PART III.

MATERIALS, CONSTRUCTION, AND STRENGTH OF MACHINERY.

CHAPTER I.

OF MATERIALS USED IN MACHINERY.

385. **General Explanations.**—The materials used in machinery are of two principal kinds—inorganic and organic.

The inorganic materials consist almost wholly of metals; for although stony and earthy materials occur in the foundations of fixed machines, and in houses which contain machinery, they are little used in machinery itself.

The organic materials consist chiefly of wood, of vegetable and animal fibre in the form of ropes and bands, and of indian rubber and gutta percha, and a few miscellaneous substances.

The present chapter gives a summary of those properties of materials upon which their use in machinery and millwork depends; and it is necessarily to a great extent identical with those parts of *A Manual of Civil Engineering* which treat of the same materials.

SECTION I.—*Of Iron and Steel.*

386. **Kinds of Iron and Steel.**—The metallic products of the iron manufacture are of three principal kinds—*malleable iron*, *cast iron*, and *steel*. Malleable iron is pure or nearly pure iron. Cast iron is a granular and crystalline compound of iron and carbon, more or less mixed with uncombined carbon in the form of plumbago. It is harder then pure iron, more brittle, and less tough. Steel is a compound of iron with less carbon than there is in cast iron; it is harder than cast iron, and tougher than wrought iron, though less ductile; and it is the strongest of all known substances *for its dimensions*. It is also the strongest of all metals *for its weight;* but in the comparison of tenacity with weight, steel and all metals are exceeded by many kinds of organic fibre. There are many intermediate gradations between pure iron and the hardest steel, some of which are known by such names as "steely iron" and "semi-steel."

387. **Impurities of Iron.**—The strength and other good qualities of iron and steel depend mainly on the absence of impurities, and especially of sulphur, phosphorus, silicon, calcium, and magnesium.

Sulphur and calcium, and probably also magnesium, make iron "*red-short*," that is, brittle at a red heat; phosphorus and silicon make it "*cold-short*," that is, brittle at low temperatures. These are both serious defects; but the latter is the worse.

Sulphur comes in general from coal or coke used as fuel. Its pernicious effects can be avoided altogether by using fuel which contains no sulphur; and hence the strongest and toughest of all iron is that which is smelted, reduced, and puddled either with charcoal, or with coke that is free from sulphur.

Phosphorus comes in most cases from phosphate of iron in the ore, or from phosphate of lime in the ore, the fuel, or the flux. The ores which contain most phosphorus are those found in strata where animal remains abound.

Calcium and *Silicon* are derived respectively from the decomposition of lime and of silica by the chemical affinity of carbon for their oxygen. The only iron which is entirely free from those impurities is that which is made by the reduction of ores that contain neither silica nor lime: such as pure magnetic iron ore, pure hæmatite, and pure sparry iron ore.

388. **Cast Iron** is the product of the process of *smelting* iron ores. In that process the ore in fragments, mixed with fuel and with flux (that is to say, with a substance such as lime, which tends to combine with the earthy constituents of the ore), is subjected to an intense heat in a blast-furnace, and the products are *slag*, or glassy matter formed by the combination of the flux with the earthy ingredients of the ore, and *pig iron*, which is a compound of iron and carbon, either unmixed, or mixed with a small quantity of uncombined carbon in a state of plumbago.

The ore is often *roasted* or calcined before being smelted, in order to expel carbonic acid and water.

The total quantity of carbon in pig iron ranges from two to five per cent. of its weight.

Different kinds of pig iron are produced from the same ore in the same furnace under different circumstances as to temperature and quantity of fuel. A high temperature and a large quantity of fuel produce *gray cast iron*, which is further distinguished into No. 1, No. 2, No. 3, and so on; No. 1 being that produced at the highest temperature. A low temperature and a deficiency of fuel produce *white cast iron*. Gray cast iron is of different shades of bluish-gray in colour, granular in texture, softer and more easily fusible than white cast iron. White cast iron is silvery white, either granular or crystalline, comparatively difficult to melt, brittle, and excessively hard.

It appears that the differences between those kinds of iron depend not so much on the total quantities of carbon which they contain as on the proportions of that carbon which are respectively in the conditions of mixture and of chemical combination with the iron. Thus, gray cast iron contains *one* per cent., and sometimes less, of carbon in chemical combination with the iron, and from *one* to *three* or *four* per cent. of carbon in the state of plumbago in mechanical mixture; while white cast iron is a homogeneous chemical compound of iron with from two to four per cent. of carbon. Ot the different kinds of gray cast iron, No. 1 contains the greatest proportion of plumbago, No. 2 the next, and so on.

There are two kinds of white cast iron, the *granular* and the *crystalline*. The granular kind can be converted into gray cast iron by fusion and slow cooling; and gray cast iron can be converted into granular white cast iron by fusion and sudden cooling. This takes place most readily in the best iron. Crystalline white cast iron is harder and more brittle than granular, and is not capable of conversion into gray cast iron by fusion and slow cooling. Gray cast iron, No. 1, is the most easily fusible, and produces the finest and most accurate castings; but it is deficient in hardness and strength; and therefore, although it is the best for castings of moderate size, in which accuracy is of more importance than strength and stiffness, it is inferior to the harder and stronger kinds, No. 2 and No. 3, for pieces requiring great strength and stiffness.

The presence of plumbago renders cast iron comparatively weak and pliable, so that the order of strength and stiffness among different kinds of cast iron from the same ore and fuel is as follows:—

Granular white cast iron.
Gray cast iron, No. 3.
" " No. 2.
" " No. 1.

Crystalline white cast iron is not introduced into this classification because its extreme brittleness makes it unfit for use in machinery.

Granular white cast iron, also, although stronger and harder than gray cast iron, is too brittle to be a safe material for the entire mass of any piece in a machine that is exposed to shocks; but it is used to form a hard and impenetrable *skin* to a piece of gray cast iron by the process called *chilling*. This consists in lining the portion of the mould, where a hardened surface is required, with suitably-shaped pieces of iron. The melted metal, on being run in, is cooled and solidified suddenly where it touches the cold iron; and for a certain depth from the chilled surface, varying from $\frac{1}{8}$th to $\frac{1}{2}$-inch in different kinds of iron, it takes the white granular condition, while the remainder of the casting takes the gray condition.

Even in castings which are not chilled by an iron lining to the mould, the outermost layer, being cooled more rapidly than the interior, approaches more nearly to the white condition, and forms a *skin*, harder and stronger than the rest of the casting.

A strong kind of cast iron called *toughened cast iron*, is produced by the process invented by Mr. Morries Stirling, of adding to the cast iron, and melting amongst it, from one-fourth to one-seventh of its weight of wrought-iron scrap.

Malleable Cast Iron is made by the following process:—The castings to be made malleable are imbedded in the powder of red hæmatite (which consists almost wholly of peroxide of iron); they are then raised to a bright red heat (which occupies about 24 hours), maintained at that heat for a period varying from three to five days, according to the size of the casting, and allowed to cool (which occupies about 24 hours more). The oxygen of the hæmatite extracts part of the carbon from the cast iron, which is thus converted into a sort of soft steel; and its tenacity (according to experiments by Messrs. A. More & Son) becomes about three times that of the original cast iron.

389. The **Strength of Cast Iron** of every kind, like that of granular substances in general, is marked by two properties: the smallness of the tenacity (which is on an average about 16,000 or 18,000 lbs. on the square inch) as compared with the resistance to crushing (which ranges from 80,000 to 110,000), and the different values of the stress immediately before rupture of the same kind of iron in bars torn directly asunder, and in beams of different forms when broken across.

For the results of experiments on the strength of various kinds of cast iron, see the tables of the following chapter.

The strength of cast iron to resist cross breaking was found by Mr. Fairbairn to be increased by *repeated meltings* up to the *twelfth*, when it was greater than at first in the ratio of 7 to 5 nearly. After the twelfth melting that sort of strength rapidly fell off.

The resistance to crushing went on increasing after each successive melting; and after the eighteenth melting it was double of its original amount, the iron becoming silvery white and intensely hard.

The transverse strength of No. 3 cast iron was found by Mr. Fairbairn not to be diminished by raising its temperature to 600° Fahr. (being about the temperature of melting lead). At a red heat its strength fell to two-thirds.

390. **Castings for Machinery.**—The best course for an engineer to take, in order to obtain cast iron of a certain strength, is not to