

special kind of steel is needed, very much smaller charges, in some cases weighing even less than half a ton, have been treated with technical success.

This has been particularly true in the manufacture of steel castings, *i. e.*, objects usually of more or less intricate shape, which are cast initially in the form in which they are to be used instead of being forged or rolled to that form from steel cast originally in ingots like those of Fig. 103. For making castings, especially those which are so thin and intricate that, in order that the molten steel may remain molten long enough to run into the thin parts of the mould, it must be heated initially very far above its melting-point, the Bessemer process has a very great advantage in that it can develop a much higher temperature than is attainable in either of its competitors, the crucible and the open-hearth processes. Indeed, no limit has yet been found to the temperature which can be reached, if matters are so arranged that not only the carbon and silicon of the pig iron, but also a considerable part of the metallic iron itself, is oxidized by the blast; or if, as in the Walrand-Legenisel modification, after the combustion of the initial carbon and silicon of the pig iron has already raised the charge to a very high temperature, a still further rise of temperature is brought about by adding more silicon in the form of ferro-silicon, and oxidizing it by further blowing.

In the crucible and the open-hearth processes the temperature attainable is limited by the danger of melting the furnace itself, both because some essential parts of it, which, unfortunately, are of a destructible shape, are placed most unfavorably in that they are surrounded by the heat on all sides, and because the furnace is necessarily hotter than the steel made within it. But no part of the Bessemer converter is of a shape easily affected by the heat, no part of it has heat on more than one side, and the converter itself is necessarily cooler than the metal within it, since the heat is generated within the metal itself by the combustion of its silicon and other calorific elements. In it the steel heats the converter, whereas in the open-hearth and crucible processes the furnace heats the steel.

285. THE BASIC BESSEMER PROCESS. —The field of this process is greatly restricted by the facts (1) that it is more expensive than the normal or acid Bessemer process, especially as regards the repairs to the converter itself, (2) that at present it can be

applied only to pig iron which contains at least 1.80 per cent of phosphorus, and (3) that there are relatively few ores from which such pig iron can be made. In short it can be used only where cheap and phosphoric pig iron is at hand. Beyond this, it is better that the pig iron used should contain at least 1.80 per cent of manganese, and it should not contain more than 1 per cent of silicon or more than 0.12 per cent of sulphur; but these latter requirements can often be complied with.

Of the ores which contain enough phosphorus to yield pig iron suitable for this process the chief is the poor but very cheap "Minette" ore of the enormous deposits of Luxemburg and Lorraine, though Sweden also has deposits of phosphoric iron ore from which much is to be expected.

Eighty-six per cent of the German and Luxemburg Bessemer steel of 1899, and 28 per cent of the British, were made by the basic process, which is important also in Belgium and Bohemia. But in the United States few phosphoric ores are so much cheaper than the non-phosphoric or "Bessemer" ores as to permit the basic process to compete with the original or "acid" Bessemer process. While it has at one time or another been used at two American steel works regularly, and experimentally at others, it is not now in use in this country, nor does it seem likely to be in the near future.

The rôle of the 1.80 per cent of phosphorus needed in the pig iron is to generate, in being oxidized to phosphoric acid by the air blown through the metal, the very high temperature, about 1600° C. (2912° F.), which the process needs in order to raise the resultant steel above its very high melting-point, so that it may remain molten and because molten can be poured into its moulds.

Silicon cannot be used here as a chief source of heat, as it is in the "acid" Bessemer process, because the resultant silica would both corrode the basic walls of the converter, and cause "rephosphorization," as explained in § 275, p. 347, unless counteracted by great additions of lime, which would not only occupy precious room, but in themselves consume most of the heat generated by the oxidation of the silicon. Further, if the silicon is much in excess of 1 per cent, it causes such frothing as to throw much of the metal out of the mouths even of these roomy converters.

Manganese to the extent of 1.80 per cent is desired as a means of preventing the resultant steel from being redshort, *i. e.*, brittle at a red or forging heat.

The pig iron should be as nearly free as possible from sulphur, because the removal of any large quantity of this element in the process itself is both difficult and expensive, and because sulphur is so injurious that but little can be tolerated in the resultant steel.

The basic lining of the converters, made of calcined dolomite mixed with 10 per cent of dehydrated coal tar, is expensive, and lasts but relatively few charges — in few works more than 200 and in some only 100 — while the silicious lining of the acid converter lasts thousands of charges. Hence, for the basic process, spare converters must be provided, so that there may always be some of them re-lining, either while standing in the same place as when in commission, or, as in Holley's arrangement, in a separate repair house, to which these gigantic vessels are removed bodily.

The slag of the process usually contains about 18 per cent of phosphoric acid, and on this account it is so valuable a fertilizer as to be a most important by-product. Its percentage composition is approximately as follows:

PHOSPHORIC ACID	SILICA	LIME	MAGNESIA	FERROUS OXIDE
16 to 19	6 to 9	50	3	13

In order that the phosphoric acid may be the more fully liberated by the humic acid, *etc.*, of the earth, a little silicious sand is mixed with the still molten slag after it has been poured off from the molten steel. The slag is used in agriculture with no further preparation, save very fine grinding.

286. DARBY'S RECARBURIZING PROCESS. — In the basic Bessemer process most of the phosphorus is not removed until after the carbon, probably because the lime, which is charged in solid lumps, melts and enters the slag so slowly that not until late in the operation does this slag itself, *i. e.*, the molten and effective part of the slag, become so basic as to be retentive of phosphoric acid. Hence in making steel rich in carbon it is not possible,

as in the acid Bessemer process, to end the operation as soon as the carbon in the metal has fallen to the point sought, but it is necessary to remove practically all of the carbon, then the phosphorus, and then "recarburize," *i. e.*, add whatever carbon the steel is to contain. On account of certain objections to adding this carbon in the form of cast iron, Darby adds gas-carbon, coke, or other carbonaceous matter, which is absorbed greedily by the molten steel. This process, which in careful hands yields regular results, is much used in connection with the basic open-hearth process, though indeed it can be used with either the acid or basic variety of the Bessemer and of the open-hearth process.

287. COMPARISON OF PROCESSES. — The puddling process, often preceded by the removal of silicon in the "refinery" process, is still widely used for making wrought iron for certain normal purposes which need great ease in welding; for purposes requiring special forms of extreme ductility which are not so confidently expected in steel; for miscellaneous purposes by many users, some ignorant, some very conservative; and for remelting in the crucible process.

All the best cutlery and tool steel is made by the crucible process, and indeed all for which any considerable excellence is claimed is supposed to be, though often incorrectly.

But the great mass of the steel of commerce is made by the Bessemer and the open-hearth processes. Open-hearth steel is generally thought better than Bessemer, and the acid variety of each of these two processes is thought to yield a better product than the basic variety. Probably this is not necessarily true, but the acid variety lends itself more readily to excellence than the basic. A very large proportion of the ores of the world cannot be made to yield cast iron either free enough from phosphorus for the acid Bessemer and the acid open-hearth processes, neither of which removes that most injurious element, or rich enough in phosphorus for the basic Bessemer process, which must rely on that element as its source of heat. But cast iron for the basic open-hearth process can be made from almost any ore, since its requirements, comparative freedom from silicon and sulphur, depend on the management of the blast-furnace rather than on the composition of the ore, whereas the phosphorus-content of the cast iron depends solely on that of the ore, since in the blast-furnace nearly all the phosphorus of the ore necessarily

passes into the cast iron. Thus the basic open-hearth process is the only one which can make merchantable steel, *i. e.*, steel containing less than 0.11 per cent of phosphorus, from cast iron containing more than 0.10 per cent but less than 1.80 per cent of phosphorus.

In cost of conversion the acid Bessemer process is the cheapest, the basic Bessemer next, and the basic open-hearth next, though the difference is not very great. Next in order of cost comes the acid open-hearth process. The crucible process, finally, is far more expensive than any of the others. Rail steel is almost always made by either the acid or the basic Bessemer process.

Between 1880 and 1901 the yearly production of open-hearth steel advanced in the United States from 9 to 53 per cent of that of Bessemer steel, and in Great Britain from 24 to 205 per cent. In the three great iron-making countries taken collectively, Great Britain, the United States, and Germany and Luxemburg, between 1880 and 1899 the production of acid open-hearth steel increased sevenfold, that of all open-hearth steel sixteenfold, that of the acid Bessemer process more than tripled, the total production of the Bessemer converter increased fourfold, the total production of steel fivefold, and the basic open-hearth and the basic Bessemer process, which were merely beginning to be used in 1880, in 1899 each produced about as much steel as the whole world produced by all processes in 1880. In these countries in 1899, 43 per cent of the total steel production was made by the acid Bessemer process, 20 per cent by the basic Bessemer, 16.5 per cent by the acid open-hearth, 18.5 per cent by the basic open-hearth, and a little over 1 per cent by the crucible and other processes.

#### Mechanical Treatment

288. DEFECTS IN STEEL INGOTS. — These are of three chief classes — pipes, blowholes, and segregation.

289. PIPES. — When molten steel is cast in an ingot in a cold cast iron mould, Fig. 103, its outer crust solidifies and cools as far as to be relatively rigid and incompressible, at a time,  $T$ , when much of the interior is still molten. In the further cooling the molten interior, because it is at this moment,  $T$ , so much

hotter than the exterior, has a greater range of temperature to pass through before becoming completely cold; and for this reason the interior will in cooling undergo more contraction than the exterior. But since the interior just filled the exterior at the moment  $T$ , it will not be large enough to fill it completely after it has undergone this excess of contraction. In particular, the interior undergoes much of this excess of contraction between the time  $T$  and the time  $T'$  when the last of the interior itself solidifies. Consequently at  $T'$  the solidifying interior no longer suffices to fill the outer crust; and on this account a deep pear-shaped contraction cavity or pipe is formed, as shown at  $C$  in Fig. 4, p. 5.

Since this pipe is due to the difference between the rate of contraction of the interior and that of the exterior, it may be lessened by retarding the cooling of the mass as a whole, because this in itself lessens the inequality of cooling. Further, the pipe

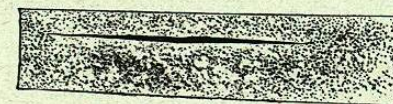


Fig. 104. Diagram Showing a Pipe so Situated as to Render most of the Length of the Ingot Unsound.

may be prevented from stretching down deep by retarding the solidification of the upper part of the ingot, as, for instance, by preheating the top of the mould, or by covering the ingot with a great mass of burning fuel or of molten slag. This keeps the upper part of the mass molten, so that it continues to flow down and feed the pipe during the early part of its formation in the lower and quicker-cooling part of the ingot. In making castings of steel, this same difficulty arises; and much of the steel founder's skill consists either in preventing these pipes, or in so placing them that they shall not occur in the finished casting, or at least not in a harmful position. In making armor-plates from steel ingots, as much as 40 per cent of the metal may be rejected because unsound from this cause. An ingot should always stand upright while solidifying, so that the unsound region due to the pipe shall be at its upper end, which may readily be cut off, leaving the rest of the ingot solid. If the ingot lay on its

side while solidifying, the pipe would occur as shown in Fig. 104 and nearly the whole length of the ingot would be rendered unsound.

*Sauveur's process.* To keep the top of the ingot molten during the solidification of the lower part, so that the molten metal at the top may run down and fill the pipe as fast as it forms, Prof. Sauveur connects a series of ingot moulds together in a long row, in such a way that the steel overflows from the first into the second, from this into the third, *etc.* Thus during the solidifying of the ingots at the beginning of the row, their upper part is kept molten by the steel which is flowing forward to fill those at the end of the row. In applying this method to the crucible steel process, a natural objection would be that, as different cruciblefuls are of different composition, this sweeping forward from mould to mould would tend to make each ingot heterogeneous in composition. This difficulty is to be met by mixing the several cruciblefuls in an appropriate vessel before the pouring proper begins.

290. BLOWHOLES. — Iron, like water and many other substances, has a higher solvent power for gases, such as hydrogen and nitrogen, when molten, *i. e.*, liquid, than when frozen, *i. e.*, solid. Hence in the act of solidifying it expels any excess of gas which it has dissolved while liquid, and this gas becomes entangled in the freezing mass, causing gas bubbles or *blowholes*, as at *A* and *B* in Fig. 4. Since the volume of the pipe represents the excess of the contraction of the interior between *T* and *T'*, any space within the ingot-crust occupied by blowholes must diminish by just so much the volume of the pipe, so that the more and larger the blowholes are, the smaller in general will the pipe be.

The position of blowholes is as important as their quantity. The interior surface of a blowhole which lies nearer the outer crust of the ingot, as at *A*, Fig. 4, is liable to become oxidized by the inward diffusion of the atmospheric oxygen, in which case it can hardly be completely welded later, since welding implies actual contact of metal with metal; it thus forms a permanent flaw. But deep-seated blowholes like those at *B*, Fig. 4, are relatively harmless, because the subsequent operation of forging or rolling usually obliterates them by welding their sides firmly together. Indeed, a slight porosity due to an incipient formation of blow-

holes is desirable in case of steel which is to be hammered or rolled, because but for such porosity a considerable shrinkage cavity or pipe forms in the axis of the ingot, which is thereby materially damaged.

Blowholes may be lessened or even wholly prevented by adding to the molten metal shortly before it solidifies either silicon or aluminium, or both; even as little as 0.002 per cent of aluminium is usually sufficient. An addition of manganese has a like effect. These additions seem to act in part by deoxidizing the minute quantity of iron oxide and carbonic oxide present, in part by increasing the solvent power of the metal for gas, so that even after freezing it can retain in solution the gas which it had dissolved when molten. But, since preventing blowholes increases the volume of the pipe, it is often better to allow them to form, but to control their position, so that they shall be deep-seated. In case of steel which is to be forged or rolled, this is done chiefly by casting the steel at a relatively low temperature, and by limiting the quantity of manganese and silicon which it contains.

Brinell finds that, for the conditions which are normal at his works at Fagersta, Sweden, if the sum of the percentage of manganese plus 5.2 times that of the silicon is as great as 2.05, the steel will be so completely free from blowholes as to have an undesirably large pipe. If this sum is 1.66, there will be just that small quantity of minute hardly visible blowholes which, while sufficient to prevent any serious pipe, is yet harmless. If this sum is less than 1.66, blowholes will occur and will be injuriously near the surface unless this sum is reduced to 0.28. He thus finds that this sum should be either about 1.66, so that the quantity of blowholes shall be harmlessly small; or as low as 0.28, so that they shall be harmlessly deep-seated.

These numbers must be varied with the variations in other conditions. In general either a higher casting temperature, or a smaller cross-section of the ingots or the use of hot or that of thin-walled moulds calls for a smaller quantity of silicon and manganese.

Brinell also finds that an addition of 0.0184 per cent of aluminium is approximately equivalent to the presence of manganese and silicon in the proportions  $Mn + 5.2Si = 1.66$  per cent; *i. e.*, it unaided gives rise to structure *B* (Table 16). Naturally,

little or none of this aluminium remains in the steel. It oxidizes to alumina, which rises to the surface of the molten metal, or is found lining the walls of the pipe.

Table 16 and Figs. 105 to 111 give some of Mr. Brinell's results.

TABLE 16. — Influence of Manganese and Silicon upon Blowholes and Pipes.

NAME OF STRUCTURE	Mn + 5.2 × Si.	POSITION, ETC., OF BLOWHOLES	QUALITY OF THE STEEL AS REGARDS BLOWHOLES AND PIPES
	Per cent		
<i>A</i>	2.05	No blowholes, but a small pipe	Injured by the pipe.
<i>B</i>	1.66	No visible blowholes, no pipe	Just compact enough; excellent.
<i>C</i>	1.16	External blowholes, no pipe	Injured by the external blowholes.
<i>D</i>	.50	Fewer blowholes and somewhat deeper seated	Blowholes still harmfully near the surface.
<i>E</i>	.28	The blowholes are very deep seated	Excellent.
<i>O</i>	Cast too hot	Many external blowholes and a pipe	Injured by the external blowholes.
<i>H</i>	" " cold	Many blowholes both external and internal	Injured by the external blowholes.

The structures *O* and *H* are those induced by too high and too low a casting temperature respectively. The steel which here has structure *O* would, if cast at normal temperature, have had structure *A*. It is thought that the reason why the excessively high temperature causes these external blowholes is that it causes the carbon of the molten steel to react on the iron oxide on the surface of the mould, with the formation of carbonic oxide gas, which itself forms these blowholes.

Mr. Brinell finds it difficult,\* for good reasons, to decide what structure the steel which here has structure *H* would have had if cast at normal temperature.

The foregoing refers to steel cast in ingots to be later rolled or hammered, so that there is an opportunity for welding up deep-seated blowholes. In case of steel castings, *i. e.*, steel objects

\* Private communication, December 31, 1902.

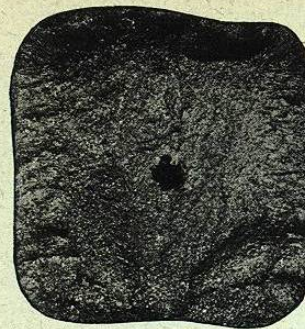


Fig. 105.

Structure *A*. No blowholes but a small pipe. The ingot is injured by the pipe. Mn + 5.2Si = 2.05 per cent.

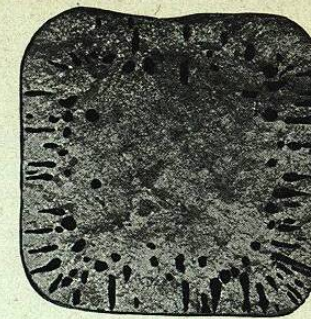


Fig. 108.

Structure *D*. Fewer blowholes and somewhat deeper-seated. Blowholes still harmfully near the surface. Mn + 5.2Si = 0.50 per cent.



Fig. 106.

Structure *B*. Excellent. Neither visible blowholes nor pipe. Just compact enough. Mn + 5.2Si = 1.66 per cent.

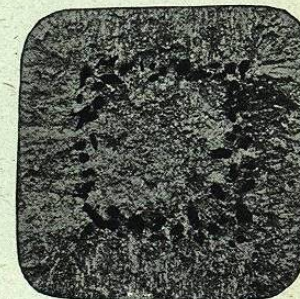


Fig. 109.

Structure *E*. Excellent. The blowholes are very deep-seated. Mn + 5.2Si = 0.28 per cent.

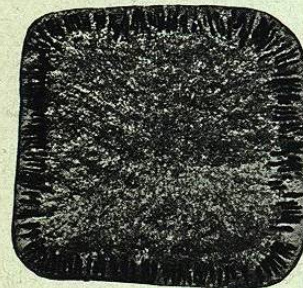


Fig. 107.

Structure *C*. External blowholes; no pipe. The ingot is injured by the external blowholes. Mn + 5.2Si = 1.16 per cent.

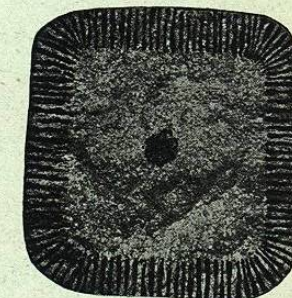


Fig. 110.

Structure *O*. Many external blowholes and a pipe. The ingot is injured by the external blowholes. Cast at too high a temperature. Had the temperature been normal the structure would have been *A*.