CHAPTER 2

Engineering Materials and their Properties

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2.1 Introduction

The knowledge of materials and their properties is of great significance for a design engineer. The machine elements should be made of such a material which has properties suitable for the conditions of operation. In addition to this, a design engineer must be familiar with the effects which the manufacturing processes and heat treatment have on the properties of the materials. In this chapter, we shall discuss the commonly used engineering materials and their properties in Machine Design.

2.2 Classification of Engineering Materials

The engineering materials are mainly classified as :

1. Metals and their alloys, such as iron, steel, copper, aluminium, etc.
2. Non-metals, such as glass, rubber, plastic, etc.

The metals may be further classified as :

(*a*) Ferrous metals, and (*b*) Non-ferrous metals.

The *__ferrous metals__* are those which have the iron as their main constituent, such as cast iron, wrought iron and steel.

The __non-ferrous__ metals are those which have a metal other than iron as their main constituent, such as copper, aluminium, brass, tin, zinc, etc.

A filament of bulb needs a material like tungsten which can withstand high temperatures without undergoing deformation.

2.3 Selection of Materials for Engineering Purposes

The selection of a proper material, for engineering purposes, is one of the most difficult problem for the designer. The best material is one which serve the desired objective at the minimum cost. The following factors should be considered while selecting the material :

1. Availability of the materials,
2. Suitability of the materials for the working conditions in service, and
3. The cost of the materials.

The important properties, which determine the utility of the material are physical, chemical and mechanical properties. We shall now discuss the physical and mechanical properties of the material in the following articles.

Valuable Metals

2.4 Physical Properties of Metals

The physical properties of the metals include luster, colour, size and shape, density, electric and thermal conductivity, and melting point. The following table shows the important physical properties of some pure metals.

* The word 'ferrous' is derived from a latin word 'ferrum' which means iron.

Table 2.1. Physical properties of metals.

Metal	*Density* (kg/m^3)	*Melting point* (°C)	*Thermal conductivity* (W/m°C)	*Coefficient of linear expansion at 20°C* (μm/m/°C)
Aluminium	2700	660	220	23.0
Brass	8450	950	130	16.7
Bronze	8730	1040	67	17.3
Cast iron	7250	1300	54.5	9.0
Copper	8900	1083	393.5	16.7
Lead	11 400	327	33.5	29.1
Monel metal	8600	1350	25.2	14.0
Nickel	8900	1453	63.2	12.8
Silver	10 500	960	420	18.9
Steel	7850	1510	50.2	11.1
Tin	7400	232	67	21.4
Tungsten	19 300	3410	201	4.5
Zinc	7200	419	113	33.0
Cobalt	8850	1490	69.2	12.4
Molybdenum	10 200	2650	13	4.8
Vanadium	6000	1750	—	7.75

2.5 Mechanical Properties of Metals

The mechanical properties of the metals are those which are associated with the ability of the material to resist mechanical forces and load. These mechanical properties of the metal include strength, stiffness, elasticity, plasticity, ductility, brittleness, malleability, toughness, resilience, creep and hardness. We shall now discuss these properties as follows:

1. ***Strength.*** It is the ability of a material to resist the externally applied forces without breaking or yielding. The internal resistance offered by a part to an externally applied force is called *stress.

2. ***Stiffness.*** It is the ability of a material to resist deformation under stress. The modulus of elasticity is the measure of stiffness.

3. ***Elasticity.*** It is the property of a material to regain its original shape after deformation when the external forces are removed. This property is desirable for materials used in tools and machines. It may be noted that steel is more elastic than rubber.

4. ***Plasticity.*** It is property of a material which retains the deformation produced under load permanently. This property of the material is necessary for forgings, in stamping images on coins and in ornamental work.

5. ***Ductility.*** It is the property of a material enabling it to be drawn into wire with the application of a tensile force. A ductile material must be both strong and plastic. The ductility is usually measured by the terms, percentage elongation and percentage reduction in area. The ductile material commonly used in engineering practice (in order of diminishing ductility) are mild steel, copper, aluminium, nickel, zinc, tin and lead.

Note : The ductility of a material is commonly measured by means of percentage elongation and percentage reduction in area in a tensile test. (Refer Chapter 4, Art. 4.11).

* For further details, refer Chapter 4 on Simple Stresses in Machine Parts.

6. *Brittleness.* It is the property of a material opposite to ductility. It is the property of breaking of a material with little permanent distortion. Brittle materials when subjected to tensile loads, snap off without giving any sensible elongation. Cast iron is a brittle material.

7. *Malleability.* It is a special case of ductility which permits materials to be rolled or hammered into thin sheets. A malleable material should be plastic but it is not essential to be so strong. The malleable materials commonly used in engineering practice (in order of diminishing malleability) are lead, soft steel, wrought iron, copper and aluminium.

8. *Toughness.* It is the property of a material to resist fracture due to high impact loads like hammer blows. The toughness of the material decreases when it is heated. It is measured by the amount of energy that a unit volume of the material has absorbed after being stressed upto the point of fracture. This property is desirable in parts subjected to shock and impact loads.

9. *Machinability.* It is the property of a material which refers to a relative case with which a material can be cut. The machinability of a material can be measured in a number of ways such as comparing the tool life for cutting different materials or thrust required to remove the material at some given rate or the energy required to remove a unit volume of the material. It may be noted that brass can be easily machined than steel.

10. *Resilience.* It is the property of a material to absorb energy and to resist shock and impact loads. It is measured by the amount of energy absorbed per unit volume within elastic limit. This property is essential for spring materials.

11. *Creep.* When a part is subjected to a constant stress at high temperature for a long period of time, it will undergo a slow and permanent deformation called ***creep.*** This property is considered in designing internal combustion engines, boilers and turbines.

12. *Fatigue.* When a material is subjected to repeated stresses, it fails at stresses below the yield point stresses. Such type of failure of a material is known as **fatigue***.** The failure is caused by means of a progressive crack formation which are usually fine and of microscopic size. This property is considered in designing shafts, connecting rods, springs, gears, etc.

Brinell Tester : *Hardness can be defined as the resistance of a metal to attempts to deform it. This machine invented by the Swedish metallurgist Johann August Brinell (1849-1925), measure hardness precisely.*

13. *Hardness.* It is a very important property of the metals and has a wide variety of meanings. It embraces many different properties such as resistance to wear, scratching, deformation and machinability etc. It also means the ability of a metal to cut another metal. The hardness is usually

* For further details, refer Chapter 6 (Art. 6.3) on Variable Stresses in Machine Parts.

expressed in numbers which are dependent on the method of making the test. The hardness of a metal may be determined by the following tests :

(*a*) Brinell hardness test,
(*b*) Rockwell hardness test,
(*c*) Vickers hardness (also called Diamond Pyramid) test, and
(*d*) Shore scleroscope.

2.6 Ferrous Metals

We have already discussed in Art. 2.2 that the ferrous metals are those which have iron as their main constituent. The ferrous metals commonly used in engineering practice are cast iron, wrought iron, steels and alloy steels. The principal raw material for all ferrous metals is pig iron which is obtained by smelting iron ore with coke and limestone, in the blast furnace. The principal iron ores with their metallic contents are shown in the following table :

Table 2.2. Principal iron ores.

Iron ore	*Chemical formula*	*Colour*	*Iron content (%)*
Magnetite	Fe_2O_3	Black	72
Haematite	Fe_3O_4	Red	70
Limonite	$FeCO_3$	Brown	60–65
Siderite	Fe_2O_3 (H_2O)	Brown	48

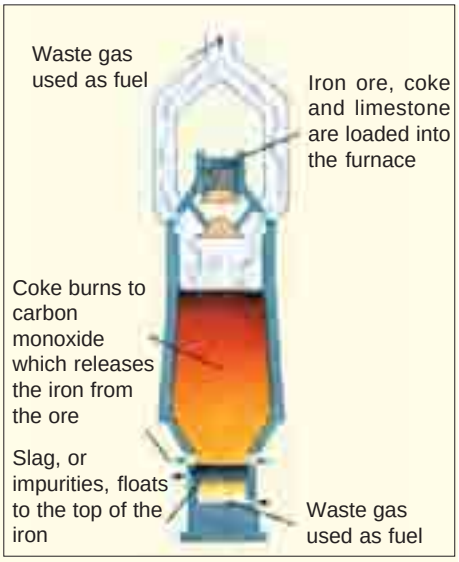
2.7 Cast Iron

The cast iron is obtained by re-melting pig iron with coke and limestone in a furnace known as cupola. It is primarily an alloy of iron and carbon. The carbon contents in cast iron varies from 1.7 per cent to 4.5 per cent. It also contains small amounts of silicon, manganese, phosphorous and sulphur. The carbon in a cast iron is present in either of the following two forms:

1. Free carbon or graphite, and **2.** Combined carbon or cementite.

Since the cast iron is a brittle material, therefore, it cannot be used in those parts of machines which are subjected to shocks. The properties of cast iron which make it a valuable material for engineering purposes are its low cost, good casting characteristics, high compressive strength, wear resistance and excellent machinability. The compressive strength of cast iron is much greater than the tensile strength. Following are the values of ultimate strength of cast iron :

Tensile strength	=	100 to 200 MPa*
Compressive strength	=	400 to 1000 MPa
Shear strength	=	120 MPa



Smelting : *Ores consist of non-metallic elements like oxygen or sulphur combined with the wanted metal. Iron is separated from the oxygen in its ore heating it with carbon monoxide derived from coke (a form of carbon made from coal). Limestone is added to keep impurities liquid so that the iron can separate from them.*

* $1MPa = 1MN/m^2 = 1 \times 10^6\ N/m^2 = 1\ N/mm^2$

2.8 Types of Cast Iron

Haematite is an ore of iron. It often forms kidney-shaped lumps, These give the ore its nickname of kidney ore.

The various types of cast iron in use are discussed as follows :

1. *Grey cast iron.* It is an ordinary commercial iron having the following compositions :

Carbon = 3 to 3.5%; Silicon = 1 to 2.75%; Manganese = 0.40 to 1.0%; Phosphorous = 0.15 to 1% ; Sulphur = 0.02 to 0.15% ; and the remaining is iron.

The grey colour is due to the fact that the carbon is present in the form of *free graphite. It has a low tensile strength, high compressive strength and no ductility. It can be easily machined. A very good property of grey cast iron is that the free graphite in its structure acts as a lubricant. Due to this reason, it is very suitable for those parts where sliding action is desired. The grey iron castings are widely used for machine tool bodies, automotive cylinder blocks, heads, housings, fly-wheels, pipes and pipe fittings and agricultural implements.

Table 2.3. Grey iron castings, as per IS : 210 – 1993.

IS Designation	*Tensile strength (MPa or N/mm^2)*	*Brinell hardness number (B.H.N.)*
FG 150	150	130 to 180
FG 200	200	160 to 220
FG 220	220	180 to 220
FG 260	260	180 to 230
FG 300	300	180 to 230
FG 350	350	207 to 241
FG 400	400	207 to 270

According to Indian standard specifications (IS: 210 – 1993), the grey cast iron is designated by the alphabets 'FG' followed by a figure indicating the minimum tensile strength in MPa or N/mm^2. For example, 'FG 150' means grey cast iron with 150 MPa or N/mm^2 as minimum tensile strength. The seven recommended grades of grey cast iron with their tensile strength and Brinell hardness number (B.H.N) are given in Table 2.3.

2. *White cast iron.* The white cast iron shows a white fracture and has the following approximate compositions :

Carbon = 1.75 to 2.3% ; Silicon = 0.85 to 1.2% ; Manganese = less than 0.4% ; Phosphorus = less than 0.2% ; Sulphur = less than 0.12%, and the remaining is iron.

The white colour is due to fact that it has no graphite and whole of the carbon is in the form of carbide (known as cementite) which is the hardest constituent of iron. The white cast iron has a high tensile strength and a low compressive strength. Since it is hard, therefore, it cannot be machined with ordinary cutting tools but requires grinding as shaping process. The white cast iron may be produced by casting against metal chills or by regulating analysis. The chills are used when a hard, wear resisting surface is desired for such products as for car wheels, rolls for crushing grains and jaw crusher plates.

3. *Chilled cast iron.* It is a white cast iron produced by quick cooling of molten iron. The quick cooling is generally called chilling and the cast iron so produced is called chilled cast iron. All castings

* When filing or machining cast iron makes our hands black, then it shows that free graphite is present in cast iron.

are chilled at their outer skin by contact of the molten iron with the cool sand in the mould. But on most castings, this hardness penetrates to a very small depth (less than 1 mm). Sometimes, a casting is chilled intentionally and sometimes chilled becomes accidently to a considerable depth. The intentional chilling is carried out by putting inserts of iron or steel (chills) into the mould. When the molten metal comes into contact with the chill, its heat is readily conducted away and the hard surface is formed. Chills are used on any faces of a casting which are required to be hard to withstand wear and friction.

4. *Mottled cast iron.* It is a product in between grey and white cast iron in composition, colour and general properties. It is obtained in castings where certain wearing surfaces have been chilled.

5. *Malleable cast iron.* The malleable iron is a cast iron-carbon alloy which solidifies in the as-cast condition in a graphite free structure, *i.e*. total carbon content is present in its combined form as cementite (Fe_3C).

It is ductile and may be bent without breaking or fracturing the section. The tensile strength of the malleable cast iron is usually higher than that of grey cast iron and has excellent machining qualities. It is used for machine parts for which the steel forgings would be too expensive and in which the metal should have a fair degree of accuracy, *e.g*. hubs of wagon wheels, small fittings for railway rolling stock, brake supports, parts of agricultural machinery, pipe fittings, door hinges, locks etc.

In order to obtain a malleable iron castings, it is first cast into moulds of white cast iron. Then by a suitable heat treatment (*i.e*. annealing), the combined carbon of the white cast iron is separated into nodules of graphite. The following two methods are used for this purpose :

1. Whiteheart process, and **2.** Blackheart process.

In a ***whiteheart process,*** the white iron castings are packed in iron or steel boxes surrounded by a mixture of new and used haematite ore. The boxes are slowly heated to a temperature of 900 to 950°C and maintained at this temperature for several days. During this period, some of the carbon is oxidised out of the castings and the remaining carbon is dispersed in small specks throughout the structure. The heating process is followed by the cooling process which takes several more days. The result of this heat treatment is a casting which is tough and will stand heat treatment without fracture.

In a ***blackheart process***, the castings used contain less carbon and sulphur. They are packed in a neutral substance like sand and the reduction of sulphur helps to accelerate the process. The castings are heated to a temperature of 850 to 900°C and maintained at that temperature for 3 to 4 days. The carbon in this process transforms into globules, unlike whiteheart process. The castings produced by this process are more malleable.

Notes : (*a*) According to Indian standard specifications (*IS : 14329 – 1995), the malleable cast iron may be either whiteheart, blackheart or pearlitic, according to the chemical composition, temperature and time cycle of annealing process.

(*b*) The ***whiteheart malleable cast iron*** obtained after annealing in a decarburizing atmosphere have a silvery-grey fracture with a heart dark grey to black. The microstructure developed in a section depends upon the size of the section. In castings of small sections, it is mainly ferritic with certain amount of pearlite. In large sections, microstructure varies from the surface to the core as follows :

Core and intermediate zone : Pearlite + ferrite + temper carbon

Surface zone : Ferrite.

The microstructure shall not contain flake graphite.

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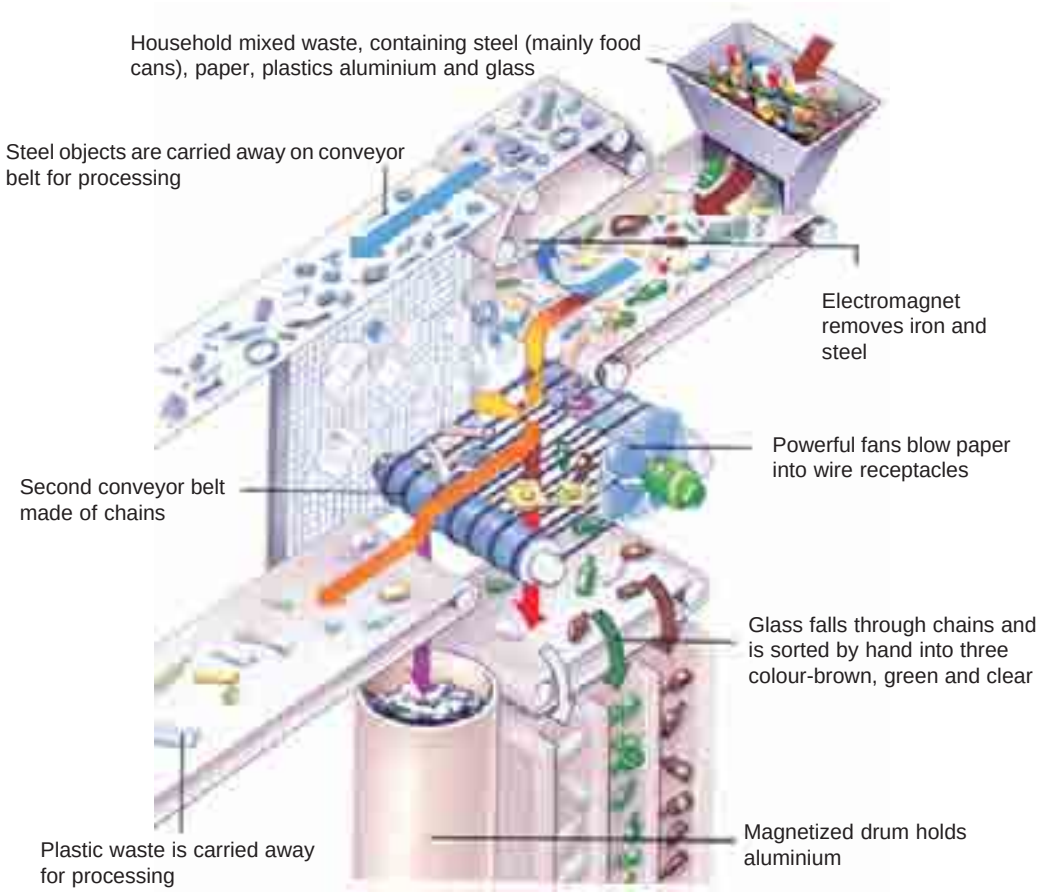
* This standard (IS : 14329-1995) supersedes the previous three standards, *i.e*.
(*a*) IS : 2107–1977 for white heart malleable iron casting,
(*b*) IS : 2108–1977 for black heart malleable iron casting, and
(*c*) IS : 2640–1977 for pearlitic malleable iron casting.



In a modern materials recovery plant, mixed waste (but no organic matter) is passed along a conveyor belt and sorted into reusable materials-steel, aluminium, paper, glass. Such recycling plants are expensive, but will become essential as vital resources become scarce.

Note : This picture is given as additional information and is not a direct example of the current chapter.

(*c*) The ***blackheart malleable cast iron*** obtained after annealing in an inert atmosphere have a black fracture. The microstructure developed in the castings has a matrix essentially of ferrite with temper carbon and shall not contain flake graphite.

(*d*) The ***pearlitic malleable cast iron*** obtained after heat-treatment have a homogeneous matrix essentially of pearlite or other transformation products of austenite. The graphite is present in the form of temper carbon nodules. The microstructure shall not contain flake graphite.

(*e*) According to IS: 14329 – 1995, the whiteheart, blackheart and pearlitic malleable cast irons are designated by the alphabets WM, BM and PM respectively. These designations are followed by a figure indicating the minimum tensile strength in MPa or N/mm^2. For example 'WM 350' denotes whiteheart malleable cast iron with 350 MPa as minimum tensile strength. The following are the different grades of malleable cast iron :

Whiteheart malleable cast iron — WM 350 and WM 400

Blackheart malleable cast iron — BM 300 ; BM 320 and BM 350

Pearlitic malleable cast iron — PM 450 ; PM 500 ; PM 550 ; PM 600 and PM 700

6. *Nodular or spheroidal graphite cast iron*. The nodular or spheroidal graphite cast iron is also called ***ductile cast iron*** or ***high strength cast iron***. This type of cast iron is obtained by adding small amounts of magnesium (0.1 to 0.8%) to the molten grey iron. The addition of magnesium

causes the *graphite to take form of small nodules or spheroids instead of the normal angular flakes. It has high fluidity, castability, tensile strength, toughness, wear resistance, pressure tightness, weldability and machinability. It is generally used for castings requiring shock and impact resistance along with good machinability, such as hydraulic cylinders, cylinder heads, rolls for rolling mill and centrifugally cast products.

According to Indian standard specification (IS : 1865-1991), the nodular or spheroidal graphite cast iron is designated by the alphabets 'SG' followed by the figures indicating the minimum tensile strength in MPa or N/mm^2 and the percentage elongation. For example, SG 400/15 means spheroidal graphite cast iron with 400 MPa as minimum tensile strength and 15 percent elongation. The Indian standard (IS : 1865 – 1991) recommends nine grades of spheroidal graphite cast iron based on mechanical properties measured on separately-cast test samples and six grades based on mechanical properties measured on cast-on sample as given in the Table 2.4.

The letter A after the designation of the grade indicates that the properties are obtained on cast-on test samples to distinguish them from those obtained on separately-cast test samples.

Table 2.4. Recommended grades of spheroidal graphite cast iron as per IS : 1865–1991.

Grade	*Minimum tensile strength (MPa)*	*Minimum percentage elongation*	*Brinell hardness number (BHN)*	*Predominant constituent of matrix*
SG 900/2	900	2	280 – 360	Bainite or tempered martensite
SG 800/2	800	2	245 – 335	Pearlite or tempered structure
SG 700/2	700	2	225 – 305	Pearlite
SG 600/3	600	3	190 – 270	Ferrite + Pearlite
SG 500/7	500	7	160 – 240	Ferrite + Pearlite
SG 450/10	450	10	160 – 210	Ferrite
SG 400/15	400	15	130 – 180	Ferrite
SG 400/18	400	18	130 – 180	Ferrite
SG 350/22	350	22	≤ 150	Ferrite
SG 700/2A	700	2	220 – 320	Pearlite
SG 600/3A	600	2	180 – 270	Pearlite + Ferrite
SG 500/7A	450	7	170 – 240	Pearlite + Ferrite
SG 400/15A	390	15	130 – 180	Ferrite
SG 400/18A	390	15	130 – 180	Ferrite
SG 350/22A	330	18	≤ 150	Ferrite

2.9 Alloy Cast Iron

The cast irons as discussed in Art. 2.8 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. 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

* The graphite flakes in cast iron act as discontinuities in the matrix and thus lower its mechanical properties. The sharp corners of the flakes also act as stress raisers. The weakening effect of the graphite can be reduced by changing its form from a flake to a spheroidal form.

gears, automobile parts like cylinders, pistons, piston rings, crank cases, crankshafts, camshafts, sprockets, wheels, pulleys, brake drums and shoes, parts of crushing and grinding machinery etc.

2.10 Effect of Impurities on Cast Iron

We have discussed in the previous articles that the cast iron contains small percentages of silicon, sulphur, manganese and phosphorous. The effect of these impurities on the cast iron are as follows:

1. ***Silicon.*** It may be present in cast iron upto 4%. It provides the formation of free graphite which makes the iron soft and easily machinable. It also produces sound castings free from blow-holes, because of its high affinity for oxygen.
2. ***Sulphur.*** It makes the cast iron hard and brittle. Since too much sulphur gives unsound casting, therefore, it should be kept well below 0.1% for most foundry purposes.
3. ***Manganese.*** It makes the 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.
4. ***Phosphorus.*** It aids fusibility and fluidity in cast iron, but induces brittleness. It is rarely allowed to exceed 1%. Phosphoric irons are useful for casting of intricate design and for many light engineering castings when cheapness is essential.

Phosphorus is a non-metallic element. It must be stored underwater (above), since it catches fire when exposed to air, forming a compound.

2.11 Wrought Iron

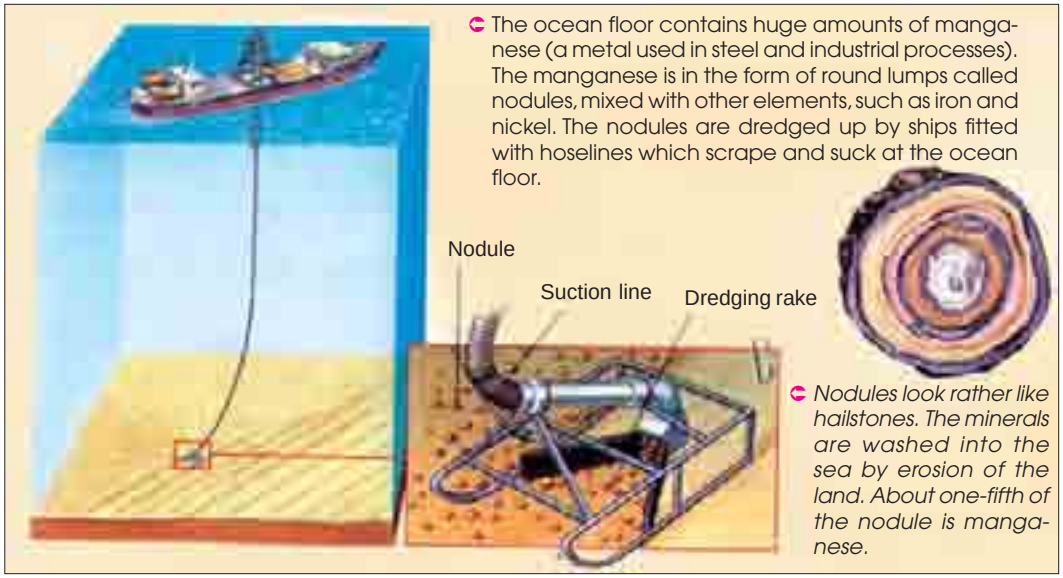
It is the purest iron which contains at least 99.5% iron but may contain upto 99.9% iron. The typical composition of a wrought iron is

Carbon = 0.020%, Silicon = 0.120%, Sulphur = 0.018%, Phosphorus = 0.020%, Slag = 0.070%, and the remaining is iron.

The wrought iron is produced from pig iron by remelting it in the puddling furnace of reverberatory type. 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 are formed. These balls are then mechanically worked both to squeeze out the slag and to form it into some commercial shape.

The wrought iron is a tough, malleable and ductile material. It cannot stand sudden and excessive shocks. Its ultimate tensile strength is 250 MPa to 500 MPa and the ultimate compressive strength is 300 MPa.

It can be easily forged or welded. It is used for chains, crane hooks, railway couplings, water and steam pipes.



Note : This picture is given as additional information and is not a direct example of the current chapter.

2.12 Steel

It is an alloy of iron and carbon, with carbon content up to a maximum of 1.5%. The carbon occurs in the form of iron carbide, because of its ability to increase the hardness and strength of the steel. Other elements *e.g.* silicon, sulphur, phosphorus and manganese are also present to greater or lesser amount to impart certain desired properties to it. Most of the steel produced now-a-days is ***plain carbon steel*** or simply ***carbon steel.*** A carbon steel is defined as a steel which has its properties mainly due to its carbon content and does not contain more than 0.5% of silicon and 1.5% of manganese. The plain carbon steels varying from 0.06% carbon to 1.5% carbon are divided into the following types depending upon the carbon content.

1. Dead mild 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

According to Indian standard *[IS : 1762 (Part-I)–1974], a new system of designating the steel is recommended. According to this standard, steels are designated on the following two basis :

(*a*) On the basis of mechanical properties, and (*b*) On the basis of chemical composition.

We shall now discuss, in detail, the designation of steel on the above two basis, in the following pages.

2.13 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 strength or yield stress. According to Indian standard **IS: 1570 (Part–I)-1978 (Reaffirmed 1993), these steels are designated by a symbol 'Fe' or 'Fe E' depending on whether

* This standard was reaffirmed in 1993 and covers the code designation of wrought steel based on letter symbols.

** The Indian standard IS : 1570-1978 (Reaffirmed 1993) on wrought steels for general engineering purposes has been revised on the basis of experience gained in the production and use of steels. This standard is now available in seven parts.

the steel has been specified on the basis of minimum tensile strength or yield strength, followed by the figure indicating the minimum tensile strength or yield stress in N/mm^2. For example 'Fe 290' means a steel having minimum tensile strength of 290 N/mm^2 and 'Fe E 220' means a steel having yield strength of 220 N/mm^2.

Table 2.5 shows the tensile and yield properties of standard steels with their uses according to IS : 1570 (Part I)-1978 (Reaffirmed 1993).

Table 2.5. Indian standard designation of steel according to IS : 1570 (Part I)-1978 (Reaffirmed 1993).

Indian standard designation	*Tensile strength (Minimum) N/mm^2*	*Yield stress (Minimum) N/mm^2*	*Minimum percentage elongation*	*Uses as per IS : 1871 (Part I)–1987 (Reaffirmed 1993)*
Fe 290	290	170	27	It is used for plain drawn or enamelled parts, tubes for oil well casing, steam, water and air passage, cycle, motor cycle and automobile tubes, rivet bars and wire.
Fe E 220	290	220	27	
Fe 310	310	180	26	These steels are used for locomotive carriages and car structures, screw stock and other general engineering purposes.
Fe E 230	310	230	26	
Fe 330	330	200	26	
Fe E 250	330	250	26	
Fe 360	360	220	25	It is used for chemical pressure vessels and other general engineering purposes.
Fe E 270	360	270	25	
Fe 410	410	250	23	It is used for bridges and building construction, railway rolling stock, screw spikes, oil well casing, tube piles, and other general engineering purposes.
Fe E 310	410	310	23	
Fe 490	490	290	21	It is used for mines, forgings for marine engines, sheet piling and machine parts.
Fe E 370	490	370	21	
Fe 540	540	320	20	It is used for locomotive, carriage, wagon and tramway axles, arches for mines, bolts, seamless and welded tubes.
Fe E 400	540	400	20	
Fe 620	620	380	15	It is used for tramway axles and seamless tubes.
Fe E 460	620	460	15	
Fe 690	690	410	12	It is used for locomotive, carriage and wagon wheels and tyres, arches for mines, seamless oil well casing and drill tubes, and machine parts for heavy loading.
Fe E 520	690	520	12	
Fe 770	770	460	10	It is used for locomotive, carriage and wagon wheels and tyres, and machine parts for heavy loading.
Fe E 580	770	580	10	
Fe 870	870	520	8	It is used for locomotive, carriage and wagon wheels and tyres.
Fe E 650	870	650	8	

Notes : 1. The steels from grades Fe 290 to Fe 490 are general structural steels and are available in the form of bars, sections, tubes, plates, sheets and strips.

2. The steels of grades Fe 540 and Fe 620 are medium tensile structural steels.

3. The steels of grades Fe 690, Fe 770 and Fe 870 are high tensile steels.

2.14 Steels Designated on the Basis of Chemical Composition

According to Indian standard, IS : 1570 (Part II/Sec I)-1979 (Reaffirmed 1991), the carbon steels are designated in the following order :

(a) Figure indicating 100 times the average percentage of carbon content,

(b) Letter 'C', and

(c) Figure indicating 10 times the average percentage of manganese content. The figure after multiplying shall be rounded off to the nearest integer.

For example 20C8 means a carbon steel containing 0.15 to 0.25 per cent (0.2 per cent on an average) carbon and 0.60 to 0.90 per cent (0.75 per cent rounded off to 0.8 per cent on an average) manganese.

Table 2.6 shows the Indian standard designation of carbon steel with composition and their uses.

Table 2.6. Indian standard designation of carbon steel according to IS : 1570 (Part II/Sec 1) – 1979 (Reaffirmed 1991).

Indian standard designation	*Composition in percentages*		*Uses as per IS : 1871 (Part II)–1987 (Reaffirmed 1993)*
	Carbon (C)	*Manganese (Mn)*	
4C2	0.08 Max.	0.40 Max.	It is a dead soft steel generally used in electrical industry.
5C4	0.10 Max.	0.50 Max.	These steels are used where cold formability is the primary requirement. In the rimming quality, they are used as sheet, strip, rod and wire especially where excellent surface finish or good drawing qualities are required, such as automobile body, and fender stock, hoods, lamps, oil pans and a multiple of deep drawn and formed products. They are also used for cold heading wire and rivets and low carbon wire products. The killed steel is used for forging and heat treating applications.
7C4	0.12 Max.	0.50 Max.	
10C4	0.15 Max.	0.30 – 0.60	
10C4	0.15 Max.	0.30 – 0.60	The case hardening steels are used for making camshafts, cams, light duty gears, worms, gudgeon pins, spindles, pawls, ratchets, chain wheels, tappets, etc.
14C6	0.10 – 0.18	0.40 – 0.70	
15C4	0.20 Max.	0.30 – 0.60	It is used for lightly stressed parts. The material, although easily machinable, is not designed specifically for rapid cutting, but is suitable where cold web, such as bending and riveting may be necessary.

Indian standard designation	*Composition in percentages*		*Uses as per IS : 1871 (Part II)–1987 (Reaffirmed 1993)*
	Carbon (C)	*Manganese (Mn)*	
15C8	0.10 – 0.20	0.60 – 0.90	These steels are general purposes steels used for low stressed components.
20C8	0.15 – 0.25	0.60 – 0.90	
25C4	0.20 – 0.30	0.30 – 0.60	
25C8	0.20 – 0.30	0.60 – 0.90	
30C8	0.25 – 0.35	0.60 – 0.90	It is used for making cold formed parts such as shift and brake levers. After suitable case hardening or hardening and tempering, this steel is used for making sprockets, tie rods, shaft fork and rear hub, 2 and 3 wheeler scooter parts such as sprocket, lever, hubs for forks, cams, rocket arms and bushes. Tubes for aircraft, automobile, bicycle and furniture are also made of this steel.
35C4	0.30 – 0.40	0.30 – 0.60	It is used for low stressed parts, automobile tubes and fasteners.
35C8	0.30 – 0.40	0.60 – 0.90	It is used for low stressed parts in machine structures, cycle and motor cycle tubes, fish plates for rails and fasteners.
40C8	0.35 – 0.45	0.60 – 0.90	It is used for crankshafts, shafts, spindles, push rods, automobile axle beams, connecting rods, studs, bolts, lightly stressed gears, chain parts, umbrella ribs, washers, etc.
45C8	0.40 – 0.50	0.60 – 0.90	It is used for spindles of machine tools, bigger gears, bolts, lead screws, feed rods, shafts and rocks.
50C4	0.45 – 0.55	0.30 – 0.60	It is used for keys, crankshafts, cylinders and machine parts requiring moderate wear resistance. In surface hardened condition, it is also suitable for large pitch worms and gears.
50C12	0.45 – 0.55	1.1 – 1.50	It is a rail steel. It is also used for making spike bolts, gear shafts, rocking levers and cylinder liners.
55C4	0.50 – 0.60	0.30 – 0.60	These steels are used for making gears, coil springs, cylinders, cams, keys, crankshafts, sprockets and machine parts requiring moderate wear resistance for which toughness is not of primary importance. It is also used for cycle and industrial chains, spring, can opener, umbrella ribs, parts of camera and typewriter.
55C8	0.50 – 0.60	0.60 – 0.90	
60C4	0.55 – 0.65	0.30 – 0.60	It is used for making clutch springs, hardened screws and nuts, machine tool spindles, couplings, crankshafts, axles and pinions.
65C9	0.60 – 0.70	0.50 – 0.80	It is a high tensile structural steel used for making locomotive carriage and wagon tyres. It is also used for engine valve springs, small washers and thin stamped parts.

Indian standard designation	*Composition in percentages*		*Uses as per IS : 1871 (Part II)–1987 (Reaffirmed 1993)*
	Carbon (C)	*Manganese (Mn)*	
70C6	0.65 – 0.75	0.50 – 0.80	It is used for making baffle springs, shock absorbers, springs for seat cushions for road vehicles. It is also used for making rail tyres, unhardened gears and worms, washers, wood working saw, textile and jute machinery parts and clutch plates, etc.
75C6	0.70 – 0.80	0.50 – 0.80	It is used for making light flat springs formed from annealed stock. Because of good wear properties when properly heat treated, it is used for making shear blades, rack teeth, scrappers and cutlivators' shovels.
80C6	0.75 – 0.85	0.50 – 0.80	These steels are used for making flat and coil springs for automobile and railway vehicles. It is also used for girder rails. The valve spring wire and music wire are special applications of steel 85 C6. After suitable heat treatment, these steels are also used for making scraper blades, discs and spring tooth harrows. It is also used for clutch parts, wood working saw, band saw and textile and jute machinery parts.
85C6	0.80 – 0.90	0.50 – 0.80	
98C6	0.90 – 1.05	0.50 – 0.80	These steels in the oil hardened and tempered condition are used for coil or spiral springs. It is also used for pen nibs, volute spring, spring cutlery, knitting needle and hacksaw blades.
113C6	1.05 – 1.20	0.50 – 0.80	

2.15 Effect of Impurities on Steel

The following are the effects of impurities like silicon, sulphur, manganese and phosphorus on steel.

1. *Silicon.* The amount of silicon in the finished steel usually ranges from 0.05 to 0.30%. Silicon is added in low carbon steels to prevent them from becoming porous. It removes the gases and oxides, prevent blow holes and thereby makes the steel tougher and harder.

2. *Sulphur.* It occurs in steel either as iron sulphide or manganese sulphide. Iron sulphide because of its low melting point produces red shortness, whereas manganese sulphide does not effect so much. Therefore, manganese sulphide is less objectionable in steel than iron sulphide.

3. *Manganese.* It serves as a valuable deoxidising and purifying agent in steel. Manganese also combines with sulphur and thereby decreases the harmful effect of this element remaining in the steel. When used in ordinary low carbon steels, manganese makes the metal ductile and of good bending qualities. In high speed steels, it is used to toughen the metal and to increase its critical temperature.

4. *Phosphorus.* It makes the steel brittle. 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%.

2.16 Free Cutting Steels

The free cutting steels contain sulphur and phosphorus. These steels have higher sulphur content than other carbon steels. In general, the carbon content of such steels vary from 0.1 to 0.45 per cent and sulphur from 0.08 to 0.3 per cent. These steels are used where rapid machining is the prime requirement. It may be noted that the presence of sulphur and phosphorus causes long chips in machining to be easily broken and thus prevent clogging of machines. Now a days, lead is used from 0.05 to 0.2 per cent instead of sulphur, because lead also greatly improves the machinability of steel without the loss of toughness.

According to Indian standard, IS : 1570 (Part III)-1979 (Reaffirmed 1993), carbon and carbon manganese free cutting steels are designated in the following order :

1. Figure indicating 100 times the average percentage of carbon,
2. Letter 'C',
3. Figure indicating 10 times the average percentage of manganese, and
4. Symbol 'S' followed by the figure indicating the 100 times the average content of sulphur. If instead of sulphur, lead (Pb) is added to make the steel free cutting, then symbol 'Pb' may be used.

Table 2.7 shows the composition and uses of carbon and carbon-manganese free cutting steels, as per IS : 1570 (Part III)-1979 (Reaffirmed 1993).

2.17 Alloy Steel

An alloy steel may be defined as a steel to which elements other than carbon are added in sufficient amount to produce an improvement in properties. The alloying is done for specific purposes to increase wearing resistance, corrosion resistance and to improve electrical and magnetic properties, which cannot be obtained in plain carbon steels. The chief alloying elements used in steel are nickel, chromium, molybdenum, cobalt, vanadium, manganese, silicon and tungsten. Each of these elements confer 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.*** It increases the strength and toughness of the steel. These steels contain 2 to 5% nickel and from 0.1 to 0.5% carbon. In this range, nickel contributes great strength 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 to be of advantage in the manufacture of boiler tubes, valves for use with superheated steam, valves for I.C. engines and spark plugs for petrol engines. A nickel steel alloy containing 36% of nickel is known as ***invar.*** It has nearly zero coefficient of expansion. So it is in great demand for measuring instruments and standards of lengths for everyday use.

2. ***Chromium.*** 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 contains 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 crankshafts, axles and gears requiring great strength and hardness.

3. ***Tungsten.*** It prohibits grain growth, increases the depth of hardening of quenched steel and confers the property of remaining hard even when heated to red colour. It is usually used in conjuction with other elements. Steel containing 3 to 18% tungsten and 0.2 to 1.5% carbon is used for cutting tools. The principal uses of tungsten steels are for cutting tools, dies, valves, taps and permanent magnets.

Table 2.7. Indian standard designation of carbon and carbon-manganese free cutting steels according to IS:1570 (Part III) – 1979 (Reaffirmed 1993).

Indian standard designation	*Composition in percentages*					*Uses as per IS : 1871 (Part III)–1987 (Reaffirmed 1993)*
	Carbon (C)	*Silicon (Si)*	*Manganese (Mn)*	*Sulphur (S)*	*Phosphorus (P) Max*	
10C8S10	0.15 Max.	0.05 – 0.30	0.60 – 0.90	0.08 – 0.13	0.06	It is used for small parts to be cyanided or carbonitrided.
14C14S14	0.10 – 0.18	0.05 – 0.30	1.20 – 1.50	0.1 – 0.18	0.06	It is used for parts where good machinability and finish are important.
25C12S14	0.20 – 0.30	0.25 Max.	1.00 – 1.50	0.10 – 0.18	0.06	It is used for bolts, studs and other heat treated parts of small section. It is suitable in either cold drawn, normalised or heat treated condition for moderately stressed parts requiring more strength than mild steel.
40C10S18	0.35 – 0.45	0.25 Max.	0.80 – 1.20	0.14 – 0.22	0.06	It is used for heat treated bolts, engine shafts, connecting rods, miscellaneous gun carriage, and small arms parts not subjected to high stresses and severe wear.
11C10S25	0.08 – 0.15	0.10 Max.	0.80 – 1.20	0.20 – 0.30	0.06	It is used for lightly stressed components not subjected to shock (nuts, studs, etc.) and suitable for production on automatic lathes. It is not recommended for general case hardening work but should be used when ease of machining is the deciding factor.
40C15S12	0.35 – 0.45	0.25 Max.	1.30 – 1.70	0.08 – 0.15	0.06	It is used for heat treated axles, shafts, small crankshafts and other vehicle parts. It is not recommended for forgings in which transverse properties are important.

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4. *Vanadium.* 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.

This is a fan blade from a jumbo jet engine. On take-off, the stress on the metal is immense, so to prevent the fan from flying apart, the blades must be both light and very strong. Titanium, though expensive, is the only suitable metal.

5. *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 uses of manganese steel is in machinery parts subjected to severe wear. These steels are all cast and ground to finish.

6. *Silicon.* The 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.

7. *Cobalt.* It gives red hardness by retention of hard carbides at high temperatures. It tends to decarburise steel during heat-treatment. It increases hardness and strength and also residual magnetism and coercive magnetic force in steel for magnets.

8. *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. These steels possess extra tensile strength and are used for air-plane fuselage and automobile parts. It can replace tungsten in high speed steels.

2.18 Indian Standard Designation of Low and Medium Alloy Steels

According to Indian standard, IS : 1762 (Part I)-1974 (Reaffirmed 1993), low and medium alloy steels shall be designated in the following order :

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

Element	*Multiplying factor*
Cr, Co, Ni, Mn, Si and W	4
Al, Be, V, Pb, Cu, Nb, Ti, Ta, Zr and Mo	10
P, S and N	100

For example 40 Cr 4 Mo 2 means alloy steel having average 0.4% carbon, 1% chromium and 0.25% molybdenum.

Notes : 1. The figure after multiplying shall be rounded off to the nearest integer.

2. Symbol 'Mn' for manganese shall be included in case manganese content is equal to or greater than 1 per cent.

3. The chemical symbols and their figures shall be listed in the designation in the order of decreasing content.

Table 2.8 shows the composition and uses of some low and medium alloy steels according to Indian standard IS : 1570-1961 (Reaffirmed 1993).

Table 2.8. Composition and uses of alloy steels according to IS : 1570-1961 (Reaffirmed 1993).

Indian standard designation	*Composition in percentages*						*Uses as per IS : 1871–1965*
	Carbon (C)	*Silicon (Si)*	*Manganese (Mn)*	*Nickel (Ni)*	*Chromium (Cr)*	*Molybdenum (Mo)*	
11Mn2	0.16 Max.	0.10 – 0.35	1.30 – 1.70	–	–	–	It is a notch ductile steel for general purposes. It is also used in making filler rods, colliery cage suspension gear tub, mine car draw gear, couplings and rope sockets.
20Mn2	0.16 – 0.24	0.10 – 0.35	1.30 – 1.70	–	–	–	These are used for welded structures, crankshafts, steering levers, shafting spindles, etc.
27Mn2	0.22 – 0.32	0.10 – 0.35	1.30 – 1.70	–	–	–	
37Mn2	0.32 – 0.42	0.10 – 0.35	1.30 – 1.70	–	–	–	It is used for making axles, shafts, crankshafts, connecting rods, etc.
47Mn2	0.42 – 0.52	0.10 – 0.35	1.30 – 1.70	–	–	–	It is used for tram rails and similar other structural purposes.
40Cr1	0.35 – 0.45	0.10 – 0.35	0.60 – 0.09	–	0.90 – 1.20	–	It is used for making gears, connecting rods, stub axles, steering arms, wear resistant plates for earth moving and concrete handling equipment, etc.
50Cr1	0.45 – 0.55	0.10 – 0.35	0.60 – .90	–	0.90 – 1.20	–	It is spring steel. It is used in a helical automobile front suspension springs.
35Mn2Mo28	0.30 – 0.40	0.10 – 0.35	1.30 – 1.80	–	–	0.20 – 0.35	These are used for making general engineering components such as crankshafts, bolts, wheel studs, axle shafts, levers and connecting rods.
35Mn2Mo45	0.30 – 0.40	0.10 – 0.35	1.30 – 1.80	–	–	0.35 – 0.55	
40Cr1Mo28	0.35 – 0.45	0.10 – 0.35	0.50 – 0.80	–	0.90 – 1.20	0.20 – 0.35	It is used for making axle shafts, crankshafts, connecting rods, gears, high tensile bolts and studs, propeller shaft joints, etc.

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Indian standard designation	*Composition in percentages*						*Uses as per IS : 1871–1965*
	Carbon (C)	*Silicon (Si)*	*Manganese (Mn)*	*Nickel (Ni)*	*Chromium (Cr)*	*Molybdenum (Mo)*	
15Cr3Mo55 25Cr3Mo55	0.10 – 0.20 0.20 – 0.30	0.10 – 0.35 0.10 – 0.35	0.40 – 0.70 0.40 – 0.70	0.30 Max. 0.30 Max.	2.90 – 3.40 2.90 – 3.40	0.45 – 0.65 0.45 – 0.65	These are used for components requiring medium to high tensile properties. In the nitrided condition, it is used for crank-shafts, cylinder liners for aero and automobile engines, gears, and machine parts requiring high surface hardness and wear resistance.
40Ni3	0.35 – 0.45	0.10 – 0.35	0.50 – 0.80	3.20 – 3.60	0.30 Max.	–	It is used for parts requiring excessively high toughness. In particular, it is used for components working at low temperatures (in refrigerators, compressors, locomotives and aircraft) and for heavy forgings, turbine blades, severely stressed screws, bolts and nuts.
30Ni4Crl	0.26 – 0.34	0.10 – 0.35	0.40 – 0.70	3.90 – 4.30	1.10 – 1.40	–	It is used for highly stressed gears and other components requiring high tensile strength of the order of 16 N/mm^2 and where minimum distortion in heat treatment is essential.
35NilCr60	0.30 – 0.40	0.10 – 0.35	0.60 – 0.90	1.00 – 1.50	0.45 – 0.75	–	It is used in the construction of aircraft and heavy vehicles for crankshafts, connecting rods, gear shafts, chain parts, clutches, flexible shafts for plenary gears, camshafts, etc.
40Ni2CrlMo28	0.35 – 0.45	0.10 – 0.35	0.40 – 70	1.25 – 1.75	0.90 – 1.30	0.20 – 0.35	It is used for high strength machine parts collets, spindles, screws, high tensile bolts and studs, gears, pinions, axle shafts, tappets, crankshafts, connecting rods, boring bars, arbours, etc.

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2.19 Stainless Steel

It is defined as that steel which when correctly heat treated and finished, resists oxidation and corrosive attack from most corrosive media. The different types of stainless steels are discussed below :

Stainless steel was invented in 1913 by British metallurgist Harry Brearley (1871-1948). He made a steel containing 13 per cent chromium. The new alloy proved to be highly resistant to corrosion: chromium reacts with oxygen in the air to form a tough, protective film which renews itself if the metal is scratched.

1. *Martensitic stainless steel.* The chromium steels containing 12 to 14 per cent chromium and 0.12 to 0.35 per cent carbon are the first stainless steels developed. Since these steels possess martensitic structure, therefore, they are called ***martensitic stainless steels.*** These steels are magnetic and may be hardened by suitable heat treatment and the hardness obtainable depends upon the carbon content. These steels can be easily welded and machined. When formability, softness, etc. are required in fabrication, steel having 0.12 per cent maximum carbon is often used in soft condition. With increasing carbon, it is possible by hardening and tempering to obtain tensile strength in the range of 600 to 900 N/mm^2, combined with reasonable toughness and ductility. In this condition, these steels find many useful general applications where mild corrosion resistance is required. Also, with the higher carbon range in the hardened and lightly tempered condition, tensile strength of about 1600 N/mm^2 may be developed with lowered ductility.

These steels may be used where the corrosion conditions are not too severe, such as for hydraulic, steam and oil pumps, valves and other engineering components. However, these steels are not suitable for shafts and parts working in contact with non-ferrous metals (*i.e.* brass, bronze or gun metal bearings) and with graphite packings, because electrolytic corrosion is likely to occur. After hardening and light tempering, these steels develop good cutting properties. Therefore, they are used for cutlery, springs, surgical and dental instruments.

Note: The presence of chromium provides good resistance to scaling upto a temperature of about 750°C, but it is not suitable where mechanical strength in the temperature range of 600 to 750°C is required. In fact, creep resistance of these steels at this temperature is not superior to that of mild steel. But at temperature below 600°C, the strength of these steels is better than that of carbon steels and upto 480°C is even better than that of austenitic steels.

2. *Ferritic stainless steel.* The steels containing greater amount of chromium (from 16 to 18 per cent) and about 0.12 per cent carbon are called ***ferritic stainless steels.*** These steels have better corrosion resistant property than martensitic stainless steels. But, such steels have little capacity for hardening by heat treatment. However, in the softened condition, they possess good ductility and are mainly used as sheet or strip for cold forming and pressing operations for purposes where moderate corrosion resistance is required. They may be cold worked or hot worked. They are ferro-magnetic, usually undergo excessive grain growth during prolonged exposure to elevated temperatures, and may develop brittleness after electric arc resistance or gas welding. These steels have lower strength

at elevated temperatures than martensitic steels. However, resistance to scaling and corrosion at elevated temperatures are usually better. The machinability is good and they show no tendency to intercrystalline corrosion.

Note: When nickel from 1.5 to 2.5 per cent is added to 16 to 18 per cent chromium steel, it not only makes more resistant to corrosion than martensitic steel but also makes it hardenable by heat treatment. Such a steel has good resistance to electrolytic corrosion when in contact with non-ferrous metals and graphite packings. Thus it is widely used for pump shafts, spindles and valves as well as for many other fittings where a good combination of mechanical and corrosion properties are required.

3. *Austenitic stainless steel.* The steel containing high content of both chromium and nickel are called ***austenitic stainless steels.*** There are many variations in chemical composition of these steels, but the most widely used steel contain 18 per cent chromium and 8 per cent nickel with carbon content as low as possible. Such a steel is commonly known as ***18/8 steel.*** These steels cannot be hardened by quenching, in fact they are softened by rapid cooling from about 1000°C. They are non-magnetic and possess greatest resistance to corrosion and good mechanical properties at elevated temperature.

These steels are very tough and can be forged and rolled but offer great difficulty in machining. They can be easily welded, but after welding, it is susceptible to corrosive attack in an area adjacent to the weld. This susceptibility to corrosion (called intercrystalline corrosion or weld decay) may be removed by softening after welding by heating to about 1100°C and cooling rapidly. These steels are used in the manufacture of pump shafts, rail road car frames and sheathing, screws, nuts and bolts and small springs. Since 18/8 steel provide excellent resistance to attack by many chemicals, therefore, it is extensively used in chemical, food, paper making and dyeing industries.

Note : When increased corrosion resistance properties are required, for some purposes, then molybdenum from 2 to 3 per cent may be added.

2.20 Heat Resisting Steels

The steels which can resist creep and oxidation at high temperatures and retain sufficient strength are called ***heat resisting steels.*** A number of heat resisting steels have been developed as discussed below :

1. *Low alloy steels.* These steels contain 0.5 per cent molybdenum. The main application of these steels are for superheater tubes and pipes in steam plants, where service temperatures are in the range of 400°C to 500°C.

2. *Valve steels.* The chromium-silicon steels such as ***silchrome*** (0.4% C, 8% Cr, 3.5% Si) and ***Volmax*** (0.5% C, 8% Cr, 3.5% Si, 0.5% Mo) are used for automobile valves. They possess good resistance to scaling at dull red heat, although their strength at elevated temperatures is relatively low. For aeroplane engines and marine diesel engine valves, 13/13/3 nickel-chromium-tungsten valve steel is usually used.

3. *Plain chromium steel.* The plain chromium steel consists of

(*a*) Martensitic chromium steel with 12–13% Cr, and

(*b*) Ferritic chromium steels with 18–30% Cr.

These steels are very good for oxidation resistance at high temperatures as compared to their strength which is not high at such conditions. The maximum operating temperature for martensitic steels is about 750°C, whereas for ferritic steels it is about 1000 – 1150°C.

4. *Austenitic chromium-nickel steels.* These steels have good mechanical properties at high temperatures with good scaling resistance. These alloys contain a minimum of 18 per cent chromium and 8 per cent nickel stabilised with titanium or niobium. Other carbide forming elements such as molybdenum or tungsten may also be added in order to improve creep strength. Such alloys are suitable for use upto 1100°C and are used for gas turbine discs and blades.

Table 2.9. Indian standard designation of high alloy steels (stainless steel and heat resisting steels) according to IS : 1570 (Part V)-1985 (Reaffirmed 1991).

Indian standard designation	*Composition in percentages*						*Uses as per IS : 1871–1965*
	Carbon (C)	*Silicon (Si)*	*Manganese (Mn)*	*Nickel (Ni)*	*Chromium . (Cr)*	*Molybdenum (Mo)*	
30Cr13	0.26 – 0.35	1.0 Max.	1.0 Max.	1.0 Max.	12.0 – 14.0	–	It is used for structural parts with high strength and kitchen utensils.
15Cr16Ni2	0.10 – 0.20	1.0 Max.	1.0 Max.	1.5 – 3.0	15.0 – 18.0	–	It is used for aircraft fittings, wind shield wiper arms, bolting materials, paper machinery etc.
07Cr18Ni9	0.12 Max.	1.0 Max.	2.0 Max.	8.0 – 10.0	17.0 – 19.0	–	It is used for aircraft fire walls and cawlings, radar and microwaves antennae, jewellery, household novelties, automotive wheel covers, refrigerator trays, kitchen utensils, railway passenger car bodies, ice making equipment, tubular furniture, screen door and storm window frames, electric switch parts, flexible couplings etc.
04Cr17Ni12 Mo2	0.08 Max.	1.0 Max.	2.0 Max.	10.5 – 14.0	16.0 – 18.5	2.0 – 3.0	It is used for high temperature chemical handling equipment for rayon, rubber and marine industries, photographic developing equipment, pulp handling equipment, steam jacketed kettles, coke plant equipment, food processing equipment, edible oil storage tanks.
45Cr9Si4	0.40 – 0.50	3.25 – 3.75	0.30 – 0.60	0.05 Max.	7.50 – 9.50	–	It is used for heat resisting outlet valves in oil engines, lorries and cars.
80Cr20Si2 Nil	0.75 – 0.85	1.75 – 2.25	0.20 – 0.60	1.20 – 1.70	19.0 – 21.0	–	It is used for highly stressed outlet valves in high speed carburetors and heavy oil engines.

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2.21 Indian Standard Designation of High Alloy Steels (Stainless Steel and Heat Resisting Steel)

According to Indian standard, IS : 1762 (Part I)-1974 (Reaffirmed 1993), the high alloy steels (*i.e.* stainless steel and heat resisting steel) are designated in the following order:

1. Letter 'X'.
2. Figure indicating 100 times the percentage of carbon content.
3. Chemical symbol for alloying elements each followed by a figure for its average percentage content rounded off to the nearest integer.
4. Chemical symbol to indicate specially added element to allow the desired properties.

For example, X 10 Cr 18 Ni 9 means alloy steel with average carbon 0.10 per cent, chromium 18 per cent and nickel 9 per cent.

Table 2.9 shows the composition and uses of some types of the stainless steels and heat resisting steels according to Indian standard IS : 1570 (Part V)-1985 (Reaffirmed 1991).

2.22 High Speed Tool Steels

These steels are used for cutting metals at a much higher cutting speed than ordinary carbon tool steels. The carbon steel cutting tools do not retain their sharp cutting edges under heavier loads and higher speeds. This is due to the fact that at high speeds, sufficient heat may be developed during the cutting operation and causes the temperature of the cutting edge of the tool to reach a red heat. This temperature would soften the carbon tool steel and thus the tool will not work efficiently for a longer period. The high speed steels have the valuable property of retaining their hardness even when heated to red heat. Most of the high speed steels contain tungsten as the chief alloying element, but other elements like cobalt, chromium, vanadium, etc. may be present in some proportion. Following are the different types of high speed steels:

Gold is found mixed with quartz rock, deep underground. Most metals occur in their ores as compounds. Gold is so unreactive that it occurs naturally as pure metal.

1. ***18-4-1 High speed steel.*** This steel, on an average, contains 18 per cent tungsten, 4 per cent chromium and 1 per cent vanadium. It is considered to be one of the best of all purpose tool steels. It is widely used for drills, lathe, planer and shaper tools, milling cutters, reamers, broaches, threading dies, punches, etc.

2. ***Molybdenum high speed steel.*** This steel, on an average, contains 6 per cent tungsten, 6 per cent molybdenum, 4 per cent chromium and 2 per cent vanadium. It has excellent toughness and cutting ability. The molybdenum high speed steels are better and cheaper than other types of steels. It is particularly used for drilling and tapping operations.

3. ***Super high speed steel.*** This steel is also called ***cobalt high speed steel*** because cobalt is added from 2 to 15 per cent, in order to increase the cutting efficiency especially at high temperatures. This steel, on an average, contains 20 per cent tungsten, 4 per cent chromium, 2 per cent vanadium and 12 per cent cobalt. Since the cost of this steel is more, therefore, it is principally used for heavy cutting operations which impose high pressure and temperatures on the tool.

2.23 Indian Standard Designation of High Speed Tool Steel

According to Indian standard, IS : 1762 (Part I)-1974 (Reaffirmed 1993), the high speed tool steels are designated in the following order :

1. Letter 'XT'.
2. Figure indicating 100 times the percentage of carbon content.
3. Chemical symbol for alloying elements each followed by the figure for its average percentage content rounded off to the nearest integer, and
4. Chemical symbol to indicate specially added element to attain the desired properties.

For example, XT 75 W 18 Cr 4 V 1 means a tool steel with average carbon content 0.75 per cent, tungsten 18 per cent, chromium 4 per cent and vanadium 1 per cent.

Table 2.10 shows the composition of high speed tool steels as per Indian standard, IS : 7291-1981 (Reaffirmed 1993).

2.24 Spring Steels

The most suitable material for springs are those which can store up the maximum amount of work or energy in a given weight or volume of spring material, without permanent deformation. These steels should have a high elastic limit as well as high deflection value. The spring steel, for aircraft and automobile purposes should possess maximum strength against fatigue effects and shocks. The steels most commonly used for making springs are as follows:

1. ***High carbon steels.*** These steels contain 0.6 to 1.1 per cent carbon, 0.2 to 0.5 per cent silicon and 0.6 to 1 per cent manganese. These steels are heated to 780 – 850°C according to the composition and quenched in oil or water. It is then tempered at 200 – 500°C to suit the particular application. These steels are used for laminated springs for locomotives, carriages, wagons, and for heavy road vehicles. The higher carbon content oil hardening steels are used for volute, spiral and conical springs and for certain types of petrol engine inlet valve springs.

2. ***Chrome-vanadium steels.*** These are high quality spring steels and contain 0.45 to 0.55 per cent carbon, 0.9 to 1.2 per cent chromium, 0.15 to 0.20 per cent vanadium, 0.3 to 0.5 per cent silicon and 0.5 to 0.8 per cent manganese. These steels have high elastic limit, resistance to fatigue and impact stresses. Moreover, these steels can be machined without difficulty and can be given a smooth surface free from tool marks. These are hardened by oil quenching at 850 – 870°C and tempered at 470 – 510°C for vehicle and other spring purposes. These steels are used for motor car laminated and coil springs for suspension purposes, automobile and aircraft engine valve springs.

Sodium is in Group I. Although it is a metal, it is so soft that a knife can cut easily through a piece. Sodium is stored in oil to stop air or moisture reacting with it.

3. ***Silicon-manganese steels.*** These steels contain 1.8 to 2.0 per cent silicon, 0.5 to 0.6 per cent carbon and 0.8 to 1 per cent manganese. These steels have high fatigue strength, resistance and toughness. These are hardened by quenching in oil at 850 – 900°C and tempered at 475 – 525°C. These are the usual standard quality modern spring materials and are much used for many engineering purposes.

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Table 2.10. Indian standard designation of high speed tool steel according to IS : 7291-1981 (Reaffirmed 1993).

Indian standard designation	*Chemical composition in percentages*								*Brinell hardness in annealed condition (HB)Max.*
	Carbon (C)	*Silicon (Si)*	*Manganese (Mn)*	*Chromium (Cr)*	*Molybdenum (Mo)*	*Vanadium (V)*	*Tungsten (W)*	*Cobalt (Co)*	
XT 72 W 18 Cr 4 V 1	0.65 – 0.80	0.15 – 0.40	0.20 – 0.40	3.75 – 4.50	–	1.00 – 1.25	17.50 – 19.0	–	255
XT 75 W 18 Co 5 Cr 4 Mo V 1	0.70 – 0.80	0.15 – 0.40	0.20 – 0.40	3.75 – 4.50	0.40 – 1.00	1.00 – 1.25	17.50 – 19.0	4.50 – 5.50	269
XT 80 W 20 Co 12 Cr 4 V 2 Mo 1	0.75 – 0.85	0.15 – 0.40	0.20 – 0.40	4.00 – 4.75	0.40 – 1.00	1.25 – 1.75	19.50 – 21.0	11.00 – 12.50	302
XT 125 W Co 10 Cr Mo 4 V 3	1.20 – 1.30	0.15 – 0.40	0.20 – 0.40	3.75 – 4.75	3.00 – 4.00	2.80 – 3.50	8.80 – 10.70	8.80 – 10.70	269
XT 87 W 6 Mo 5 Cr 4 V 2	0.82 – 0.92	0.15 – 0.40	0.15 – 0.40	3.75 – 4.75	4.75 – 5.50	1.75 – 2.05	5.75 – 6.75	–	248
XT 90 W 6 Co Mo 5 Cr 4 V 2	0.85 – 0.95	0.15 – 0.40	0.20 – 0.40	3.75 – 4.75	4.75 – 5.50	1.70 – 2.20	5.75 – 6.75	4.75 – 5.25	269
XT 110 Mo 10 Co 8 Cr 4 W 2	1.05 – 1.15	0.15 – 0.40	0.15 – 0.40	3.50 – 4.50	9.0 – 10.0	0.95 – 1.35	1.15 – 1.85	7.75 – 8.75	269

Notes: 1. For all steels, sulphur (*S*) and phosphorus (*P*) is 0.030 per cent Max.

2. If sulphur is added to give free machining properties, then it shall be between 0.09 and 0.15 per cent.

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2.25 Heat Treatment of Steels

The term heat treatment may be defined as an operation or a combination of operations, involving the heating and cooling of a metal or an alloy in the solid state for the purpose of obtaining certain desirable conditions or properties without change in chemical composition. The aim of heat treatment is to achieve one or more of the following objects :

1. To increase the hardness of metals.
2. To relieve the stresses set up in the material after hot or cold working.
3. To improve machinability.
4. To soften the metal.
5. To modify the structure of the material to improve its electrical and magnetic properties.
6. To change the grain size.
7. To increase the qualities of a metal to provide better resistance to heat, corrosion and wear.

Following are the various heat treatment processes commonly employed in engineering practice:

1. ***Normalising.*** The main objects of normalising are :
   1. To refine the grain structure of the steel to improve machinability, tensile strength and structure of weld.
   2. To remove strains caused by cold working processes like hammering, rolling, bending, etc., which makes the metal brittle and unreliable.
   3. To remove dislocations caused in the internal structure of the steel due to hot working.
   4. To improve certain mechanical and electrical properties.

The process of normalising consists of heating the steel from 30 to 50°C above its upper critical temperature (for hypoeutectoid steels) or Acm line (for hypereutectoid steels). It is held at this temperature for about fifteen minutes and then allowed to cool down in still air.

This process provides a homogeneous structure consisting of ferrite and pearlite for hypoeutectoid steels, and pearlite and cementite for hypereutectoid steels. The homogeneous structure provides a higher yield point, ultimate tensile strength and impact strength with lower ductility to steels. The process of normalising is frequently applied to castings and forgings, etc. The alloy steels may also be normalised but they should be held for two hours at a specified temperature and then cooling in the furnace.

Notes : (*a*) The upper critical temperature for a steel depends upon its carbon content. It is 900°C for pure iron, 860°C for steels with 2.2% carbon, 723°C for steel with 0.8% carbon and 1130°C for steel with 1.8% carbon.

(*b*) Steel containing 0.8% carbon is known as ***eutectoid steel,*** steel containing less than 0.8% carbon is called ***hypoeutectoid steel*** and steel containing above 0.8% carbon is called ***hypereutectoid steel.***

2. ***Annealing.*** The main objects of annealing are :
   1. To soften the steel so that it may be easily machined or cold worked.
   2. To refine the grain size and structure to improve mechanical properties like strength and ductility.
   3. To relieve internal stresses which may have been caused by hot or cold working or by unequal contraction in casting.
   4. To alter electrical, magnetic or other physical properties.
   5. To remove gases trapped in the metal during initial casting.

The annealing process is of the following two types :

(a) Full annealing. The purpose of full annealing is to soften the metal to refine the grain structure, to relieve the stresses and to remove trapped gases in the metal. The process consists of

(*i*) heating the steel from 30 to 50°C above the upper critical temperature for hypoeutectoid steel and by the same temperature above the lower critical temperature *i.e.* 723°C for hypereutectoid steels.

(*ii*) holding it at this temperature for sometime to enable the internal changes to take place. The time allowed is approximately 3 to 4 minutes for each millimetre of thickness of the largest section, and

(*iii*) cooling slowly in the furnace. The rate of cooling varies from 30 to 200°C per hour depending upon the composition of steel.

In order to avoid decarburisation of the steel during annealing, the steel is packed in a cast iron box containing a mixture of cast iron borings, charcoal, lime, sand or ground mica. The box along with its contents is allowed to cool slowly in the furnace after proper heating has been completed.

The following table shows the approximate temperatures for annealing depending upon the carbon contents in steel.

Table 2.11. Annealing temperatures.

S.No.	*Carbon content, per cent*	*Annealing temperature, °C*
1.	Less than 0.12 (Dead mild steel)	875 – 925
2.	0.12 to 0.45 (Mild steel)	840 – 970
3.	0.45 to 0.50 (Medium carbon steel)	815 – 840
4.	0.50 to 0.80 (Medium carbon steel)	780 – 810
5.	0.80 to 1.50 (High carbon or tool steel)	760 – 780

(*b*) *Process annealing.* The process annealing is used for relieving the internal stresses previously set up in the metal and for increasing the machinability of the steel. In this process, steel is heated to a temperature below or close to the lower critical temperature, held at this temperature for sometime and then cooled slowly. This causes complete recrystallisation in steels which have been severely cold worked and a new grain structure is formed. The process annealing is commonly used in the sheet and wire industries.

3. *Spheroidising.* It is another form of annealing in which cementite in the granular form is produced in the structure of steel. This is usually applied to high carbon tool steels which are difficult to machine. The operation consists of heating the steel to a temperature slightly above the lower critical temperature (730 to 770°C). It is held at this temperature for some time and then cooled slowly to a temperature of 600°C. The rate of cooling is from 25 to 30°C per hour.

The spheroidising improves the machinability of steels, but lowers the hardness and tensile strength. These steels have better elongation properties than the normally annealed steel.

4. *Hardening.* The main objects of hardening are :

1. To increase the hardness of the metal so that it can resist wear.
2. To enable it to cut other metals *i.e.* to make it suitable for cutting tools.

Clay can be hardened by heat. Bricks and ceramic items are made by firing soft clay objects in a kiln.

The process of hardening consists of

(*a*) heating the metal to a temperature from 30 to 50°C above the upper critical point for hypoeutectoid steels and by the same temperature above the lower critical point for hypereutectoid steels.

(*b*) keeping the metal at this temperature for a considerable time, depending upon its thickness.

(*c*) quenching (cooling suddenly) in a suitable cooling medium like water, oil or brine.

It may be noted that the low carbon steels cannot be hardened appreciably, because of the presence of ferrite which is soft and is not changed by the treatment. As the carbon content goes on increasing, the possible obtainable hardness also increases.

Notes : 1. The greater the rate of quenching, the harder is the resulting structure of steel.

2. For hardening alloy steels and high speed steels, they are heated from 1100°C to 1300°C followed by cooling in a current of air.

5. *Tempering*. The steel hardened by rapid quenching is very hard and brittle. It also contains internal stresses which are severe and unequally distributed to cause cracks or even rupture of hardened steel. The tempering (also known as ***drawing***) is, therefore, done for the following reasons :

1. To reduce brittleness of the hardened steel and thus to increase ductility.
2. To remove the internal stresses caused by rapid cooling of steel.
3. To make steel tough to resist shock and fatigue.

The tempering process consists of reheating the hardened steel to some temperature below the lower critical temperature, followed by any desired rate of cooling. The exact tempering temperature depends upon the purpose for which the article or tool is to be used.

6. *Surface hardening or case hardening*. In many engineering applications, it is desirable that a steel being used should have a hardened surface to resist wear and tear. At the same time, it should have soft and tough interior or core so that it is able to absorb any shocks, etc. This is achieved by hardening the surface layers of the article while the rest of it is left as such. This type of treatment is applied to gears, ball bearings, railway wheels, etc.

Following are the various *surface or case hardening processes by means of which the surface layer is hardened:

1. Carburising, **2.** Cyaniding, **3.** Nitriding, **4.** Induction hardening, and **5.** Flame hardening.

2.26 Non-ferrous Metals

We have already discussed that the non-ferrous metals are those which contain a metal other than iron as their chief constituent. The non-ferrous metals are usually employed in industry due to the following characteristics :

1. Ease of fabrication (casting, rolling, forging, welding and machining),
2. Resistance to corrosion,
3. Electrical and thermal conductivity, and
4. Weight.

The various non-ferrous metals used in engineering practice are aluminium, copper, lead, tin, zinc, nickel, etc. and their alloys. We shall now discuss these non-ferrous metals and their alloys in detail, in the following pages.

2.27 Aluminium

It is white metal produced by electrical processes from its oxide (alumina), which is prepared from a clayey mineral called ***bauxite*.** It is a light metal having specific gravity 2.7 and melting point 658°C. The tensile strength of the metal varies from 90 MPa to 150 MPa.

* For complete details, please refer authors' popular book **'A Text Book of Workshop Technology'.**

In its pure state, the metal would be weak and soft for most purposes, but when mixed with small amounts of other alloys, 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 is widely used for overhead cables. The high resistance to corrosion and its non-toxicity makes it a useful metal for cooking utensils under ordinary condition and thin foils are used for wrapping food items. It is extensively used in aircraft and automobile components where saving of weight is an advantage.

2.28 Aluminium Alloys

The aluminium may be alloyed with one or more other elements like copper, magnesium, manganese, silicon and nickel. The addition of small quantities of alloying elements converts the soft and weak metal into hard and strong metal, while still retaining its light weight. The main aluminium alloys are discussed below:

1. ***Duralumin.*** It is an important and interesting wrought alloy. Its composition is as follows:

Copper = 3.5 – 4.5%; Manganese = 0.4 – 0.7%; Magnesium = 0.4 – 0.7%, and the remainder is aluminium.

This alloy possesses maximum tensile strength (upto 400 MPa) after heat treatment and age hardening. After working, if the metal is allowed to age for 3 or 4 days, it will be hardened. This phenomenon is known as ***age hardening*****.**

It is widely used in wrought conditions for forging, stamping, bars, sheets, tubes and rivets. It can be worked in hot condition at a temperature of 500°C. However, after forging and annealing, it can also be cold worked. Due to its high strength and light weight, this alloy may be used in automobile and aircraft components. It is also used in manufacturing connecting rods, bars, rivets, pulleys, etc.

2. ***Y-alloy.*** It is also called copper-aluminium alloy. The addition of copper to pure aluminium increases its strength and machinability. The composition of this alloy is as follows :

Copper = 3.5 – 4.5%; Manganese = 1.2 – 1.7%; Nickel = 1.8 – 2.3%; Silicon, Magnesium, Iron = 0.6% each; and the remainder is aluminium.

This alloy is heat treated and age hardened like duralumin. The ageing process is carried out at room temperature for about five days.

It is mainly used for cast purposes, but it can also be used for forged components like duralumin. Since *Y*-alloy has better strength (than duralumin) at high temperature, therefore, it is much used in aircraft engines for cylinder heads and pistons.

3. ***Magnalium.*** It is made by melting the aluminium with 2 to 10% magnesium in a vacuum and then cooling it in a vacuum or under a pressure of 100 to 200 atmospheres. It also contains about 1.75% copper. Due to its light weight and good mechanical properties, it is mainly used for aircraft and automobile components.

4. ***Hindalium.*** It is an alloy of aluminium and magnesium with a small quantity of chromium. It is the trade name of aluminium alloy produced by Hindustan Aluminium Corporation Ltd, Renukoot (U.P.). It is produced as a rolled product in 16 gauge, mainly for anodized utensil manufacture.

2.29 Copper

It is one of the most widely used non-ferrous metals in industry. It is a soft, malleable and ductile material with a reddish-brown appearance. Its specific gravity is 8.9 and melting point is 1083°C. The tensile strength varies from 150 MPa to 400 MPa under different conditions. It is a good conductor of electricity. It is largely used in making electric cables and wires for electric machinery and appliances, in electrotyping and electroplating, in making coins and household utensils.

It may be cast, forged, rolled and drawn into wires. It is non-corrosive under ordinary conditions and resists weather very effectively. Copper in the form of tubes is used widely in mechanical engineering. It is also used for making ammunitions. It is used for making useful alloys with tin, zinc, nickel and aluminium.

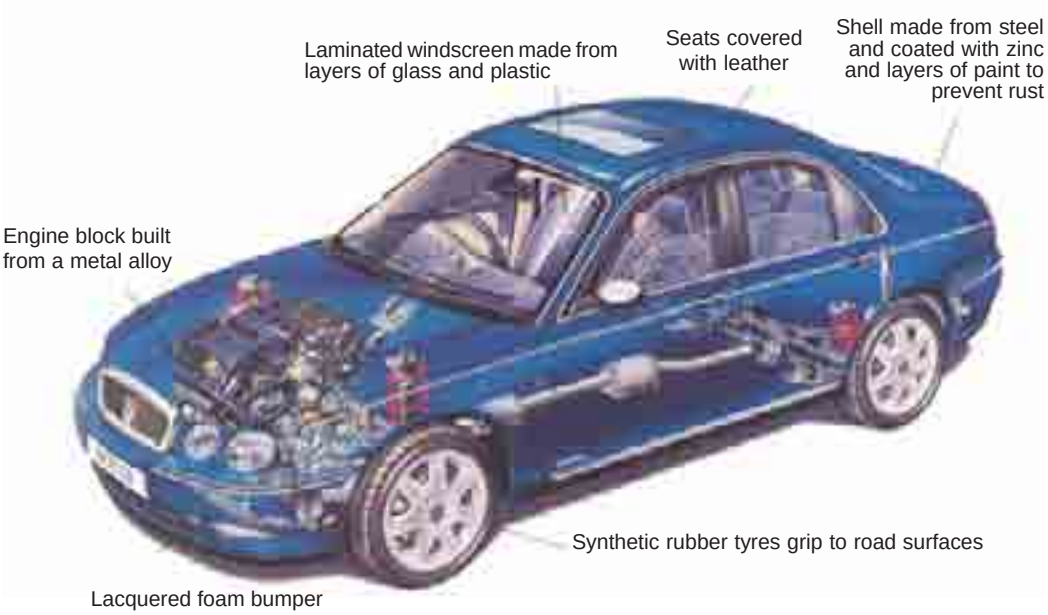
2.30 Copper Alloys

The copper alloys are broadly classified into the following two groups :

1. *Copper-zinc alloys* (*Brass*). The most widely used copper-zinc alloy is brass. There are various types of brasses, depending upon the proportions of copper and zinc. This is fundamentally a binary alloy of copper with zinc each 50%. By adding small quantities of other elements, the properties of brass may be greatly changed. For example, the addition of lead (1 to 2%) improves the machining quality of brass. It has a greater strength than that of copper, but have a lower thermal and electrical conductivity. Brasses are very resistant to atmospheric corrosion and can be easily soldered. They can be easily fabricated by processes like spinning and can also be electroplated with metals like nickel and chromium. The following table shows the composition of various types of brasses according to Indian standards.

Malachite is an ore of copper. Its dramatic bands of dark green make it popular in jewellery.

Electrical cables often consist of fine strands of copper wire woven together and encased in a plastic sleeve.



Materials are used to build a modern car.

Table 2.12. Composition and uses of brasses.

Indian standard designation	*Composition in percentages*		*Uses*
Cartridge brass	Copper Zinc	= 70 = 30	It is a cold working brass used for cold rolled sheets, wire drawing, deep drawing, pressing and tube manufacture.
Yellow brass (Muntz metal)	Copper Zinc	= 60 = 40	It is suitable for hot working by rolling, extrusion and stamping.
Leaded brass	Copper Zinc Lead	= 62.5 = 36 = 1.5	
Admiralty brass	Copper Zinc Tin	= 70 = 29 = 1	These are used for plates, tubes, etc.
Naval brass	Copper Zinc Tin	= 59 = 40 = 1	It is used for marine castings.
Nickel brass (German silver or Nickel silver)	Copper Zinc Nickel	= 60 – 45 = 35 – 20 = 5 – 35	It is used for valves, plumbing fittings, automobile fitting, type writer parts and musical instruments.

2. *Copper-tin alloys* (*Bronze*). The alloys of copper and tin are usually termed as bronzes. The useful range of composition is 75 to 95% copper and 5 to 25% tin. The metal is comparatively hard, resists surface wear and can be shaped or rolled into wires, rods and sheets very easily. In corrosion resistant properties, bronzes are superior to brasses. Some of the common types of bronzes are as follows:

(*a*) *Phosphor bronze*. When bronze contains phosphorus, it is called phosphor bronze. Phosphorus increases the strength, ductility and soundness of castings. The tensile strength of this alloy when cast varies from 215 MPa to 280 MPa but increases upto 2300 MPa when rolled or drawn. This alloy possesses good wearing qualities and high elasticity. The metal is resistant to salt water corrosion. The composition of the metal varies according to whether it is to be forged, wrought or made into castings. A common type of phosphor bronze has the following composition according to Indian standards :

Copper = 87–90%, Tin = 9–10%, and Phosphorus = 0.1–3%.

It is used for bearings, worm wheels, gears, nuts for machine lead screws, pump parts, linings and for many other purposes. It is also suitable for making springs.

(*b*) *Silicon bronze*. It contains 96% copper, 3% silicon and 1% manganese or zinc. It has good general corrosion resistance of copper combined with higher strength. It can be cast, rolled, stamped, forged and pressed either hot or cold and it can be welded by all the usual methods.

It is widely used for boilers, tanks, stoves or where high strength and good corrosion resistance is required.

(*c*) *Beryllium bronze*. It is a copper base alloy containing about 97.75% copper and 2.25% beryllium. It has high yield point, high fatigue limit and excellent cold and hot corrosion resistance. It is particularly suitable material for springs, heavy duty electrical switches, cams and bushings. Since the wear resistance of beryllium copper is five times that of phosphor bronze, therefore, it may be used as a bearing metal in place of phosphor bronze.

It has a film forming and a soft lubricating property, which makes it more suitable as a bearing metal.

(*d*) *Manganese bronze.* It is an alloy of copper, zinc and little percentage of manganese. The usual composition of this bronze is as follows:

Copper = 60%, Zinc = 35%, and Manganese = 5%

This metal is highly resistant to corrosion. It is harder and stronger than phosphor bronze. It is generally used for bushes, plungers, feed pumps, rods etc. Worm gears are frequently made from this bronze.

(*e*) *Aluminium bronze.* It is an alloy of copper and aluminium. The aluminium bronze with 6–8% aluminium has valuable cold working properties. The maximum tensile strength of this alloy is 450 MPa with 11% of aluminium. They are most suitable for making components exposed to severe corrosion conditions. When iron is added to these bronzes, the mechanical properties are improved by refining the grain size and improving the ductility.

Aluminium bronzes are widely used for making gears, propellers, condenser bolts, pump components, tubes, air pumps, slide valves and bushings, etc. Cams and rollers are also made from this alloy. The 6% aluminium alloy has a fine gold colour which is used for imitation jewellery and decorative purposes.

2.31 Gun Metal

It is an alloy of copper, tin and zinc. It usually contains 88% copper, 10% tin and 2% zinc. This metal is also known as ***Admiralty gun metal.*** The zinc is added to clean the metal and to increase its fluidity.

It is not suitable for being worked in the cold state but may be forged when at about 600°C. The metal is very strong and resistant to corrosion by water and atmosphere. Originally, it was made for casting guns. It is extensively used for casting boiler fittings, bushes, bearings, glands, etc.

2.32 Lead

It is a bluish grey metal having specific gravity 11.36 and melting point 326°C. It is so soft that it can be cut with a knife. It has no tenacity. It is extensively used for making solders, as a lining for acid tanks, cisterns, water pipes, and as coating for electrical cables.

The lead base alloys are employed where a cheap and corrosion resistant material is required. An alloy containing 83% lead, 15% antimony, 1.5% tin and 0.5% copper is used for large bearings subjected to light service.

2.33 Tin

It is brightly shining white metal. It is soft, malleable and ductile. It can be rolled into very thin sheets. It is used for making important alloys, fine solder, as a protective coating for iron and steel sheets and for making tin foil used as moisture proof packing.

A tin base alloy containing 88% tin, 8% antimony and 4% copper is called ***babbit metal.*** It is a soft material with a low coefficient of friction and has little strength. It is the most common bearing metal used with cast iron boxes where the bearings are subjected to high pressure and load.

Note : Those alloys in which lead and tin are predominating are designated as ***white metal bearing alloys.*** This alloy is used for lining bearings subjected to high speeds like the bearings of aero-engines.

2.34 Bearing Metals

The following are the widely used bearing metals :

1. Copper-base alloys, **2.** Lead-base alloys, **3.** Tin-base alloys, and **4.** Cadmium-base alloys

The **copper base alloys** are the most important bearing alloys. These alloys are harder and stronger than the white metals (lead base and tin base alloys) and are used for bearings subjected to heavy pressures. These include brasses and bronzes which are discussed in Art 2.30. The **lead base** and **tin base alloys** are discussed in Art. 2.32 and 2.33. The **cadmium base alloys** contain 95% cadmium and 5% silver. It is used for medium loaded bearings subjected to high temperature.

The selection of a particular type of bearing metal depends upon the conditions under which it is to be used. It involves factors relating to bearing pressures, rubbing speeds, temperatures, lubrication, etc. A bearing material should have the following properties:

1. It should have low coefficient of friction.
2. It should have good wearing qualities.
3. It should have ability to withstand bearing pressures.
4. It should have ability to operate satisfactorily with suitable lubrication means at the maximum rubbing speeds.
5. It should have a sufficient melting point.
6. It should have high thermal conductivity.
7. It should have good casting qualities.
8. It should have minimum shrinkage after casting.
9. It should have non-corrosive properties.
10. It should be economical in cost.

2.35 Zinc Base Alloys

The most of the die castings are produced from zinc base alloys. These alloys can be casted easily with a good finish at fairly low temperatures. They have also considerable strength and are low in cost. The usual alloying elements for zinc are aluminium, copper and magnesium and they are all held in close limits.

The composition of two standard die casting zinc alloys are as follows :

1. Aluminium 4.1%, copper 0.1%, magnesium 0.04% and the remainder is zinc.
2. Aluminium 4.1%, copper 1%, magnesium 0.04% and the remainder is zinc.

Aluminium improves the mechanical properties and also reduces the tendency of zinc to dissolve iron. Copper increases the tensile strength, hardness and ductility. Magnesium has the beneficial effect of making the castings permanently stable. These alloys are widely used in the automotive industry and for other high production markets such as washing machines, oil burners, refrigerators, radios, photographs, television, business machines, etc.

This copper statue, believed to be the world's oldest metal sculpture, is an image of Egyptian pharaoh Pepi I. This old kingdom pharaoh reigned from 2289 to 2244 BC.

2.36 Nickel Base Alloys

The nickel base alloys are widely used in engineering industry on account of their high mechanical strength properties, corrosion resistance, etc. The most important nickel base alloys are discussed below:

1. ***Monel metal.*** It is an important alloy of nickel and copper. It contains 68% nickel, 29% copper and 3% other constituents like iron, manganese, silicon and carbon. Its specific gravity is 8.87 and melting point 1360°C. It has a tensile strength from 390 MPa to 460 MPa. It resembles nickel in appearance and is strong, ductile and tough. It is superior to brass and bronze in corrosion resisting properties. It is used for making propellers, pump fittings, condenser tubes, steam turbine blades, sea water exposed parts, tanks and chemical and food handling plants.

2. *Inconel.* It consists of 80% nickel, 14% chromium, and 6% iron. Its specific gravity is 8.55 and melting point 1395°C. This alloy has excellent mechanical properties at ordinary and elevated temperatures. It can be cast, rolled and cold drawn. It is used for making springs which have to withstand high temperatures and are exposed to corrosive action. It is also used for exhaust manifolds of aircraft engines.

3. *Nichrome.* It consists of 65% nickel, 15% chromium and 20% iron. It has high heat and oxidation resistance. It is used in making electrical resistance wire for electric furnaces and heating elements.

4. *Nimonic.* It consists of 80% nickel and 20% chromium. It has high strength and ability to operate under intermittent heating and cooling conditions. It is widely used in gas turbine engines.

2.37 Non-metallic Materials

The non-metallic materials are used in engineering practice due to their low density, low cost, flexibility, resistant to heat and electricity. Though there are many non-metallic materials, yet the following are important from the subject point of view.

1. *Plastics.* The plastics are synthetic materials which are moulded into shape under pressure with or without the application of heat. These can also be cast, rolled, extruded, laminated and machined. Following are the two types of plastics :

(*a*) Thermosetting plastics, and

(*b*) Thermoplastic.

The ***thermosetting plastics*** are those which are formed into shape under heat and pressure and results in a permanently hard product. The heat first softens the material, but as additional heat and pressure is applied, it becomes hard by a chemical change known as phenol-formaldehyde (Bakelite), phenol-furfural (Durite), urea-formaldehyde (Plaskon), etc.

Reinforced plastic with fibreglass makes the material to withstand high compressive as well as tensile stresses.

The ***thermoplastic*** materials do not become hard with the application of heat and pressure and no chemical change occurs. They remain soft at elevated temperatures until they are hardened by cooling. These can be remelted repeatedly by successive application of heat. Some of the common thermoplastics are cellulose nitrate (Celluloid), polythene, polyvinyl acetate, polyvinyl chloride (P.V.C.), etc.

The plastics are extremely resistant to corrosion and have a high dimensional stability. They are mostly used in the manufacture of aeroplane and automobile parts. They are also used for making safety glasses, laminated gears, pulleys, self-lubricating bearing, etc. due to their resilience and strength.

2. *Rubber.* It is one of the most important natural plastics. It resists abrasion, heat, strong alkalis and fairly strong acids. Soft rubber is used for electrical insulations. It is also used for power transmission belting, being applied to woven cotton or cotton cords as a base. The hard rubber is used for piping and as lining for pickling tanks.

3. *Leather.* It is very flexible and can withstand considerable wear under suitable conditions. It is extensively used for power transmission belting and as a packing or as washers.

4. *Ferrodo.* It is a trade name given to asbestos lined with lead oxide. It is generally used as a friction lining for clutches and brakes.

QUESTIONS

1. How do you classify materials for engineering use?
2. What are the factors to be considered for the selection of materials for the design of machine elements? Discuss.
3. Enumerate the most commonly used engineering materials and state at least one important property and one application of each.
4. Why are metals in their pure form unsuitable for industrial use?
5. Define 'mechanical property' of an engineering material. State any six mechanical properties, give their definitions and one example of the material possessing the properties.
6. Define the following properties of a material :
   (*i*) Ductility, (*ii*) Toughness, (*iii*) Hardness, and (*iv*) Creep.
7. Distinguish clearly amongst cast iron, wrought iron and steel regarding their constituents and properties.
8. How cast iron is obtained? Classify and explain different types of cast irons.
9. How is grey cast iron designated in Indian standards?
10. Discuss the effect of silicon, manganese, sulphur and phosphorus on cast iron.
11. Define plain carbon steel. How it is designated according to Indian standards?
12. Define alloy steel. Discuss the effects of nickel, chromium and manganese on steel.
13. What are the common materials used in Mechanical Engineering Design? How can the properties of steel be improved?
14. State the alloying elements added to steel to get alloy steels and the effect they produce. Give at least one example of each.
15. Give the composition of 35 Mn 2 Mo 45 steel. List its main uses.
16. Write short notes on free cutting steel, and stainless steel.
17. Select suitable material for the following cases, indicating the reason;
    1. A shaft subjected to variable torsional and bending load ; 2. Spring used in a spring loaded safety valve; 3. Nut of a heavy duty screw jack; and 4. Low speed line-shaft coupling.
18. Select suitable materials for the following parts stating the special property which makes it most suitable for use in manufacturing:
    1. Turbine blade, 2. Bush bearing, 3. Dies, 4. Carburetor body, 5. Keys (used for fastening), 6. Cams, 7. Heavy duty machine tool beds, 8. Ball bearing, 9. Automobile cylinder block, 10. Helical springs.
19. Suggest suitable materials for the following parts stating the special property which makes it more suitable for use in manufacturing:
    1. Diesel engine crankshaft ; 2. Automobile tyres ; 3. Roller bearings ; 4. High pressure steam pipes ; 5. Stay bar of boilers ; 6. Worm and worm gear ; 7. Dies; 8. Tramway axle ; 9. Cam follower ; 10. Hydraulic brake piston.
20. Write short notes on high speed tool steel and spring steel.
21. Explain the following heat treatment processes:
    1. Normalising; 2. Hardening; and 3. Tempering.
22. Write short note on the type of bearing metals.
23. Discuss the important non-metallic materials of construction used in engineering practice.

OBJECTIVE TYPE QUESTIONS

1. Which of the following material has the maximum ductility?
   (*a*) Mild steel (*b*) Copper
   (*c*) Zinc (*d*) Aluminium
2. According to Indian standard specifications, a grey cast iron designated by 'FG 200' means that the
   (*a*) carbon content is 2%
   (*b*) maximum compressive strength is 200 N/mm^2
   (*c*) minimum tensile strength is 200 N/mm^2
   (*d*) maximum shear strength is 200 N/mm^2

3. Steel containing upto 0.15% carbon is known as
   (*a*) mild steel (*b*) dead mild steel
   (*c*) medium carbon steel (*d*) high carbon steel
4. According to Indian standard specifications, a plain carbon steel designated by 40C8 means that
   (*a*) carbon content is 0.04 per cent and manganese is 0.08 per cent
   (*b*) carbon content is 0.4 per cent and manganese is 0.8 per cent
   (*c*) carbon content is 0.35 to 0.45 per cent and manganese is 0.60 to 0.90 per cent
   (*d*) carbon content is 0.60 to 0.80 per cent and manganese is 0.8 to 1.2 per cent
5. The material commonly used for machine tool bodies is
   (*a*) mild steel (*b*) aluminium
   (*c*) brass (*d*) cast iron
6. The material commonly used for crane hooks is
   (*a*) cast iron (*b*) wrought iron
   (*c*) mild steel (*d*) aluminium
7. Shock resistance of steel is increased by adding
   (*a*) nickel (*b*) chromium
   (*c*) nickel and chromium (*d*) sulphur, lead and phosphorus
8. The steel widely used for motor car crankshafts is
   (*a*) nickel steel (*b*) chrome steel
   (*c*) nickel-chrome steel (*d*) silicon steel
9. A steel with 0.8 per cent carbon is known as
   (*a*) eutectoid steel (*b*) hypereutectoid steel
   (*c*) hypoeutectoid steel (*d*) none of these
10. 18/8 steel contains
    (*a*) 18 per cent nickel and 8 per cent chromium
    (*b*) 18 per cent chromium and 8 per cent nickel
    (*c*) 18 per cent nickel and 8 per cent vanadium
    (*d*) 18 per cent vanadium and 8 per cent nickel
11. Ball bearing are usually made from
    (*a*) low carbon steel (*b*) high carbon steel
    (*c*) medium carbon steel (*d*) high speed steel
12. The process which improves the machinability of steels, but lower the hardness and tensile strength is
    (*a*) normalising (*b*) full annealing
    (*c*) process annealing (*d*) spheroidising
13. The metal suitable for bearings subjected to heavy loads is
    (*a*) silicon bronze (*b*) white metal
    (*c*) monel metal (*d*) phosphor bronze
14. The metal suitable for bearings subjected to light loads is
    (*a*) silicon bronze (*b*) white metal
    (*c*) monel metal (*d*) phosphor bronze
15. Thermoplastic materials are those materials which
    (*a*) are formed into shape under heat and pressure and results in a permanently hard product
    (*b*) do not become hard with the application of heat and pressure and no chemical change occurs
    (*c*) are flexible and can withstand considerable wear under suitable conditions
    (*d*) are used as a friction lining for clutches and brakes

ANSWERS

1. (*a*)	**2.** (*c*)	**3.** (*b*)	**4.** (*c*)	**5.** (*d*)
6. (*b*)	**7.** (*c*)	**8.** (*b*)	**9.** (*a*)	**10.** (*b*)
11. (*c*)	**12.** (*d*)	**13.** (*b*)	**14.** (*d*)	**15.** (*b*)