

ganese steel or of brass elongates far more uniformly over its whole length. For some purposes this uniform stretch may be better, for others worse, than the necking and localized stretch of carbon steel; suffice it here to point out that the two are different, and, therefore, not strictly comparable as a measure of ductility; and further that, thanks to the nearly uniform stretch of manganese steel over the

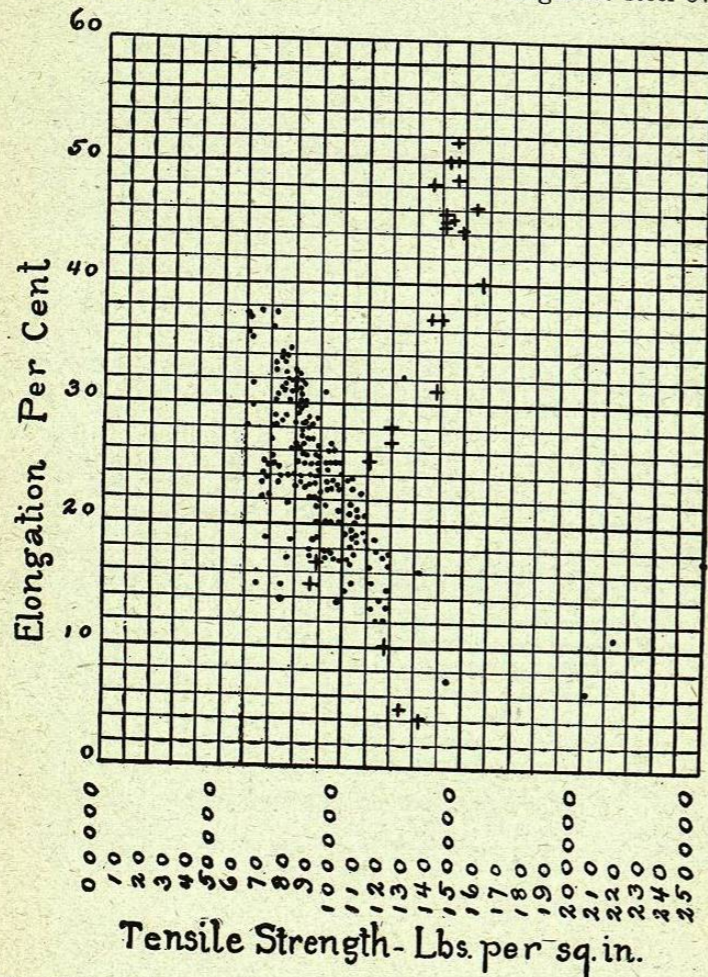


Fig. 85. Tensile Strength and Ductility of Carbon Steel and of Manganese Steel.

Legend:
 • = Carbon steel.
 + = Water-toughened or suddenly cooled manganese steel.

whole length of the test-bar, its percentage of elongation may be held to give an exaggerated idea of the metal's true ductility.

261. CHROME STEEL, which usually contains about 2 per cent of chromium and 0.80 to 2 per cent of carbon, owes its value to

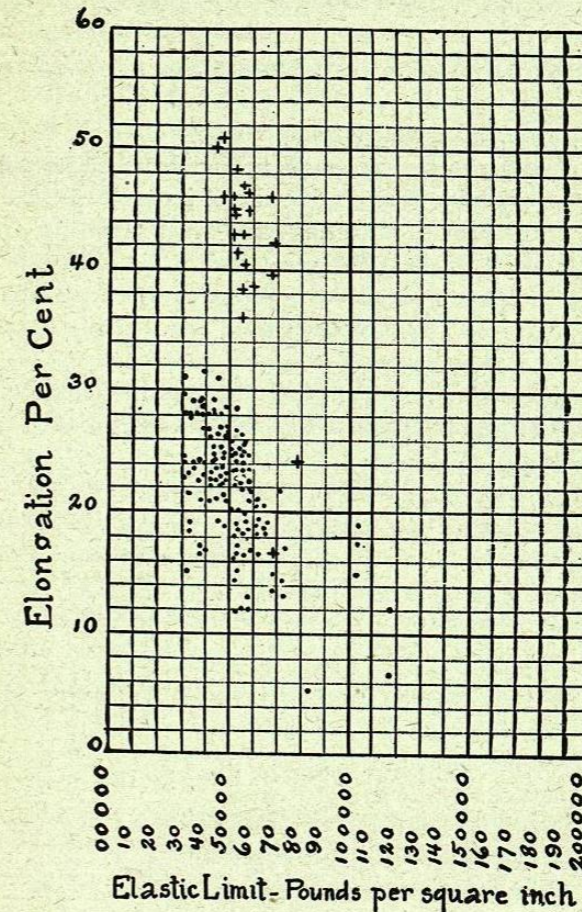


Fig. 86. Elasticity and Ductility of Carbon Steel and of Manganese Steel.

Legend:
 • = Carbon steel.
 + = Water-toughened or suddenly cooled manganese steel.

combining, when in the "hardened" or suddenly cooled state, intense hardness with a high elastic limit, so that it is neither deformed permanently nor cracked by extremely violent shocks. For

this reason it is the material generally if not always used for armor-piercing projectiles. It is much used also for certain rock-crushing machinery (the shoes and dies of stamp-mills), and for safes. These last are made of alternate layers, usually five in number, of chrome steel and wrought iron, welded together, and then cooled suddenly so as to harden the chrome steel. The hardness of the hardened chrome steel resists the burglar's drill, and the ductility of the wrought iron the blows of his sledge.

262. TUNGSTEN STEEL, which usually contains from 5 to 10 (and sometimes even 24) per cent of tungsten and from 0.4 to 2 per cent of carbon, is used for magnets, because of its great retentivity, and for lathe and similar metal-cutting tools which are to cut off a very thick slice at each stroke. The great friction, due to the thickness of the cut, heats the tool to a temperature at which the temper of common or "carbon" steel is drawn. The merit of tungsten steel is that, like manganese steel, it retains its extreme hardness, even after it has been heated to 400° C. (752° F.). Under these conditions the Taylor and White variety retains its cutting power even when the friction is so great that the chips of metal cut are so hot as to glow visibly, and even the edge of the tool itself grows red-hot. I have watched these tools at work very carefully, and they certainly appeared to be red-hot at their cutting edge, while still cutting steel rapidly and efficiently.

The normal composition of this Taylor-White steel is as follows:

	For Cutting Soft Steel and Gray Cast Iron	For Cutting Hard Steel
Carbon, per cent	0.75 to 1.00	1.25
Chromium, per cent	3.00	4.00
Tungsten, per cent	8.50	8.50

The composition of many of the good self-hardening steels of the present time lies between the following limits:*

Carbon	0.40 to 2.19 per cent
Chromium	0.00 to 6.00 "
Tungsten	3.44 to 24.00 "
Silicon	0.21 to 3.00 "

The present tendency appears to be in the direction of replacing the chromium of steels for high-speed cutting tools with from 1.25 to 4 per cent of manganese.

* J. A. Mathews, Ph. D., private communication.

263. MOLYBDENUM STEEL. — Molybdenum is now often used instead of tungsten, 1 per cent of the former replacing 2 per cent of the latter, so that the ratio between their effects appears to be that which their atomic weights would lead us to expect. In other words, one molecule of molybdenum appears to have the same effect as one molecule of tungsten.

264. DEEP CARBURIZING; HARVEY AND KRUPP PROCESSES. — Much of the heavy side armor of war-vessels is made of nickel steel initially containing so little carbon that it cannot be hardened, *i. e.*, it remains very ductile even after sudden cooling. The impact face of these plates is given the intense hardness needed, by being converted into high-carbon steel, and then hardened by sudden cooling. Harvey carburized the impact face to a depth of about an inch by heating the plate for about a week to about 1200° C. (2192° F.), with that face strongly pressed against a bed of charcoal. The Krupp process, a newer one, carburizes the impact face by exposing it at a high temperature to illuminating gas. This is decomposed by the heat, and deposits on the face of the plate a layer of fine carbon, which is absorbed by the steel as in the cementation process. In either case the impact face thus carburized is cooled suddenly from a red heat, *e. g.*, by spraying it with iced brine. An intensely hard impact surface results, the hardness decreasing gradually from this face inwards. Thanks to the glass-hardness of the face, the projectile is arrested so abruptly that it is shattered, and its energy is delivered piecemeal by its fragments; but as the face is integrally united with the unhardened, ductile, and slightly yielding interior and back, the plate, even if it is bent backwards somewhat by the blow, neither cracks nor flakes.

265. THE GENERAL SCHEME OF IRON MANUFACTURE is shown diagrammatically in Fig. 87. To explain, practically all the iron ore mined is smelted in the iron blast-furnace, and its iron is thereby converted into the crude form of pig iron or cast iron. This cast iron may, following path 1, be used in the arts in the form of castings of cast iron, or, following path 2, it may be converted into wrought iron or steel, which may be used in the common form of rolled or hammered products, or in case of steel, in the form of steel castings.

If path 1 is followed the castings may be either (A) gray, (B) chilled, or (C) malleable. The quantity of gray cast iron

castings used is incomparably greater than that of either chilled or malleable cast iron castings.

(A) In making gray cast iron castings, the crude cast iron undergoes very little chemical change, indeed simply that incident to its remelting in the foundry for the purpose of casting it.

(B) In making chilled cast iron castings though the ultimate composition of the cast iron is changed very little, special hardness is given by chilling, *i. e.*, rapidly cooling the metal when it is poured into its moulds, and in many cases further metamorphic changes, *i. e.*, changes in the microscopic constitution, are brought about by heat-treatment (annealing).

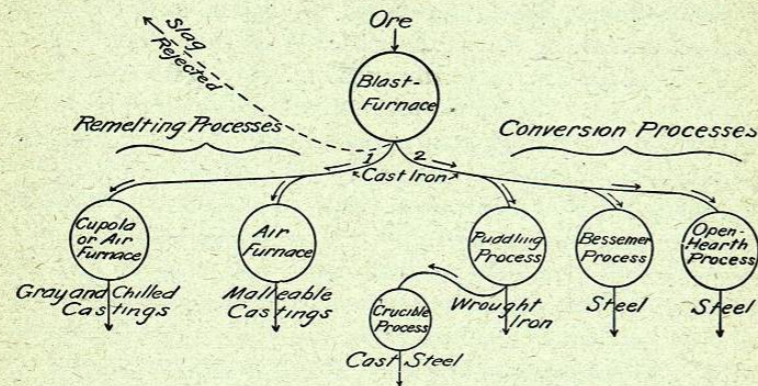


Fig. 87. The General Scheme of Iron Manufacture.

(C) In making malleable cast iron castings the ultimate composition of the metal is first changed somewhat by an oxidizing melting, which, however, leaves the metal still in the condition of white cast iron, an exceedingly brittle substance. This is cast into the various forms in which the metal is to be used in the arts, and these brittle castings are then made relatively strong and malleable by a long heating or "annealing" process, which acts chiefly through inducing a metamorphic change, *i. e.*, a change in the microscopic constitution, changing the condition of the carbon and iron from that of the glass-hard, brittle cementite, Fe₃C, to that of soft ductile free iron or ferrite, intermingled with very finely divided graphite. Moreover a small quantity of the carbon is removed by surface oxidation.

If path 2 is followed the metal has to undergo a very great purification, and it is of this purification that its conversion into wrought iron or steel really consists.

To explain, the blast-furnace process by which the cast iron is made, is necessarily a highly carburizing one, so that the cast iron necessarily contains much carbon. Further, the iron ore usually contains much silica (SiO₂), and some phosphoric acid in the form of apatite (3CaO, P₂O₅), together with more or less manganese in the form of manganic oxide (MnO₂) and sulphur in the form of pyrites (FeS₂). Now the blast-furnace process is so very strongly deoxidizing that most of this phosphoric acid is deoxidized, as is much of the manganic oxide and some of the silica; and the unoxidized phosphorus, manganese and silicon which result unite with the molten cast iron, because they are unoxidized. At the same time some of the sulphur initially present as pyrites passes into the cast iron, which thus consists of metallic iron contaminated with these other elements, or impurities.

The following reactions may serve as types of those by which the deoxidation takes place in the blast-furnace:

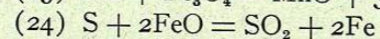
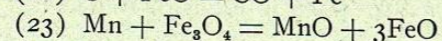
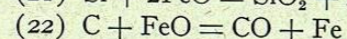
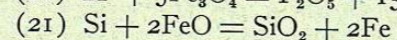
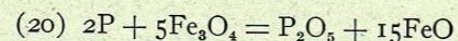
- (15) SiO₂ + 2C = Si + 2CO
- (16) P₂O₅ + 5C = 2P + 5CO
- (17) MnO₂ + 2C = Mn + 2CO
- (18) Fe₂O₃ + 3CO = 2Fe + 3CO₂
- (19) FeO + C = Fe + CO

The essential difference between cast iron on one hand and wrought iron and steel on the other, is that the former contains always much more carbon, usually more silicon, and often more manganese, phosphorus and sulphur than are permissible in the latter; and the essence of all the processes by which cast iron is converted into wrought iron or steel is the elimination of these foreign elements. The difference between the two classes may be illustrated by the following case.

	Cast Iron for the Basic Bessemer Process, Per cent	Basic Bessemer Steel, Per cent
Carbon	3.50	0.10
Silicon	1.00	0.01
Manganese	1.80	0.50
Phosphorus	1.80	0.07
Sulphur	0.10	0.07

The carbon, silicon, phosphorus and manganese are eliminated by oxidizing them, and the same is true of sulphur to a certain extent. The ultimate source of the oxygen may be either the atmospheric air as in the Bessemer process, or iron oxide such as native magnetite as in the puddling process, or both these jointly as in the open-hearth process. But even when atmospheric oxygen is used it appears that this acts rather indirectly than directly. That is to say, the atmospheric oxygen appears to act by oxidizing some of the iron itself to ferrous oxide, FeO, or by oxidizing ferrous oxide to magnetic oxide (FeO to Fe₃O₄); and the actual oxidation of the carbon and other foreign elements seems to be effected by the means of the iron oxides thus formed rather than by the means of the atmospheric oxygen directly.

The reactions by which the oxidation takes place are of the following types:



These reactions must be taken only as types. In case of each of these five foreign elements it is probable that the oxidation may take place either through ferrous oxide (FeO), or magnetic oxide (Fe₃O₄).

Of the oxidized products of these reactions the oxides of carbon and sulphur (carbonic oxide, CO, carbonic acid, CO₂, and sulphurous acid, SO₂) are volatile and immediately escape. The oxides of phosphorus, silicon and manganese (phosphoric acid, P₂O₅, silica, SiO₂, and manganous oxide, MnO) separate mechanically from the iron as oil separates from water, and coalesce with any other oxidized substances present to form the slag, which is an opaque, earthy, lava-like or vitreous mass, chiefly a silicate of iron oxide, lime, magnesia, and alumina in very varying proportions, together with phosphoric acid under certain conditions. This slag, when molten, floats upon the molten metallic iron, because it is relatively light, and the two therefore are very readily separated mechanically.

These purifying reactions are brought about (1) in the puddling process by stirring iron oxide (in the form of a silicate very

rich in that oxide) into the molten cast iron as it lies in a thin boiling layer on the hearth of a reverberatory furnace (Fig. 96, p. 345); (2) in the Bessemer process by blowing cold atmospheric air through the molten cast iron in a deep clay-lined or dolomite-lined retort called a converter, the rapidity of the oxidation itself raising the temperature rapidly; and (3) in the open-hearth process by exposing the molten cast iron in a thin and very broad layer on the bottom of a reverberatory furnace to an overlying layer of slag containing iron oxide, and usually enriched in that oxide by throwing into it lumps of iron ore (Fig. 97, p. 348). In this last process, in addition to this purification of the cast iron by these oxidizing reactions, its impurities are in most cases also greatly diluted by adding much relatively pure steel scrap.

In the Bessemer and open-hearth processes the oxidation cannot readily be made thorough enough to remove just the desired quantity of the several impurities initially present, and yet both leave just the quantity of carbon desired, and also leave the iron itself free from oxygen, a most hurtful element, but one easily removed. Hence the purifying or, as it is called, the "fining" phase of each process is usually followed by an extremely brief adjusting or "recarburizing" or "refining" phase, in which the composition is adjusted accurately, chiefly by adding carbon to give the desired percentage of that element, and manganese both to give the needed percentage of manganese and to remove from the iron any oxygen which it may have taken up.

In the crucible process a very small quantity of wrought iron or steel is remelted in a closed crucible and cast into ingots, or into castings. The desired percentage of carbon is given either (1) by previously carburizing the solid metal by very long heating in contact with charcoal; or (2) by adding charcoal or a rich iron carbide (washed-metal) to the charge in the crucible itself. The crucible process is thus in effect a simple remelting process, with or without simultaneous carburizing, and is thus distinguished sharply from the puddling and Bessemer processes, which are essentially purifying processes. The open-hearth process may be conducted either chiefly as a remelting process (pig and scrap) or as a purifying process (pig and ore), or it may combine both principles (pig and scrap and ore).

265 A. CLASSIFICATION OF PROCESSES.—We may roughly classify the more important processes as follows:

1. THE EXTRACTION PROCESSES, the blast-furnace, and the "direct processes" of making steel or wrought iron direct from the ore; these latter are unimportant to-day.

2. THE CONVERSION OR PURIFYING PROCESSES, the Bessemer, open-hearth and puddling processes. The Bell-Krupp process is one of arrested or incomplete purification. The purification consists chiefly in removing by oxidation the excess of carbon, silicon, phosphorus and manganese introduced in the blast-furnace process, over that desired in the steel or wrought iron.

3. THE ADJUSTING PROCESSES, adjusting the composition. These include the *carburizing processes*, cementation, case-hardening and the Harvey and Krupp processes; and the process of making *malleable cast iron*.

4. THE SHAPING PROCESSES. These include the *mechanical processes*, rolling, hammering, wire-drawing, *etc.*, and the *remelting processes*, those of the iron foundry and the crucible process. The pig and scrap variety of the open-hearth process may, from one point of view, be put here.

Such classifications can rarely be complete or consistent. For instance, while the crucible process as carried out in Great Britain is essentially a remelting process, as carried out in this country it is at once a remelting and an adjusting (carburizing) process. Nevertheless these classifications have their use.

Extraction of Iron from its Ores

266. THE BLAST-FURNACE PROCESS. — To-day practically all of the iron ore mined is smelted in the iron blast-furnace and there converted into cast or pig iron; and this is the case whether the resultant iron is to be used in the form of cast iron, or whether it is to be converted into one of the two other great commercial classes of iron, wrought iron and steel. It is true that there are many direct processes, by which wrought iron or steel may be made directly from the ore, without first converting it into cast iron, *i. e.*, without first putting into it more carbon and silicon than it needs in its finished form, and then taking them out at great expense. But these processes are to-day of little more than historical or scientific interest. Whatever promise they may have had in recent decades has been killed by the great cheapening of the blast-furnace process.

It is also true that a little ore is used in the puddling and open-hearth processes, and that a part of the iron of this ore is recovered. But the quantity of ore used for this purpose is trifling compared with that smelted in the blast-furnace.

The blast-furnace has a very great advantage over the direct processes of extracting wrought iron or steel from the ore, in recovering nearly the whole of the iron present, and in delivering both its products, the metal and the slag, in a molten state, in which they can be handled far more cheaply than if solid or pasty. It is not easy to see how either of these things can be accomplished by any direct process. The advantages of the blast-furnace are so great, that not only have the direct processes practically ceased to exist, but we can hardly see in what way they are to be revived, unless it be through some modification of the blast-furnace process itself, which shall bring the composition of its product nearer to that of steel, *i. e.*, shall give it less carbon and silicon than are present in cast iron as now made.

The stumbling-block in the way of developing such a modification is the removal of sulphur, a most hurtful element of which most ores contain more than is permissible in the steel. The processes for converting cast iron into steel can now remove phosphorus easily, but the removal of sulphur in them is so difficult that it has to be accomplished for the most part in the blast-furnace process itself; and we do not see how the blast-furnace process can keep its desulphurizing power and yet cease to introduce much carbon and silicon into the pig iron.

The cheapening which has taken place in the blast-furnace process has been in very large part through the introduction of mechanical appliances for handling the ore, flux, and fuel on one hand, and the products, the iron and slag, on the other; through better protection of the inner walls of the furnace by more effective water cooling; and through a remarkable increase in the rate of production per furnace chiefly due to the use of extremely powerful blowing engines and blast-heating stoves. But the latest great advance, the use in gas engines of the waste gases escaping from the top of the furnace, is perhaps the most striking and important of all. We will now take these points up in series.

267. THE HANDLING OF RAW MATERIALS.—That any of the raw materials should be shovelled by hand is a thing no longer even to be considered in designing new works, at least in the United