

FERROUS MATERIALS

4.1 INTRODUCTION

Engineering materials used to manufacture of articles or products, dictates which manufacturing process or processes are to be used to provide it the desired shape. Sometimes, it is possible to use more than one manufacturing processes, then the best possible process must be utilized in manufacture of product. It is therefore important to know what materials are available in the universe with it usual cost. What are the common characteristics of engineering materials such as physical, chemical, mechanical, thermal, optical, electrical, and mechanical? How they can be processed economically to get the desired product. The basic knowledge of engineering materials and their properties is of great significance for a design and manufacturing engineer. The elements of tools, machines and equipments should be made of such a material which has properties suitable for the conditions of operation. In addition to this, a product designer, tool designer and design engineer should always be familiar with various kinds of engineering materials, their properties and applications to meet the functional requirements of the design product. They must understand all the effects which the manufacturing processes and heat treatment have on the properties of the engineering materials. The general classification

4.2 CLASSIFICATION OF ENGINEERING MATERIALS

A large numbers of engineering materials exists in the universe such as metals and non metals (leather, rubber, asbestos, plastic, ceramics, organic polymers, composites and semi conductor). Some commonly used engineering materials are broadly classified as shown in Fig. 4.1. Leather is generally used for shoes, belt drives, packing, washers etc. It is highly flexible and can easily withstand against considerable wear under suitable conditions. Rubber is commonly employed as packing material, belt drive as an electric insulator. Asbestos is basically utilized for lagging round steam pipes and steam pipe and steam boilers because it is poor conductor of heat, so avoids loss of heat to the surroundings. Engineering materials may also be categorized into metals and alloys, ceramic materials, organic polymers, composites and semiconductors. The metal and alloys have tremendous applications for manufacturing the products required by the customers.

Metals and Alloys

Metals are polycrystalline bodies consisting of a great number of fine crystals. Pure metals possess low strength and do not have the required properties. So, alloys are produced by

melting or sintering two or more metals or metals and a non-metal, together. Alloys may consist of two more components. Metals and alloys are further classified into two major kind namely ferrous metals and non-ferrous metals.

- (a) Ferrous metals are those which have the iron as their main constituent, such as pig iron, cast iron, wrought iron and steels.
- (b) Non-ferrous metals are those which have a metal other than iron as their main constituent, such as copper, aluminium, brass, bronze, tin, silver zinc, invar etc.

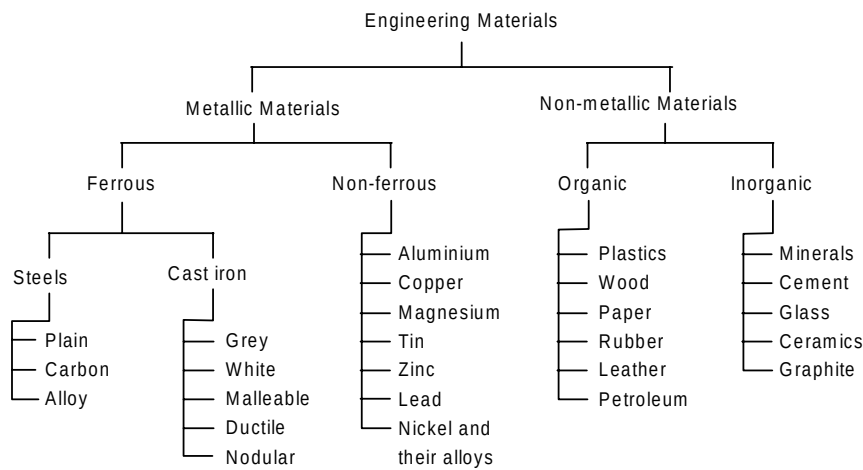


Fig. 4.1 Classification of engineering materials

4.3 FERROUS METALS

Ferrous metals are iron base metals which include all variety of pig iron, cast iron wrought iron and steels. The ferrous metals are those which have iron as their main constituents. The ferrous metals commonly used in engineering practice are cast iron, wrought iron, steel and alloy steels. The basic principal raw material for all ferrous metals is pig iron which is obtained by smelting iron ore, coke and limestone, in the blast furnace. The principal iron ores with their metallic contents are shown in Table 4.1.

Table 4.1 Types of Iron Ore

S.No.	Iron ore	Color	Iron %
1.	Haematite (Fe ₃ O ₄)	Red	70%
2.	Magnetite (Fe ₂ O ₃)	Black	72%
3.	Limonite	Brown	62.5%
4.	Siderite	Brown	48%

4.3.1 Main Types of Iron

- 1. Pig iron
- 2. Cast iron

- (A) White cast iron
- (B) Gray cast iron
- (C) Malleable cast iron
- (D) Ductile cast iron
- (E) Meehanite cast iron
- (F) Alloy cast iron
- 3. Wrought iron
- 4. Steel
 - (A) Plain carbon steels
 - 1. Dead Carbon steels
 - 2. Low Carbon steels
 - 3. Medium Carbon steels
 - 4. High Carbon steels
 - (B) Alloy steels
 - 1. High speed steel
 - 2. Stainless steel

Some important ferrous metals, their extraction, composition, properties and their common applications are discussed in detail as under.

4.3.2 Pig Iron

Pig iron was originated in the early days by reduction of iron ores in blast furnace and when the total output of the blast furnace was sand cast into pigs which is a mass of iron roughly resembling a reclining pig. It is roughly of 20" × 9" × 4" in size. It is produced in a blast furnace and is the first product in the process of converting iron ore into useful ferrous metal. The iron ore on initial refining and heating in blast furnace becomes pig iron when the impurities are burnt out in a blast furnace. Pig iron acts as the raw material for production of all kinds of cast iron and steel products. It is obtained by smelting (chemical reduction of iron ore in the blast furnace). It is of great importance in the foundry and in steel making processes. It is partly refined in a cupola furnace that produces various grades of cast iron. By puddling processes, wrought iron is produced from pig iron. Steel is produced from pig iron by various steel making processes such as bessemer, open-hearth, oxygen, electric and spray steel making. The charge in the blast furnace for manufacturing pig iron is

- (a) Ore Consisting of iron oxide or carbonate associated with earth impurities.
- (b) Coke A fuel
- (c) Limestone A flux

In addition to iron, pig iron contains various other constituents in varying form of impurity such as carbon, silicon, sulphur, manganese and phosphorus etc. It has the following approximate composition which is as given as under.

Carbon	—	4 to 4.5%	Phosphorus	—	0.1 to 2.0%
Silicon	—	0.4 to 2.0%	Sulphur	—	0.4 to 1.0%
Manganese	—	0.2 to 1.5 %	Iron	—	Remainder

Carbon exists in iron in free form (graphite) and/or in combined form (cementite and pearlite). Pig iron is classified on the basis of contents of free and combined carbon as follows. These classifications are also termed as grades.

1. Grey pig iron (Grades 1, 2 and 3)

Grey pig iron contains about 3% carbon in free form (i.e., graphite form) and about 1% carbon in combined form. This is a soft type of pig iron.

2. White pig iron (Grades 4)

White pig iron is hard and strong. It contains almost all of the carbon in the combined form.

3. Mottled pig iron (Grade 5)

This type of pig iron is in between the grey and white variety. It has an average hardness and mottled appearance. The free and combined forms of carbon are in almost equal proportion in mottled pig iron.

4.3.3 Cast Iron

Cast iron is basically an alloy of iron and carbon and is obtained by re-melting pig iron with coke, limestone and steel scrap in a furnace known as cupola. The carbon content in cast iron varies from 1.7% to 6.67%. It also contains small amounts of silicon, manganese, phosphorus and sulphur in form of impurities elements.

4.3.3.1 General properties of cast iron

Cast iron is very brittle and weak in tension and therefore it cannot be used for making bolts and machine parts which are liable to tension. Since the cast iron is a brittle material and therefore, it cannot be used in those parts of machines which are subjected to shocks. It has low cost, good casting characteristics, high compressive strength, high wear resistance and excellent machinability. These properties make it a valuable material for engineering purposes. Its tensile strength varies from 100 to 200 MPa, compressive strength from 400 to 1000 MPa and shear strength is 120 MPa. The compressive strength of cast iron is much greater than the tensile strength. The carbon in cast iron is present either of the following two forms:

1. Free carbon or graphite.
2. Combined carbon or cementite.

The cast iron is classified into seven major kinds as follows:

(a) Grey cast iron, (b) White cast iron, (c) Mottled cast iron (d) Malleable cast iron, (e) Nodular cast iron, (f) Meehanite cast iron. (g) Alloy cast iron and The chemical composition, extraction, properties and general applications of these types of cast iron are discussed as under.

4.3.3.2 Grey cast iron

Grey cast iron is grey in color which is due to the carbon being principally in the form of graphite (C in free form in iron). It contains:

$$C = 2.5 \text{ to } 3.8\%.$$

$$Si = 1.1 \text{ to } 2.8 \%$$

Mn = 0.4 to 1.0%
 P = less than 0.15%
 S = less than 0.1%
 Fe = Remaining

It is produced in cupola furnace by refining or pig iron.

Properties

- (i) When fractured it gives grey color.
- (ii) It can be easily cast.
- (iii) It is marked by presence of flakes of graphite in a matrix of ferrite and pearlite or austenite; graphite flakes occupy 10% of metal volume.
- (iv) It can be easily machined and possesses machinability better than steel.
- (v) It possesses lowest melting of ferrous alloys.
- (vi) It possesses high vibration damping capacity.
- (vii) It has high resistance to wear.
- (viii) It possesses high fluidity and hence can be cast into complex shapes and thin sections.
- (ix) It possesses high compressive strength.
- (x) It has a low tensile strength.
- (xi) It has very low ductility and low impact strength as compared with steel.

Applications

The grey iron castings are mainly used for machine tool bodies, automotive cylinder blocks, pipes and pipe fittings and agricultural implements. The other applications involved are

- (i) Machine tool structures such as bed, frames, column etc.
- (ii) Household appliances etc.
- (iii) Gas or water pipes for under ground purposes.
- (iv) Man holes covers.
- (v) Piston rings.
- (vi) Rolling mill and general machinery parts.
- (vii) Cylinder blocks and heads for I.C. engines.
- (viii) Frames of electric motor.
- (ix) Ingot mould. And
- (x) General machinery parts.
- (xi) Sanitary wares.
- (xii) Tunnel segment.

4.3.3.3 White cast iron

The white color is due to the fact that the carbon in this iron is in combined form as iron carbide which is commonly specified as cementite. It is the hardest constituent of iron. It is

produced in cupola furnace by refining or pig iron. The white cast iron may be produced by casting against metal chills or by regulating analysis. The chills are used when a hard and wear resistance surface is desired for products such as for wheels, rolls crushing jaw, crusher plates. The chemical composition of white cast iron is given as under.

C	= 3.2 to 3.6%
Si	= 0.4 to 1.1 %
Mg	= 0.1 to 0.4%
P	= less than 0.3%
S	= less than 0.2%
Fe	= Remaining

Properties

- (i) Its name is due to the fact that its freshly broken surface shows a bright white fracture.
- (ii) It is very hard due to carbon chemically bonded with iron as iron carbide (Fe_3C), which is brittle also.
- (iii) It possesses excellent abrasive wear resistance.
- (iv) Since it is extremely hard, therefore it is very difficult to machine.
- (v) Its solidification range is $2650\text{-}2065^\circ\text{F}$.
- (vi) Shrinkage is $1/8$ inch per foot.
- (vii) The white cast iron has a high tensile strength and a low compressive strength.

Applications

- (i) For producing malleable iron castings.
- (ii) For manufacturing those component or parts which require a hard, and abrasion resistant surface such as rim of car.
- (iii) Railway brake blocks.

4.3.3.4 Ductile cast iron

When small quantities of magnesium or cerium is added to cast iron, then graphite content is converted into nodular or spheroidal form and it is well dispersed throughout the material. The resulting structure possesses properties more like cast steel than like the other grades of cast iron. A typical structure of spheroidal cast iron is shown in Fig. 4.2. Graphite is in spheroidal form instead of in flaky form. Its structure may be modified by alloys or heat treatment, as in steel to produce austenite, acicular, martensite, pearlite, and ferrite structure. Compositions of ductile cast iron are as follows:

Carbon	= 3.2 to 4.2%
Silicon	= 1.0 to 4.0 %
Magnesium	= 0.1 to 0.8%
Nickel	= 0.0 to 3.5%
Manganese	= 0.5 to 0.1%
Iron	= Remaining

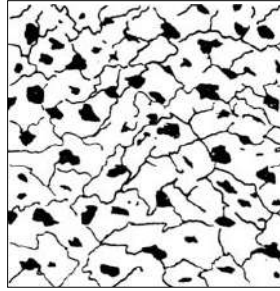


Fig. 4.2 Typical structure of spheroidal cast iron

Silicon is also used as an alloying element since it has no effect on size and distribution of carbon content. The magnesium controls the formation of graphite. But it has little influence on the matrix structure. Nickel and manganese impart strength and ductility. Ductile cast iron has high fluidity, excellent castability, strength, high toughness, excellent wear resistance, pressure tightness, weldability and higher machinability in comparison to grey cast iron.

4.3.3.5 Malleable cast iron

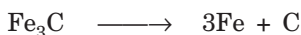
The ordinary cast iron is very hard and brittle. Malleable cast iron is unsuitable for articles which are thin, light and subjected to shock. It can be flattened under pressure by forging and rolling. It is an alloy in which all combined carbon changed to free form by suitable heat treatment. Graphite originally present in iron in the form of flakes which is the source of weakness and brittleness. Carbon in this cast iron is dispersed as tiny specks instead of being flaky or in combined form. The tiny specks have not such weakening effect and casting would not break when dropped. The tensile strength of this cast iron is usually higher than that of grey cast iron. It has excellent machining quality and is used for making machine parts for which the steel forging and in which the metal should have a fair degree of machining accuracy e.g., hubs of wagon, heels small fittings for railway rolling brake supports, parts of agricultural machinery, pipe fittings, hinges, locks etc.

It can be obtained by annealing the castings. The cast iron castings are packed in an oxidizing material such as iron ore or in an inert material such as ground fire clay depends upon the process used either white heart or black heart. The packed casting is put into an oven and is heated around 900°C temperature and is kept at that temperature for about two days and it is then allowed to cool slowly in the furnace itself. Iron ore acting as an oxidizing agent reacts with C and CO₂ escape. Thus annealed cast product is free from carbon. If the castings are packed in an inert material then slow cooling will separate out the combined carbon to temper carbon. To produce malleable casting, first casting is produced which has all combined carbon. The produced castings are then heat-treated in a special manner according to white heart method or black heart method.

White heart malleable iron casting

The castings taken out of the mould are put into a drum having sand and powdered slag. The drum is then closed and kept in the air furnace and it is raised to highly temperature slowly. The temperature is raised to 920°C in two days time, kept at this temperature for nearly up to 50 to 80 hours then the drum is allowed to cool in the furnace (generally air furnaces) at the rate 5 to 10°C per hour till it reaches to room temperature. The whole cycle takes about one week. During this treatment combined carbon separates out and all the

carbon does not change into graphite state but change in other form of free carbon called tempered carbon.



This makes the casting less brittle and malleable. The fracture portion of such a casting is dark grey or black in appearance. These castings are specially used in automobile industries.

Black heart malleable iron casting

The castings packed in a drum of oxidizing media which is generally powdered iron ore or powered scale (film of Fe_3O_4 on surface). This close drum is kept in the furnace and heated to 900°C . It is then maintained at this temperature to nearly 40 to 70 hours and allowed to cool slowly in a furnace itself. The castings become malleable like white heart cast iron. The percentage of carbon and silicon should be so selected that it can promote the development of free carbon when these castings are annealed.

Properties

1. Malleable cast iron is like steel than cast iron.
2. It is costly than grey cast iron and cheaper than softer steel.

Applications

Malleable cast iron are generally used to form automobile parts, agriculture implementation, hinges, door keys, spanners mountings of all sorts, seat wheels, cranks, levers thin, waned components of sewing machines and textiles machine parts.

4.3.3.6 Meehanite cast iron

Meehanite cast iron is an inoculated iron of a specially made white cast iron. The composition of this cast iron is graphitized in the ladle with calcium silicide. There are various types of meehanite cast iron namely heat resisting, wear resisting and corrosion resisting kind. These materials have high strength, toughness, ductility and good machinability. It is highly useful for making castings requiring high temperature applications.

4.3.3.7 Alloy cast iron

The cast irons as discussed above contain small percentages of other constituents like silicon, manganese, sulphur and phosphorus. These cast irons may be called as plain cast irons. The alloy cast iron is produced by adding alloying elements like nickel, chromium, molybdenum, copper and manganese in sufficient quantities in the molten metal collected in ladles from cupola furnace. These alloying elements give more strength and result in improvement of properties. The alloy cast iron has special properties like increased strength, high wear resistance, corrosion resistance or heat resistance. The alloy cast irons are extensively used for automobile parts like cylinders, pistons, piston rings, crank cases, brake drums, parts of crushing and grinding machinery etc.

4.3.3.8 Effect of impurities on cast iron

The cast iron contains small percentages of carbon, silicon, sulphur, manganese and phosphorus. The affect of these impurities on the cast iron are as follows:

- (1) **Carbon.** Carbon is one of the important elements in cast iron. It reduces melting point of iron. Pure iron has a melting point of about 1500°C but iron with 3.50% C has melting point of about 1350°C . When carbon is in free form i.e. as graphite form,

the resulting cast iron is known grey cast iron. On the other hand, when the iron and carbon are chemically combined form of cementite, the cast iron will be hard and known as white cast iron.

- (2) **Silicon.** Presence of silicon in cast iron promotes the decomposition of cementite into graphite. It also helps to reduce the shrinkage in cast iron when carbon is changed to graphite forms.
- (3) **Sulphur.** It makes the cast iron hard and brittle. Since too much sulphur gives unsound casting, therefore, it should be kept below 0.1% for most casting purposes. It is often responsible for creating troubles to foundry men. It will make cast iron hard thereby counteracting the softening influences of silicon. It decreases strength and increases brittleness. It also promotes oxidation of cast iron. Hence, it is kept as low as possible in cast iron.
- (4) **Manganese.** It makes cast iron white and hard. It is often kept below 0.75%. It helps to exert a controlling influence over the harmful effect of sulphur. It reduces the harmful effects of the sulphur by forming the manganese sulphide which is not soluble in cast iron.
- (5) **Phosphorus.** It increases fusibility and fluidity in cast iron but induces brittleness. It is rarely allowed to exceed 1 %. Phosphorus in irons is useful for casting of intricate shapes and for producing very cheap and light engineering castings. Phosphorus has no effect on the carbon as well as on shrinkage in the cast iron.

4.3.3.9 Comparison among grey, white and spherodidal cast iron

The comparison among grey, white and spherodidal cast iron is given in Table 4.2.

TABLE 4.2 Comparison among Grey, White and Spherodidal Cast Iron

S.No	Grey Cast Iron	White Cast Iron	Spherodidal Cast Iron
1.	It is an alloy of carbon and silicon with iron having grey color when fractured. It is marked by the presence of flakes of matrix of ferrite, pearlite or austenite. Carbon in iron exists in free form as graphite	White cast iron has almost all its carbon as iron carbide. Its broken surface shows a bright white fracture.	Graphite appears as around Particles or spheroids.
2	It has good machinability, high resistance to wear, high vibration damping capacity and high compressive strength.	It has poor machinability, excellent abrasive wear resistance.	It has good machinability, good damping, excellent castability and sufficient wear resistance
3	It is used in machine tool structure, Main-hole covers, cylinder blocks, heads for I.C. engines, gas or water pipes for underground purposes, frames for electric motors, piston rings and sanitary wares.	It is used for producing malleable iron castings and manufacturing those structural component parts which require a hard and abrasion resistant material.	It is used in I.C. engines, paper Industry machinery, machinery for farming and tractor, application, earth moving machinery, valve and fittings, pipes, pumps, compressors and construction machinery.

4.3.4 Wrought Iron

Wrought iron is the assumed approximately as purest iron which possesses at least 99.5% iron. It contains a large number of minute threads of slag lying parallel to each other, thereby giving the metal a fibrous appearance when broken. It is said as a mechanical mixture of very pure iron and a silicate slag. It can also be said as a ferrous material, aggregated from a solidifying mass of pasty particles of highly refined metallic iron with which a minutely and uniformly distributed quantity of slag is incorporated without subsequent fusion. This iron is produced from pig iron by re-melting it in the puddling furnace or air furnace or reverberatory furnace. The molten metal free from impurities is removed from the furnace as a pasty mass of iron and slag. The balls of this pasty mass, each about 45 to 65 kg in weight, are formed. These balls are then mechanically worked to squeeze out the slag and to form it into some commercial shape. This iron contains practically no carbon and therefore can not be hardened.

Chemical Composition

A chemical composition range of typical wrought iron includes:

C = 0.02 – 0.03%	P = 0.05 – 0.25%	Si = 0.02 – 0.10%
S = 0.008 – 0.02%	Mn = 0.0 – 0.02%	Slag = 0.05 – 1.5%
Fe = remainder		

Properties

The wrought iron can be easily shaped by hammering, pressing, forging, etc. It is never cast and it can be easily bent when cold. It is tough and it has high ductility and plasticity with which it can be forged and welded easily. Its ultimate strength can be increased considerably by cold working followed by a period of aging. It possesses a high resistance towards corrosion. It can accommodate sudden and excessive shocks loads without permanent injury. It has a high resistance towards fatigue. Its ultimate tensile strength is 2,500 kg/cm² to 5,000 kg/cm² and the ultimate compressive strength is 3,000 kg/cm². It can be elongated considerably by cold working. It has high electrical conductivity. The melting point of wrought iron is about 1530°C. It has elongation 20% in 200 mm in longitudinal direction and 2–5 % in transverse direction. Its poison's ratio is 0.30. It can be easily formed when cold, without the outer side cracking at the formed portion.

Applications

It is used for making chains, crane hooks, railway couplings, and water and steam pipes. It has application in the form of plates, sheets, bars, structural works, forging blooms and billets, rivets, and a wide range of tubular products including pipe, tubing and casing, electrical conduit, cold drawn tubing, nipples and welding fittings, bridge railings, blast plates, drainage lines and troughs, sewer outfall lines, weir plates, sludge tanks and lines, condenser tubes, unfired heat exchangers, acid and alkali process lines, skimmer bars, diesel exhaust and air brake piping, gas collection hoods, coal equipment, cooling tower and spray pond piping.

4.3.5 Steels

Steel is an alloy of iron and carbon with carbon content maximum up to 1.7%. The carbon occurs in the form of iron carbide, because of its ability to increase the hardness and strength of the steel. The effect of carbon on properties of steel is given in Fig. 4.3. Other elements e.g. silicon, sulphur, phosphorus and manganese are also present to greater or lesser amount to import certain desired properties to it. Most of the steel produced now-a-days is plain

carbon steel. Carbon steel has its properties mainly due to carbon content and does not contain more than 0.5% of silicon and 1.5% of manganese.

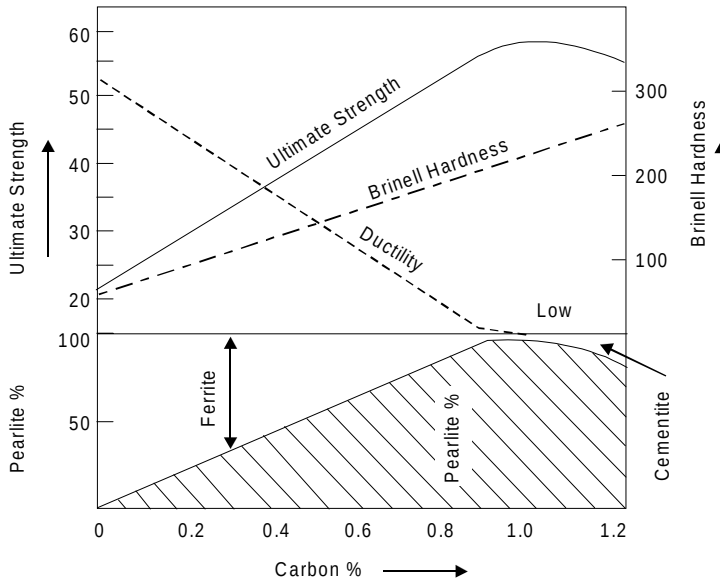


Fig. 4.3 Effect of carbon on properties of steel

For checking microstructure of steel, its specimen is prepared by preparing a flat mirror surface on small piece of metal through rubbing by sand papers, polishing and buffing etc. This surface is then followed by etching with a chemical solution. The chemical solution reacts with various constituents in varying degree to reveal crystal structure clearly. The revealed structure is then viewed through powerful microscope. The viewed micro structures for different steel are depicted in Fig. 4.4.

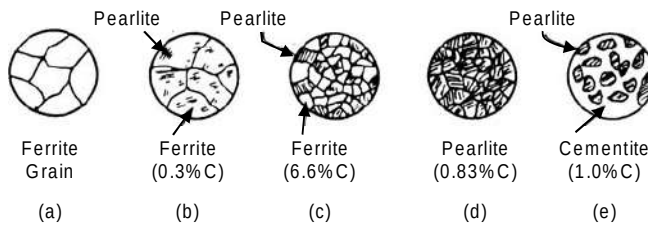


Fig. 4.4 Micro structure of steel

4.3.5.1 Effect of impurities on steel

The effects of impurities like silicon, sulphur, manganese and phosphorus, on steel as discussed under.

1. **Silicon.** Silicon content in the finished steel usually ranges from 0.05 to 0.30%. It is added in low carbon steels for preventing them from becoming porous. It helps in removing the gases and oxides. It prevents blow holes there by making steel tougher and harder.

2. **Sulphur.** It renders free cutting properties in steel. It is found in steel either as iron sulphide or manganese sulphide. Iron sulphide due to its low melting point, produces brittleness whereas manganese sulphide does not affect so much. Therefore, manganese sulphide is less objectionable in steel than iron sulphide.
3. **Manganese.** It serves as a valuable deoxidizing and purifying agent, in steel. Manganese also combines with sulphur and thereby decreases the harmful effect of this element remaining in the steel. It increases wear resistance, hardness and strength and decreases machineability. When used in ordinary low carbon steels, manganese makes the metal ductile and of good bending quantities. In high speed steels, it is used to toughen the metal and to increase its critical temperature.
4. **Phosphorus.** It induces brittleness in steel. It also produces cold shortness in steel. In low carbon steels, it raises the yield point and improves the resistance to atmospheric corrosion. The sum of carbon and phosphorus usually does not exceed 0.25%.

To produce needed improvement in properties of plain carbon steel, certain elements in steel are alloyed for specific purposes to increase wearing resistance, electrical and mechanical properties which cannot be obtained in plain carbon steels.

The steel may be of various kinds and few important types are explained as under.

4.3.5.2 Plain carbon steel

Plain carbon steel is an alloy of iron and carbon. It has good machineability and malleability. It is different from cast iron as regards the percentage of carbon. It contains carbon from 0.06 to 1.5% whereas cast iron possesses carbon from 1.8 to 4.2%. Depending upon the carbon content, a plain carbon steels can divided to the following types:

- | | | |
|-----------------------------|---|-----------------------|
| 1. Dead carbon steel | — | up to 0.15% carbon |
| 2. Low carbon or mild steel | — | 0.15% to 0.45% carbon |
| 3. Medium carbon steel | — | 0.45% to 0.8% carbon |
| 4. High carbon steel | — | 0.8% to 1.5% carbon |

Each type is discussed as under.

DEAD CARBON STEEL

It possesses very low percentage of carbon varying from 0.05 to 0.15%. It has a tensile strength of 390 N/mm² and a hardness of about 115 BHN. Steel wire, sheets, rivets, screws, pipe, nail and chain are made from this steel. This steel is used for making camshafts, sheets and strips for fan blades, welded tubing, forgings, chains, stamping, rivets, nails, pipes, automobile body etc.

LOW CARBON OR MILD STEEL

Low carbon steel is sometimes known as mild steel also. It contains 0.20 to 0.30% C which has tensile strength of 555 N/mm² and hardness of 140 BHN. It possesses bright fibrous structure. It is tough, malleable, ductile and more elastic than wrought iron. It can be easily forged and welded. It can absorb shocks. It rusts easily. Its melting point is about 1410°C. It is used for making angle, channels, case hardening steel, rods, tubes, valves, gears, crankshafts, connecting rods, railway axles, fish plates, small forgings, free cutting steel shaft and forged components etc.

Applications

1. Mild steel containing 0.15 to 0.20% carbon

It is used in structure steels, universal beams, screws, drop forgings, case hardening steel, bars, rods, tubes, angles and channels etc.

2. Mild steel containing 0.20-0.30% carbon

It is used in making machine structure, gears, free cutting steels, shafts and forged components etc.

MEDIUM CARBON STEELS

Medium carbon steel contains carbon from 0.30 to 0.8%. It possesses having bright fibrous structure when fractured. It is tough and more elastic in comparison to wrought iron. It can be easily forged, welded, elongated due to ductility and beaten into sheets due to its good malleability. It can easily absorb sudden shocks. It is usually produced as killed or semi killed steels and is harden able by treatment. Hardenability is limited to thin sections or to the thin outer layer on thick parts. Its tensile strength is better than cast iron and wrought iron but compressive strength is better than wrought iron but lesser than cast iron. It rusts readily. Its melting point is 1400°C. It can be easily hardened and it possesses good balance of strength and ductility.

It is generally used for making railway coach axles, bolts, connecting rods, key stock, wires and rods, shift and break levers, spring clips, gear shafts, small and medium forgings, railway coach axles, crank pins on heavy machines, spline shafts, crankshafts, forging dies, set screws, die blocks, self tapping screws, clutch discs, valve springs, plate punches, thrust washers etc. The applications of different kinds of medium carbon steel are given as under.

Applications

1. **Plain carbon steels having carbon % 0.30 to 0.45.** Axles, special duty shafts, connecting rods, forgings, machinery steel, spring clips, turbine, rotors, gear shafts, key stock, forks and bolts.
2. **Plain carbon steels having carbon % 0.45 to 0.60.** Railway coach axles, crank pins, crankshafts, axles, spline shafts, loco tyres.
3. **Plain carbon steels having carbon % 0.60 to 0.80.** Drop forging dies, die blocks, bolt heading dies, self-tapping screws, valve spring, lock washers, hammers, cold chisels, hacksaws, jaws for vices etc.

HIGH CARBON STEELS

High carbon steels (**HCS**) contain carbon from 0.8 to 1.5%. Because of their high hardness, these are suitable for wear resistant parts. Spring steel is also high carbon steel. It is available in annealed and pre-tempered strips and wires. High carbon steel loses their hardness at temperature from 200°C to 250°C. They may only be used in the manufacture of cutting tools operating at low cutting speeds. These steels are easy to forge and simple to harden. These steels are of various types which are identified by the carbon percentage, hardness and applications

HCS containing 0.7 to 0.8% carbon possesses hardness of 450-500 BHN. It has application for making cold chisels, drill bits, wrenches, wheels for railway service, jaws for vises, structural wires, shear blades, automatic clutch discs, hacksaws etc.

Steel containing 0.8 to 0.9% C possesses hardness of 500 to 600 BHN. This steel is used for making rock drills, punches, dies, railway rails clutch discs, circular saws, leaf springs, machine chisels, music wires,

Steel containing 0.90 to 1.00% carbon is also known as high carbon tool steel and it possesses hardness of 550-600 BHN. Such steel is used for making punches, dies, springs keys and shear blades.

Steel containing 1.0 to 1.1 % C is used for making railway springs, mandrels, taps, balls, pins, tools, thread metal dies.

Steel containing 1.1 to 1.2% C is used for making taps, twist drills, thread dies, knives.

Steel containing 1.2 to 1.3% carbon is used for making files, reamers Files, dies for wire drawing, broaches, saws for cutting steel, tools for turning chilled iron.

Cutting tool materials imply the materials from which various lathe tools or other cutting tools are made. The best tool material to use for a certain job is the one that will produce the machined part at the lowest cost. To perform good during cutting, the tool material should possess the following properties for its proper functioning.

1. A low coefficient of friction between tool material and chip material.
2. Ability to resist softening at high temperature.
3. Ability to absorb shocks without permanent deformation.
4. Sufficient toughness to resist fracture and bear cutting stresses.
5. Strength to resist disintegration of fine cutting edge and also to withstand the stresses developed, during cutting, in the weakest part of the tool.
6. High hardness that means tool must be harder than the material being cut.

According to Indian standard IS 1570-1961, plain carbon steels are designated by the alphabet 'C' followed by numerals which indicate the average percentage of carbon in it. For example C40 means a plain carbon steel containing 0.35% to 0.45% C (0.40% on average), although other elements like manganese may be present. In addition to the percentage of carbon, some other specification may include e.g. C55Mn75 means the carbon content lies between 0.50% to 0.60% and the manganese content lies between 0.60 to 0.90%. It may be noted that only average contents are specified in such designation of steel.

4.3.5.3 Alloy steel

For improving the properties of ordinary steel, certain alloying elements are added in it in sufficient amounts. The most common alloying elements added to steel are chromium, nickel, manganese, silicon, vanadium, molybdenum, tungsten, phosphorus, copper, that the titanium, zirconium, cobalt, columbium, and aluminium. Each of these elements induces certain qualities in steels to which it is added. They may be used separately or in combination to produce desired characteristics in the steel. The main purpose of alloying element in steel is to improve machinability, elasticity, hardness, case hardening, cutting ability, toughness, wear resistance, tensile strength, corrosion resistance, and ability to retain shape at high temperature, ability to resist distortion at elevated temperature and to impart a fine grain size to steel. Like carbon, a number of alloying elements are soluble to produce alloys with improved strength, ductility, and toughness. Also carbon, besides forming an inter-metallic compound with iron, combines with many alloying elements and form 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. The addition of alloying elements almost always affects the austenite-ferrite transformation mechanism. 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 steel.

4.3.5.4 Effect of alloying elements in steel

The chief alloying elements used in steel are nickel, chromium, molybdenum, cobalt, vanadium, manganese, silicon and tungsten. Each of these elements possesses certain qualities upon the steel to which it is added. These elements may be used separately or in combination to produce the desired characteristic in steel. Following are the effects of alloying elements on steel.

1. **Nickel.** Steels contain 2 to 5% nickel and from 0.1 to 0.5% carbon increase its strength and toughness. In this range, nickel contributes great tensile strength, yield strength, toughness and forming properties and hardness with high elastic limit, good ductility and good resistance to corrosion. An alloy containing 25% nickel possesses maximum toughness and offers the greatest resistance to rusting, corrosion and burning at high temperature. It has proved beneficial in the manufacture of boiler tubes, valves for use with superheated steam, valves for I.C. engines and sparking plugs for petrol engines. A nickel steel alloy containing 36% of nickel is known as invar. It has nearly zero coefficient of expansion. Therefore, it is in great demand for making measuring instruments for everyday use.
2. **Chromium.** It improves corrosion resistance (about 12 to 18% addition). It increases tensile strength, hardness, wear resistance and heat resistance. It provides stainless property in steel. It decreases malleability of steel. It is used in steels as an alloying element to combine hardness with high strength and high elastic limit. It also imparts corrosion resisting properties to steel. The most common chrome steels contain from 0.5 to 2% chromium and 0.1 to 1.5% carbon. The chrome steel is used for balls, rollers and races for bearings. A Nickel-Chrome steel containing 3.25% nickel, 1.5% chromium and 0.25% carbon is much used for armour plates. Chrome nickel steel is extensively used for motor car crank shafts, axles and gears requiring great strength and hardness.
3. **Tungsten.** It increases hardness, wear resistance, shocks resistance and magnetic reluctance. It increases ability to retain hardness and toughness at high temperature. It prohibits grain growth and increases wear resistance, shock resistance, toughness, and the depth of hardening of quenched steel. The principal uses of tungsten steels are for cutting tools, dies, valves, taps and permanent magnets.
4. **Vanadium.** It improves tensile strength, elastic limit, ductility, fatigue resistance, shock resistance and response to heat treatment. It also acts as a degasser when added to molten metal. It aids in obtaining a fine grain structure in tool steel. The addition of a very small amount of vanadium (less than 0.2%) produces a marked increase in tensile strength and elastic limit in low and medium carbon steels without a loss of ductility. The chrome- vanadium steel containing about 0.5 to 1.5% chromium, 0.15 to 0.3% vanadium and 0.13 to 1.1% carbon have extremely good tensile strength, elastic limit, endurance limit and ductility. These steels are frequently used for parts such as springs, shafts, gears, pins and many drop forged parts.

5. **Molybdenum.** A very small quantity (0.15 to 0.30%) of molybdenum is generally used with chromium and manganese (0.5 to 0.8%) to make molybdenum steel. It increases hardness, wear resistance, thermal resistance. When added with nickel, it improves corrosion resistance. It counteracts tendency towards temper brittleness. It makes steel tough at various hardness levels. It acts as a grain growth inhibitor when steels are heated to high temperatures. Molybdenum steels possess hardness, wear resistance, thermal resistance and extra tensile strength. It is used for airplane fuselage and automobile parts. It can replace tungsten in high speed steels.
6. **Cobalt.** When added to steel, it refines the graphite and pearlite and acts as a grain refiner. It improves hardness, toughness, tensile strength and thermal resistance.
7. **Titanium.** It acts as a good deoxidizer and promotes grain growth. It prevents formation of austenite in high chromium steels. It is the strongest carbide former. It is used to fix carbon in stainless steels and thus prevents the precipitation of chromium carbide.
8. **Aluminium.** It is used as a deoxidizer. If present in an amount of about 1 %, it helps promoting nitriding.
9. **Copper.** It improves resistance to corrosion. It increases strength. More than 0.6 per cent copper for precipitation.
10. **Silicon.** It improves magnetic permeability and decreases hysteresis losses. It decreases weldability and forgeability. It is also added as a deoxidizer during casting of ingots. It takes care of oxygen present in steel by forming SiO_2 . Silicon steels behave like nickel steels. These steels have a high elastic limit as compared to ordinary carbon steel. Silicon steels containing from 1 to 2% silicon and 0.1 to 0.4% carbon and other alloying elements are used for electrical machinery, valves in I.C. engines, springs and corrosion resisting materials.
11. **Manganese.** It improves the strength of the steel in both the hot rolled and heat treated condition. The manganese alloy steels containing over 1.5% manganese with a carbon range of 0.40 to 0.55% are used extensively in gears, axles, shafts and other parts where high strength combined with fair ductility is required. The principal use of manganese steel is in machinery parts subjected to severe wear. These steels are all cast and ground to finish.
12. **Carbon.** It increases tensile strength and hardness. It decreases ductility and weldability. It affects the melting point.

4.3.5.5 Free cutting steel

The important features of free cutting steels are their high machinability and high quality surface finish after finishing. These properties are due to higher sulphur and phosphorus. Sulphur exists in the form of manganese sulphide (MnS) which forms inclusions in steel. These inclusions promote the formation of discontinuous chips and also reduce friction on the surface being machined so produces good surface finish easily. Phosphorus is dissolved in the ferrite and increases hardness and brittleness. Lead up to 0.35% can be added to improve the machinability of steel. These have high sulphur content present in form of manganese sulphide inclusions causing the chips to break short on machining. Mn and P make steel hardened and brittle. Lead (0.2% to 0.35%) is sometimes added to steel improving machinability properties of steel. This consists of three Bessemer grades B1111, B1112, B1113 which differ in sulphur content and the sulphurised steels from C1108 to C1151. 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. However, it must be noted 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 or work hardened form. These cold drawn steels have a high tensile strength and hardness but less ductile when compared to other kind of steels.

Applications of free cutting steel

These steels are used for manufacturing axles, bolts, screws, nuts, special duty shafts, connecting rods, small and medium forgings, cold upset wires and rods, solid turbine rotors, rotor and gear shaft, armature, key stock, forks and anchor bolts screw stock, spring clips, tubing, pipes, light weight rails, concrete reinforcing etc.

4.3.5.6 Nickel steel

The percentage of Nickel varies from 2 to 45 in steel. Steel having 2% Ni makes steel more suitable for rivets, boiler plates, bolts and gears etc. Steel having Ni from 0.3 to 5% raises elastic limit and improves toughness. Steel containing Nickel has very high tensile strength. Steel having 25% Ni makes it stainless and might be used for I.C. engine turbine blade etc. If Ni is present up to 27%, it makes the steel non-magnetic and non-corrodible. Invar (Ni 36%) and super-invar (Ni 31%) are the popular materials for least coefficient of expansion and are used for measuring instruments, surveyor tapes and clock pendulums. Steel having 45% Ni steel possesses extension equal to that of glass, a property very important making links between the two materials i.e. in electronic valves and bulbs.

4.3.5.7 Vanadium steel

Vanadium when added even in small proportion to an ordinary low carbon increases significantly its elastic limit and fatigue resistance property. Vanadium makes steel strong and tough. When vanadium is added up to 0.25%, the elastic limit of the steel is raised by 50% can resist high alternating stresses and severe shocks.

Applications

1. It is widely used for making tools.
2. It can also be used for shafts, springs, gears, steering knuckles and drop forged parts

4.3.5.8 Manganese steel

Manganese when added in steel between 1.0 to 1.5% makes it stronger and tougher. Manganese between 1.5 to 5% in steel makes it harder and more brittle. 11 to 14% manganese in steel with carbon 0.8 to 1.5% makes it very hard, tough, non-magnetic and possesses considerably high tensile strength. Manganese steel may be forged easily but it is difficult to machine and hence it is usually ground. It is weldable and for welding it, a nickel manganese welding rod is used.

Applications

1. Because of work hardening, it is suitable for jaws of stone and ore crushers, grinding plants, tramway and railway points and crossing etc.
2. Manganese steel in the form of bars is now widely used for screening coke.
3. It is also used for helmets and shields.
4. It is used for agricultural implements such as shovels etc.

4.3.5.9 Tungsten Steel

Tungsten when added to steel improves its magnetic properties and hardenability. When tungsten is added to an extent of 6% to high carbon steel, it retains the magnetic properties to high degree and produce field more intense than ordinary steel. Steel having 8% tungsten gives sufficient hardness to it to scratch even glass.

Applications

It is used for making permanent magnets and high speed cutting tools.

4.3.5.10 Silicon steel

Silicon addition improves the electrical properties of steel. It also increases fatigue strength and ductility.

Applications

1. Steel with
Mn = 1 %, Si = 2% and C = 0.4 to 0.6%
has very high elastic limit and is used for springs.
2. Steel containing 5 to 7% silicon
retains its hardness and resistance to oxidation at high temperature. It is used for making internal combustion engines.
3. Steel possessing 13% Si has a very high corrosion resistance and it can be used in chemical industrial applications.
4. Steel possessing 1% Si and up to 0.95% Mn is suitable for structural purposes.

4.3.5.11 Magnetic steels

Steels having 15 to 40% Co, 0.4 to 1 % C, 1.5 to 9% Cr, 0-10% W and remaining Fe possesses very good magnetic properties. High Cobalt steels, when correctly heat treated, are frequently used in the making of permanent magnets for magnetos, loud speakers and other electrical machines. An important permanent magnet alloy called Alnico contains approximately 60% Iron, 20% Nickel, 8% Cobalt and 12% Aluminium. This alloy cannot be forged and is used as a casting hardened by precipitation heat treatment.

4.3.5.12 Heat resisting steels

Heat resisting steels are practically suitable for working at even very high temperatures. Such steels must resist the influences which lead to failure of ordinary steels when put to work under high temperatures. Alloy steel containing 23-30% chromium with less than 0.35% C are mainly used to impart heat resisting service in the temperature range between 815-1150 °C. The furnace parts and annealing boxes are generally made by this steel. These steels are particularly suitable for working at high temperatures and are thus stable at high temperatures. A steel containing chromium, nickel and tungsten, with the carbon content suitably controlled provide useful combination of non-scaling and strength retaining properties at high temperature. Such steels can work satisfactory up to 700°C and contains 0.15% C, 0.5 to 2 % Si, 0.5% Mn, 1.0 to 6%, Cr and 0.5%. Mo.

Applications

These are used in nuclear power plant, furnaces, supersonic aircrafts, missiles, annealing boxes etc.

4.3.5.13 Spring steels

Spring steels are used for the making springs. Various types of these steel along with their composition and uses are discussed as under.

- (i) **Carbon-manganese spring steels.** This type of steel contains

C = 0.45 to 0.6, Si = 0.1 to 0.35% and Mn = 0.5 to 1.0%.

These steels are quenched and tempered up to 350 BHN. They are widely used for laminated springs for railway and general purposes.

- (ii) **Hyper-eutectoid spring steels.** This type of steel contains

C = 0.9 to 1.2%, 0.3% (max) and Mn = 0.45 to 0.70%.

These steels are oil quenched and tempered at low temperature. This type of steel is used for volute and helical springs.

- (iii) **Silicon-manganese spring steels.** This type of steel contains

C = 0.3 to 0.62%, Si = 1.5 to 2% and Mn = 0.6 to 1 %.

These steels are hardened and tempered. This type of steel is used for the manufacturing of railway and road springs generally.

4.3.5.14 Structural steels

Structural steels possess high strength and toughness, resistance to softening at elevated temperatures and enough resistance to corrosion. In addition, they should possess weldability, workability and high hardenability. The principal alloying elements in structural steels are chromium, nickel and manganese. These steels has various applications which are given as under:

Applications

They are used for structural members of bridges, buildings, rail road, cars etc. They are also used for manufacturing components subjected to static and dynamic loads. These components include valves, pins, studs, gears, clutches, bushes, shafts etc.

4.3.5.15 Stainless steel

Stainless steel contains chromium together with nickel as alloy and rest is iron. It has been defined as that steel which when correctly heat treated and finished, resists oxidation and corrosive attack from most corrosive media. Stainless steel surface is responsible for corrosion resistance. Minimum chromium content of 12% is required for the film's formation, and 18% is sufficient to resist the most severe atmospheric corrosive conditions. Their principal alloying element is chromium while some other elements like nickel, manganese etc. can also be present in small amounts. Addition of nickel improves ductility and imparts strength. Corrosion resistance to stainless steels increases with increase in nickel content against neutral chloride solution and weakly oxidizing acids. Addition of molybdenum improves its resistance to sulphuric, sulphurous and organic acids. Addition of manganese increases hot workability of these steels.

Steels having 15 to 20% Ni and about 0.1 % carbon possesses great strength and toughness and extremely good resistance to corrosion. Such steels are called stainless steels. Another type of stainless steel containing 11 to 14% chromium and about 0.35% carbon is used for cutlery, surgical and dental instruments and other purposes where hard edges are required. Maximum resistance to corrosion is obtained when this steel is ground and polished after heat-treating.

A steel containing 18% chromium and 8% nickel is widely used and is commonly referred to as 18/8 steel. Stainless steel is highly resistance to corrosion and oxidation. It can be classified into three major categories according to the type of micro structures.

General Properties of Stainless Steels

It possesses wide range of strength and hardness, high ductility, formability, high corrosion resistance, good creep resistance, good thermal conductivity, good machinability, good weldability, high hot, cold workability, high resistance to scaling and oxidation at elevated temperatures, excellent surface appearance and finish.

Classification of Stainless Steel

On basis of their structure, stainless steels are classified as follow:

1. Martensitic stainless steels
2. Ferritic stainless steels
3. Austenitic stainless steels.

These types of stainless steel are discussed as under.

Martensitic Stainless Steels

These steels contain 12 to 16% chromium and 0.1 to 1.2 per cent carbon. The structure consists of hard martensite phase after hardening. The general utility chromium stainless steel with 12% chromium and 0.15% carbon are ferromagnetic and air hardening. It is very hard and possesses high strain and high corrosion resistance properties.

Applications

Stainless steels containing 12 to 14% chromium and 0.3% carbon are extensively used for table cutlery, tools and equipments etc. Stainless steels containing 16-18% chromium and 0.2% carbon are used as springs, ball bearing, valves, knife blades and instruments under high temperature and corrosive conditions. These steels are generally used for making utensils, surgical and dental instruments, and springs of high temperature operations, ball valves and toilet seats.

Ferritic Stainless Steels

Ferritic stainless steels are non hardenable and contain 16 to 30% chromium and 0.08 to 0.2 per cent carbon. Structure of these steel consists of ferrite phase which cannot be hardened by heat treatment. They have very low carbon and possess considerable ductility, ability to be worked hot or cold, excellent corrosion resistance and are relatively in expensive. They are always magnetic and retain their basic microstructure up to the melting point.

Applications

These are extensively used for kitchen equipment, dairy machinery interior decorative work, automobile trimmings, chemical engineering industry, stainless steel sinks, food containers, refrigerator parts, beer barrels, automobile trimming etc. These are also used as high temperature furnace parts when chromium content is high.

Austenitic Stainless Steel

Addition of substantial quantities of Ni to high Cr alloys gives rise to, austenitic steel. It has good resistance to many acids (even hot or cold nitric acid). Slight amount of W and Mo are added in such steels to increase its strength at elevated temperatures. This steel

contains 16 to 24% Cr, 8 to 22% Ni and less than 0.2% C. Addition of nickel stabilizes austenite, and hence the structure of these steels consists of austenite at room temperature. A steel containing 18% Cr and 8% Ni is very widely used and is commonly referred to as 18/8 stainless steel. These steels do not harden by heat treatment but can be rolled hard. These steels possess a brilliant luster when polished. These are highly resistant to many acids even nitric acids. The heat conductivity of steel is low, about 5% that of copper. Tungsten and molybdenum are added to increase the strength at elevated temperatures, silicon and aluminium to improve the resistance to scaling and selenium and sulphur are added to improve machinability. This steel is easily weldable. After welding, it is susceptible to corrosive attack in the area adjacent to the weld.

Applications

It is used for making heat exchangers, conveyors chains, furnaces, spokes, brewery, dairy and chemical industrial components, cutlery parts, surgical and dental instruments, household appliances such as kitchen utensils, sinks and saucepans. These are also used in making components in power stations, especially in nuclear power stations, steam pipes, boiler tubes, radiator and super heater tubes.

4.3.5.16 High speed steels

High Speed Steels (HSS) have been given this name due to the fact that these steels may be operated as cutting tools at much higher speeds that are possible with plain carbon tool steel. High speed steels cutting tools operate at cutting speed 2 to 3 times higher than for High carbon steels. At higher cutting speeds, sufficient heat may be developed during the cutting process. This heat causes the cutting edge of the tool to reach a high heat (red heat). This heat softens the carbon tool steel and thus the tool will not work efficiently for a longer period. These steels have the property of retaining their hardness even when heated to red heat. High hardness at elevated temperatures is developed by addition of elements such as tungsten, chromium vanadium to high carbon steels. These steel are generally used for making lathe cutting tools, planner cutting tools, shaper cutting tools, slotting cutting tools, drills, reamers, broaches, milling cutter and punches. There are four general types of high speed steels used in machine shop.

1. High speed steel (18:4:1)

High speed steels (HSS) are most commonly operated as cutting tools at much higher speed i.e. twice or thrice where as tool steel. It is the most common kind of cutting tool. It contains 18% tungsten, 4% chromium and 1 % vanadium, 0.8 carbon and remaining iron. It is considered to be one of the best of all purpose tool steels. This brand of high speed steel is used for machining operations on steel and non-ferrous materials. This is generally used for lathe, planer and shaper tools, drills, millings cutters, punches etc.

2. Molybdenum based high speed steel

It contains 6% Mo, 6% W, 4% Cr, 2% V, 0.8% C and remaining Fe. It has excellent toughness and cutting ability. Molybdenum high speed steels are cheaper than other types of steels and are particularly used for drilling and tapping tools. These steels are also used for making rough cutting tools, lathe tools and various kinds of milling cutters.

3. Cobalt based high speed steel

It contains 1 to 12% Co, 20% W, 4% Cr, 2% V, 0.8 carbon and remaining iron. This is also known as super high speed steel, because cutting tool made of this steel can be operated

at much higher speeds in comparison to high speed steel of 18:4:1 kind. In this steel, cobalt is added from 2 to 15 per cent in order to increase the cutting efficiency especially at high temperature. Cobalt high speed steel generally contains 20% W, 4% Cr, 2% V and 12% Co and remaining Fe. Since the cost of this steel is more, therefore, it is principally used for making cutting tools for heavy operations which impose high pressure and temperature on the tool. It is extensively used for making high production tools of heavy work for high production lathe, planer, shaper, milling and boring machine.

4. Vanadium High Speed Steel

Generally, this steel contains more than 1% V and 0.70% C. This steel possesses better abrasive resistance in comparison to normal HSS type steel. It is preferred for machining materials which are highly difficult to machine by conventional means. These steels cutting tools are close competitors of carbides cutting tools such as drills, reamers, milling cutters etc. In addition to having heat resistance properties of high speed steels possesses desirable properties of high hardness, high compressive strength and outstanding wear resistance.

4.3.5.17 Availability of steel in market

Steel are available in market in various rolled forms like sheets, plates, strips, rods, beams, channels, angles, tees etc. The common structural shapes for market form of supply are reflected in Fig. 4.5. Steels are generally identified, coded and designated according to suitable standards by a group of symbols indicating the important characteristics.

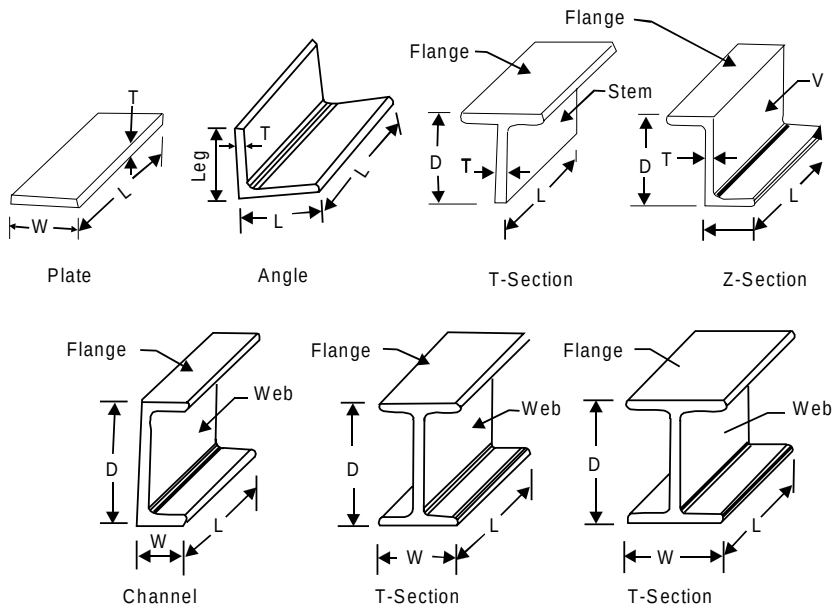


Fig. 4.5 Market forms of steel structure shapes

4.3.5.18 Designation of steels

Bureau of Indian Standards (BIS) designates the various grades of steels by a system of codification which bears direct relationship with the important characteristics of steel such as