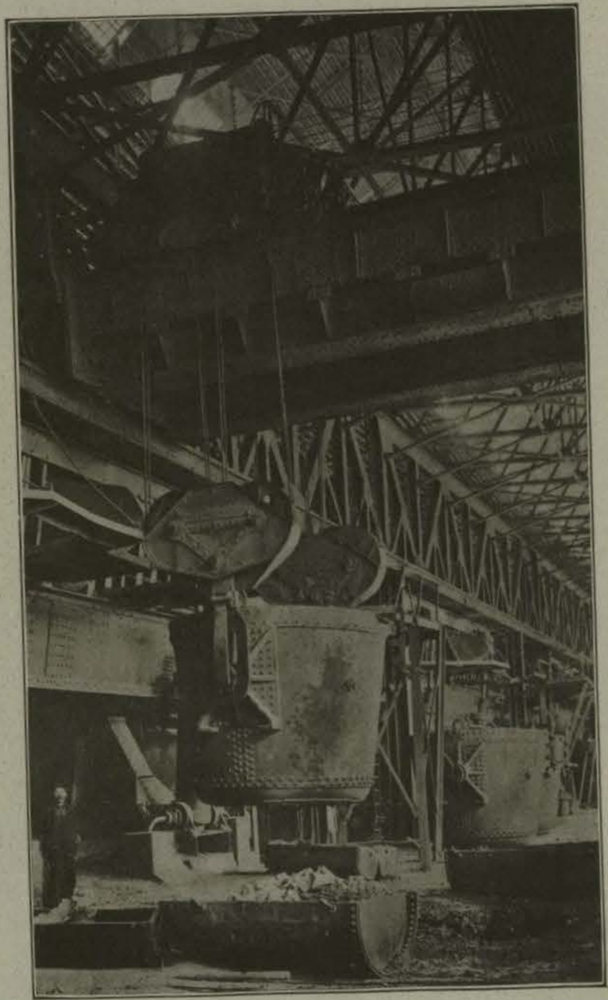

Fig. 11. — Tilting ladles.

converter house in a steady stream; coming in one side empty, getting filled and going out the other side.

Pig iron with about 1% of silicon is preferred for the Bessemer process, as the lower this is kept the shorter will be the blow, and as it is the chief slag producer it will reduce the iron loss by limiting the amount of slag made. If too low, however, the blow will be cold and it is only by working rapidly and allowing no unnecessary waits between blows, thus

keeping the converter and ladles very hot, that as low as 1% of silicon in the pig iron can be used successfully.

In the acid Bessemer process it is impossible to reduce the phosphorus. All of the phosphorus that goes into the blast furnace in the ore and coke will come out in the pig iron, and after this pig iron has been refined in the converter it will be found in the steel. Hence it is necessary to start with ores and coke that are low in phosphorus if a good steel is to be produced.

In Europe, however, the basic Bessemer converter is used to a certain extent. This is the same as the acid, except that the lining of the

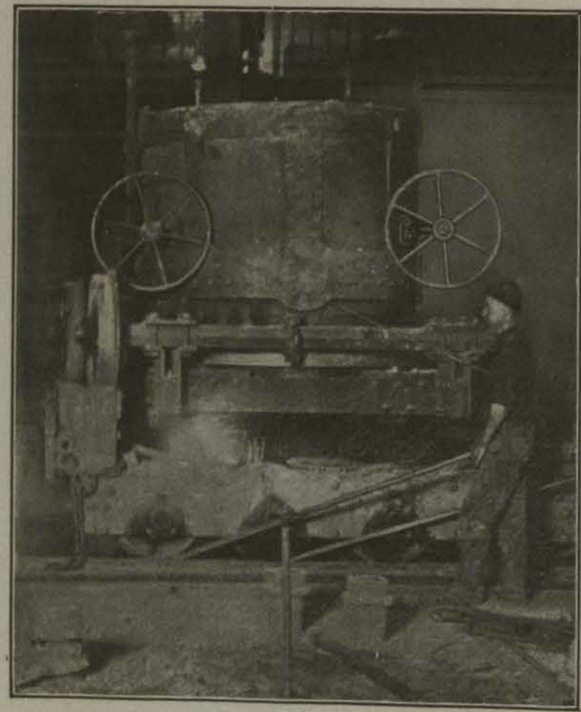

Fig. 12. — Bottom-pour ladles.

furnace is of some basic material such as calcined dolomite. A basic slag is also carried, the chemical action of which removes the phosphorus, but pig iron low in silicon must be used.

The Bessemer process being the cheapest way of converting iron into steel, much of the cheaper and ordinary grades of steel are made by it, such as steel rails, wire, merchant bar, etc.

Where several Bessemer converters are in operation it takes quite a number of blast furnaces to supply them, as it takes two furnaces to furnish iron enough for one converter. As the product of each furnace is liable to vary in chemical composition, it is necessary to have some means of mixing the product of the different furnaces, before they are poured into the converter, if a uniform grade of steel is to be taken out of the converter. For that reason a large reservoir, shaped something like the housewife's chopping bowl, but with a large spout on it, and capable of holding from 200 to 500 tons, is used. Into this is poured the metal from the various furnaces and from it are taken the charges for the converters.

This keeps the molten metal continually coming in and going out, and it does not get a chance to chill, as there is such a large mass. But

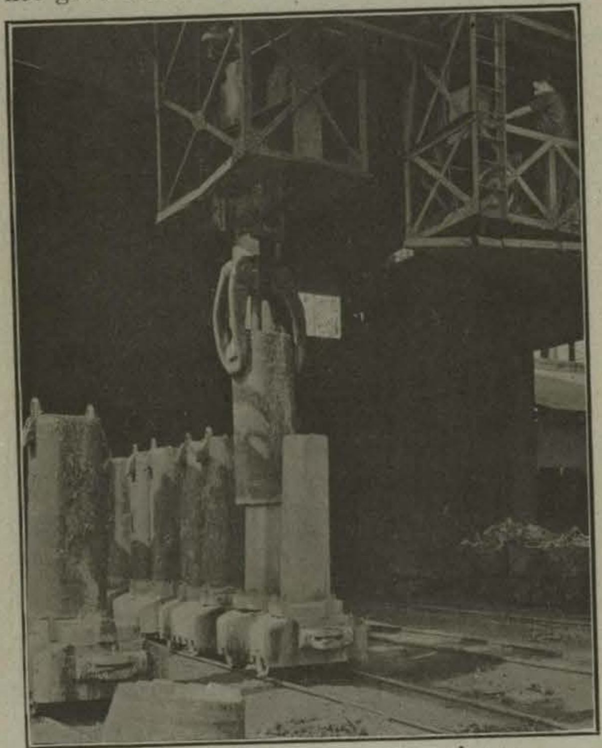

Fig. 13. — Stripping the mold from ingots.

should this happen it is supplied with gas burners that would bring the heat up to the proper temperature again. The metallurgist is thus able to control the composition to a large degree, as he can order the different furnaces to dump in the mixer the amount he desires. In conjunction with this he also has cupolas in which to melt any composition needed to bring the mixer bath up to the desired standard.

When the ingots are poured and solidified the molds are at a red heat, and it has been a problem to find a metal for the molds that would stand the heat. Cast iron is used, but the molds can only be used about 100 times. Titanium treated iron is said to last much better as it does not heat up as quickly. Quite recently one of the large mills added about

1% titanium to their ingot mold iron, and when the ingots were poured it was found that the ordinary iron molds were red hot, while the titanium iron molds were dark colored.

As no fuel is used in the Bessemer process of converting blast-furnace iron into steel, it is the cheapest method of making steel as far as manufacturing cost is concerned, but it requires a more expensive pig iron as raw material and it also makes the poorest grade of steel, as the phosphorus and sulphur are apt to be higher than in steels made by the other processes, and the occluded gases are not removed to the same extent.

For the purpose of getting these occluded gases out of the metal a new material has been brought into use, in the shape of ferro-titanium,

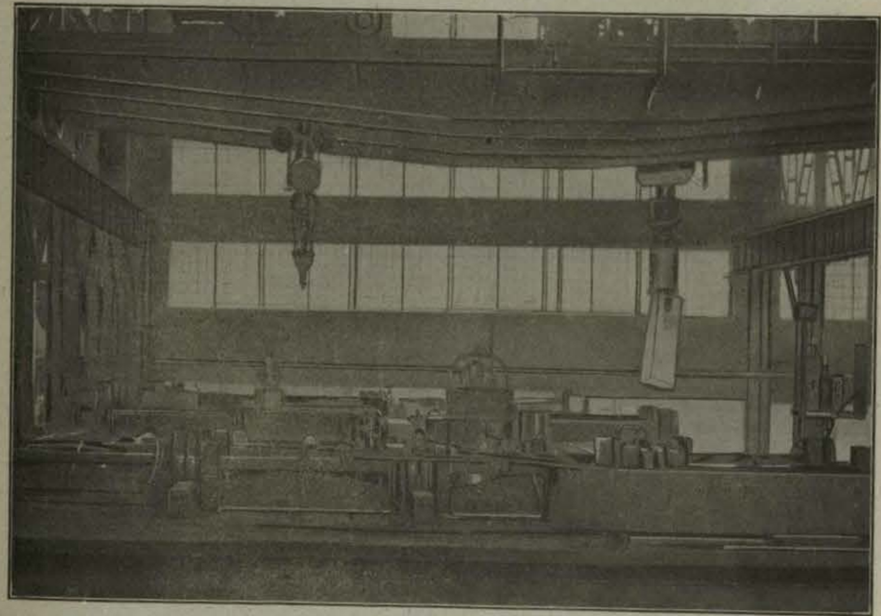

Fig. 14. — Soaking pit for ingots.

that greatly strengthens the metal and increases its wearing quality, when used for such purposes as steel rails. This ferro-titanium is an alloy of about 15% titanium with iron and usually some carbon. It is never necessary to add more than 1% of titanium to the steel, while in most cases very much less will give the desired results.

It is shoveled into the ladle while it is being filled from the converter and the ladle allowed to stand for at least 6 minutes, so the titanium will have time to unite with the nitrogen and other gases, for which it has a great affinity, and carry these off into the slag. It is difficult to get steel makers to allow a ladle of molten metal to stand idle that length of time, but the titanium prevents its chilling and in fact may leave the molten metal slightly hotter at the end of the 6 minutes than when it left the converter. In one case the metal was held in the ladle for 20 minutes and was still sharp enough to teem successfully.

Sulphur must be kept low in steel for rails and other products which are rolled, since, if high, it makes the metal "hot-short" so that it cracks in rolling. Phosphorus, on the other hand, if too high makes steel "cold-short," and some railroad accidents, caused by broken rails, could be traced to too high a percentage of phosphorus. High-phoshporus rails,

Fig. 15. — Carrying ingot from soaking pit to slabbing mill.

however, have good wearing qualities, and when titanium is properly added to the molten metal it seems to remove to some extent the hot and cold brittleness that a comparatively high percentage of sulphur and phosphorus give to the metal.

Many of the fractures in steel rails have been due to miniature gas bubbles in the steel, that have, when rolled, produced long microscopic cracks, and started the fracture; others have been caused by manganese sulphide which rolled out into long threads.

However, by the use of titanium these faults can be largely overcome

and Bessemer rails can be made as good, if not better, than open-hearth rails, and the additional cost is only about $2 per ton. A part of this added cost comes from the extra time consumed in allowing the ladle to stand.

After solidifying the ingot the mold cars are run under the stripper, which is located in a tower, as shown in Fig. 13, and from there a long finger comes down on top of the ingot to hold it, while two iron loops come down over lugs on either side of the mold and lift it off the ingot. The ingot is then gripped by a huge pair of tongs on a traveling crane and these pick it up and carry it to the coaking pit shown in Fig. 14. After remaining in here long enough to reach a proper rolling temperature

Fig. 16. — Slabbing mill.

throughout, it is placed on the "buggy," which is an iron car operated by electricity, and carried by this to the slabbing mill where it is automatically dumped onto the rolls and the buggy returned for another ingot.

In some cases an overhead traveling tongs, similar to that shown in Fig. 15, is used to convey the ingots from the soaking pit to the slabbing mill. A typical modern slabbing mill is shown in Fig. 16.

It was formerly the custom to roll them into "blooms" or large billets about 10 inches square, and reheat again before rolling them into marketable shapes, but in the more modern mills the ingots now are taken directly to the slabbing mill, which in some cases reduces their size 1 inch at a pass, and there rolled into slabs, which are transferred to other rolls and rolled into the desired shape before they get cold.