

## FERROUS METALS AND ALLOYS

### 4.1 INTRODUCTION

Ferrous metals and alloys are widely used because of the development of a technology that has produced thousands of different alloys and grades that provide a wide range of properties not found in any other family of materials. Further, they are economical on a basis of cost per unit of length.

The Latin word of iron is *ferrum*. So metals which contain iron are all classified as ferrous metals. The principal ferrous metals used in engineering are classified under the following groups :

1. Pig iron.
2. Cast iron.
3. Wrought iron.
4. Carbon steel.
5. Alloy steel.

### 4.2 PIG IRON

All iron and steel products are derived originally from pig iron. This is the raw material obtained from the chemical reduction of iron ore in a blast furnace. The process of reduction of iron ore to pig iron is known as smelting. The main raw materials required for pig iron are : (1) iron ore, (2) cooking coal, and (3) flux.

*Iron ores* are generally carbonates, hydrates or oxides of the metal, the latter being the best. These iron ores are found in India in several states namely Bihar, Orissa, Madhya Pradesh, Andhra Pradesh, Karnataka, Tamilnadu, and some other places. Table 4.1 shows the chief iron ores and their approximate yield.

The coke used in the blast furnace should be a very high class hard coke obtained from good quality coking coals containing as low phosphorus and sulphur as possible. It is produced by heating what is commonly called "dry distillation" of the coking coals in coke ovens made of silica bricks in the absence of air to avoid giving off valuable gases. A light porous, sufficiently firm fuel which burns well is thus obtained.

TABLE 4.1 THE CHIEF ORES AND THEIR APPROXIMATE YIELD OF METAL

Ore	Appearance	Composition	Percentage of metal	
Magnetite	Steel-grey or black	$\text{Fe}_3\text{O}_4$	72	62
Red hematite	Crystalline or granular earthy or rock, red	$\text{Fe}_2\text{O}_3$	70	60
Brown hematite	Brown, dense, earthy	$2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$	60	42
Siderite or spathic Iron stone	A shy grey, crystalline; Grey to light brown; Compact, earthy or stony	$\text{FeCO}_3$	48	35
		$\text{FeCO}_3$	42	30

Flux is a mineral substance that is charged into a blast furnace to lower the melting point of the ore and to promote the removal of the ash, sulphur and the residues of the burnt fuel. Flux combines with the ashes of the fuel and the ore to form fusible products which separate from the metal as slag. The most commonly used blast furnace flux is limestone. Dolomite is less frequently used. They come straight from the mines. In some cases siliceous alumina fluxes are charged into a blast furnace and in others, only silica.

#### BLAST FURNACE

The blast furnace (Fig. 4.1) is a vertical furnace designed for continuous operation. The smelting room of the blast furnace comprises a *throat, stack, body, bosh* and *hearth*.

The raw materials (alternate layers of ore, coke and flux), known as the *charge*, are taken to the top of the furnace by a specially designed bucket called "skip" running along an incline. The charge is then introduced into the throat of the furnace by means of a double *bell* and *hopper arrangement* to prevent the escape of blast furnace gas which is used as a fuel. The proportions of the raw materials are approximately one-half iron ore, one-third fuel, and one-sixth flux. It may be pointed out, for instance, to make 100 tonnes of pig iron it requires about 180 tonnes of iron ore, nearly 95 tonnes of coke, 50 tonnes of flux, and about 350 tonnes of preheated air blast. In addition to the pig iron, about 60 tonnes of slag and 500 tonnes of gas are produced.

A hot blast is forced into the furnace through a number of nozzles called *tuyeres*. The tuyeres are cooled by water circulating between the pipe walls. The air blast is heated to minimize fuel consumption by passing the cold air blast through the heated checker-work of *hot blast stoves* (not shown).

The temperature of the furnace just above the level of the tuyeres (melting zone) being 1,000°C to 1,700°C all substances inside the furnace start melting in the heat. The limestone that serves as a flux is combined with the ore to form a molten slag which floats on the top of the molten iron. The slag is tapped off from the furnace through the slag hole. The molten iron is tapped at intervals from six to twelve hours through a tapping hole, the blast being turned off meanwhile. The furnace is kept in operation until it gets worn-out.

According to the type of plant the molten iron may be used in one or more of the following ways.

1. Cast in pig bed.
2. Cast in pig-casting machine.
3. Transferred in hot metal ladles direct to an adjacent steel-making process.

Pig beds are sand moulds in the form of a grid prepared in the ground alongside the furnace. The bars (pigs) cast in this way are about 1 m long with a D-shaped cross-section measuring about 100 mm each way. The modern method of casting pig iron which has largely superseded the older pig-bed method is to employ a pig casting machine. This consists of a series of haematite iron or steel moulds, each about 660 mm × 200 mm × 90 mm, fixed to an endless chain conveyor, the assembly being mounted on a suitable construction arranged on a slight slope.

While the iron is in the furnace it picks up 3 to 4 per cent of carbon and a small amount of sulphur from the coke. The silicon, manganese and phosphorus as well as most of the sulphur in the pig iron are derived from the ore. The high amount of carbon makes the pig iron very hard and brittle and unsuitable for making any useful article. Pig iron is, therefore, refined and remelted to produce other varieties of iron and steel. Table 4.2 shows the chemical compositions of the different forms of iron and steel.

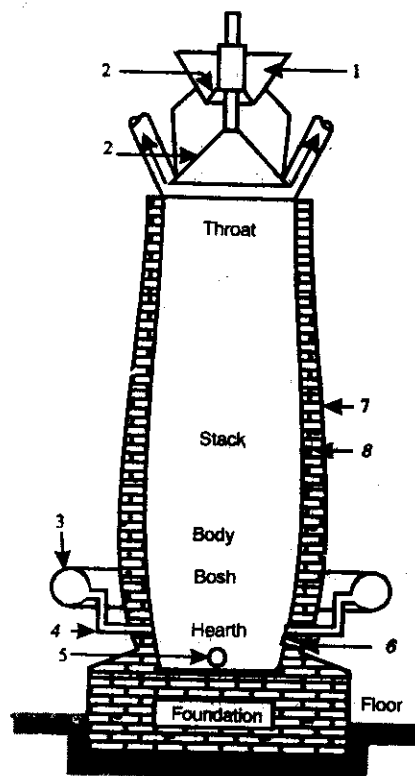
#### 4.3 MODERN DEVELOPMENT

Electric pig iron furnaces are becoming popular where suitable metallurgical coke is not available in sufficient quantities and where electricity is cheap. The advantage with the furnace is that coke consumption is reduced by 50 per cent, as heating is done by electricity and only reduction of the iron ore is done by coke. A medium sized furnace of the type can produce 100 to 110 tonnes per day. Charging of raw

materials and other operation principles are practically same as that of the other common methods. Now-a-days, *low shaft blast furnaces* are being developed to make use of low grade coke and iron ore. Oxygen also is used to help the reaction.

Another process which is also being developed is *the sponge iron process*. This new process for treating low grade iron ore by direct reduction, in place of the conventional blast furnace method, is being fast developed. It will be of great advantage to a country like India where large quantities of low grade iron ore remain unused.

A certain amount of scrap, about 25 per cent of the total iron, is mixed. This scrap generally consists of cast iron may include also contain mild steel scrap. When considerable steel scrap is used along with pig iron, small amount say from 2 to 4 pre cent, of ferro-manganese is also used as a deoxidizer.



**Figure 4.1 The blast furnace**

1. cup or hopper, 2. cone or bell, 3. main air blast pipe, 4. tuyers, 5. tapping hole, 6. slag hole, 7. steel plate shell, 8. refractory brick

#### 4.4 CAST IRON

Cast iron is pig iron remelted and thereby refined together with definite amount of limestone, steel scrap, and spoiled castings in a cupola or other form of remelting furnace, and poured into suitable moulds of required shape. It contains about 2 to 4 per cent of carbon, a small per centage of silicon, sulphur, phosphorus and manganese and certain amount of alloying elements, e.g., nickel chromium, molybdenum, copper and vanadium.

Carbon in cast iron usually exists in two forms associated together :  
(1) as the *compound cementite* i.e., in a state of chemical combination and

the iron is known as *white cast iron*, and (2) as *free carbon*, i.e., in a state of mechanical mixture. Carbon in the first form is called "combined carbon", and in the latter is called *grey cast iron*. An intermediate stage between these two varieties of iron shows patches of grey in the white structure. This iron is called *mottled iron*.

TABLE 4.2 CHEMICAL COMPOSITIONS (APPROXIMATE) OF IRON AND STEEL PRODUCTS

Material	Carbon (per cent)	Silicon (per cent)	Manganese (per cent)	Sulphur (per cent)	Phosphorus (per cent)
Pig iron	3.00-4.00	0.50-3.00	0.10-1.00	0.02-0.10	0.03-2.00
Grey cast iron	2.50-3.75	1.00-2.50	0.40-1.00	0.06-0.12	0.10-1.00
Malleable cast iron	2.20-3.60	0.40-1.10	0.10-0.40	0.03-0.30	0.10-0.20
White cast iron	1.75-2.30	0.85-1.20	0.10-0.40	0.12-0.35	0.05-0.20
Wrought iron	0.02-0.03	0.10-0.20	0.02-0.10	0.02-0.04	0.05-0.20
Carbon steel	0.05-2.00	0.05-0.30	0.30-1.00	0.02-0.20	0.02-0.15

The quality of cast iron thus depends not upon the absolute amount of carbon it contains, but upon the conditions in which that carbon exists. The varieties of cast iron in common use are :

1. Grey cast iron.
2. White cast iron.
3. Malleable cast iron.
4. Nodular cast iron.
5. Chilled cast iron.
6. Alloy cast iron.
7. Mechanite cast iron.

#### GREY CAST IRON

This is obtained by allowing the molten metal to cool and solidify *slowly*. On solidifying, the iron contains the greater part of carbon in the form of graphite flakes.

Grey cast iron contains large quantities of carbon and relatively small quantities of the other element, e.g., silicon phosphorus, sulphur, and manganese (Table 4.2).

It presents a dull grey crystalline or granular structure and a strong light will give a glistening effect due to reflection of the free graphite

flakes. The presence of this free graphite is also seen when filing or machining cast iron as it makes hands black.

The cast iron is brittle and may easily be broken if a heavy hammer is used. The strength of iron is much greater in compression than in tension. The ultimate tensile strength of cast iron varies between 12 to 13 kgf per mm<sup>2</sup> (120 to 300 Newton per mm<sup>2</sup>) and depends on the composition of the iron. In compression, gray cast iron will withstand about 60 to 75 kgf per mm<sup>2</sup> (600 to 750 Newton per mm<sup>2</sup>) before fracturing, whilst in shear its strength is approximately 15 to 22 kgf per mm<sup>2</sup> (150 to 225 Newton per mm<sup>2</sup>). The hardness ranges from 150 to 240 BHN.

The main advantages in favour of its use are : (1) its cheapness, (2) its low melting temperature (1,150°C to 1,200°C), and fluidity when in the molten condition, and (3) it is easily machined. A further good property of cast iron is that the free graphite in its structure seems to act as a lubricant, and when large machine slides are made of it a very free-working action is obtained. The fluidity analysis of the iron enables it to be used widely for making castings of parts having intricate shapes and in almost all cast iron forms.

#### WHITE CAST IRON

White cast iron contains carbon exclusively in the form of cementite (iron carbide). This is obtained by the presence of relatively large quantities of manganese, a very small amount of silicon, and by *rapid cooling*. The ordinary rate of cooling in sand produces free graphite while rapid cooling helps to produce cementite. Moreover, manganese encourages the formation of carbide. The approximate chemical composition of white cast iron is given in Table 4.2.

The white cast iron is very hard (the hardness ranges from 400 to 600 BHN) and brittle, and its fractured surface has a silvery metallic appearance. From the engineering point of view, white cast iron has limited application. This is due to its unmachinability and to its having, in general, relatively poor mechanical properties. It is widely used in the manufacture of wrought iron. White cast iron is also cast as the intermediate material for making malleable cast iron.

White cast iron does not rust so much as the grey kind.

#### MALLEABLE CAST IRON

The ordinary cast iron is hard and brittle. It is, therefore, unsuitable for articles which are thin, light and subjected to shock and vibration or for small castings used in various machine components.

The application of the term 'malleable' to castings is rather a

misnomer because they are not very malleable when compared with the standards of malleability. When compared with grey iron castings, however, which are fairly brittle, malleable castings do possess a degree of toughness, and this is probably why they have been so named.

Malleable castings are first made from an iron having all of its carbon in the combined form, i.e., from white cast iron. Two methods are then used for malleabilizing the castings: (1) white heart, and (2) black heart. The names refer to the colour of the fracture given by castings produced by each method. The approximate chemical compositions for both varieties are given in Table 4.3.

**TABLE 4.3 CHEMICAL COMPOSITIONS (APPROXIMATE) IN PERCENTAGE OF MALLEABLE CAST IRON**

Type	Carbon (per cent)	Silicon (per cent)	Manganese (per cent)	Sulphur (per cent)	Phosphorus (per cent)
White iron	3.2-3.6	0.4-1.1	0.1-0.4	0.10-0.3	0.1
Black iron	2.2-2.8	0.7-1.1	0.3-0.4	0.03-0.1	0.1

In the *white heart process* the castings, composed of cast iron with most of its carbon in the combined state, are packed in iron or steel boxes and surrounded with a mixture of used and new haematite ore. The boxes are slowly heated to a temperature of 950° to 1,000°C and maintained at that temperature for about 5 days. After heating for several days in such a way, part of the carbon is oxidized out of the castings, and the remainder is dispersed in finely divided forms throughout the structure. This process of decarburisation is known as malleabilizing. The heating period is followed by a very slow cooling which occupies several more days and the result is a casting which is tough and which will stand heat treatment without fracture. It is primarily used for thin-walled components, the weight of which ranges from a few grams to about 20kg.

In the *black heart process*, the white castings are heated to a temperature of about 1,000°C for 2 to 3 days in a neutral atmosphere which does not give off oxygen, e.g., quartz sand or protective gas. The temperature is so controlled that the whole iron carbide in white cast iron is decomposed into what is known as temper carbon. The microstructure of the graphite formed will appear in a ball-like form. This separation of carbon in the form of temper carbon from the combined state makes the final castings less brittle or, in other words, tough. It is used for thick-walled workpieces weighing up to 100 kg, especially those which have to be machined by means of cutting tools.

It is, therefore, seen that malleable cast iron, both white heart and

black heart, compared with ordinary cast iron, is less brittle and therefore, stronger and tougher. It has the advantage of being more fluid. The maximum thickness of castings suitable for making this malleabilizing process is about 20 mm for the white heart and 25 to 35 mm for black heart process. The tensile strength of malleable castings is about 18 kgf per mm<sup>2</sup> (180 Newton per mm<sup>2</sup>).

On account of the special manner in which malleable cast iron is produced, it is employed mainly for thin-walled and small workpiece. Such parts are, for example, hinges, door keys, spanners, mountings of all sorts, gearwheels, cranks, levers, thin-walled components of sewing machines, textile machines, and others.

Malleable cast iron which has been a very suitable material for small and medium size mass produced castings of high strength for a long time, has recently been superseded in several fields by spheroidal graphite iron. This is commonly called ductile iron.

#### DUCTILE IRON

*Spheroidal graphite iron*, also called *nodular cast iron*, is of a higher grade because graphite is precipitated not in the form of flakes but in the form of spheroids. This can be achieved by various methods, e.g., by the addition of one of the following elements: magnesium, cerium, calcium, bismuth, zinc, cadmium, titanium or boron. Ferro-silicon is also used as an inoculant.

Spheroidal cast iron can be produced in thicker pieces than those produced by malleable cast iron. Outstanding characteristics of spheroidal cast iron are high fluidity, which permits the castings of intricate shapes, and an excellent combination of strength and ductility. The tensile strength of this iron is about 33 kgf per mm<sup>2</sup> (330 Newton per mm<sup>2</sup>). This material is also known as *ductile iron*.

Spheroidal cast iron is widely used in cast parts where density and pressure tightness is a highly desirable quality. They include hydraulic cylinders, valves, pipes and pipe fittings, cylinder-head for compressors and diesel engines. Rolls for rolling mills and many types of centrifugally cast parts are also made of spheroidal cast iron.

#### CHILLED CAST IRON

Quick cooling is called "chilling" and the iron so produced is "chilled iron". All castings are chilled at their outer surface by coming in contact with the cool sand in the mould. Since cast iron has a higher thermal conductivity than sand, the chilled portions of the casting undergo rapid solidification and cooling and, thereby produce a hard surface. But this



hardness only penetrates about 1 to 2 mm in depth. Sometimes a casting is chilled intentionally and sometimes becomes chilled accidentally to a small depth. Intentionally chilling is carried out by using cast iron instead of sand for those portions of the mould where hard surfaces are required. Where these are touched by the molten metal, its surface is suddenly cooled and converted into white cast iron.

Chills are used on those castings where some parts are required to have the hardness of white cast iron, while others are required to have relatively soft and tough core of grey cast iron.

#### ALLOY CAST IRON

Alloy cast irons have been developed in recent years to overcome certain inherent deficiencies in ordinary cast iron and to give qualities more suitable for special purposes. The addition of nickel, chromium, molybdenum, titanium, silicon, copper and other alloying elements confer special properties to this cast iron.

The use of 1 or 2 per cent of nickel is suitable good quality iron offers a simple and effective means of improving the properties to this cast iron.

The use of 1 to 2 per cent of nickel is suitable good quality iron offers a simple and effective means of improving the properties and the service given by iron castings. It ensures machinability and uniformity of structure of the cast iron. By the use of nickel of the order of 25 per cent, enhanced life can also be obtained in parts subjected to abrasive wear. Cylinders or cylinder liners of all sizes from the smallest to the largest afford outstanding examples. Nickel cast iron is also used in withstanding caustic corrosion. For this reason, it is widely employed for making caustic pots, pipes and other castings in contact with caustic liquor. The addition of only 1 per cent of nickel gives as all round benefit for this purpose. The most useful reason for using nickel in cast iron is to obtain density and pressure tightness in castings with large and varying sections. This has led to the application of nickel cast for many parts of steam and hydraulic machinery, compressors and internal combustion engines.

Where improvement in the wearing quality is of importance, chromium additions with the nickel are often found useful. Cast iron alloyed in this manner finds wide application for pumps of all types in which frictional, as well as erosive, wear has to be considered. Alloy cast iron containing 10 to 30 per cent chromium and 1 to 3 per cent total carbon, also exhibits a high degree of heat resistance combined with strength at high temperatures.

Cast iron alloyed with 10 per cent nickel and 6 per cent manganese become non-magnetic. A special non-magnetic patented cast iron is known under the name of "Nomag".

#### MEEHANITE CAST IRON

Cast irons, in which metal has been treated with calcium silicide, are known by the trade name of *meehanite*. Calcium silicide acts as a graphitiser and produces a fine graphite structure giving a cast iron of excellent mechanical properties. The high qualities of meehanite iron are, however, not solely due to the use of calcium silicide but also due to careful control of all the factors involved in the melting of the iron in the copula or electric furnace and in the moulding of the casting. Very little calcium silicide remains in the iron after solidification.

The metal used is low in silicon, moderately low in carbon which is limited, about 2.5 to 3 per cent. This normally would be white if cast, but graphitising by meehanite system of control provides a range of materials to meet the broad requirements of engineering industries.

There are in all more than twenty six types of meehanite metal available at present under five broad classifications : (a) general engineering, (b) heat resisting, (c) wear resisting, (d) corrosion resisting, (e) nodular 'S' type.

All meehanite irons have high strength toughness, ductility and easy machinability. They therefore claim to bridge the gap between ordinary cast iron and steel. The castings weigh from 500 to 6,000 kg. The metal is close-grained and shows a Brinell number of 200 to 210.

Meehanite iron responds to heat treatment unlike ordinary grey cast iron. It can be hardened either wholly or on the surface. It can also be toughened by suitable treatment. Of the various applications, it is ideally suited for machine tool casting.

#### 4.5 WROUGHT IRON

Wrought iron is a highly refined iron with a small amount of slag forged out into fibres. The chemical analysis of the metal shows as much as 99 per cent of iron. The slag characteristic of wrought iron is useful in blacksmithing operations and gives the material its peculiar fibrous structure. The non-corrosive slag constituent causes wrought iron to be resistant to progressive corrosion. Moreover, the presence of slag produces a structure which diminishes the effect of fatigue caused by shocks and vibrations.

TABLE 4.4 PROPERTIES, CHARACTERISTICS AND USES OF CAST IRON

Type	Form of carbon	Composition and strength	Tensile strength		Compressive yield MPa	Elastic modulus	Percent elongation	Hardness	Typical application
			Yield MPa	Ultimate MPa					
Grey iron	Flakes	Slow cooling of a high Si cast iron melt	-	135	240	105	1	130	Ingot moulds, automotive pistons, machine castings, etc..
White cast iron	Carbide Fe <sub>3</sub> C	Quench cooling of a low Si cast iron melt	-	410	690	138	-	400	Ploughshares, chilled rolls, dies, wearing plates, stamping shoes, balls, etc..
Nodular or spheroidal graphite iron	Spheroids	Alloying elements added to spheroidise carbon during slow cooling	310	410	550	170	15	180	Machine castings subjected to bending and vibrations & other applications where strength and ductility are important
Ferritic malleable iron	Temper carbon	Annealed white iron castings	225	345	225	170	14	120	Valve bodies, hinges, manhole covers, machine castings, etc..
Pearlitic malleable iron	Temper carbon	Annealed white iron castings	475	650	475	170	10	200	Camshafts, crankshafts, gears, cams, rocker arms, gunmounts, spanners, wrenches.

It is tough, malleable and ductile and has an ultimate tensile strength of about 35 kgf per mm<sup>2</sup> (350 Newton per mm<sup>2</sup>). It cannot be melted, but at a white heat, it becomes soft enough to take any shape under the hammer, i.e., it can be forged. It admits readily of being welded. This iron has the property of being able to withstand sudden and excessive shock loads without permanent injury. It rusts more quickly than cast iron but stands salt water better. It can neither be hardened nor tempered like steel. The approximate chemical composition of wrought iron is given in Table 4.2.

Bolts and nuts, chains, crane hook, railway coupling, pipe and pipe fittings, plates, sheets, bars and boiler tubes are the principal forms in which wrought iron is used. This is produced by two commercial methods known as (1) puddling process, and (2) Aston or Byers process.

#### PUDDLING PROCESS

Pig iron for this purpose is first subject to a preliminary process of refining, the object of which is to remove silicon as completely as possible together with the greater part of the phosphorus, and to convert the graphite into combined carbon and this produces white iron.

The next process is to convert the white iron into wrought iron. To do this the slabs of white iron are broken into pieces and taken to the puddling furnace which is a coal fired reverberatory furnace. The products obtained is known as blooms having a mass of about 50 kg. The hot metal is then passed through grooved rollers which convert *blooms* into bars called *muck bars* or *puddle bars*, which have a cross-section of approximately 15 to 100 mm. These bars are cut into short length, fastened together in piles, reheated to a welding temperature and again rolled into bars.

#### ASTON OR BYERS PROCESS

In the Aston or Byers process, to produce wrought iron, the pig iron is first melted in a cupola furnace and refining of molten metal is done in a Bessemer converter. At the same time, a quantity of iron silicate slag is prepared in an open hearth furnace. The refined iron so made in the Bessemer converter is poured at predetermined rate into a ladle containing the molten slag already prepared.

After the excess slag is poured from the ladle, the remaining mass of iron and slag is taken to a press where some slag is removed. The rectangular block formed in the press is known as *bloom*. The hot bloom as before is immediately passed through rolling mills to produce products of wrought iron of different shapes and sizes.

#### 4.6 EFFECT OF CHEMICAL ELEMENTS ON IRON

Besides carbon, cast iron and wrought iron generally contain small amounts of silicon, sulphur, manganese, etc. Some ideas of the effect of these elements on the iron are given hereunder.

*Carbon* is dissolved in pure liquid iron, and if the solution is solidified slowly the carbon tends to separate out giving a structure which is a mixture of pure iron and graphite. This gives a fairly tough iron which breaks with a dark glistening fracture. It is easily machined. If the same iron is cast and cooled quickly, it is hard, has a higher tensile strength, is difficult to machine and breaks with a close, white fracture. The white constituent is iron carbide, called *cementite*.

*Silicon* in cast iron may be present up to 2.5 per cent. It promotes the formation of free graphite which makes the iron soft and easily machinable. At the same time, this element inhibits the pick-up of carbon during the melting of iron. It also produces sound castings free from blowholes because of its high affinity for oxygen.

A very small percentage of silicon makes wrought iron hard, brittle and unforgeable.

*Sulphur* is generally regarded as harmful in cast iron. It lowers the viscosity of the melt and tends to make the cast iron hard and brittle. So it should be kept well below 0.1 per cent for most foundry purposes.

In wrought iron, 0.02 to 0.04 per cent of sulphur produces shortness—that is, the metal becomes brittle and unworkable at red heat, although possessing the usual qualities when cold.

*Manganese* tends in a different way to whiten and harden cast iron by encouraging the formation of carbide. It is therefore, often kept below 0.75 per cent. But it helps to exert a controlling influence over the harmful effect of sulphur, and for any particular purpose these two impurities should be considered in conjunction.

*Phosphorus* in cast iron aids fusibility and fluidity but induces brittleness. It is rarely allowed to exceed 1.0 per cent. Phosphoric irons are useful, however, for castings when cheapness is essential.

In wrought iron, the presence of only a very small amount of phosphorus is very injurious; only 0.1 per cent is sufficient to make the iron cold-short, that is, the metal is brittle and liable to crack when cold, but may be malleable and easily worked at red heat.

*Nickel* acts as a graphitizer but is only half as effective as silicon. Small amounts help to refine the sizes of grains and graphite flakes. Most additions are from 0.25 to 2.0 per cent. Larger amounts from 14 to 38 per

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cent are added in grey irons to resist heat and corrosion and have low expansivity .

*Chromium* acts as a carbide stabilizer in cast iron. Thus it intensifies chilling of cast iron, increases strength, hardness and wear-resistance and is conducive to fine grain structure. Most additions of chromium range from 0.15 to 0.90 per cent with or without other alloying elements. Chromium of 1.0 per cent or more make castings hard to machine. With 3.0 per cent chromium, white cast iron is formed. Special irons to resist corrosion and high temperatures contain as much as 35 per cent chromium.

*Molybdenum* ranges from 0.25 to 1.5 per cent. This is added along or with other elements to improve tensile strength, hardness, and shock resistance of castings. The presence of molybdenum in cast iron produces fine and highly dispersed particles of graphite and good structural uniformity. This improves toughness, fatigue strength, machinability, hardenability, and high temperature strength.

*Copper* promotes formation of graphite. It usually presents in cast iron from 0.02 to 2.5 per cent.

*Vanadium* amounts from 0.10 to 0.50 per cent. This is to increase strength, hardness and machinability.

### 4.7 STEELS

Steel is fundamentally an alloy of iron and carbon, with the carbon content varying upto 1.5 per cent. The carbon is distributed throughout the mass of the metal, not as elemental or free carbon but as a compound (chemical combination) with iron.

If however, the carbon is increased above 1.5 per cent, a stage soon arrives when no more carbon can be contained in the combined state and any excess must be present as free carbon (graphite). It is at this stage that the metal merges into the group termed cast iron. Therefore, for a material to be classed as steel there must be no free carbon in its composition ; immediately free graphite that occurs passes into the category of cast iron.

Besides carbon, there are other elements present in the steel, e.g., sulphur, silicon, phosphorus, manganese, etc.; but carbon is by far the most important modifying element. Iron forms the mass of the alloy ; it is the quantity partner while on carbon falls the duty of determining the quality of the steel to meet demand which iron alone can not satisfy. The importance of carbon in steel lies not in its relative volume but in its remarkable influence on the internal structural changes and subsequently cooled by various methods. The approximate chemical composition of carbon steel is given in Table 4.2.

#### 4.8 STEEL MAKING PROCESSES

The commercial processes for making steel are : (1) Bessemer process, (2) L-D process, (3) Open-hearth process, (4) Crucible process, (5) Electric process, (6) Duplex process.

The Bessemer, open hearth and electric process can be subdivided into (a) acid process and (b) basic process, according to the type of lining used in the furnace. In each of these processes, the steel is produced either by adding carbon to wrought iron or by removing the proper portion of carbon from pig iron by first completely decarburising pig iron, and then adding the proper amount of carbon.

#### 4.9 THE BESSEMER PROCESS

The Bessemer process consists in blowing air through molten pig iron contained in a special furnace known as a converter which shaped like a huge concrete mixer (Fig . 4.2). The converter is made of steel plates lined inside with a refractory material. The type of refractory lining used depends upon the character of the steel-making process, i.e., upon the acid process or basic process.

In the acid process, the converter is lined with silica brick which is known in the refractory trade as "acid". The acid process does not eliminate phosphorus or sulphur from the metal. In the basic process, the converter is lined with dolomite, which is known as "basic". It removes phosphorus and to some extent sulphur.

Three clearly distinctive stages may be noted in the conversion of normal pig iron steel.

These are : (1) the slag formation or blowing period, (2) the brilliant flame blowing period, and (3) the reddish smoke period.

The *first stage* commences as soon as the blast is put on under a pressure of about 2 to 2.5 atm (200 to 250  $\text{kN/m}^2$ ) gauge, and the vessel turned upright. The blast is introduced

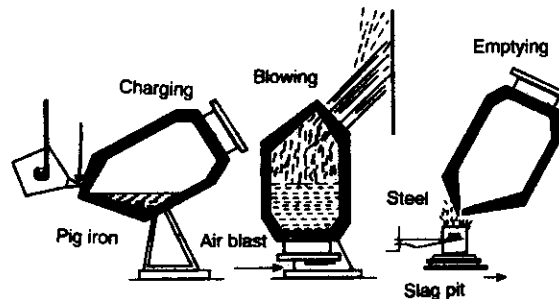


Figure 4.2 The stages of the bassemer process

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through the tuyeres in the bottom. The oxygen of the blast oxidizes the iron to ferrous oxide. As a slag, the ferrous oxide mixes with the metal. Having a greater affinity for oxygen, the silicon and manganese which separate as oxides (insoluble in the molten metal) go into the slag. These reactions are accompanied by the evolution of a large amount of heat which raises the temperature from 1,250°C to 1,525°C. This stage lasts for three or four minutes, and may also be called the silicon blow.

The *second stage* commences after the oxidation of iron, silicon and manganese, when the metal has reached a sufficiently high temperature. This creates favourable conditions for intensive burning of carbon from the molten bath. The dissolved carbon is oxidized by the ferrous oxide of the slag. The gas evolved during this stage is rich in carbon monoxide which burns at the nose of the converter with a dazzling white flame. It takes about eight to twelve minutes, as a rule, to eliminate the carbon.

The *third stage* begins when the flame “drops”—a sign that the carbon has been practically removed from the charge. This stage lasts for one or two minutes after which the converter is turned to the horizontal position. The additions of deoxidizers such as ferromanganese, ferrosilicon or aluminium are made to the metal bath to eliminate the oxygen and to bring the manganese and silicon content of the steel to the specified value.

The daily production of a converter for 25 to 30 tones per heat in size is 1200 tonnes. This is enough to cater for the output of a big blast furnace.

### 4.10 THE L-D PROCESS

The latest development in steel making processes is the L-D process. The name of this process comes from the initials of two separate plants in Austria, at Linz and Donawitz. The local Austrian ore is too low in phosphorus to enable the air-blown basic Bessemer method to be used. Since air, a mixture of nitrogen and oxygen, is used, the resulting steel contains nitrogen which makes steels liable to brittleness under certain conditions. Further the bulk of the nitrogen which is not dissolved carries away so much heat that only a metal of high phosphorus content will generate enough heat to give the required temperature of the liquid steel. The remedy has been to replace the air blast by oxygen or a gas mixture containing no nitrogen.



The L-D process consists of blowing a jet of almost pure oxygen (about 99.5 per cent) at high pressure and travelling at supersonic speed through a water cooled lance on to the surface of molten iron held in a converter lined with basic refractories such as dolomite or magnesite (Fig. 4.3). The tip of the lance is within about 1200 mm of the surface of the bath. The blowing of oxygen at supersonic speed produces intense heat (about 2,500°C to 3,000°C) and reduces blowing time which is 18 to 20 per cent of the original. The latter is achieved by increasing the proportion of steel scrap in the charge up to 30 to 33 per cent instead of the usual 5 to 8 per cent.

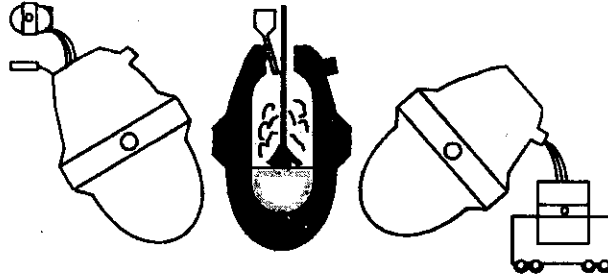


Figure 4.3 The stages of the L-D process

These advantages have won the L-D process general recognition. It is expected that over 20 million tonnes of steel will be produced by this process annually in the near future. The capacity of L-D converters is steadily increasing, the most commonly used size being 100 tonnes per heat. In modern combined blow techniques, oxygen is blown simultaneously from top as well as through bottom of the furnace. Output increases to 400 tonnes per heat.

#### 4.11 THE OPEN HEARTH PROCESS

In the open hearth process for producing steel, pig iron, steel scrap, and iron oxide in the form of iron ore or scale are melted in a *Siemens-Martin open hearth furnace* (Fig. 4.4), so called because the molten metal lies in a comparative shallow pool on the furnace bottom or hearth. The hearth is surrounded by a roof and walls of refractory bricks. The charge is fed through a charging door and heated to 1,600°C to 1,650°C mainly by radiation of heat from the burning of gaseous fuels above it. It is not the amount of heat but rather the high temperature heat that is essential for the purpose.

In practice, a considerable quantity of steel scrap is previously charged and heated in the furnace and a partly purified molten iron known as blown metal from the Bessemer converter is added to this. Thus the impurities in the pig iron are 'diluted' and the refining process does not take so long period as if the entire charge were pig iron. Very often more than 60 per cent of the charge consists of scrap. The process of making steel in this way is known as the *duplex* process because it has two stages, viz., (1) blowing molten pig iron in the Bessemer converter, and (2) further purification of the blown metal in the open-hearth furnace.

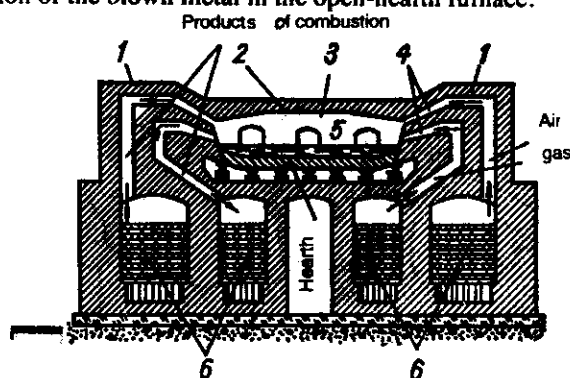


Figure 4.4 The open-hearth furnace

1. walls of refractory bricks, 2. roof, 3. melting chamber,
4. air and gas ducts, 5. charging doors, 6. checkerwork

At the end of the process, when the impurities (silicon, manganese, etc.) have been brought down to the required level, the metal is tapped off through a tap hole in the furnace. Additions of ferromanganese and ferrosilicon are made to bring the steel to the correct composition ; later a small addition of aluminium is made to deoxidize the metal further. In some cases the carbon is reduced practically to zero and then additions are made to bring it to the correct amount, but a more usual method is to catch the carbon at the desired amount.

In *acid practice*, a lining of silica sand is used on the hearth and an acid slag high in silica is produced on the metal during the refining process. Acid slag cannot remove phosphorus for which basic lining is used. In basic practice, a lining of magnesite is used and limestone is charged with the raw material. A basic slag high in lime is produced on the bath after the metal melts.

Steel made by the acid open hearth process is considered to be of better quality due to the fact that carefully selected materials low in sulphur and phosphorus are used in it. However, most of the steel is now-a-days

made by the basic open hearth process as it has got certain advantages. At the present time, about 85 per cent of steel is produced in open hearth furnace.

The complete cycle of operation lasts from 5 to 15 hours and open hearth furnaces have been built in capacities of 2 to 700 tonnes per charge. But the most common types are of 250 to 500 tonnes per charge.

#### 4.12 THE CRUCIBLE PROCESS

In the crucible process for making steel, mixtures of wrought iron, steel scrap and ferromanganese are melted down with charcoal in an air tight crucible. Other ferro alloys may be added when alloy steel is produced by this process. In the crucible process, carbon is added to the iron as the carbon content of wrought iron is low. Necessary carbon is taken up by the metal from the charcoal during melting. After the materials are melted and thoroughly alloyed, the crucibles are taken from the furnace known as *regenerative furnace* which is heated by a gaseous fuel as in the open-hearth furnace, and finally the steel is poured into ingot mould. The length of time between placing the crucible in the furnace and withdrawing the crucible is approximately four hours.

The process is primarily a melting and alloying process and no refining of the metal takes place in the crucible.

#### 4.13 THE ELECTRIC FURNACE PROCESS

Within recent years, the melting of steel by electric furnaces has developed rapidly for the availability of cheap electric power. Electricity is used solely for the production of heat and does not impart any special properties to the steel. Nevertheless, the electric furnace has the following advantageous features.

1. It generates extremely high temperature, about  $2,000^{\circ}\text{C}$ , in the melting chamber without introducing oxygen or nitrogen from the air or impurities from the fuel. This facilitates the removal of the harmful impurities such as oxygen, sulphur and phosphorus, and also nonmetallic inclusions.
2. The temperature at all times may be easily controlled and regulated.
3. It permits the addition of expensive alloying elements such as chromium, nickel, tungsten, etc. without loss by oxidation.

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4. A great variety of steels, differing in carbon content and with any content of alloying elements, can be manufactured.

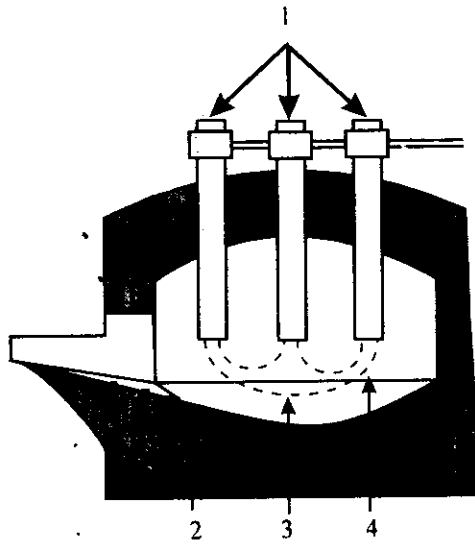
On account of the above considerations, high grade alloy steel, stainless and heat-resisting steels are made almost exclusively by that process. But this process is more expensive in operation than any other steel making process and the output is very low. When the average open-hearth furnace can produce 800 tonnes of steel, the Bessemer converter about 1,200 tonnes, the average electric furnace between 30 to 80 tonnes, every 24 hours. In the electric furnace process also both basics and acid methods are used. As in the previous processes, in the basic method, the lining is made of basic materials such as magnesite or dolomite, and in the acid process the lining consists of silica bricks.

Two types of electric furnaces used in the manufacture of steel are: (1) direct arc furnace, and (2) high-frequency induction furnace.

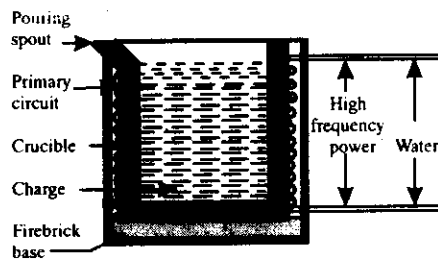
### THE DIRECT ARC FURNACE

The direct arc furnace, illustrated in Fig. 4.5 consists of a steel shell lined with refractory bricks and a removable roof through which carbon or graphite electrodes (about 2 m long) pass. Graphite electrodes offer less resistance to current and are considered to be more durable at high temperatures but they are more expensive than the carbon electrodes. The number of electrodes correspond to the number of phases.

The electrodes are lowered into the furnace and the current is switched on. The heat generated by a powerful spark between the electrodes and the metallic charge on the hearth melts the charge. The charge usually consists of steel scrap and iron oxide in the form of iron oxide ore. Pig iron is not directly treated in the electric furnaces, though sometimes it is partly purified in an open hearth furnace and then transferred to electric furnaces for final treatment and alloying. When the furnace is in operation, the electrodes are consumed and they become shorter. So a definite distance must be maintained between the electrodes and the charge by raising or lowering them by automatic controls. Whenever necessary, a new electrode is built up (screwed) on top of the old one.



**Figure 4.5 The direct arc furnace**  
 1. electrode, 2. refractory lining, 3. arc, 4. molten metal



**Figure 4.6 High frequency induction furnace**

Modern arc furnaces are built in 0.5 to 80 tonnes capacity but most favoured are those with capacities of up to 80 tonnes. A melt is produced in 6 to 8 hour for an arc furnace 30 to 35 tonnes in capacity.

**HIGH FREQUENCY INDUCTION FURNACE**

The principle of an induction furnace, illustrated in Fig. 4.6, resembles that of a transformer. It has a primary coil about which an alternating magnetic field is set up with magnetic lines of force of a definite density when an alternating current is passed through the coil. The magnetic field induces alternating eddy currents in the secondary circuit which comprises a crucible containing the metal charge. The eddy currents heat up and melt the metal.

An induction crucible furnace comprises a refractory crucible and a coil or inductor. The latter is made of copper tubing through which cooling water circulates and is arranged inside the refractory crucible. An insulating lining is provided between the coil and the crucible. The metal to be melted is charged into the crucible where it is melted down by the heavy secondary currents induced by the magnetic flux of the primary coil. The crucible can be tilted on horizontal trunions to pour the molten metal.

Induction furnaces usually operate, on an alternating current with a

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frequency of 500 to 2500 hertz. The generator rating is selected so as to obtain from 1 to 0.4 kW per kg of the metallic charge.

Induction furnaces are most often employed in making high alloy steels and special purpose alloys. An advantage of these furnaces is that they do not require electrodes. This prevents carburisation of the metal and simplifies control of the process. A vigorous stirring action is produced by the electromagnetic force in the crucible. This circulation of the metal accelerates chemical reactions and enables homogeneous metal to be obtained.

Induction furnaces are available in a wide range of capacities from 50 Kg to 10 tonnes.

### 4.14 DUPLEX PROCESSES

Combination methods of steel making known as duplex processes are carried out in two steel making units. The following combinations are usually done.

1. Basic and acid open-hearth furnaces.
2. A basic open-hearth furnace and a basic electric furnace.
3. A Bessemer converter and a basic open hearth furnace.

### 4.15 CLASSIFICATION OF STEEL

According to IS : 7598-1974 steels shall be classified as :

1. Unalloyed steels, commonly called plain carbon steels, and
2. Alloy steels.

#### UNALLOYED STEELS OR PLAIN CARBON STEELS

The principal factors affecting the properties of plain carbon steels are the carbon content and the microstructure. Carbon is the principal determinant of many performance properties. It has a strengthening and hardening effect. At the same time, it lowers ductility, as evidenced by a decrease in elongation and reduction of area. In addition, a rise in carbon content lowers machinability and decreases weldability. The amount of carbon present also affects physical properties and corrosion resistance. With an increase in carbon content, thermal and electrical conductivity decline, magnetic permeability decreases drastically, and corrosion resistance is lowered.

The microstructure is determined by the composition of steel, i.e.,

carbon manganese, silicon, phosphorus and sulphur which are always present and residual elements including oxygen, hydrogen, and nitrogen, and by the final rolling, forging, or heat-treating operation. However, most of the plain carbon steels are used without a final heat treatment and, consequently the rolling and forging operations influence the microstructure.

Carbon steel are predominantly paralytic in the cast, rolled, or forged conditions. The constituents of hypoeutectoid steels (steels containing from and below 0.87 per cent carbon) are therefore ferrite and pearlite and of the hypereutectoid steels (containing from and above 0.87 per cent carbon) cementite and pearlite.

**Types according to carbon content.** On the basis of the carbon content plain carbon steels are commonly divided as :

1. Low carbon or mild steel— 0.05-0.30 per cent carbon
2. Medium carbon steel – 0.03-0.06 per cent carbon
3. High carbon steel – 0.60-1.50 per cent carbon
4. Tool steel (high carbon)— 0.90-1.50 per cent carbon

It should be noted that carbon content of these four types of carbon steel are not rigid, and there may be a certain amount of overlapping from one type to next.

**Types according to deoxidation practice.** Steel are often identified as to the degree of deoxidation resulting during steel production :

1. *Killed steels.* They are strongly deoxidized, and are characterized by high composition and property uniformity . All forging steels and , in general, all steels containing more than 0.25 per cent carbon are killed. The essential quality of killed steels is soundness (freedom from blow holes and segregation). When the steel is deoxidized sufficiently, there is no evolution of gas and the top surface of the ingot solidifies almost immediately. The symbol K stands for killed steel.

2. *Semi-killed steels or balanced steels.* They are intermediate between those of killed and rimmed steels and have variable degree of uniformity. Structural steels containing 0.15 to 0.25 per cent carbon are generally semi-killed. In semi-killed steel the aim is to produce metal free from surface blowhole and pipe. The surface should have a sound skin of considerable thickness. Plates and structural products are normally made from semi-killed steel. No symbol is used to denote semi-killed quality of steel which comprises 90 per cent of the total production of steel.

3. *Rimmed steels.* In rimming, the steel is partially deoxidized. In rimmed steel, the aim is to produce a clean surface in carbon content. A wide variety of steels for deep drawing is made by the rimming process, specially where ease of forming and surface finish are major considerations. These steels are therefore, ideas for rolling. Sheets and strips made from rimmed steels have excellent surface-quality and cold-forming characteristic. The symbol *R* is used for rimmed steel.

#### 4.16 APPLICATIONS OF CARBON STEELS

The mild and medium carbon steels are widely used and high carbon steels are used mainly for tools and for specialized work requiring high quality and very good performance. Mechanical properties and typical use of carbon steels are listed in Table 4.5.

#### 4.17 INFLUENCE OF THE CONSTITUENTS ON STEEL

The properties of steel are dependent primarily on the carbon content and to a large extent upon silicon, manganese, sulphur and phosphorus. Therefore, an understanding of the effect of each of the chemical elements on the properties of steel is necessary in the selection of steel for definite purposes.

*Carbon* increases strength, elasticity (determined by yield point) and hardness, and lowers the ductility (characterized by elongation) and impact strength. An important fact is that above 0.3 per cent carbon, the steel can be hardened by heating and quenching in water or oil.

*Silicon* in the finished steel usually ranges from 0.05 to 0.30 per cent. Silicon is put in carbon steels to prevent them from becoming porous. It acts as a very good deoxidiser and removes the gases and oxides, prevents blowholes, and thereby makes the steel tougher and harder.

*Manganese* also serves as a valuable deoxidizing and purifying agent. Manganese also combines with sulphur and thereby decreases the harmful effect of this element remaining in the steel. When uses in ordinary low carbon steels, manganese makes the metal ductile and of good bending qualities. The manganese content of carbon steel is usually less than 1.00 per cent and commonly ranges from 0.30 to 1.00 per cent.

*Sulphur* occurs in steel either as iron sulphide or as manganese sulphide. Iron sulphide, because of its low melting point, produces *red-shortness*, i.e., increased brittleness at elevated temperatures, whilst manganese sulphide does not affect so much. Therefore, manganese sulphide is less objectionable in steel than iron sulphide. The presence of a



**TABLE 4.5 MECHANICAL PROPERTIES AND APPLICATIONS OF CARBON STEEL**

Type of steel	% Carbon	BHN number	Tensile strength MPa	Yield strength MPa	% elongation	% Re-duction in area	Uses
Dead mild	0.05-0.15	100-110	390	260	40	60	Chains, stampings, rivets, nails, seamwelded pipes, tin plate, automobile body steel, and materials subject to drawing and pressing
Mild steel	0.10-0.20	120-130	420	355	36	66	Structural steels, universal beams, screw, drop forgings, case hardening steel.
	0.20-0.30	130-150	555	480	21	55	Machine and structural work, gears, free cutting steel, shafting and forgings.
Medium steel	0.30-0.40	150-160	700	550	18	51	Connectin rods, shafting, axels, crankhooks forging.
	0.40-0.50	350	770	580	20	53	Crank shafts, axels, gears, shafts, die-block rotors, tyres, skin wheels.
High carbon	0.50-0.60	350-400	1200	750	10	35	Loco tyres, rails, wire ropes.
	0.60-0.70	400-450	1235	780	12	40	Drop hammer dies, saws, screw-drivers.
	0.70-0.80	450-500	1420	1170	12	35	Band saws, anvil faces, hammers, wrenches, laminated springs, cable wire, large dies for cold presses.
	0.80-0.90	500-600	665	645	12	33	Cold chisels, shear blades, punches, rocks drills.
Tool steels	0.90-1.10	550-600	580	415	13	26	Axes, knives, drill, taps, screw ring dies, picks.
(high carbon)	1.10-1.50	600-750	500	375	13	20	Ball bearingss, files, broaches, razors, boring and finishing tools machine parts where resistance to wear is essential.

substantial amount of sulphur (sulphur inclusion) in steel unfavorably affects other properties of steel, e.g., tensile strength, yield point, fatigue limit, etc., and decreases its corrosion resistance.

*Phosphorus* imparts *cold-shortness*, i.e., high brittleness at normal and especially at low temperatures. It increases the tensile strength but at the same time reduces the impact strength and the ductility. At a phosphorus content of slightly over 0.2 per cent the impact strength has a zero value. The embrittlement effect of phosphorus increases with an increase in the carbon content of steel. The sum of carbon and phosphorus usually does not exceed 0.25 per cent. Tool steels of the best quality do not contain more than 0.02 per cent.

The content of sulphur and phosphorus is strictly limited because of their harmful effect on the quality of the steel.

Table 4.5.

#### 4.18 BRIGHT STEELS

Bright steels are produced by various processes of cold working therefore, they may be said as cold-worked steels. They are made in a very wide range of sizes, e.g., in rounds, squares, hexagons, flats and special sections. Bright steel bars are characterized by a clean, smooth finish of close dimensional tolerance.

The advantage of cold working in bright steels is that the machinability of steels of the lower carbon grades is improved. The ferrite constituent which is the main one in low carbon steels is work hardened by cold working and this leads to crisper machining, less tendency to drag, better finish and smoother threading.

#### 4.19 FREE CUTTING STEELS

Free cutting (also free machining) steels are extensively applied for machining parts subject to comparatively light loads (bolts, nuts, screws, etc.) and produced on automatic screw machines or multiple spindle automatics. These steels are intended for uses where easy machining is the primary requirement.

The distinguishing features of free cutting steels, i.e., high machinability and high quality surface finish after machining, are due to the higher sulphur and phosphorus content.

Sulphur exists in the free cutting steel in the form of manganese sulphide which forms inclusions stretched out in the direction of rolling. These inclusions promote the formation of short brittle chips, reduce the

friction on the surface being machined, and enable a satisfactory surface finish to be obtained at high cutting speed. Phosphorus dissolves in the ferrite (pure iron) and increases its brittleness. This also makes the chip more brittle and enables a smooth bright surface to be obtained in cutting. The addition of 0.15 to 0.35 per cent phosphorus considerably improves the machinability without reducing the physical and mechanical properties of the steel.

The tool life achieved in machining free cutting steels is from 2 to 2.5 times higher than when carbon steels of the same carbon content are machined. It must be noted, however, that free cutting steels have lower dynamic strength characteristics and are more susceptible to corrosion.

Free cutting steels are frequently supplied in the cold drawn (work-hardened) form. These cold drawn steels have a high tensile strength and hardness but less ductile when compared to ordinary carbon steels.

#### **4.20 ALLOY STEEL**

Alloy steels may be defined as steels to which elements other than carbon are added in sufficient amounts to produce improvements in properties. The most common alloying elements added to steel are chromium, nickel, manganese, silicon, vanadium, molybdenum, tungsten, phosphorus, copper, titanium, zirconium, cobalt, columbium, and aluminium. Each of these elements confers certain qualities upon the steels to which it is added. They may be used separately or in combination to produce desired characteristics in the steel.

Like carbon, a number of alloying elements are soluble to produce alloys with improved strength, ductility, and toughness. Also carbon besides forming an intermetallic compound with iron, combines with many alloying elements and forms alloy carbides. These alloy carbides as well as iron-alloy carbides are usually hard and lack in toughness. Some alloying elements are added to prevent or restrict grain growth. Aluminium is considered the most effective in this respect. Others are zirconium, vanadium, chromium, and titanium. Structurally, the addition of alloying elements almost always affects the austenite-ferrite transformation mechanism by changing the temperature at which the transformation from gamma to alpha iron takes place. Some alloying elements lower and some raise the critical temperature.

The compositional and structural changes produced by alloying elements change and improve the physical, mechanical and processing properties of iron and steel. In general, alloy steels can give better strength,

ductility, and toughness properties that cannot be obtained in carbon steel. Consequently, the production, design engineer should consider alloy steels in designs subject to high stresses and /or impact loading.

Almost all alloy steels are produced with fine-grained structures. Fine-grained steels have less tendency to crack during heat treatment but have better toughness and shock-resistance properties. Coarse-grained steels exhibit better machining properties and may be hardened more deeply than fine-grained steels.

#### EFFECTS OF THE ALLOYING ELEMENTS

In order to select the alloy steel that is best suited for a given design, the effects of primary alloying elements must be taken into account. They are :

*Nickel* provides toughness, corrosion resistance, and deep hardening.

*Chromium* improves corrosion resistance, toughness and hardenability.

*Manganese* deoxidizes, contributes to strength and hardness, decreases the critical cooling rate.

*Silicon* deoxidizes promotes resistance to high temperature oxidation, raises the critical temperature for heat treatment, increases the susceptibility of steel to decarburization and graphitization.

*Molybdenum* promotes hardenability, increases tensile and creep strength at high temperature.

*Vanadium* deoxidizes and promotes fine-grained structure.

*Copper* increases resistance to corrosion and acts as strengthening agent.

*Aluminium* deoxidizes, promotes fine-grained structure, and aids nitriding.

*Boron* increases hardenability.

A summary of the effects of the chief alloying elements in steel is given in Table 4.6.

#### 4.21 CLASSIFICATION OF ALLOY STEELS

Alloy steels may be classified according to their chemical composition, structural class and purpose.

*Classification according to chemical composition.* In this aspect alloy steels are divided into three-component steels, containing one alloying element in addition to iron and carbon : *four component steels*, containing two alloying elements, etc.

*Classification according to structural class.* On the basis of the structure obtained when specimens of small cross-section are cooled in air. Alloy steels may be classified as: 1. *pearlitic*, 2. *martensitic*, 3. *austenitic*, 4. *ferritic* and 5. *carbide*.

*Classification according to purpose.* As to the uses for which their properties fit them alloy steels can be classified :

1. Structural steels.
2. Tool steels.
3. Steels with special physical properties.

#### 1. ALLOY STRUCTURAL STEELS

They are divided into three groups : low alloy (up to 5 per cent alloying elements) , medium alloy (over 5 per cent) and high alloy (more than 10 per cent) . IS : 7598-1974.

Alloy structural steels are widely employed in engineering industry for parts that are subject to both static and dynamic loads in operation. They have a more favourable set of mechanical properties than carbon steels especially for articles of large cross-section. The alloying elements strengthen the ferrite, which is the chief constituent in the structure of these steels; increase the hardenability, refine the grain size; and increase the resistance to softening on heating to moderate temperatures.

The principal alloying elements in structural steels are chromium, nickel, and manganese. Tungsten, molybdenum, vanadium, and titanium are not usually employed as independent additions, They are added in conjunction with chromium, nickel and manganese.

#### 2. ALLOY TOOL STEELS

They are employed in tool manufacture in cases when the tool life provide by carbon steel is insufficient.

The tool industry is supplied with :

1. Low alloy steels which retain high hardness at temperatures up to 250°C.
2. Medium and high alloy steels, e.g., high speed steels which retain high hardness at temperatures up to 620°C. They acquire high cutting properties only after suitable heat treatment.

Alloy tool steels are smelted in open-hearth and electric furnaces and belong to high quality classes.

**3. ALLOY STEELS WITH SPECIAL PHYSICAL PROPERTIES**

They may be divided into several groups as (1) stainless steels, (2) scale and heat resisting steels, (3) wear resisting steels, (4) magnet steels, and (5) steels with special thermal properties such as creep resisting steels, etc.

**TABLE 4.6 SUMMERY OF THE EFFECT OF THE CHIEF ALLOYING ELEMENTS IN STEEL (AFTER BULLENS-BATTELLE)**

Strengthen ferrite : P, very strong Si, Mn, strong Ni, Cu, Cr, Mo, W, fairly strong V, weak	Form carbides : Ti, Nb, V, very strong Cr, Mo, W strong Mn, fairly strong P, Ni, Cu, Si, no carbide
Confer depth hardening :  Mo, W, Mn, Cr, strong Si, medium Cu, Ni weak V, very weak	Stabilize mortensite and troostite on tempering : Mo, W strong V fairly strong Cr weak Mn very weak other elements little effect
Restrain grain growth of austenite All very strong V, Ti, Zr fairly strong Mo, medium Cr, Si weak Mn, very weak	Decrease eutectoid content : Mn, Cr, V considerably Ni, Mo, W somewhat Si, Cu, Al, no appropriate effect
Specific effect : Mo minimizes temper-brittleness Mo, W confer high-temperature strength, especially in the presence of other carbide-forming elements. Cu, between 0.15 and 0.30 per cent, either alone or in conjunction with P confers improved resistance to atmospheric corrosion.	Ni confers toughness without brittleness and especially confers low-temperature impact toughness. Cr, in large amounts, confers resistance to corrosion under oxidizing conditions and to oxidation on heating.

**4.22 SPECIAL ALLOY STEELS**

In service situations where steels must resist high temperatures, corrosion, shock, etc. special alloy steels are invaluable. The most important groups of special alloy steels are described in the following discussions.

### MAGNET STEELS

High cobalt steels, when correctly heat treated, are frequently used in the making of permanent magnets for magnetos, loud speakers and other electrical machines and instruments. Steels having compositions 15 to 40 per cent cobalt 0.4 to 10 per cent tungsten possess improved magnetic properties.

### HEAT RESISTING STEELS

Heat resisting steels are those which are particularly suitable for working at high temperatures. Such steels must resist the influences which lead to the failure of ordinary steels when put to work under high temperature. A steel containing chromium, nickel and tungsten, with the carbon content suitably controlled (developed for the stainless series) provides a useful combination of nonscaling and strength-retaining properties together with resistance to acid corrosion comparable with that of stainless steels.

Alloy steels containing 23 to 30 per cent chromium with the carbon less than 0.35 per cent are used principally for service at temperatures between 815°C and 1150°C. Furnace parts, annealing boxes and other equipments requiring resistance to high temperatures are often made of these steels.

### SHOCK RESISTING STEELS

Shock resisting steels are those which resist shock and severe fatigue stresses. One grade of steel for this purpose contains 0.50 per cent carbon, 2.25 per cent tungsten, 1.50 per cent chromium and 0.25 per cent vanadium. Another grade of shock resisting steel, known as silicon manganese steels, contains 0.55 per cent carbon, 2.00 per cent silicon, 0.80 per cent manganese, and 0.30 per cent molybdenum. This kind of steel is mainly used for leaf and coil springs.

### STAINLESS STEELS

Stainless steels are essentially those containing chromium, together with other elements such as nickel, and are grouped as under.

**Austenitic stainless steels.** Probably the most important under this group is that containing 15 to 20 per cent chromium and 7 to 10 per cent nickel. A steel containing 18 per cent chromium and 8 per cent nickel is very widely used and is commonly referred to as 18/8 stainless steels. Such a steel may be readily cold-worked so that the hardness and tensile strength are markedly increased and wire may be produced by cold working. Owing

to the high ductility, the steel lends itself readily to manipulation and fabrication, and is used extensively for the production of pressings. The steel is readily weldable after welding, it is susceptible to corrosive attack in an area adjacent to the weld. Additions of molybdenum are made to certain grades to increase their corrosion resistance, whilst others have titanium or niobium added to stabilize the carbon. They cannot be hardened by heat treatment. Austenite in these steels is stable at all service temperatures. Austenitic stainless steels are nonmagnetic.

**Martensitic stainless steels.** This group often termed plain chromium types of stainless steel, which contain 10 to 14 per cent chromium and, with the odd exception, have no other major alloying element. These steels are all hardenable by heat treatment.

**Ferritic stainless steels.** This group contains mainly 14 to 18 or 23 to 30 per cent chromium again with no other major alloying element. They cannot be hardened by heat treatment.

Stainless steels have great strength and toughness and extremely good resistance to corrosion and heat. The heat resisting properties are increased by the addition of about 3 per cent of silicon. They find wide application in the brewery, dairy and chemical industries, in making cutlery, all types of surgical and dental instruments, household appliances such as kitchen utensils, sinks, saucepans, and many others. Considerable amounts of these steels are also used for components in power stations, particularly in the field of nuclear power-production because of the excellent combination of resistance to heat and corrosion, and maintenance of high strength at elevated temperatures, which they provide.

When the carbon content is reduced as low as 0.09 per cent the *produce* is called stainless iron. Irons of this classification usually have chromium in excess of 23 per cent. They are highly resistant to corrosion and they may be used in parts for heat exchangers, conveyor chains, furnaces, stokers, and other similar high temperature applications.

#### MARAGING STEELS

They are iron based alloys containing 18 Ni 8 Co 5 Mo with small amounts of Al and Ti and less than 0.03 per cent C. The strength is maintained with increase in section thickness and also up to 350°C. These steels are used for air frame and engine components, injection moulds and dies.

On cooling from the austenitic condition the alloy transforms to a fine lath type martensite, and precipitation hardening is induced by maraging at 480°C.

The steels have high fracture toughness due to a combination of fine



grain size of the martensite and the high dislocation density, leading to fine precipitation.

### HIGH-SPEED STEELS

High-speed steels (HSS) get their name from the fact that they may be operated as cutting tools at much higher cutting speeds than is possible with plain carbon tool steels. High-speed steels operate at cutting speed 2 to 3 times higher than for carbon steels. When a hard material is machined at high speed with heavy cuts, sufficient heat may be developed to cause the temperature of the cutting edge to reach a red heat. This temperature would soften carbon tool steel containing even up to 1.5 per cent carbon to the extent of destroying their cutting ability. Certain highly alloyed steels, designated as high-speed steels, therefore, have been developed which must retain their cutting properties at temperatures up to 600°C to 620°C.

There are four general types of high-speed steel :

1. **18-4-1 high-speed steel.** This steel, containing 18 per cent tungsten, 4 per cent chromium, and 1 per cent vanadium with about 0.75 per cent carbon is considered to be one of the best of all-purpose tool steels. This steel is extensively used for lathe, planer and shaper tools, drills and milling cutters.
2. **Cobalt high-speed steel.** This is known as super high speed steel. Normally cobalt is added from 5 to 8 per cent to increase better hot hardness and wear resistance than 18 : 4 : 1 type. One analysis of cobalt high-speed steel contains 20 per cent tungsten, 4 per cent chromium, 2 per cent vanadium and 12 per cent cobalt.
3. **Vanadium high-speed steel.** This steel contains 0.70 per cent carbon and more than 1 per cent vanadium. High vanadium with carbon high-speed steel is superior to 18 : 4 : 1 type for difficult-to-machine materials. This has excellent abrasive resistance.
4. **Molybdenum high-speed steel.** This steel containing 6 per cent molybdenum, 6 per cent tungsten, 4 per cent chromium and 2 per cent vanadium have excellent toughness and cutting ability.

**Effect of alloying elements on HSS.** Carbon produces carbides and a hardenable matrix. Melting point is decreased with increase in carbon content. A low carbon content increases the impact strength but reduces the matrix hardness. Chromium reduces tendency to scaling. It is mainly present in the ferritic matrix and is largely responsible for the air hardening of HSS. Vanadium increases the abrasion resistance, cutting quality of the tools and the tendency to air hardening. Tungsten provides hot hardness by

forming carbides and form-stability. Molybdenum increases hardenability, while cobalt improves hot hardness and makes the cutting tool more wear resistant.

#### 4.23 CUTTING ALLOYS

Cutting alloys are used on tools that operate at very high cutting speeds with high temperatures up to 1,000°C to 1,100°C developing on the cutting edges. Since they cannot be machined by ordinary methods, they are applied to cutting tools either by means of hard-facing techniques (as a weld deposit or tips brazed to the tool shank or body).

As to the method by which they are produced, cutting alloys are classified as cemented carbides and cast cutting alloys (stellites).

##### CEMENTED CARBIDES

They are made of a powdery mixture of tungsten and titanium carbides and metallic cobalt which is first compacted and then sintered, thus employing the well-known powder metallurgy process.

In their finished form cemented carbides consist of extremely fine grains of tungsten and titanium carbides with a cobalt binder. These alloys are extremely hard with Rockwell hardness number up to 85 and even higher and they retain this hardness at temperatures up to 1,000°C.

The one most widely used grade of cemented carbides contains 2 to 15 per cent cobalt and the remainder is tungsten carbide; and the other grade contains a few per cent cobalt and 5, 14, 30 and 60 per cent titanium carbide respectively, the remainder again, being tungsten carbide.

The cutting properties of cemented considerably exceed those of high-speed steel. They are extremely resistant to wear and for this purpose they are valuable for wire-drawing dies and other similar applications.

##### STELLITES

They contain large amounts of metals like cobalt and tungsten, have high hardness (Rhn = 60 to 65) and melt at very high temperatures. Tips or rods from 5 to 10 mm thick, cast of these alloys, are used in the hard-facing of tools by welding techniques to increase the life of the cutting edges. Dies and wear surfaces of various machine parts are hard-faced in the same manner.

## 4.24 CODING OF IRON AND STEEL

### CASTING

The code designation of plain castings shall consist of the following in the order given (IS : 4843-1968) :

1. Symbols indicating the type of casting.
2. Symbols for mechanical properties.

or

1. Symbols indicating the type of casting.
2. Symbol for chemical composition similar to the designation of steels.

The code designation of alloy castings shall consist of the following in the order given :

1. Symbols indicating the type of castings.
2. Average carbon content in hundredths of a per cent following the type symbols of casting.
3. Chemical symbols for the significant elements in descending order.
4. Alloy index number for average per centages of alloying elements.

### EXAMPLES

#### *CS-Steel castings*

CS 1250 – Unalloyed steel castings with minimum tensile strength 1250 N/mm<sup>2</sup>.

CSM 350 – Unalloyed special steel castings with minimum tensile strength 350 N/mm<sup>2</sup>

GS 50 Cr 1 V 20 – Alloy steel casting with average per centage of C = 0.50, Cr = 1.00, V = 2.20.

#### *FG – Grey iron casting.*

FG 150 – Grey iron casting with minimum tensile strength 150 N/mm<sup>2</sup>

FG 35 Si 15 – Special grey iron castings with minimum total carbon percentages = 3.5 and average silicon percentage = 1.50.

### STEEL

For the purpose of code designation, steel be classified as [IS : 1962 (part 1)–1974] :

1. Steels designated on the basis of mechanical properties .
2. Steels designated on the basis of chemical compositions.

**Steels designated on the basis of mechanical properties.** These steels are carbon and low alloy steels where the main criterion in the selection and inspection of steel is the tensile or yield stress.

The code designation shall consist of the following in the order given :

1. Symbol 'Fe' or 'FeE' depending on whether the steel has been specified on the basis of minimum tensile strength or yield strength.
2. Figure indicating the minimum tensile strength or yield stress in N/mm<sup>2</sup>.
3. Chemical symbols for elements the presence of which characterize the steels.
4. Symbol indicating special characteristics covering method of deoxidation, steel quality, surface condition, weld-ability, formability, etc.

**EXAMPLES**

Fe 410 Cu K — Killed steel (K) containing copper as alloying element with a minimum tensile strength of 410 N/mm<sup>2</sup>.

FeE 300 P 35— Semikilled steel with a minimum yield strength of 300 N/mm<sup>2</sup> and degree of purity S & P = 0.035 Max.

**Steels designated on the basis of chemical composition unalloyed steels.** IS : 7598. The code designation shall be rounded off to the nearest integer.

1. Letter 'C'.
2. Figures indicating 10 times the average percentage of manganese content. The result shall be rounded off to the nearest integer.
3. Symbol indicating special characteristics.

**EXAMPLES**

45 C 10 G — Steel with average 0.45 per cent carbon, 1 per cent manganese and guaranteed hardenability.

**Unalloyed tool steels.** The designation shall contain of :

1. Figure indicating 100 times the average percentage of carbon.
2. Symbol 'T' for tool steel.
3. Figure indicating 10 times the average per cent manganese content.

## EXAMPLES

75 T 5 — Unalloyed tool steel with average 0.75 per cent carbon and 0.5 per cent manganese.

**Low and medium alloy steels (total alloying elements not exceeding 10 per cent) IS 1962 (Part I) – 1974.** The designation of steels consists of :

1. Figure indicating 100 times the average percentage of carbon.
2. Chemical symbols for alloying elements each followed by the figure for its average percentage content multiplied by a factor as given below.

<i>Element</i>	<i>Multiplying factor</i>
Cr, Co, Ni, Mn, Si and W	4
Al, Be, V, Cu, Nb, Ti, Ta, Zr and Mo.	10
P, S, N	100

3. Symbol indicating special characteristics.

## EXAMPLES

25Cr4Mo2G — Steel with guaranteed hardenability and having average 0.25 per cent carbon, 1 per cent chromium and 0.25 per cent molybdenum.

**Indian standard designation of high alloy steels (total alloying elements more than 10 per cent). [IS : 1570 (Part V) – 1985.]**

1. Letter 'X'
2. Figure indicating 100 times the percentage carbon content.
3. Chemical symbol for alloying elements each followed by the figure for its average percentage content.
4. Chemical symbol to indicate specially added element to attain the desired properties.
5. Symbol indicating specific characteristics.

## EXAMPLES

X 10 Cr 18 Ni 9 S 3 — Steel in pickled condition with average carbon 0.10 per cent, chromium 18 per cent and nickel 9 per cent.

**Alloy tool steels. (IS : 7291 – 1981).** The steel designation shall be as for low, medium and high alloy steels as given above except that the symbol 'T' will be included in the beginning of the designation of *low alloy and medium alloy tool steels* and 'XT' instead of 'X' in the case of *high alloy tool steels*.

**TABLE 4.7 SOME IMPORTANT INDIAN STANDARD SPECIFICATIONS WITH SIMILAR FOREIGN SPECIFICATION**

Sl No.	Type	Indian	British	American	Russian	German	Japanese
1.	Structural steel	IS. 226	BS. 15	ASTM. A75		DIN. 17100	JIS. G. 3101
2.	Galvanised steel	IS. 227	BS. 2989 BS. 3083	ASTM. A283 ASTM. A36 ASTM. 163		DIN. 59231	JIS. G. 3302
3.	Concrete re-inforcement (Plain standard quality)	IS. 432	BS. 4449	ASTM. A93 ASTM. A61 ASTM. A15 ASTM. A16		DIN. 488	JIS. G. 3112
4.	Concrete re-inforcement (Deformed)	IS. 1786	BS. 4461			DIN. 1045 DIN. 488	JIS. G. 3112
5.	Strips	IS. 4030		ASTM. A109		DIN. 1624	JIS. G. 3308 JIS. G. 3303
6.	Black plates	IS. 597	BS. 2920	ASTM. A345 (non-grain oriented)			JIS. C. 2551, (Sheets)
7.	High Silicon steel NGO for electric stamping GO			AISI. M14 to M19 (grain oriented)			JIS. C. 2552 (Strips) JIS. C. 2553 (grain oriented strips)
8.	High Tensile Structural Steel	IS. 961 Fe 570-HT (St. 55-HT) and Fe 540 W-HT St. 55- HTW	BS. 548 BS. 968 BS. 4360 (Grades 50 & 55 only)	ASTM. A242, ASTM. A440 ASTM. A94, ASTM. A441 (Mn-V steel), ASTM. A449 (Re-rolled rail steel) ASTM. A514, (Alloy steel plates), AISI Grades (945A, C, X950, A, B, C, D, X995, X, 960X, 965X, 970X)	GOST. 5058 (10 G <sub>2</sub> S1)	DIN. 17100 (St. 50, 52, 60 70)	CORTEN-A JIS. A. 5528 (Sheet piles H.S.)

**TABLE 4.7 SOME IMPORTANT INDIAN STANDARD SPECIFICATIONS WITH SIMILAR FOREIGN SPECIFICATION (contd.)**

Sl No.	Type	Indian	British	American	Russian	German	Japanese
9.	Fusion Weldable Structural Steel	IS. 2062/69	BS. 4360 (Gr. 40 & 43) BS. 2762 (Notch ductile)	ASTM. A373	GOST. 4637	DIN. 17100 (St. 34, 37, 42)	JIS. G. 3106 JIS. G. 3113
10.	Boiler Quality (Plates)	IS. 2002/62 IS. 2041/62 IS. 2100/62	BS. 14 (Marine boiler) BS. 1633 (Land boiler) BS. 1501	ASTM. A285 (C-Si Plates) ASTM. A212 (C-Si Plates) ASTM. A299 (Mn-V Plates) ASTM. A515 (Mn-Si Plates) ASTM. A30 (Loco Boilers) ASTM. A414 (sheets for boiler) ASTM. A131	ASTM. 201 (C-Si Plates) ASTM. A225 ASTM. A537	DIN. 17155	JIS. G. 3103
11.	Ship building Structural Steel	IS. 3039 IS. 2985	Lloyd Specns. (Grades A, B, C, D, E)			DIN. 1016	
12.	Cold forming/deep drawing/flanging steels	IS. 513	BS. 1449 Part 2B. (Plates) (EN 2A-DD EN 2A/1-EDD)	ASTM. A365 ASTM. A366 ASTM. A42 (Plates drawing and flanging quality)		DIN. 1623 (St. 12-DD) St. 13 DDO St.14-EDDO	JIS. G. 3310 (das 2 & 3-EDD) (das/DD) RRST. 1405 (DDO-Sheets)

**TABLE 4.7 SOME IMPORTANT INDIAN STANDARD SPECIFICATIONS WITH SIMILAR FOREIGN SPECIFICATION**  
(Contd)

Sl. No.	Type	Indian	British	American	Russian	German	Japanese
		IS. 1079	BS. 1449 Part 2A (Sheet) (EN 2A-DD, EN 2A/1-DDQ EN '2B-Flaming Quality)	ASTM. A415 ASTM. A425 ASTM. 569 (Drawing quality)		DIN. 1624 (St. 1, 2-DO St. 3-DDQ St. 4-EDDO)	JIS. G. 3141 (D. DD, EDDO) JIS. G. 3301 (All EDD) JIS. G. 3132
		IS. 3747 (Flaming and Pressing quality)	BS. 1449 (Strip and Skelp) Part 3A EN 2A-DD EN 2A/1-DDQ			TGL. 9553 (St. ZU GDR Sp. EDDO)	JIS. G. 3307, (Sheet Hoop), JIS. G. 3131 (SAPH-DO SPHC-DDO), Ten grade (EDD) JIS. G. 4051
13.	Carbon Constructional Steel (i) Bars for Machining	IS. 2073/62	BS. 970 (EN-3, 4, 5, 6, 8, 9, 14, 15, 41, 43, 49)	AISI. 1010 1012 1015 1020 1023 1025 1030 1033 1035 1038 1040 1041 1042 1045 1055 1060 1070 1080 1085 1095 1335 1340 1345 1078 1086		DIN. 17210 DIN. 1623	
	(ii) Bars for Forging	IS. 1875 (Semis) IS. 4369/67 (Bars)		ASTM. A73, ASTM. A235 ASTM. A236, ASTM. A273		DIN. 17222 (C 53, C 75) DIN. 1613 DIN. 1654	JIS. G. 3251, (Semis) JIS. G. 320, (Bars) JIS. G. 3505 (Wire rods) JISE. 1101, JISE. 1103, JISE. 1105 (Tram Rails)
14.	Rail Steel	IRS. T-12 IRS. T-18	BS. 11/59, (Flat bottom Rails)	ASTM. A1, ASTM. A2			

Note : While ordering for steel actual specifications may be ordered for details.



## EXAMPLES

X T 75 W 18 Cr 4 V — High alloy steel with average carbon 0.75 per cent, chromium 4 per cent and vanadium 1 per cent.

**Note** : Symbols indicating special characteristics are given in *IS : 1762 (part 1) - 1974*.

## 4.25 COMPARISON OF INDIAN &amp; OVERSEAS STANDARDS

A comparison of Indian and overseas standards for wrought steels for general engineering purposes has been compiled by the ISI. This comparison includes Indian, British, American (SAE, AISI, ASM and ASTM), German (DIN) and (Werkstoff), Japanese and Russian Standards for wrought steels. Some important Indian standard specifications with similar foreign specifications are given in Tables 4.7.

## 4.26 CLASSIFICATION OF STEELS BY SAE AND AISI

In USA, the Society of Automotive Engineers (SAE) have developed a classification scheme for steels based on chemical composition. The classification scheme consists of a four – or five-digit number. The first digit identify the type of steel (for example carbon steel is 1). The second digit identifies the approximate percentage of the prominent alloying metal, and the third and fourth digit together indicate the percentage of carbon in hundredth. American Iron and Steel Institute (AISI) adds a prefix denoting the manufacturing process of the metal and the new augmented

TABLE 4.8 SAE-AISI NUMERICAL DESIGNATION OF ALLOY STEEL

Car steel		Corrosion and heat resistant	
Plain carbon	10XX	Chromium	41XX
Free cutting	11XX	Chromium-nickel	43XX
Manganese steel	13XX	Nickel	46XX & 48XX
Nickel steels		Chromium steel	
0.5% nickel	20XX	Low chromium	50XX
1.5% nickel	21XX	Medium chromium	51XX
3.5% nickel	23XX	High chromium	52XX
Nickel-chromium steels			
1.25% nickel, 0.65% chromium	31XX	X-Represents per cent of carbon	
1.75% nickel, 1.00% chromium	32XX	in hundredth	

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code is implemented as their code. The manufacturing codes are ; B – Acid bessemer, carbon steel, C – Basic open hearth carbon steel, D – Acid open hearth carbon steel, E – Electric furnace alloy steel. Table 4.8 shows the scheme.

### REVIEW QUESTIONS

1. List the principal iron, and give the chemical symbol for each.
2. What are the raw materials and products of a blast furnace?
3. Describe a blast furnace.
4. What different kinds of iron are produced.
5. What are the constituents of cast iron and how do they vary in grey, white, malleable and nodular cast irons?
6. State the properties and uses of grey cast iron, white cast iron, malleable cast iron, chilled cast iron, spheroidal cast iron, alloy cast iron, and meehanite cast iron.
7. How are malleable iron castings made ?
8. How is spheroidal iron castings made ?
9. How is wrought iron made ?
10. List the elements in cast iron and wrought iron and state the influence of each.
11. What is the difference between cast iron, wrought iron & steel ?
12. What is smelting ? What is the use of coke and flux in smelting.
13. List advantages of using electric arc furnace for steel making.
14. How does a Bessemer converter refine steel ?
15. State the advantages of L.D. process of making steel.
16. Describe the process of making steel by open-hearth process.
17. What is the principle of operation of electric induction furnace ?
18. How does an electric arc furnace melt metal ?
19. How are steels classified ?
20. Give a list of various applications of carbon steel.
21. List the elements in steel and state the influence of each.
22. What is a bright steel ? State its advantages.
23. What is a free-cutting steel? State the applications and advantages of free-cutting steels.
24. What is alloy steel? why are alloying elements added to steel ?
25. Classify alloy steels.
26. State the effects of important alloying elements in steel.
27. Give a list of common alloy steels and state their uses.
28. What are the differences between killed steel and rimmed steel ? List them.
29. Write short notes on : (1) stainless steels, (2) high-speed steels, (3) cemented carbides, and (4) stellites.
30. State why cutting alloys are superior to high-speed steels.

## NONFERROUS METALS AND ALLOYS

### 5.1 INTRODUCTION

Nonferrous metals are those which do not contain iron as base. Their melting points are generally lower than that of ferrous metals. Nonferrous metals suffer generally from hot-shortness, possess low strength at high temperature, and their shrinkage is generally more than that of ferrous metals. Nonferrous metals are used for the following reasons :

1. Resistance to corrosion.
2. Special electrical and magnetic properties.
3. Softness and facility of cold working.
4. Fusibility and ease of casting.
5. Good formability.
6. Low density.
7. Attractive colour.

The principal nonferrous metals used in engineering purposes are : aluminium, copper, lead, tin, zinc, nickel, etc. and their alloys.

### 5.2 ALUMINIUM AND ITS ALLOYS

Aluminium is a white metal produced by electrical processes from the oxide (alumina), which is prepared from a clayey mineral called *bauxite*. In India they are chiefly available in Bihar, Madhya Pradesh, Karnataka, Maharashtra and Tamilnadu.

It is silvery-white in colour and extensively used where a light noncorrosive metal is desired as in aircraft and automobile components where the saving of weight is an advantage. In its pure state the metal would be weak and soft for most purposes, but when mixed with small amounts of other metals it becomes hard and rigid. So it may be blanked, formed, drawn, turned, cast, forged, and die-cast. Its good electrical

conductivity is an important property and aluminium is used for overhead cables. The high resistance to corrosion and its non-toxicity make it a useful metal for cooking utensils ; under ordinary conditions, water and air have practically no effect on it. Since pure aluminium is more corrosion resistant than any alloy of aluminium, a thin layer of pure aluminium is generally cladded on the sheets of aluminium alloy to eliminate corrosion. Again pure aluminium is not heat treatable. Aluminium alloy cladded by thin layer of aluminium can be heat treated. In this composite, the core containing aluminium alloy can be hardened. Roll bonding, a technique used for cladding sheets is shown in Fig. 5.1. Aluminium has the property of being beaten into foil and this aluminium foil is now widely used as silver foil. Aluminium metal of high purity have got high reflecting power and is, therefore, widely used for reflectors, mirror, and telescopes. The melting point of aluminium is  $658^{\circ}\text{C}$  and is having a specific gravity of 2.65.

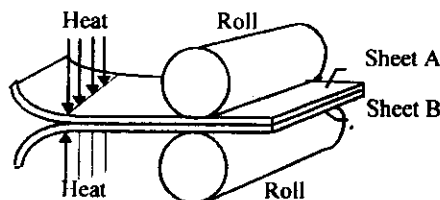


Figure 5.1 Roll bonding method

#### ALUMINIUM ALLOYS

Aluminium finds its widest uses when alloyed with small amounts of other metals. The addition of small quantities of other alloying elements converts this soft, weak metal into a hard and strong metal, while still retaining its light weight. Alloys can be classified as *cast* or *wrought*, both groups containing alloys that are age-hardened. The alloys in each of these two classes are further classified according to whether they respond to heat treatment of the strengthening type.

For the casting of general engineering use, aluminium is alloyed with small amounts of copper and zinc in the proportion of 12.5 to 14.5 per cent zinc and 2.5 to 3.0 per cent copper. An important series of casting and forging alloys having high strength have recently been developed for use in aeroplane construction. One example of such alloys is : zinc 5 per cent, magnesium 3 per cent, copper 2.2 per cent, nickel up to 1 per cent, aluminium the remainder.

An important and interesting wrought alloy is known as *duralumin*. This is composed of 3.5 to 4.5 per cent copper, 0.4 to 0.7 per cent