3. The castings do not normally require any riser, venting or chilling as the cooling rate is very slow.
4. Any ordinary pattern of wood, metal, or epoxy resin may be employed.
5. Highly suitable for precision parts which include forging dies, dies for plastic moulding, dies for drawing, extrusion, die casting, patterns for shell moulding, impellers of pumps having very narrow passages, parts for aircrafts, atomic reactors etc.

Disadvantages of ceramic moulding are :

1. Impractical to control dimensional tolerances across the parting line to the same tolerance as within one-half of the mould.
2. The process is expensive as the mould materials are high in cost and expendable.

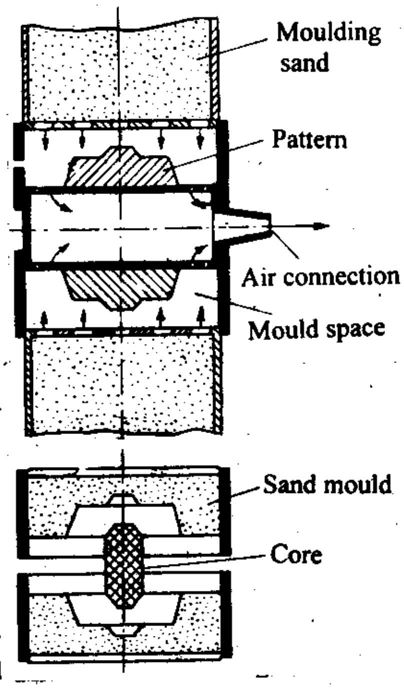

Figure 11.81 Suction moulding

SUCTION MOULDING

In this method, a vacuum is created by withdrawing air from the mould space. Subsequently moulding sand is sucked in, and the cavity is filled up. The sand can thereafter be rammed in the pattern. The processes is used for casting iron, steel and aluminium. The weight of casting ranges from 200 gm to 120 kg. Fig. 11.81 shows the operation. Mould is used once and is made from wet artificial crashed sand. The process is different from *vacuum moulding* where plastic sheet is vacuum moulded to the contour of the pattern, back filled with fine grained binder free quartz sand and sealed with another plastic sheet. The mould is constantly connected to a vacuum source before, during and after the casting.

Advantages of the suction moulding process are :

1. Optimum mould compactation around the pattern.

2. Decreasing hardness of compacted sand from inside to the outside.
3. High surface quality.
4. Dimensionally stable casting
5. Reduced cleaning.

Disadvantages of the process are :

1. High cost of manufacturing.
2. Change-over time high.

11.27 PERMANENT MOULD CASTING

While in the sand castings the moulds are destroyed after solidification of castings, the moulds are reused repeatedly in the permanent mould castings. This requires a mould material that has a sufficiently high melting point to withstand erosion by the liquid metal at pouring temperature, a high enough strength not to deform in repeated use, and high thermal fatigue resistance to resist premature crazing (the formation of thermal fatigue cracks) that would leave objectionable marks on the finished castings. Finally, and ideally, it should also have low adhesion.

The material used for making moulds (dies) may be cast iron, although alloy steels are the most widely used. For higher-melting alloys such a brasses and ferrous alloys, the mould steel must contain large proportion of stable carbides. More recently refractory metal alloys, particularly molybdenum alloys, have found increasing application. Graphite moulds can also be used for steel although only for relatively simple shapes. The resistance of the mould to the melt can be increased with refractory coatings (mould washes) and adhesion can be reduced by graphite, silicon, or other parting compounds.

All cast metals can be cast by permanent mould method. Zinc, copper, aluminium, lead, magnesium and tin alloys are most often cast by this process. Grey iron castings can also be produced by this method though a thin refractory coating or lining of sodium silicate or phosphoric acid is given so as to withstand high temperature of the molten metal.

In general, castings to be produced by permanent mould methods should be relatively simple in design with fairly uniform wall thickness and without undercuts or complicated coring. Undercuts on the exterior of castings complicate the mould design, resulting in additional mould parts and increased costs. Cores, if required, are made in sand.

Permanent mould castings have some distinct advantages over the typical sand mould casting. These include closer dimensional tolerances, better surface finish, greater mechanical strength, lower per centage of rejection, and more economical production in larger quantities. Some disadvantages of permanent moulds are their lack of permeabilities, the high cost of the moulds, the inability of the metallic mould to yield to the contraction forces of the solidifying metal, and difficulty in removing the casting from the mould since the mould cannot be broken up.

Permanent metal moulds can be advantageously used for small- and medium-sized (upto 10 kg) nonferrous castings, but would be impractical for large castings, and metals and alloys of very high melting temperature.

SLUSH CASTING

Slush casting, a form of permanent mould casting, is limited to some tin-, zinc-, or lead-base alloys. The principle involves pouring the molten metal into a permanent mould. After the skin has frozen, the mould is turned upside down or slung to remove the metal still liquid. A thin-walled casting (shell) results, the thickness depending on the chilling effect from the mould and the time of operation. In this process hollow castings can be produced without the use of cores.

Slush castings find wide application in the production of such products as toys, ornaments, and lighting fixtures, where strength is not of prime importance and good appearance is an absolute necessity.

DIE CASTING

Die casting is the art of rapidly producing accurately dimensioned parts by forcing molten metal under pressure into split metal dies which resemble a common type of permanent mould. Within a fraction of a second, the fluid alloy fills the entire die, including all the minute details. Because of the low temperature of the die (it is water-cooled), the casting solidifies quickly, permitting the die halves to be separated and the casting ejected. If the parts are small, several parts may be cast at one time in what is known as multiple-cavity die.

This process is particularly suitable for lead, magnesium, tin, and zinc alloys. The advantages of die casting practice lie in the possibility of obtaining castings of sufficient exactness and in the facility for casting thinner sections that can not be produced by any other casting method.

Two main types of machines are used to produce die castings (1) the hot chamber, exemplified here by the plunger-type machine, and (2) the cold chamber machine (Fig. 11.82).

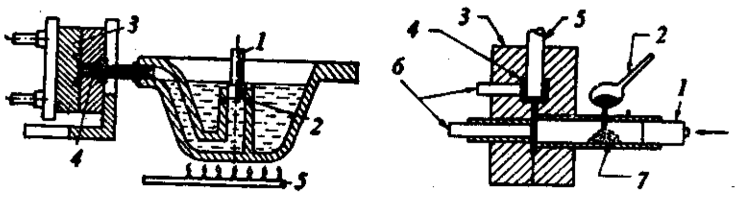

Figure 11.82 Die casting machine
(a) Hot chamber die-casting, (b) Cold chamber die-casting, machines

In a *hot chamber submerged plunger-type machine*, the plunger operates in one end of a gooseneck casting which is submerged in the molten metal. With the plunger in the upper position, metal flow by gravity into this casting through holes *2* just below the plunger and the entrapped liquid metal is forced into the die *3* through the gooseneck channel and in-gate *4*. As the plunger retracts, the channel is again filled with the right amount of molten metal. The plunger made of refractory material may be actuated manually or mechanically and hydraulically, that is by means of air pressure below 150 kgf/cm^2 (about 15 MN/m^2). Heating *5* is continued throughout the operation to keep the molten metal sufficiently liquid. The range of alloys that can be handled is limited by the pump material.

In a *horizontal plunger cold-chamber machine*, the plunger *1* is driven by air or hydraulic pressure to force the charge into the die *3*. As soon as the ladle *2* is emptied, plunger moves to the left and forces the metal into the cavity *4*. After the metal solidified, the core *5* is withdrawn, and then the die is opened. Ejectors *6* are employed to remove the casting automatically from the die.

The old chamber machine is ideal for metals such as aluminium alloys which cannot be cast in hot chamber machines due to the ready reactivity with molten aluminium with steel. High melting temperature alloys of the nonferrous type are also best die cast in cold chamber. Pressures loosely in cold chamber machine range from 300 to 1600 kgf/cm^2 (about 29 to 157 MN/m^2).

Advantages of die casting are :

1. Very high rate of production is achieved.
2. Close dimensional tolerances of the order of ± 0.025 mm is possible.
3. Surface finish of 0.8 microns can be obtained.

4. Very thin sections of the order of 0.50 mm can be cast.
5. Fine details may be produced.
6. Longer die-life is obtained.
7. Less floor space is required.
8. Unit cost is minimum.

Disadvantages of this process are :

1. Not economical for small runs.
2. Only economical for nonferrous alloys.
3. Heavy castings cannot be cast. In fact, the maximum size is limited by the size of the dies and the capacity of the die casting machines available.
4. Cost of die and die casting equipment is high.
5. Die castings usually contain some porosity due to the entrapped air.

CENTRIFUGAL CASTING

In the centrifugal casting, molten metal is poured into moulds while they are rotating. The metal falling into the centre of the mould at the axis of rotation is thrown out by the centrifugal force under sufficient pressure towards the periphery, and the contaminants or impurities present being lighter in weight are also pushed towards the centre. This is often machined out any way. Solidification progresses from the outer surface inwards, thus developing an area of weakness in the centre of the wall. This is caused by the meeting of the grain boundaries at final solidification and the entrapment of impurities in the central section. The grain is refined and the castings are completely free from any porosity defect by the forced movement of the molten metal, thus making dense and sound castings which are less subject to directional variations than static castings. The use of gates, feeders, and cores is eliminated, making the method less expensive and complicated.

Hollow cylindrical bodies such as cast iron water supply and sewerage pipes, steel gun barrels, and other symmetrical objects such as gears, disk wheels, pulleys, are conveniently cast without core by the centrifugal casting.

Centrifugal casting can be classified into three general types: true centrifugal, semicentrifugal, and centrifuged.

True centrifugal casting. This employs moulds of rotational symmetry made of steel (with a refractory mould wash or even a green- or dry-sand lining) or of graphite. The melt is poured while the mould rotates at its axis, which may be horizontal, vertical or inclined at any suitable angle between 0 to 90°, although horizontal axis of rotation is a more common practice. While rotating, the molten metal is carried to the walls of the cavity by centrifugal force (Fig. 11.83). The metal then solidifies forming a hollow casting without the use of a central core. The outside of the mould is water-cooled to accelerate solidification.

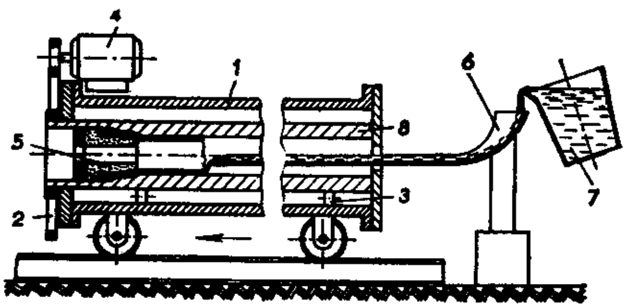

Figure 11.83 Centrifugal casting
1. Casting, 2. Toothed rim, 3. Roller, 4. Motor,
5. Core, 6. In-gate, 7. Ladle, 8. Rotating mould

By proper control of flow rates and movement of the pouring orifice, long and large tubes of very uniform quality and wall thickness can be cast. If desired, the outer contour of the casting can be varied, while the inside remains cylindrical.

The method is ideal for hollow cylindrical castings such as bushings, gun barrels, cast iron pipes, etc.

Semicentrifugal casting. This is a means of forming symmetrical shapes about the rotative axis, which is usually vertical in a balanced state. The molten metal is introduced through a gate which is placed on the axis, and flows outward to the rim by the centrifugal force. If a central bore is required in the casting, a dry sand core is best suited. The central gate acts as a riser for the hub portion.

Since the speeds are low, high pouring pressures are not produced and the impurities are not rejected towards the centre as effectively as in the true centrifugal casting.

This method is generally employed for making large-sized castings which are symmetrical about their own axis such as gears, disked wheels, propellers and pulleys.

Centrifuged. In this process several identical or nearly similar moulds are located radially about a vertically arranged central riser or sprue which feeds the metal into the cavities through a number of radially gates. The entire mould is rotated with the central sprue which acts as the axis of rotation. Thus, it is not a purely centrifugal process.

This type of casting is suitable for small, intricate parts where feeding problems are encountered. This method can be used to advantage for stack moulding of six or more moulds mounted one above the other.

CONTINUOUS CASTING

Continuous casting is used in general for the production of rods, pipes, sheet metal and other articles known as semifinished products in an uninterrupted process.

The main feature of the process is the pouring of molten steel through a tower nearly 300 m high ; this replaces the casting of ingots, the removal of moulds from ingots, the re-heating of ingots, and their primary rolling. To understand what this shortcut means, one has only to go over the principal operations in a conventional plant.

In a conventional plant, after pig iron has been turned into steel– say, first, in a Bessemer converter and then in what is known as an openhearth furnace– the white-hot molten steel flows into a huge ladle ; the ladle is carried by a crane and the molten steel is poured from it into a number of moulds to form ingots, i.e., pieces of steel of manageable size for further processing; the ingots have to be allowed to cool before the moulds can be removed ; the ingots are then carried to a mill for rolling; they are first re-heated and then put between rollers; the products emerge

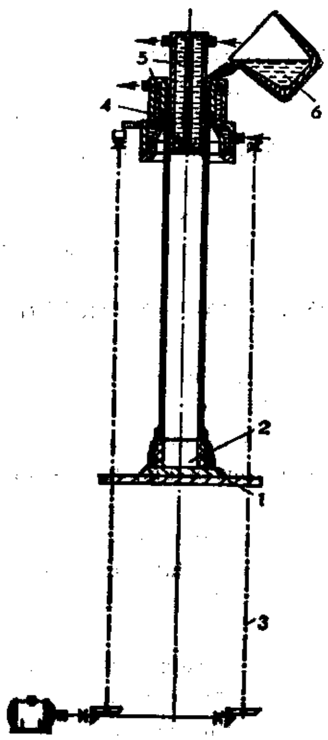

Figure 11.84 Continuous casting
1. Pulling plate, 2. Sand core, 3. Spindle for lowering the pulling plate, 4. Iron chill, 5. Water for cooling the core, 6. Molten metal

in a uniform, elongated shape, chopped off into convenient lengths, for use in the final fabrication of steel products.

The method of continuous casting dispenses with these separate and somewhat cumbersome stages. Instead of making ingots and then re-heating them for rolling, molten steel is poured steadily from the top of a tower into a long mould, cooled by water, and the passage of the steel through the mould is so controlled that the metal emerges from the other end in the shape of the products of a primary rolling mill.

The main task is to devise a suitable mould that will withstand the heat and fasten the solidifying steel into desired shape, without obstructing its steady flow. The substance used for the mould is copper, with an efficient cooling system.

The method has not yet been developed to such an extent as to lead to its universal introduction; questions of economics and quality are still being examined.

This is illustrated in Fig. 11.84. Molten metal *6* is poured into a metal mould which is cooled by water *5* without interruption by appropriate device. Thus, the casting solidifies and is fed still red-hot to a rolling mill or cut into pieces of required length. The pulling plate 1 is used to pull the solid product in a continuous length.

11.28 GATING AND RISERING OF CASTINGS

The term gate is defined as one of the channels which actually leads into the mould cavity, and the term gating or gating system refers to all channels by means of which molten metal is delivered to the mould cavity. The functions of a gating system are :

1. To provide continuous, uniform feed of molten metal, with as little turbulence as possible to the mould cavity. Excessive turbulence results in the aspiration of air and the formation of dross.
2. To supply the casting with liquid metal at best location to achieve proper directional solidification and optimum feeding of shrinkage cavities.
3. To fill the mould cavity with molten metal in the shortest possible tome to avoid temperature gradient.
4. To provide with a minimum of excess metal in the gates and risers. Inadequate rate of metal entry, on the other hand, will result many defects in the casting.
5. To prevent erosion of the mould walls.

6. To prevent slag, sand and other foreign particles from entering the mould.

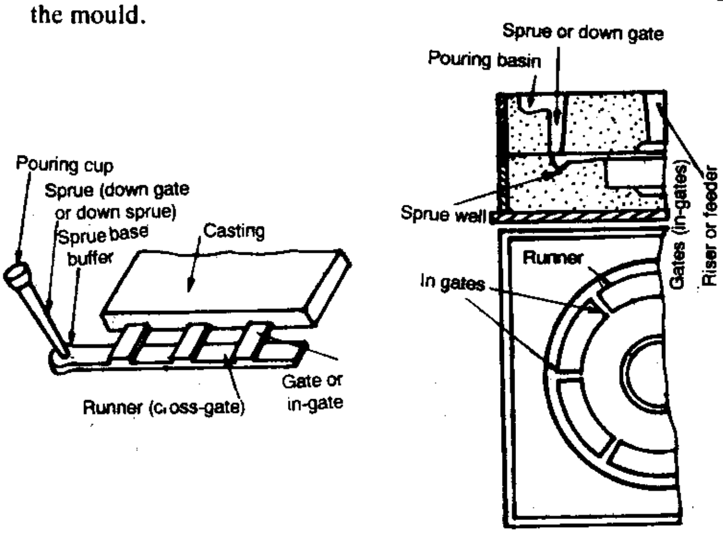

Figure 11.85 Parts of gating system

GATING SYSTEM

A gating system is usually made up of (1) pouring basin, (2) sprue, (3) runner, and (4) flow-off gate. They are shown in Fig. 11.85.

Pouring basin. This part of the gating system is made on or in the top of the mould. Sometimes, a funnel-shaped opening which serves as pouring basin, is made at the top of the sprue in the cope. The main purpose of the pouring basin is to direct the flow of metal from ladle to the sprue, to help maintaining the required rate of liquid metal flow, and to reduce turbulence and vortexing at the sprue entrance.

The basin should be made substantially large and should be placed near to the edge of the moulding box to fill the mould quickly. Also, it must be deep enough to reduce vortex formation and kept full during the entire pouring operation to compensate metal shrinkage or contraction.

Sprue. The vertical passage that passes through the cope and connects the pouring basin with the runner or gate is called the sprue.

The cross-section of a sprue may be square, rectangular, or circular. The sprues are generally tapered downward to avoid aspiration of air and metal damage. Sprues upto 20 mm diameter are round in section whereas larger sprues are often rectangular. A round sprue has a minimum surface exposed to cooling and offers the lowest resistance to the flow of metal. In a rectangular sprue, aspiration and turbulence are minimised.

Runner. In large castings, molten metal is usually carried from the sprue base to several gates around the cavity through a passageway called the runner. The runner is generally preferred in the drag, but it may sometimes be located in the cope, depending on the shape of the casting. It should be streamlined to avoid aspiration and turbulence.

Gate. A gate is a passage through which molten metal flows from the runner to the mould cavity. The location and size of the gates are so arranged that they can feed liquid metal to the casting at a rate consistent with the rate of solidification. A gate should not have sharp edges as they may break during passage of the molten metal and consequently sand particles may pass with the liquid metal into the mould cavity. However, the gates should be located where they can be easily removed without damaging the casting.

According to their position in the mould cavity, gating may be broadly classified as (1) top gating, (2) parting-line gating, and (3) bottom gating. However, different types of gating are illustrated in Fig. 11.86.

Top gates. In top gating, the molten metal from the pouring basin flows down directly into it. A *strainer*, made of dry sand or ceramic material, is mostly used at the pouring basin to control the metal flow and to allow only clean metal to enter.

In the case of light castings, wedge-shaped gates called *wedge gates* may be provided. For massive iron castings, *pencil gates* are used. In this type of gating, the sprue is made up of a series of slits fed from a pouring cup. It does control the rate of metal flow since the weight of molten metal is divided equally into its various slits or branches thus reducing the effective weight of head to a great extent. Moreover, slag (or dross) gets removed from the liquid metal in the pouring cup over the gate. In the *finger gate*, a modification of the wedge gate, the metal is again allowed to reach in a number of streams. The ring gate uses a core to break the fall of the molten metal and sends the molten metal in the mould in proper position, and at the same time retains the slag.

The advantage of top gating is that all metal enters the casting at the top, and the hottest metal therefore comes to rest at the top of the casting. As a result, proper temperature gradients favourable for directional solidification towards the risers located on the top of the casting are attained. The gates themselves may be made to serve as the risers. The disadvantage of top gating is the erosion of the mould by the falling metal. The mould cavity should, therefore, be hard and strong enough to resist the impact.

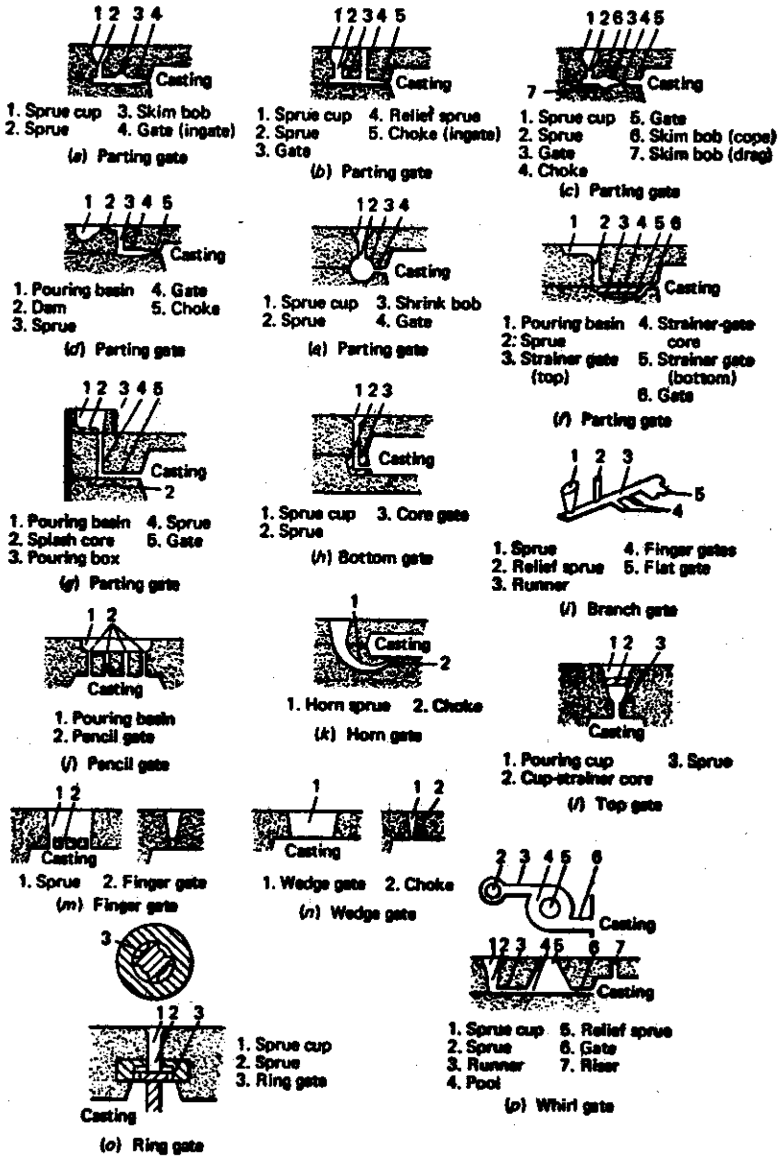

Figure 11.86 Type of gating

The advantage of top gating is that all metal enters the casting at the top, and the hottest metal therefore comes to rest at the top of the casting. As a result, proper temperature gradients favourable for directional solidification towards the risers located on the top of the casting are attained. The gates themselves may be made to serve as the risers. The disadvantage of top gating is the erosion of the mould by the falling metal. The mould cavity should, therefore, be hard and strong enough to resist the impact.

Parting gates. In parting line gates, the liquid metal enters the mould cavity from the side of the mould at the same level as the mould joint or parting line. The arrangement of providing a gate at the parting line in a direction horizontal to the casting allows the use of devices that can effectively trap any slag, dirt, or sand, which passes with the metal down the sprue.

In a *skimming gate*, any foreign matter which is lighter than the parent metal rises up through the vertical passage of the skimming gate and is thus trapped. Parting line gate with *skimbob* and *choke* is used to trap the slag and foreign matter in the mould and to serve as a restriction to control the rate of flow of the metal. Another effective method to trap the slag is to use a skimming gate with a whirlpool runner, usually called *whirlpool gate*. The slag, due to whirlpool action, comes to the centre from where it rises up in the whirlpool gate. *Gate with shrink bob* serves the dual function of slag-or dross-collector and as a metal reservoir to feed the casting as it shrinks.

Parting line gates are very simple to construct, and very fast to make. They produce very satisfactory result when the drag is not very deep, and prove to be very advantageous when they can be fed directly into the riser. In this system, the hottest metal reaches the riser, thereby promoting directional solidification. Moreover, cleaning costs of castings are reduced by gating into risers, because no additional gate is required to connect the mould cavity with riser. The disadvantage lies in the fact that some turbulence may occur as the liquid metal falls into the mould cavity.

Bottom gates. In bottom gates, the metal from the pouring basin flows down to the bottom of the mould cavity in the drag.

The *horn gate* resembles the horn of a cow. It enables the mould to be made in cope and drag only; there is no need of a "check". The horn gate tends to produce a fountain effect in the mould cavity. In another type, *dry sand* core forms the bottom gate. The sprue is curved at the bottom end to form a dirt-trap for slag, dirt, etc. This type of gate enables the mould to be made in two boxes.

The main advantage of bottom gates is that the turbulence of metal is kept at a minimum while pouring and mould erosion is prevented. Metal is allowed to rise gently in the mould and around the cores. Bottom gates, however, suffer from certain disadvantages: the metal continues to lose its heat as it rises in the mould cavity. Directional solidification is thus difficult to achieve. Besides, the riser cannot be placed near the gate entrance where the metal is hottest.

GATING RATIO

The rate of flow of metal through the mould cavity is a function of the cross-sectional area of the sprue, runners, and gates. The dimensional characteristics of a gating system can be expressed in terms of gating ratio. The term "gating ratio" is used to describe the relative cross-sectional areas of the components of a gating system taking the sprue base area as unity, followed by the total runner area and finally the total ingate area. A gating system having a sprue of 1 cm^2, a runner of 3 cm^2, and three gates, each having 1 cm^2 cross-sectional area, will have a gating ratio of 1 : 3 : 3.

The gating ratio reveals whether the total cross-section decreases or increases towards the mould cavity. Accordingly, there are two types of gating systems: *pressurised* and *non-pressurised*, or free flowing like a sewer system.

The pressurised system has less total cross-sectional are at the ingates to the mould cavity than at the sprue base. Thus a pressurised system would have ratio of 1: 0.75 : 0.5, 1 : 2: 1 and 2 : 1 : 1. This provides a *choke effect* which pressurises the liquid metal in the system. As this system is small in volume for a given metal flow rate, it results in a smaller loss of metal and greater yield. On the other hand, as this system keeps itself full of metal and provides a choke effect , high metal velocities may tend to cause severe turbulence at the junctions and corners and in the mould cavity. This is, however, generally suitable for ferrous metals and brass.

In the unpressurised system, the cross-sectional area of the sprue is less than the total area of the runner and than that of the ingates. The ratio used are 1 : 2 : 2. 1 : 3 : 3, etc. This system of gating therefore produces lower metal velocities and permits greater flow rates. As a result, it reduces turbulence in the gating system and spurting in the mould cavity. This system is generally adapted for metals such as aluminium and magnesium.

GATING DESIGN

Basic requirements expected from a gating system are to minimise turbulence and the aspiration of air and gases, to avoid dross formation to decrease the velocity of metal so as to minimise mould erosion, to avoid premature freezing of metal and assist in developing proper temperature gradient. To achieve these points, the design of pouring basin, sprue base, runner and gates must be carefully decided.

The area of sprue base

$$A_S = R_a (d\sqrt{2gH})$$

where R_a is the adjusted pouring rate, d the density of the molten metal, and H the sprue height.

The adjusted pouring rate

$$R_a = \frac{R}{k.c}$$

where R is the pouring rate, k the metal fluility and c the friction coefficient. The pouring rate R for ferrous metals and copper base alloys is given by the empirical formula,

$$R = \frac{(W)^p}{\left(0.95 + \dfrac{t}{0.853}\right)}$$

where W is the weight of the casting, t the critical casting thickness (thinnest section of the casting found out from the drawing), and p a quotient whole value depends upon the weight of the casting. The value of p for different castings is as follows :

Weight of casting	*Value of p*
upto 500 kg	0.50
500 — 5000 kg	0.67
5000 — 15000 kg	0.70

For light metal castings : $R = b\sqrt{W}$

where the value of b depends on the wall thickness

Wall thickness	*Value of b*
Below 6 mm	1.48
6 — 12 mm	1.25
Above 12 mm	0.70

In the case of cast iron, the metal fluidity k can be found out from the composition factor.

Composition factor = % total carbon + 1/4 % silicon + phosphorous

Composition factor	*Metal fluidity (k)*
3.2	0.5 to 0.7
3.6	0.6 to 0.9
4.0	0.75 to 1.0
4.2	0.90 to 1.2

In the case of other metals, k can be taken as unity.

The c factor has a value of 0.85 to 0.90 for tapered sprues and 0.70 to 0.75 for straight sprues.

The effective sprue height H according to the placement of the pattern in the mould :

(a) Pattern entirely in drag, $H = h$; h' = height of sprue.

(b) Pattern entirely in cope, $H = h - (C/2)$ where C is the height of casting.

(c) Split pattern, partly in drag and partly in cope :

$$H = \frac{P^2}{2C}$$

P = height of casting in cope,
C = total height of casting.

If P less than 25 mm, disregard $\frac{P^2}{2C}$

The effective sprue height H can also be determined as :

$$H = h - \frac{a^2}{2C}$$

Where h is the height of the sprue, C the total height of the casting (mould

TABLE 11.11 DIAMETER OF SPRUE AND BOTTOM FOR GRAY IRON

Wt. of casting (kg)	*Critical thickness (mm)*				
	12	*18*	*25*	*35*	*50*
5	12.0	—	—	—	—
10	15.0	13.5	—	—	—
15	16.5	15.0	13.5	—	—
20	16.5	15.0	15.0	—	—
35	18.0	16.5	15.0	13.5	—
40	20.0	18.0	16.5	15.0	—
50	22.0	18.0	18.0	16.5	13.5
75	23.5	22.0	20.0	16.5	15.0

Use gating ratio of 1 : 4 :4 for tapered round sprues and 1: 3 : 3 for straight round sprues.

cavity), and *a* the height of the mould cavity in the cope.

Using the appropriate gating ratio, according to the type of metal cast and type of sprue (tapered or straight), cross-sectional areas of runner and ingates and their corresponding sectional sizes may be found out.

A simple way which gives fairly reliable results is to select from the Table 11.11, the diameter of sprue at the bottom from the casting weight and critical thickness (predominant value).

11.29 RISERING OF CASTINGS

A *riser* or a *feeder head* is a passage of sand made in the cope to permit the molten metal to rise above the highest point in the casting after the mould cavity is filled up. Risers serve a dual function : they compensate for solidification shrinkage which is a very common casting defect, and are a heat source so that they freeze last and promote directional solidification. Risers provide thermal gradients from a remote chilled area to the riser. Besides, they enable the pourer to see the metal as it falls into that the mould cavity. If the metal does not appear in the riser, it indicates that the mould cavity has not been completely filled up. Risers also permit the escape of steam, gas, and air as the mould cavity is being filled up with the molten metal.

The main requisites of an effective riser are :

1. It must have such a volume that it has enough reservoir of feed-metal in order to feed the last part of the casting to freeze.
2. The solidification time of metal in the riser should be greater than that in the mould cavity.
3. It should derive sufficient feeding pressure either by atmospheric pressure of by metallostatic pressure.
4. It should be so designed that it establishes and effects temperature gradients suitable for directional solidification towards the riser.

The main considerations of the riser are :

1. Type, shape, size, and location.
2. Economics in the moulding and ease of removal of risers from the casting.
3. In general, all hot spots are to be risered.
4. Number of risers required will have to work out on the basis of feeding distance of the risers.

TYPES OF RISERS

There are two types of risers : top or open risers and side or blind risers.

In the *top* or *open riser*, the upper surface is *open* to the atmosphere and the riser is usually placed above the volume to be fed or at the parting surface of the mould. The open riser never extends downwards into the drag. The liquid metal in the riser is fed to the solidifying casting under the force of gravity and atmospheric pressure till the top surface of the riser–metal solidifies.

RISER SHAPE AND SIZE

The metal in the riser should remain in the molten state for a longer time than in The mould cavity. The heat loss in the riser should therefore be kept to a minimum. It means a riser must freeze more slowly than the casting. Thus their shape should be such as to give volume-to-surface-area ratio a maximum value. This ratio is maximum for a sphere. This is therefore the ideal shape of a riser. But because of difficulties in moulding this is not in very much use. For the same volume, the next best shape is a cylinder.

As regards the height of the riser, it must be tall enough to ensure that any pipe formed in it does not penetrate the casting . The ratio of height to diameter usually varies from 1 : 1 to 1.5 : 1. For general guidance, the empirical formulae derived by Chvorinov can be used.

Chvorinov's rule states that *freezing time* is proportional to $(V/A)^2$ ratio, where V/A is the ratio of the volume of the casting to its surface area. If the metal in the riser has to remain liquid for a longer time, V/A should be large or A/V ratio should be small. To determine a suitable riser diameter, the $(V/A)^2$ ratio of a given casting is computed and a riser whose $(V/A)^2$ is slightly larger than that of the casting, say 10 to 15 per cent larger, is chosen.

A major simplifications obtained, however, by the device of introducing the *shape factor* $(L + W)/T$. The length L, width W and thickness T are computed by using the maximum dimensions of the parent section of the casting,. The relationship between shape factor and, ratio of Vr/Vc, where Vr is the volume of the riser and Vc the volume of the casting is available in handbooks for different cast metals. From this ratio, the casting volume being known, the riser volume can be found out. Thus the riser diameter can be calculated from its volume once the riser height is decided. In 1950's the Naval Research Laboratory devised The shape factor chart and riser height and volume chart.

RISER LOCATION

In addition to the shape and size, a riser must be properly located to obtain a sound casting. A riser must have adequate metallostatic head and must maintain positive pressure of liquid metal on all portions of the solidifying casting, it is required to feed. The location of the riser should therefore be chosen keeping in view the metal to be cast, the design of the casting, and the feasibility of directional solidification. The riser may be located either at the top of the casting or at the side. Top risering is advisable for light metals as it develops feeding pressure due to the metallostatic pressure in the riser. Frequently. more than one riser have be to used to secure soundness in the casting. In such cases, their spacing should be carefully arranged so as to minimise the shrinkage. The feeding range, the distance a riser can feed the metal in a casting, thus becomes an important consideration in riser location. It is usual practice to maintain a feeding range of about 4.5 times the thickness (T) for plate type castings and 2 to 2.5 T or 6 $\sqrt{T}$ for bar type castings.

11.30 USE OF PADDING AND CHILLS

In certain casting such as plates, directional solidification is achieved with great difficulty. In such cases, *padding* is applied to promote directional solidification . The padding is a wedge shaped extra metal added to the casting so that its thickness becomes greatest at the point nearest to the feeder and least at the point furthest from the feeder. This extra metal, if not desired, can later be removed by machining.

Exothermic materials serve to produce directional solidification by the generation of heat. These are mixtures of the oxides of the metal to be cast and aluminium metal in powder form which produce large amount of heat when come in contact with hot metal. The exothermic material also serves as an insert in the form of a core in the mould at the desired position to help in controlling directional solidification.

Directional solidification can also be accomplished by *chilling* the metal in those portions of the casting that are far away from the liquid metal source. If a casting consists of sections of uneven thickness, the thin sections tend to solidify quicker than the thick ones resulting in uneven contraction and severe distortion. This difficulty is also removed by embedding chills in thin sections and thus making them also to solidify at a faster rate. Chills also help in making the metal dense, thereby avoiding internal flaws. The chills are broadly of two types : external and internal. External chills are placed in the mould walls, while internal chills are placed right in the mould ca[illegible] and these become a part of the casting when liquid metal is poured in the mould cavity.

The use of exothermic material chills induces conductivity of sand moulds.

11.31 MELTING FURNACES FOR FERROUS METALS : CUPOLA

Various types of melting furnaces are used in different foundry shops, depending upon the quantity of metal to be melted at a time, and the nature of work that is carried out in the shop. Converters, open-hearth, and electric furnaces for melting iron and steel have already been explained in Chapter 4 of this book. Only cupola furnace used in foundries for melting and refining pig iron along with scrap is described below.

The primary objective in cupola is to produce iron of desired composition, temperature and properties at the required rate in the most economical manner. Besides, this furnace has many distinct advantages over the other types, e.g., simplicity of operation, continuity of production, and increased output coupled with a high degree of efficiency.

DESCRIPTION OF A CUPOLA

The cupola furnace (Fig. 11.87) consists of a vertical, cylindrical *steel sheet*, 6 to 12 mm thick, and lined inside with acid *refractory* bricks or acid tamping clay. The refractory bricks or the tamping clay used consist of silicon oxide acid (SiO_2) and alumina (Al_2O_3). The lining is generally thicker in the lower region where the temperatures encountered are higher than in the upper region. The shell is mounted either on a brick work foundation or on steel columns. In a steel column arrangement, used on most modern cupolas, the bottom of the shell is provided with *drop-bottom doors* through which debris, consisting of coke, slag, etc. can be discharged at the end of a melt. In drop--bottom cupolas, the working bottom is built up with moulding sand which covers the drop-doors. This bottom slopes towards the metal *tapping hole* situated at the lowest point at the front of the cupola. Opposite this tap hole, and somewhat above it, is another hole, called the *slag hole*, which enables the slag to be taken out.

A constant volume of air for combustion is obtained from a motorised blower. The air is carried from the blower through a pipe called *wind pipe* (air blast inlet), first to a circular jacket around the shell called *windbox* and then into the furnace through a number of openings called *tuyeres* which are provided at a height of between 450 to 500 mm above the working bottom or bed of the cupola, These tuyeres are generally 4, 6, or 8 in numbers depending on the size of the cupola and they may be fitted in one or more number of rows. The total area of the tuyeres should be about one-fifth to one-sixth of the cross-sectional area of the cupola inside the lining at tuyere level. Usually tuyeres have a size of 50×150 mm or 100×300 mm. Auxiliary tuyeres are sometimes provided to raise melting efficiency.

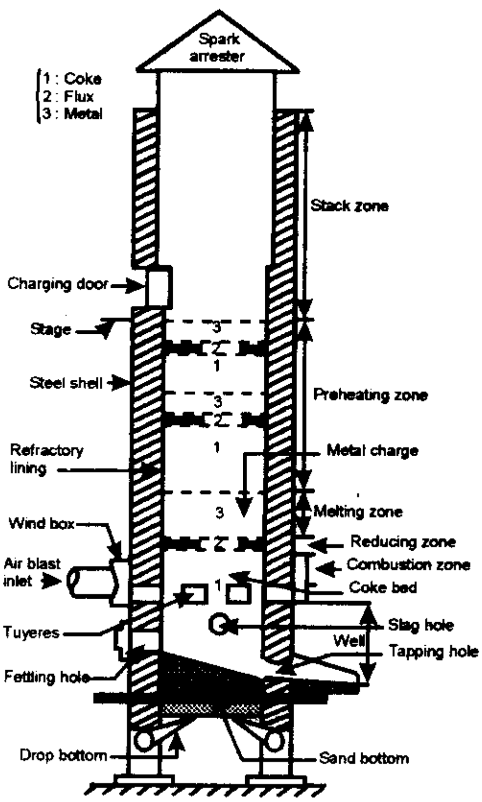

Figure 11.87 The cupola

A *valve* is provided in the blast pipe to control the supply of air. Depending on the size of the cupola, the type of iron melted, and the compactness of the charge the pressure of air may very from 250 mm to 400 mm of water for small and medium-sized furnaces and from 400 mm to 850 mm for large-sized furnace. A *volume meter* is sometimes installed to know the volume of air passing. The amount of air, required to melt one tonne of iron depends upon the quality of coke and the coke-iron ratio. Long practice proves that it takes about 800 to 900 cu m of air to melt one tonne of iron in a cupola, assuming that a 10 to 1 ratio of iron to coke is used. For lower ratio, higher volumes of air will be needed.

A *charging door* is provided through which metal, coke and flux are fed into the furnace, and this is situated 3 to 6 m above the tuyeres, according to the size of the cupola. A large *platform* or *stage* usually surrounds the cupola at the level of about 300 mm below the bottom of the charging door. The shell is usually continued for 4.5 to 6 m, above the charging door to form a chimney. At the top of the furnace a conical cap called the spark arrested, prevents the spark from emerging to the outside. The spark arrested cools down the sparks and allows only smoke to escape from the opening. Sometimes, a cupola may be fitted with a *collector, fitter,* and *precipitator* to minimize atmospheric pollution.

Zones in a cupola. On the basis of combustion reactions, the entire shaft of the cupola may be divided as under :

Crucible zone is between top of the sand bed and bottom of the tuyeres. The molten iron is accumulated here. This is also called the *well* or *hearth.*

Combustion or *oxidizing zone* is situated normally 150 to 300 mm above the top of the tuyeres. All the oxygen in the air blast is consumed here owing to the actual combustion taking place in this zone. Thus a lot of heat is liberated and this is supplied from here to other zones . Heat is also evolved due to the oxidation of silicon and manganese. Due to this high heat, the temperature being 1550° to 1850°C , molten drops of cast iron pour into the hearth. The chemical reactions which occur in this zone are :

$$C + O_2 \rightarrow CO_2 + \text{Heat}$$
$$Si + O_2 \rightarrow SiO_2 + \text{Heat}$$
$$2\,Mn + O_2 \rightarrow 2\,MnO_2 + \text{Heat}$$

Reducing zone extends from the top of the combustion zone to the top of the coke bed. In this zone, the reduction of CO_2 to CO occur and the temperature drops to about 1200°C at the coke bed. Due to the reducing atmosphere, the charge is protected from any oxidizing influence. The reaction taking place in this zone is :

$$CO_2 + C\,(\text{coke}) \rightarrow 2\,CO - \text{Heat}$$

Melting zone starts from the first layer of metal charge above the coke bed and extend up to a height of 900 mm. Highest temperature is developed in this zone for complete combustion of the coke and iron is thus melted here. The temperature in this zone is around 1600°C. A considerable carbon pick-up by the molten metal also occurs in this zone according to the following reactions :

$$3\,Fe + 2\,CO \rightarrow Fe_3C + CO_2$$

Preheating zone or *charging zone* starts form above the melting zone and extends up to the bottom of the charging door. Preheating zone contains cupola charge as alternate layers of coke, flux and metal and they are preheated there at a temperature of about 1100°C before coming to the melting zone.

Stack zone extends from above the preheating zone to the top of the cupola. It carries the gases generated within the furnace to the atmosphere.

Capacity of a cupola. The output of a cupola is defined as the tonnes of molten metal obtained per hour of the heat. Cupola capacities (sizes) vary from 1 to 15 tonnes (or even more) of melted iron per hour. The size depends not only upon the cross-sectional area of the cupola, but upon the intensity of coke consumption as well. But the intensity of coke consumption is meant the tonnes of coke burned per sq. m of the cross-sectional area of the cupola in unit time. It has been observed that 14 cm^2 of cupola plan area burns about 1 kg of coke per hour. The diameter of cupola varies from 1 to 2 m with a height of from 3 to 5 times the diameter.

CUPOLA OPERATION

The different steps involued in cupola operation are :

1. Preparation of cupola. The first operation in preparing a cupola is to clean out the slag and refuse on the lining and around the tuyeres from the previous run. Any bad spots or broken bricks are repaired with a daubing mixture of fire clay and silica sand or ganister. The preparation of the sand bottom in the cupola is begun as soon as the patching of the lining has been completed. The bottom doors are raised and held in this position by metal props. The bottom sand is introduced through the charging door and is rammed well around the lining and across the intersection of the bottom doors. This layer of sand is built up to a height of 100 to 200 mm above the cast iron door. The surface of the sand bottom is sloped from all directions towards the tapping hole so that the molten metal can be drained completely from the cupola at any time. An opening about 35 mm diameter is provided for the removal of the slag, and a tap hole is formed around a wooden pattern about 20 mm in diameter. The cupola should be thoroughly dried before firing.

2. Firing the cupola. In firing a cupola, a fire of kindling wood is ignited on the sand bottom. This should be done 2.5 to 3 hours before the molten metal is required. On the top of the kindled wood, a bed of coke is built. When the wood is burning well coke is dumped into the well from above in several portions making sure that the coke begins to burn too. The coke is added to a level slightly above the tuyeres and the air blast is turned on at a lower than normal blowing rate to ignite the coke. As soon as red spots begin to show over the top of the fuel bed, additional coke is introduced into the cupola to reach a height of 700 to 800 mm above the upper row of tuyeres. The coke bed must be thoroughly hot before it is finished off to its final height. The height of the coke bed is determined by using a measuring rod which has been prepared to indicate the distance from the sill of the charging door to the top of the coke bed. The layer of coke resting on the sand bottom before beginning the heat is called *bed charge*. The amount of coke in the bed is dependent upon the pressure of the air supplied to the cupola. The height of the bed charge or coke-bed is very important to the cupola operation ; it affects the temperature, melting rate, and chemical composition. Other things being equal, a low bed will yield cooler metal than one which than one which is high.

3. Charging the cupola. As soon as the coke bed is built up to the correct height and ignited uniformly throughout, alternate layers of pig iron, coke and flux (limestone) are charged from the charging door until the cupola is full. Suitable scrap is also added along with the pig iron, to control the chemical com-position of the iron produced. The proportion of this scrap is ordinarily from 25 to 50 per cent of the total weight of the metal poured. When considerable steel scrap is used along with pig iron., a small amount, say from 2 to 4 per cent of ferro-manganese is used as a deoxidiser. The weight of the metal charge should be from 10 to 15 per cent of the hourly out-put of the cupola. The object of adding flux is to remove impurities in the iron, and to protect the iron from oxidation, to reduce the melting point of the slag, and to increase its fluidity for easy disposal. Besides limestone, fluorspar and soda ash are also sometimes used as fluxing material. The quantity of limestone required may be 30 to 40 kg per tonne of iron melted or 25 per cent by weight of the coke charged. The ratio between the metal melted and coke charged depends on a great number of factors. So it is not possible to give definite recommendations for this ratio which can be achieved on different classes of work. Table 11.11 is given only as a guide and shows good average practice in the industry. More commonly it is kept 10 : 1. This means that 1 tonne of coke is required to melt 10 tonnes of iron.

TABLE 11.12 RATIO OF METAL MELTED TO COKE CHARGED

Class of work	*Metal to charge coke ratio*
Charges containing more than 75 per cent steel scrap	12:1—15:1
High-phosphoric iron for fairly heavy castings	11:1—14:1
High-phosphoric iron for light castings	10:1—12:1
Medium-phosphoric iron for engineering castings	8:1—10:1
Low-phosphoric iron for high duty & automobile castings	6:1— 7:1
Charges containing 50-75 per cent steel scrap	6:1— 8:1

4. Soaking of iron. After the cupola is fully charged upto the charging door, the charge should soak in the heat for about 45 minutes. The charge gets slowly heated since the air blast is kept at a lower than normal blowing rate (practically kept shut) during this time. This causes the iron to get soaked.

5. Air blast. At the end of the soaking period, full blast is turned on. Before turning on the blast, the tuyere openings and the tapping hole are kept closed. After the blast has been on for a few minutes, say about 10 minutes, molten metal starts accumulating in the hearth. When the metal in the cupola starts melting, the rate of charging should be equal to the rate of melting, so that the furnace is kept full throughout the heat. At the end of the melt the charging is stopped but the blast is kept on until all the metal has melted.

6. Tapping and slagging. The first tapping can be made 40 to 50 minutes after the full air blast is turned on. During this period, sufficient metal is collected in the hearth above the sand bed. When slag accumulates in the well, the slag hole is opened and the slag is run off, preferably into a bogie for easy removal. Molten metal is collected in ladles and is carried to the moulds for pouring. The same procedure is repeated until all the metal is melted and the operation is over.

7. Closing the cupola. When the operation is over, the blast is shut off and the prop under the bottom door is knocked down so that the bottom plates swing open. This enables the cupola remains to drop on to the floor or into a bucket. They are then quenched and removed from underneath the cupola.

Generally, cupolas are run continuously as are blast furnaces, but are worked only for such periods as may be required. At many foundries the melting period does not exceed 4 hours, but cupolas may be operated continuously for 10 hours or more.

EFFICIENCY OF CUPOLA

Thermal or melting efficiency of a cupola in per cent is expressed as :

$$\frac{\text{Heat utilised in preheating, melting and superheating}}{\text{Potential heat in coke + heat from oxidation of Fe, Si, Mn + heat in the air blast}} \times 100$$

The efficiency of a cupola varies from 30 to 50 per cent depending on

1. coke rate or coke ratio expressed as the inverse of the metal-fuel ratio in percentage,
2. blast rate, and
3. mean coke size.

AIR REQUIREMENTS FOR CUPOLA

For complete combustion of the fuel in the furnace, about 8.4 cu m of air is required per kg of coke at normal atmospheric pressure and temperature. If the ratio of meal to coke charged 10 : 1, which is considered a satisfactory figure, the coke required per tonne of iron will be 1000/10 kg, i.e. 100 kg. Thus , the volume of air required per tonne of melted is

$$8.4 \times 100 = 840 \text{ cu m.}$$

To allow for leakage, etc., the air supplied is generally a little in excess i.e. about 900 cu m per ton of iron.

DIMENSIONS OF A CUPOLA

The principal dimensions of a cupola are selected on the basis of empirical data. Thus, the cross-sectional area A_c of a cupola depends upon the designed hourly output and is determined from the formula

$$A_c = \frac{\pi d^2}{4} = \frac{Q}{Q_1} \; m^2$$

Where d = cupola diameter in the clear , m,

Q = designed cupola output, tonnes per hour,

Q_1 = specific output per sq. m of cross-sectional area, tonnes per hour. As a rule, Q_1 = 6 to 8 tonnes per hour.

The useful height of a cupola (distance from the axis of the main tuyeres to the lower edge of the charging hole) depends upon the diameter and is designed according to the ratio H : d = from 3 to 5.

The cupola height directly affects the melting rate, fuel consumption and the temperature and quality of molten metal. If it is too high the coke may be crushed as the charge drops ; if it is too low the metal is not heated to a sufficient degree, the draught is reduced and the cupola output is decreased.

The inside diameter of the cupola determines the amount of coke consumed and the amount of iron melted per unit of time. It has been found that 14 cm² of cupola plan area burns about 1 kg of coke per hour. Thus, a cupola having a capacity of 3 tonnes per hour will require (3×100)or 300 kg of coke per hour, assuming a metal-fuel ratio of 10 : 1 . The cupola area will therefore be equal to (14x300) or 4200 cm². The internal diameter will then be

$$\frac{\sqrt{4200\times4}}{\pi} = 73 \text{ cm (approx.)}$$

Problem 11.1 : A fan supplies 100 cu m of air per minute to a cupola. If the air required to melt one tonne of metal is 1000 cu m hour, calculate the capacity of the cupola. Assume 10 per cent leakage in the pipe line.

The amount of air reaching the cupola per hours is

$$\frac{100\times60\times90}{100} = 5400 \text{ cu m.}$$

If the capacity of the cupola is m tonnes per hour, the amount of air required will be 1000xM. Therefore

$$1000\times M = 5400$$

$$M = 5400 / 1000 = \mathbf{5.4 \text{ tonnes per hour.}}$$

Problem 10.2 : A cupola 70 cm in diameter has a melting of 10 : 1, How much iron is melted per hour ? How much coke is consumed per hour ? Assume a melting rate of 0.5 kg/hr/cm^2.

$$\text{Iron melted} = \pi/4\ d^2 \times M$$
$$= \pi/4\ (70)^2 \times 0.5$$
$$= 1.96 \text{ tonne/hr.}$$
$$\therefore \text{coke consumed} = 1960/10 = \mathbf{196\ kg/hr.}$$

CUPOLA CHARGES

If products of uniform quality are desired, a careful consideration must be given to the cupola charge. Usually, several grades of pig iron and scrap are available to the foundry man. To achieve a desired composition of the cast metal, these grades need to be adjusted and controlled. Since the various elements in metal undergo chemical changes during the re-melting operation, allowances have to be given for their loss or gain while making up the charge. The loss or gain of various elements is as follows.

1. *Carbon*. Molten metal picks up carbon as it passes through the incandescent coke forming the bed. With properly controlled melting conditions, a gain of 0.15 per cent may be expected. While the carbon content of the metal increases because of carbon absorption from the coke, the same suffers a little loss due to oxidation.
2. *Silicon*. Silicon suffers some loss due to oxidation as the drops of the molten iron trickle past the tuyeres. The loss may be 10 per cent of the silicon present in the charge.
3. *Manganese*. Manganese also has a tendency to get lost along with silicon during melting. The loss may be about 15 to 20 per cent of the manganese present in the charge.
4. *Sulphur*. Sulphur is picked up from coke, scrap and flux, etc. Generally, the gain in sulphur content is assumed to be about 0.03 to 0.05 per cent.
5. *Phosphorus*. There is practically no loss or gain in the phosphorus content.
6. *Iron*. Iron itself also tends to get oxidized and lost, but the loss which is quite small, may be assumed to be about 3 to 4 per cent.

TABLE 11.13 COMPOSITIONS OF SOME TYPICAL METALS FOR CUPOLA MELTING (Percent)

	Carbon	*Silicon*	*Mangenese*	*Phosphorus*	*Sulphur*
No. 1 pig iron	3.5	2.50	0.72	0.18	0.016
No. 2 pig iron	3.5	3.00	0.63	0.12	0.018
Cast iron scrap	3.4	2.30	0.50	0.20	0.030
Returns from foundry	3.3	2.50	0.65	0.17	0.035

Calculations for different mixtures. The following example shows how the calculations for different mixtures are made. It is assumed that 3000 kg of iron are needed and will be fed into the cupola. The typical raw materials available in the foundry are listed in **Table 11.13** with their compositions.

The materiel is to be used in the following proportions : No. 1 pig iron —10 percent; No. 2 pig iron — 20 percent ; returns — 40 Percent ; new scrap — 30%.

1. *Carbon content.* Some carbon is oxidized, but the same amount is picked up from the fuel.

No. 1 pig iron	3000×0.10×0.035	= 10.6 kg
No. 2 pig iron	3000×0.20×0.035	= 21.0 kg
New scrap	3000×0.30×0.034	= 30.6 kg
Returns	3000×0.40×0.033	= 39.6 kg
		101.7 kg

The final percentage of carbon $= 100\times(101.7/3000)$
$= \mathbf{3.39}$

2. *Silicon content.* The silicon content can be expected to be reduced 15% by oxidation .

No. 1 pig iron	3000×0.10×0.025	= 7.5 kg
No. 2 pig iron	3000×0.20×0.030	= 18.0 kg
New scrap	3000×0.30×0.023	= 20.7 kg
Returns	3000×0.40×0.025	= 30.0 kg
		76.2 kg

The final percentage of silicon $= \dfrac{[76.2 - (76.2\times0.15)]\times100}{3000} = \mathbf{2.19}$

3. *Manganese content.* The manganese content can be expected to be reduced by 20%.

No. 1 pig iron	3000×0.10×0.0072	= 2.16 kg
No. 2 pig iron	3000×0.20×0.0063	= 3.78 kg
New scrap	3000×0.30×0.0050	= 4.50 kg
Returns	3000×0.40×0.0065	= 7.80 kg
		18.24 kg

$$\text{The final percentage of manganese} = \frac{[18.24-(18.24\times 0.2)]\times 100}{3000}$$

$= \mathbf{0.49}$

4. ***Phosphorus content.*** Phosphorus loss in the cupola is negligible.

No. 1 pig iron	3000×0.10×0.0018	= 0.54 kg
No. 2 pig iron	3000×0.20×0.0012	= 0.72 kg
New scrap	3000×0.30×0.0020	= 1.80 kg
Returns	3000×0.40×0.0017	= 2.04 kg
		5.10 kg

The final percentage of phosphorus = [5.10 × 100]/300 = **0.17**

5. *Sulphur content.* The iron loses almost no sulphur in melting but picks up about 4per cent of the sulphur in the coke.

No. 1 pig iron	3000×0.10×0.00016 =	0.048 kg
No. 2 pig iron	3000×0.20×0.00018 =	0.108 kg
New scrap	3000×0.30×0.00030 =	0.270 kg
Returns	3000×0.40×0.00035 =	0.420 kg
		0.846 kg

Assuming a coke to iron melting ratio of 1 to 10 and a coke with a sulphur content of 0.5 per cent,

[3000 × 0.005]/10	=	1.5 kg of sulphur
pick up 4per cent	=	1.5 × 0.04
	=	0.060 kg
The final percentage of sulphur	=	[(0.846+0.060) × 100]/3000
	=	**0.0302**

Problem 10.3 : The per cent of silicon in the aforesaid analysis of iron is 2.19. If The desired analysis requires a silicon content of 2.5 per cent adjust the charge and calculate the final proportions of charge constituents.

Desired silicone content	=	2.5 per cent
Calculated silicon centent	=	2.19 per cent
Additional silicon required	=	0.31 per cent
or silicon required for 3000 kg		
	=	0.31× 3000/100
of charge	=	9.3 kg.

To have a net additional silicon of 9.3 kg, total silicon required to be added (assuming 10 per cent loss) is

$$= \quad [9.3 + 10/100] \times 9.3 \quad = \mathbf{10.23\ kg}$$

Silicon content can be increased by adding ferro-silicon which normally contains 50 per cent silicon. By adding 1 kg of ferro-silicon, we get 0.5 kg of silicon in the charge. To keep the total charge as 3000 kg, 1 kg of foundry return is to be reduced. Since 1 kg of foundry returns contains 0.025 kg of silicon taking into consideration that the returns in the aforesaid composition have 2.50 per cent silicon, reduction of 1kg of foundry return means loss of 0.025 kg of silicon from the charge . Therefore, net increase in silicon content is

$$0.500 - 0.025 = 0.475 \text{ kg}$$

Thus, to compensate 10.25 kg of silicon, 10.23/0.475 = 21.5 kg of ferro-silicon will be required to be added and the foundry return will be reduced by the same amount.

Thus the final proportions of the said cupola charge will be :

pig iron No. 1	=	**300.00 kg**
pig iron no. 2	=	**600.00 kg**
Cast iron scrap	=	**900.00 kg**
Return	=	**1178.50 kg**
Ferro-silicon	=	**21.50 kg**
		3000.00 kg

Instead of using the foregoing procedure, a more rational and modern method of liner programming can be adapted to arrive at the exact cupola charges. The application of such a method, however requires a knowledge of operations research and system analysis.

11.32 MELTING FURNACES FOR NONFERROUS METALS

For melting nonferrous metals and alloys, crucible furnaces and metal pot furnaces are mainly used. Here the metal is melted out of contact with the fuels and there is very little change in composition during melting . The crucible and pot furnaces may be fired by either liquid, gaseous or pulverised fuels. The capacities range from 30 to 150 kg.

CRUCIBLE FURNACES

There are two principal types of crucible furnaces (Fig. 11.88) :
(1) pit type, and (2) tilting type. In these furnaces, graphite crucibles are used to hold the charge for melting.

Pit type furnace. As the name implies, it is made in the form of a pit below the ground level, so that the crucible can be conveniently lifted, operating from the floor of the shop. The furnace is usually fired with coke, sufficient coke being packed round and above the crucible pot to melt and superheat the charge without reheating with coke. In the bottom of the furnace it is provided with a removable fire gate and an ash pit below it. The inner lining of the furnace above the grate is made of fire-bricks and the natural draught provided by a tall chimney is controlled by means of a loose brick or damper at the foot of the stack.

Tilting furnaces. Tilting furnaces are raised above floor level, mounted on two pedestals, and rotated by means of a geared hand-wheel or a hydraulic ram. Forced draught is employed and the furnace is fired by coke, oil or gas. The coke-fired tilting furnaces are provided with an enclosed ash pan.

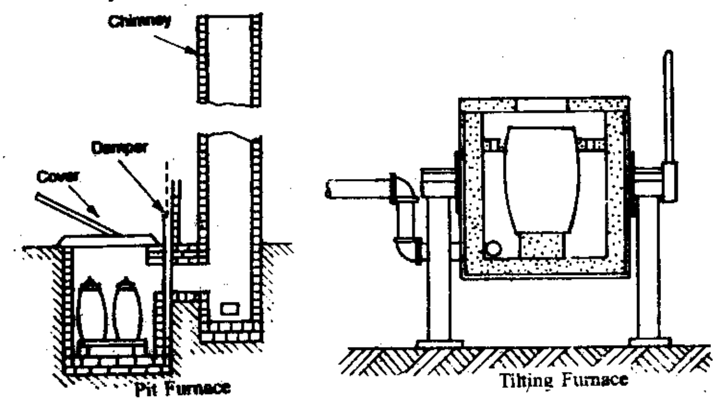

Figure 11.88 Crucible furnaces

In an oil furnace, instead of coke, oil is used as the fuel. A drum of kerosine oil is placed at a height of 5 to 6 m above floor level. Oil and air are admitted at a pressure of 3.5 kg per sq. m and directed through a nozzle generally placed in tangential position. Thus the flame of burning gases heats the crucible uniformly. Sometimes, oil flames are directed from the top of the furnace.

In those furnaces using coal or coke, the crucible rests on the fuel bed, and in the gas-fired and oil-fired furnaces the crucible is supported on a block of refractory material.

METAL-POT FURNACES

The alloys of aluminium, magnesium, antimony, zinc, lead, cadmium and tin can be melted in a metal pot which is usually made of cast iron or steel. The metal container is preferred for melting those alloys which have relatively low melting points.

The metal pot (Fig. 11.89) is supported by its rim in a stationary furnace which is fired by gas or oil fuel. The products of combustion are discharged through a flue and do not come in contact with the metal.

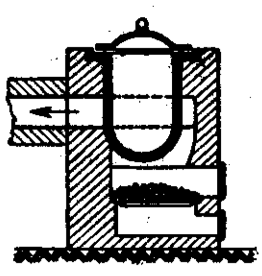

Figure 11.89 Pot furnace

11.33 LADLES

Several types of containers are used to move the molten metal from the furnace to the pouring area. Common practice is to run the molten metal from the cupola or furnace into a large receiving ladle. From that, metal is distributed to smaller pouring ladles.

There are various types of ladles, depending upon the method of carrying them (see Fig. 11.90). The most commonly used ladle in the shop is the *hand type*. It resembles a bucket with a removable, long-handle shank. A hand ladle normally holds from 15 to 30 kg of metal. A *shank ladle* also called *bull ladle* holds more metal and is handled by two men. The bull ladle holds from 30 to 150 kg of metal. Large casting of the floor and pit type are poured with a *bottom pouring ladle*. This ladle finds wide application in steel foundries, although it may also be used for pouring cast iron. For small and medium-sized mould, the *teapot ladle* is used. Bottom-pouring and teapot ladled have a built-in spout which allows the metal to be taken from the bottom and does not disturb the slag that forms on top. Thus the floating slag is controlled. So they may be called *self-skimming ladles*. A mechanical device called a *ladle handler* enables one man to handle and pour with large ladles. It is hung from a monorail which makes it easy to remove.

The inside of the ladle bowl is lined with fire clay, generally about 25 mm in thickness. Large ladles require a thicker lining. The fire clay is mixed by adding the right amount of water to mix it into a so-called "mud". It is then plastered on the inside of the ladle and allowed to dry.

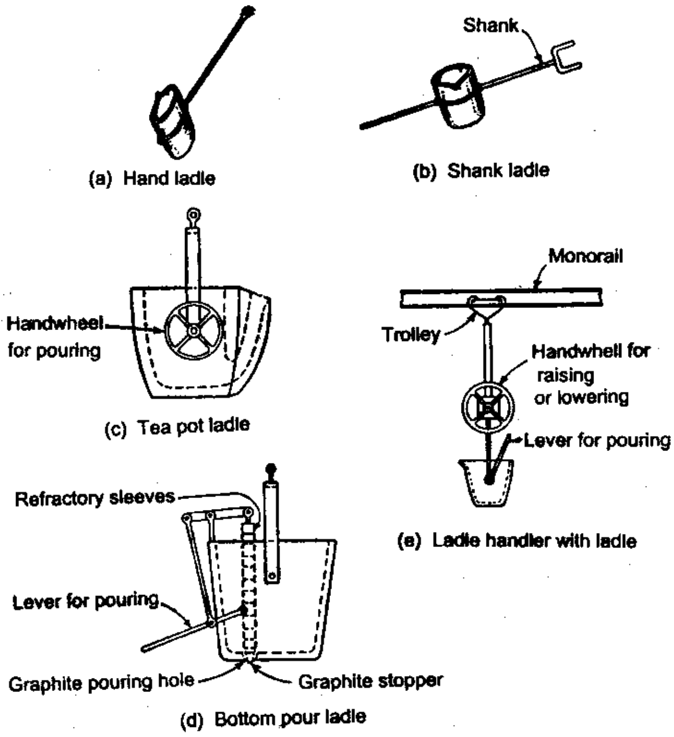

Figure 11.90 Ladles

1 .34 POURING THE METAL

Pouring the metal must be as carefully controlled at any part of the casting process. Pouring should be done continuously and at a uniform rate until the mould, gates, and risers are full. The temperature of the metal must be just right. If it is too hot, the hot gases will produce blow-holes ; if it is too cold, the metal will solidify prematurely and will not fill the entire cavity. Temperatures are easily checked with an optical pyrometer (Fig. 6.9) although most casters, after a sufficient period of experience, can visually judge the temperature of the metal with remarkable accuracy.

During the actual discharge of the ladle into the mould, an assistant should skim back the floating slag with a skimming bar. Scum or slag is always present on molten grey iron. It must not be allowed to enter the mould, or slag pockets will form in the casting produced.

11.35 CLEANING OF CASTINGS

After the molten metal has been poured into the mould, it is permitted to cool and solidify. When the casting has solidified, it is removed from the sand in the moulding box. This operation is called shake-out. This *shake-out* can be effected either manually or mechanically, but generally, mechanical shake-outs are used for large-scale work.

Casting, when taken out of the mould, are not in the same condition in which they are desired since they have sprue, risers, gates, etc. attached to them. Besides, they are not completely free of sand particles. This operation of cutting off the unwanted parts, cleaning and finishing the casting is known as *fettling*. This includes :

1. Removal of cores from the castings.
2. Removal of gates, risers, runners, etc. from the castings.
3. Removal of fins, and other unwanted projections from the castings.
4. Removal of adhering sand and oxide scale from the surface of the castings (surface cleaning).
5. Repairing castings to fill up blowholes, straightening the warped or deformed casting.

Dry sand cores may be removed by rapping or knocking with an iron bar. Pneumatic or hydraulic devices may be employed for quick knocking.

Gates, risers, sprues, and runners are removed by knocking off or breaking with a hammer, sawing, torch cutting, electric-arc cutting, abrasive wheel cutting etc.

The operation of removing unwanted metal fins, projections, etc. from the surface of the casting is called *snagging*. The methods for snagging include grinding, chipping with hand or pneumatic tools, gouging and flame cutting, air-carbon arc touch cutting, filing, etc.

Besides, there is always more or less sand adhering to the casting. This sand must be removed before they are sent to other places for finishing operations. In small foundries this is done by wire bushes. In big foundries, where work is done on a commercial basis, this is done in tumbling barrels and sand-blasting, pneumatic shot-blasting, and hydro-blasting machines which are known as fettling machines. Light castings may be cleaned in tumbling barrels. The castings are loaded into the barrel with jack stars made of white cast iron. Rotation of the barrel causes the castings to tumble and abrade one another, and thereby the adhering moulding sand is removed. Sand-blasting and shotblasting machines are employed for cleaning surface of light, medium and heavy castings. In these machines dry sand or cast iron shot is blown by a stream of compressed air against the surfaces of the casting. The impact of the sand or shot , moving at a high velocity on the surface removes the adhering sand. In hydro-blasting, a high velocity stream of water and sand is blasted on the castings. This action results in more efficient cleaning and polishing. The hydro-blast method is better adapted to nonferrous castings since ferrous ones tend to get corroded by the action of water.

Sometimes *pickling* in a suitable acid (sulphuric acid, hydro- fluoric acid or nitric acid) helps in removing any adhering sand from the casting. After pickling in acid, the casting is pickled in alkaline solutions and, finally, hot water to neutralise the acid remaining on the casting. Pickling is used principally for preparing the surfaces of casting for plating, although it is occasionally used for cleaning fragile castings.

Defects such as blow holes, gas holes, cracks, warping, deformation, etc. may often occur in castings. Such defective castings cannot be rejected outright for reasons of economy and they are therefore repaired by suitable means which include various types of welding, soldering, resin impregnation, epoxy filling metal spraying etc. Derormed or warped castings can be straightened in a press by applying pressure.

11.36 DEFECTS IN CASTINGS

Sand casting , particularly, are subject to certain defects which in a well designed casting, are controllable by proper foundry technique, but are not wholly preventable. However , the common types of defects found in castings, their causes and remedies are explained hereunder.

1. *Shifts*. This is an external defect in a casting caused due to core misplacement or mismatching of top and bottom parts of the casting usually at a parting line. Mis-alignment of flasks is another likely cause of shift.

   The defect can be prevented by ensuring proper alignment of the pattern or die part, moulding boxes, correct mounting of patterns on pattern plates, and checking of flasks, locating pins, etc. before use.
2. *Warpage*. Warpage is unintentional and undesirable deformation in a casting that occurs during or after solidification. Due to different rates of solidification different sections of a casting, stresses are set up in adjoining walls resulting in warpage in these areas. Large and flat sections or intersecting sections such as ribs are particularly prone to

warpage.

The remedy is to produce large areas with wavy, corrugated construction, or add sufficient ribs or rib-like shapes, to provide equal cooling rates in all areas. A proper casting design can go a long way in reducing the warpage of the casting.

3. *Fin*. A thin projection of metal, not intended as a part of the casting, is called the fin. Fins usually occur at the parting of the mould or core sections. Moulds and cores incorrectly assembled will cause fins. Insufficient weighting of the moulds, or improper clamping of flasks may again produce the fin.

   The remedy lies on the use of sufficient weight on top part of the mould so that the two parts fit tightly together, and correct assembly of the moulds and cores used for the casting.

4. *Swell*. A swell is an enlargement of the mould cavity by metal pressure, resulting in localised or overall enlargement of the casting. This is caused by improper or defective ramming of the mould.

   To avoid swells, the sand should be rammed properly and evenly.

5. *Blowholes*. Blow holes are smooth, round holes appearing in the form of a cluster of a large number of small holes below the surface of a casting. These are entrapped bubbles of gases with smooth walls. Blow holes are caused by excessive moisture in the sand, or when permeability of sand is low, sand grains are too fine, sand is rammed too hard, or when venting is insufficient.

   To prevent blowholes, the moisture content in sand must be well adjusted, sand of proper grain size should be used, ramming should not be too hard, and venting should be adequate.

6. *Drop*. A drop occurs when the upper surface of the mould cracks, and pieces of sand fall into the molten metal. This is caused by low strength and soft ramming of the sand, insufficient fluxing of molten metal and insufficient reinforcement of sand projections in the cope.

   The above factors are eliminated to avoid drop.

7 *Dirt*. In some cases , particles of dirt and sand are embedded in the casting surface. This is caused by crushing of the mould due to improper handling, sand wash and presence of slag particles in the molten metal.

   Dirt may be prevented from entering the mould cavity by proper fluxing and the use of dirt traps.

8. *Honeycombing* or *sponginess*. This is an external defect consisting of a number of small cavities in close proximity. Honey-combing is caused by dirt or "scurf" held mechanically in suspension in the molten metal, and is due to imperfect skimming in the ladle.

The remedy is to prevent the sand wash and to remove the slag particles present in the molten metal by the proper skimming in the ladle.

9. *Metal penetration and rough surface*. This defect appears as an uneven and rough external surface of the casting. The metal penetration between the sand grains occurs due to low strength, large grain size , high permeability and soft ramming of sand.

   Remedies involve removing the causes mentioned above.

10. *Sand holes*. Sand holes are found on external surface or inside the casting. They are caused by loose sand washing into the mould cavity and fusing into the interior of the casting or rapid pouring of the molten metal.

    Sand holes are prevented by proper cleaning of the mould and careful pouring of the molten metal.

11. *Pin holes*. Pinholes are numerous small holes, usually less than 2 mm, visible on the surface of the casting cleaned by shot blasting. They are caused by sand with high moisture content, absorption of hydrogen or carbon monoxide gas or when steel is poured from wet ladles or is not sufficiently gasified.

    The defect can be minimised by using good melting and fluxing practices, by reducing the moisture content of moulding sand and increasing its permeability, and by promoting a rapid rate of solidification.

12. *Scabs*. Scabs are a sort of projection on the casting that occur when a portion of the face of the mould or core lifts and metal flows underneath in a thin layer. In other words, liquid metal penetrates behind the surface layer of sand. Scabs can be identified as rough, irregular projections on the surface containing embedded sand. They are caused by using too fine sand, sand having low permeability and moisture content, and by uneven mould ramming or intermittent or slow running of molten metal over the sand surface thereby producing intense local heating.

    Mixing additives such as wood flour, sea coal, or dextrine, into the sand is one step which will eliminate the defect.

13. *Shrinkage cavity*. Shrinkage cavity is a void or depression in the casting caused mainly by uncontrolled and haphazard solidification of the metal. This may also be produced the pouring temperature is too high.

    The defect can be eliminated by applying the principle of directional solidification in mould design and by judicious use of chills, padding, etc.

14. *Hot tears (Pulls)*. They are internal or external cracks having ragged edges occurring immediately after the metal has solidified. Hot tears may be produced if the casting is poorly designed and abrupt sectional changes take place, no proper fillets and corner radii are provided, and chills are wrongly placed, Incorrect pouring temperatures and improper placement or gates and risers and hard ramming can also create hot tears.

    Improved design, proper directional solidification, even rate of cooling, correct pouring temperatures, and control of mould hardness eliminate hot tears.

15. *Cold shut and mission*. A cold shut is an external defect formed due to imperfect fusion of two steams of metal in the mould cavity or unequal sections of pattern assembled together. The defect may appear like a crack or seam with rounded edges. A misrun casting is one which lacks completeness due to the failure of the metal to fill The mould cavity. The reasons for cold shut or misrun may be too thin sections and wall thickness, improper gating system. damaged patterns, slow and intermittent pouring, poor fluidity of metal caused by low pouring temperature, improper alloy composition , etc.

    Use of hotter metal , frequent inspection and replacement of patterns and core boxes and proper design of the casting keeping in mind the fundamental principles of gating and risering are some of the steps that may be used to eliminate cold shut and misrun.

16. *Poured short*. When the metal cavity is not completely filled at one pouring, the defect is called poured short.

    Sufficient metal in the ladle at correct temperature will eliminate this defect.

17. *Internal air pocket*. This appears as small holes inside the casting and is caused by pouring boiling metal or by rapid pouring of the molten metal in the mould. Faulty and poor quality of metal, and excessively moist sand may also create air pockets.

    Correct pouring temperature of the molten metal, right quality of metal and dry sand minims this defect to a great extent.

11.37 INSPECTION AND QUALITY CONTROL

Inspection is an act of checking the acceptability of a casting. After the castings have been cleaned, they are inspected to check if they will perform specified functions during service. It broadly covers a large number of methods and techniques used to check the quality of castings. These methods, explained in Chapter 3 of this text, may be classified into five categories :

1. Visual inspection,
2. dimensional inspection ,
3. mechanical testing ,
4. flaw detection by nondestructive methods, and
5. metallurgical inspection.

The main purpose of quality control is "to prevent the occurrence of defects in castings to be produced in future rather than merely detect" defective parts. Quality control in its true sense, deals with the whole system of production and the methods employed to establish and achieve an economic production and desired quality and standard. An efficient quality control, therefore simplifies the task of meeting specifications and can reduce the amount of inspection needed. Quality control using statistical techniques known as statistical quality control (S.Q.C.) has several applications in the foundry in all stages of its working.

11.38 MODERNISATION AND MECHANISATION OF FOUNDRIES

Persons engaged in founding industry have to lead a very hazardous life because of the unhealthy atmosphere prevailing inside a foundry. There is thus a vital need for modernisation in this particular field of industry. measures that lead to increased production, improved quality and reduction in production costs, measures that aim to improve working conditions with an eye to ensuring a safe, healthy and happy life for the worker deserve both modernisation and machanisation.

MODERNISATION

Modernisation of foundries include : (1) changing over to better and newer foundry equipments; (2) employing newer, better, and more economical moulding, melting and casting techniques ; and (3) creating conditions which do not make a foundry dirty, dusty and smoke-filled, i.e. improving working condition in foundries, providing adequate illumination, air circulation, dust extraction, etc.

Advantages of modernisation. Modernisation when properly planned carry several advantages which include the following :

1. Improving quality of the casting.

2. Boosting production.
3. Reducing production cost.
4. Increasing safety to the workers.
5. Making working conditions pleasant and less tiring.
6. Building up morale of the workers.

MECHANISATION

Mechanisation implies the utilisation of machinery to accomplish the work previously done by hand. Machinery may be used for preparing sand, moulding and core making, pouring, material handling and many other similar conditions. The extent to which a foundry can be mechanized depends upon the quantity and type of production. For small orders as well as for the production of large-sized castings, mechanisation is both uneconomical and unpractical. on the other hand, a foundry making automobile parts , electric motors, and similar others where the jobs are of a repetitive nature, mechanisation is economical and practical.

Areas of mechanisation. Mechainsation has a distinct impact on areas concerned with the preparation and control of sand, moulding and core making, melting and pouring , shake-out operations, material handling, and the control of dust and fume.

1. *Sand preparation unit.* The sand preparation unit consists of a magnetic separator which removes iron particles from return sand, a auto-riddle which rids foreign materials, a muller which kneads the sand for re-use, and aerator which helps to improve the flowability of sand, and a hopper which acts as storage for sand before it is sent for mulling.
2. *Moulding and core making unit.* This unit uses a large number of different types of moulding and core making machines, which have already been described earlier. The extent to which these equipments can be used depends on the nature of production.
3. *Melting, pouring and shake-out unit.* It consists of various types of melting furnaces, mechanical charging devices for furnaces, mechanically operated ladles, cranes, lifting tackles, conveyors and vibrating shake-out mechanisms, etc., etc.
4. *Material handling unit.* This unit includes various types of material handling equipments such as belt conveyors, apron conveyors, flight conveyors, reciprocating and oscillating conveyors, roller conveyors, bucket elevators, mono-rail hoists, different types of cranes and many others for transportation of sand, moulds, cores, molten metal, castings and raw materials required for production.
5. *Dust and fume controlling unit.* This unit consists of a well-designed

dust and fume collector which can clear the polluted air and maintain hygienic working conditions. This includes filter, cyclone, centrifugal dust collector, scrubbers, etc.

Fig. 11.91 Shows an automated line for medium moulds with pattern circulating facility, semiautomatic pouring and secondry cooling. The layout presents a section of Künkel, Wagner & Condition., West Germany.

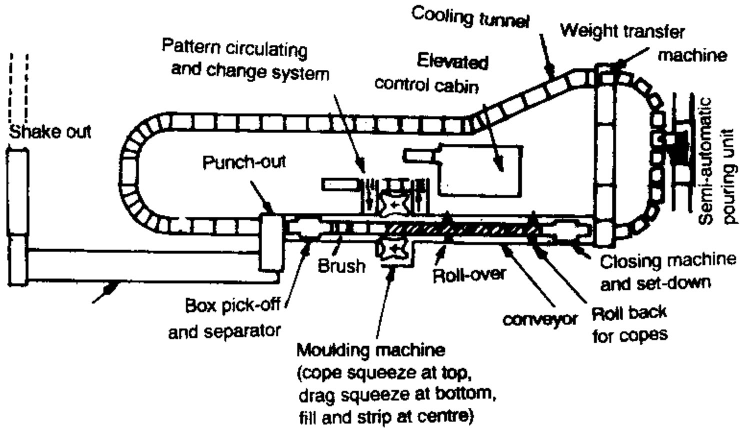

Figure 11.91 Automated line for medium size mould production

Advantages of mechanisation. Foundry mechanisa- tion provides the following advantages :

1. Increased production from a given foundry floor space and higher productivity.
2. Production of castings that possesses a higher degree of accuracy, closures tolerance, and better surface finish.
3. Enormous saving of time and labour since all operations are carried out mechanically.
4. More hygienic and healthy working conditions, and improved job satisfaction .
5. Minimised casting defects.
6. Reduced production cost and higher profits.
7. Increased earnings of the workers.

11.39 DESIGN OF CASTINGS

The important factors to keep in mind when designing a casting to obtain maximum strength and minimum casting include :

1. Design for directional solidification.
2. Design for minimum stresses.
3. Design for metal flow.
4. Cast-well design.
5. Design for minimum casting.
6. Design for expected tolerances.
7. Functional design

They are, in general related with the following design consideration.

1. Section thickness should be uniform as far as possible. Variations, if necessary. should be gradual. The aim should be to reduce *hot spots* which develop due to improper solidification.
2. Extra cores should be placed in thickest sections to reduce the cross-sections. These cored openings are intended to avoid concentration of metal in webs, ribs and hubs and to assure porosity-free castings.
3. Ribs or webs can be staggered, if design permits, to eliminate hot spots.
4. The minimum number of sections should be brought together. If it is not possible to limit the number of sections coming at a junction, a casting is made in segments which may be joined by welding. The aim is to reduce hot spots.
5. In the case of an *L* or a *V* section. radii at junctions should be so provided as to make the section thinner than principal width at the junction.
6. Sharp corners and abrupt section changes at adjoining sections should be eliminated by employing fillets and blending radii since stress concentration develops in any sharp inside corner during cooling resulting a hot check or hot tear . There are illustrated in Fig. 11.92.
7. Smoothly tapered sections should also be used to eliminate high stress concentrations.
8. Thin ribs joining to a heavy section cause high stresses and cracking and this should therefore be avoided . Thin ribs will freeze first and pull away from the heavier mass.
9. Cored holes in the ribs or webs should be rather oval than rectangular with longer dimension in the direction of the stress.
10. Ribs in compression , in general, offer a greater factor of safety than ribs in tension. They should, therefore, be used only in compression.
11. The best location where material should be fed into the part should be determined.

12. Minimum section which permits metal to flow and fill the complete casting taking into consideration the necessary strength or weight should be used. This is a function of metal composition, fluidity of molten metal, and molten metal temperature.
13. Since long and complex cast parts tend to w~~p or tear, the casting should be made in separate parts and then welded together.
14. Factors for economic considerations should include the use of proper types of tooling, multiple-cavity castings, fabrication, the use of cores, subsequent machining operations, and weight reduction.
15. Proper dimensional tolerances should be provided on castings so that correct method of production can be selected, machining allowances be kept to minimum values, correct matching between components be ensured, and right size of tools, jigs and fixures be used. Table 11.13 shows that tolerances that can normally be used in different types of moulding practice.
16. Function which a casting is supposed to perform is more important that its cost, ease of manufacture or appearance. A thorough analysis should, therefore, be carried out before going for any rejection or for another new design.

11.41 SAFETY IN CASTING

Casting, like any other primary forming processes involve hazardous

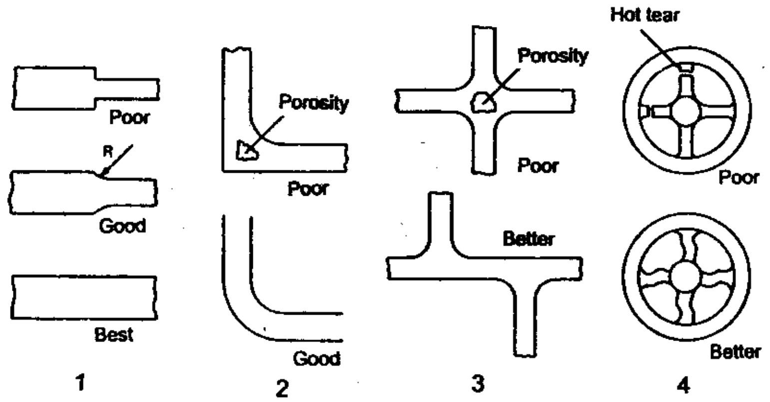

Figure 11.92 Design features of casting
1. Wall thickness variation, 2. hotspot in corner,
3. hot spot at cross-ribs, 4. hot tearing

operation involving red hot or molten metal. Protective headgear, safety foot-wear, protective glasses must be worm in the working area. All precautions taken against fire, must be available here. It must be seen that at no time hot or molten metal comes in contact with water as it may generate steam at an explosive rate. In the shop floor adequate ventilation must be provided. Burn injury cases must be treated immediately by medical personnel.

11.42 SPRAY METAL CASTING

For making metallic pipes, a continuous casting method, known as *Osprey process* is utilized. This method is cheaper to produce metallic pipes in comparison to traditional pipe manufacturing techniques. In this process molten metal is sprayed over a rotating mandrel to produce seamless tubing and pipes. The Osprey Process is essentially a rapid solidification technique for the direct conversion of liquid metal into shaped preforms by means of an integrated gas-atomizing/spray-depositing operation. In the Osprey process, a controlled stream of molten metal is poured into a gas-atomizing device where it is impacted by high-velocity jets of gas, usually nitrogen or argon. The resulting spray of metal particles is directed onto a "collector" where the hot particles re-coalesce to form a highly dense preform. Figure 11.93 shows the Osprey process.

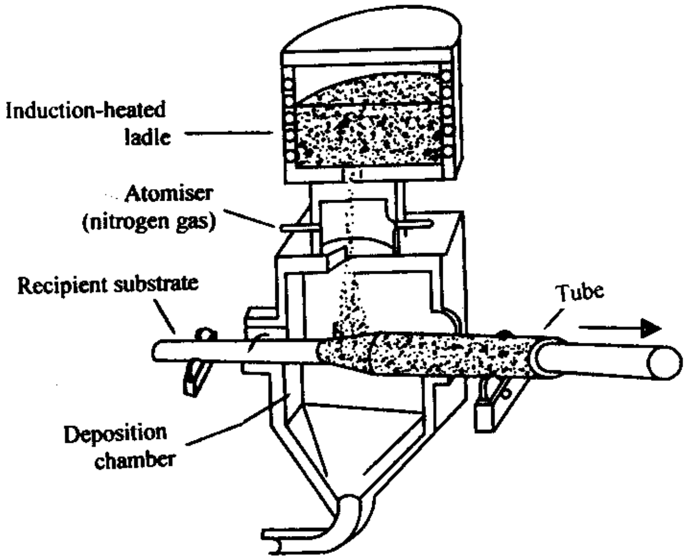

Figure 11.93 The Spray casting method

TABLE 11.14 TOLERANCES USED IN MOULDING

Basic size (mm)	Tolerance values for *Shell moulding*	*Machine moulding (metal or epoxy patterns*	*Hand moulding (wooden patterns, sweep or skeleton patterns)*
0—25	0.8—1.0	1.2—2.0	2.0—2.5
(25)—50	1.0—1.2	2.0—2.5	2.5—3.5
(50)—100	1.2—1.5	2.5—3.5	3.5—4.5
(100)—200	1.5—1.8	3.5—4.5	4.5—6.0
(200)—400	1.1—2.4	4.5—6.0	6.0—8.0
(400)—800	2.4—3.2	6.0—7.5	8.0—11.0
(800)—1500		7.5—10.5	11.0—14.0
(1500)—2500		10.5—14.0	14.0—17.0
(2500)—4000			17.0—20.0

REVIEW QUESTION

1. What are the common materials used for pattern-making ? Discuss their relative merits and demerits.
2. What are the factors which govern the selection of a proper material for pattern-making ?
3. What are the common allowances provided on pattern and why ?
4. How are patterns classified ? Describe them with neat sketches and state the uses of each of them.
5. What considerations are necessary while designing a pattern ?
6. How is layout of a pattern made ? State the procedure for pattern construction.
7. Write short notes on: (a) follow board, (b) strickle board, (c) stop-off pieces, (d) loose-pieces, (e) coreprints, and (f) core boxes, giving suitable sketches wherever necessary.
8. Classify and describe different tools and equipments used in foundries.
9. What are the main characteristics which a good moulding sand should posses ? How these characteristics influence the performance of a moulding sand during moulding and casting ?
10. Explain how the grain size and shape affect the performance of a foundry sand.
11. What is the function of additives in moulding sands ? Explain the effects of various additives used in moulding sand.
12. Explain the process of sand preparation and sand conditioning.
13. Why testing of foundry sand is necessary ? What are the common tests performed on foundry sands ?
14. What are the main characteristics of a good core sand ? (b) What are the main core binders ? Discuss their uses in making core sand. What

is oil sand? How is core baked ? State the different types of cores.

15. Classify different types of moulds and state the advantages of the following: (a) dry sand moulds over green sand moulds, (b) loam moulds over dry sand moulds, and (c) permanent moulds over dry sand moulds.
16. Draw a sketch of a typical mould and name its principal parts.
17. Distinguish between green sand moulding and dry sand moulding.
18. Write short notes on the following : (a) floor moulding, (b) bench moulding, (c) pit moulding, (d) sweep moulding, (e) plate moulding, and (f) machine moulding.
19. Sketch and describe the following techniques, stating clearly their advantages and special applications : (a) use of false cope, (b) use of dry sand cores, (c) use of drawbacks, (d) bedded-in, and (e) coping down.
20. Write short notes on : (a) skin-dried moulds, (b) air-dried moulds, (c) shell moulding, (d) CO_2 moulding, (e) ferro-silicon moulding, (f) cement-sand moulding (g) investment moulding, (h) plaster moulding, (I) ceramic moulding, (j) slush casting, (k) die casting, (l) centrifugal casting, and (m) continuous casting.
21. What are the main advantages and disadvantages of die-casting ? How does a cold chamber die casting machine differ from a hot chamber machine ? Describe the various alloys commonly cast in die casting processes.
22. What do you understand by the term gating system ? State the main requirements expected of an ideal gating. How a gate is designated ?
23. What different types of gates you know ? Explain them with neat sketches stating their relative merits and demerits.
24. What is meant by the term "risering" ? State the advantages that are provided by a riser. What is the best shape and size of a riser ? Why ?
25. Write notes on : (a) use of padding, (b) use of exothermic material, and (c) use of chills.
26. Sketch a cupola and label the essential parts, (b) Describe the operation of a cupola, (c) How is the thermal efficiency of a cupola determined ? (d) How a cupola is specified.
27. State step by step how will you calculate the metal charge of a cupola in order that the production casting will have a desired composition.
28. State the methods of cleaning castings. What is (a) snagging and (b) pickling ?
29. What are the common defects of casting ? State their causes and remedies.
30. What do you understand by foundry (a) modernisation and (b) mechanisation ? Explain them in brief.
31. State how inspection and quality control help to produce quality product.
32. Summarise the principles of design of casting.

12

POWDER METALLURGY

12.1 INTRODUCTION

The preparation and processing of powdered iron and nonferrous metals is called powder metallurgy. Parts made in this way exhibit properties which cannot be produced in any other way. Simple shaped parts can be made to size with high precision (about 0.1 mm), without waste, and completely or almost ready for installation. The powder metallurgy process has provided a practical solution to the problem of producing refractory metals, which have now become the basis of making heat-resistant materials and cutting tools of extreme hardness. Another very important and useful item of the products made from powdered metals is porous "self-lubricating" bearing. In short, modem technology is inconceivable without powder metallurgy products, the various fields of application of which expand every year.

12.2 PROCESS DESCRIPTION

In powder metallurgy the articles are produced by pressure and heat. Usually the pressure and heating stages are separate and are termed *compacting* and *sintering* stages respectively. The compacting is also called briquetting or compressing.

The manufacture of parts by powder metallurgy process usually involves a series of steps as follows : the manufacture of the powders, blending, compacting, PRESINTERING and sintering; and a number of secondary operations such as sizing, coining, machining, impregnation, infiltration, plating and heat treatment.

The essence of powder metallurgy is that a mixture, composed of specially selected and prepared powders, is compressed in dies under pressures of 10.2 to 102 kgf/mm^2 (100 to 1000 MN/m^2). The half-finished object obtained (the pressing) has a strength which, although insufficient for the articles to be used, permits transportation to the next technological operation. the final mechanical strength of the materials is achieved only as a result of a high temperature treatment-sintering, which is conducted at a temperature below the melting point of the basic metal which goes into the mixture (66 to 75 per cent of melting point).

As a result of this technique, the particles in powder materials are always in contact with each other, but the nature of this contact is different from that between the grains in continuous bodies. In a continuous metal, the area of contact is almost independent of outside pressure, whilst in powders the area of contact surface increases in proportion to pressure applied.

The increase of contact area can be accomplished by changing the shape of the particles by the action of external forces, i.e., by pressing and sizing or by drawing the atoms in the metals towards the contact regions, a phenomenon which is caused by the movement of atoms at an elevated temperature (sintering). As a result of the increase in contact surface, the bonding between the particles grows. Consequently, the strength of the products is raised and their properties are altered. The contact surface of bodies is defined as the size of the contact areas of contiguous particles, separated by distance less than the range of molecular forces, i.e., the size of the contact areas through which the stresses are transmitted between contiguous particles.

12.3 MANUFACTURE OF METAL POWDERS

The powders of almost all metals and of a large quantity of alloys are used at the present times. The powders most commonly used are copper-base and iron-base materials. But stainless steel, titanium, nickel, chromium, metal powders are also used.

Amongst powder properties, composition, size, form and structure of particle, specific surface, porosity and volume characteristics, fluidity, strength, hardness, permeability regarding liquids and gases, electric conductivity, compressibility and sinterability are of great interest in powder metallurgy.

The particle size of powders fall into a range of 0.1μ to several millimeters (1μ = 10^{-6} mm). In the majority of powders, the size of the particles varies from several microns to 0.5 mm. There are various methods of producing powders of those size. The most commonly used methods are mechanical, atomization, reduction, electrolysis, and shotting.

Mechanical. In this method metals are disintegrated to produce the size of the powder required by crushing, rolling and milling. In the final stage the crushed metal is finally ground in a ball mill in which many steel balls impinge upon the powder to grind it to needed size. Fig 12.1 shows the method.

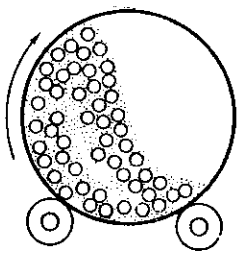

Figure 12.1 Mechanical method for making metal powder

Atomization. In this process, molten metal is forced through a nozzle into a stream of water or air. The air is usually supplied at a pressure if about 2 to 3×10^{-2} kgf/mm^2 (2 to 3×10N/m^2). Upon contact with the stream, the molten metal is solidified into particles by the air pressure, nozzle size and metal flow rate.

Reduction. This is the process adapted for some of the refractory metals. For example, pulverized tungsten oxide is heated in a current of hydrogen to produce a fine tungsten powder.

Iron powder is also produced by reducing iron chloride in hydrogen. Copper is another metal for which chemical reduction can be used.

Electrolysis. In this process the metal plates are placed in a tank of electrolyte which is an acid solution. The plates act as anodes, while other plates are placed into the tank to act as cathodes. High electric current produces a powdery deposit on the cathodes. The cathodes are removed from the tank, rinsed to remove the electrolyte solution and then dried. After a drying period, the deposit is scraped off and pulverized to produce powder of the desired size.

Shotting. In this method the molten metal is made to pass through a sieve and the particles are dropped in a liquid (water or kerosine)

12.4 BLENDING OF POWDERS

The first step in the forming of powder metal parts is the mixing or blending of the powders. The blend of the powders determines many different properties that can be obtained. Many combinations of metals and of metals with ceramics or other materials that can be used as melted alloys are possible. These often give characteristics of heat resistance, frictional properties, heavy weight and hardness that are not obtainable by other methods.

The mixing may be done either wet or dry and an efficient mixer is used to produce a homogeneous mixture. The type of mechanical mixer used will depend on the amount of powder handled and the type of powder.

12.5 COMPACTING

Compacting or briquetting is the process of converting loose powder into a "green compact" as it is called, of accurately defined size and shape. The briquette is considered fairly fragile, but it can be handled.

The compacting stage is carried out at room temperature in a die set-up on press. The die consists of a cavity, the shape of the desired part, but from two to ten times deeper, according to the material to be handled. Metal powder is poured in the cavity, and leveled off flush with the top of the die. The punches usually work from the top and the bottom of the die. Owing to interparticle friction, pressure applied from one direction will not be distributed uniformly throughout the part. This necessitates the use of the both top and bottom die. The dies are forced together under pressure into the die cavity and the powder is compressed to the desired shape to approximately one-third of its original volume. In addition to two punches, a core rod extending up through the lower punch and die barrel is also used for forming a hole in any cylindrical piece. Dies are made usually of high grade steel, finely finished and hardened, but carbide dies are used for long production runs.

The process used for compacting may be either mechanical or hydraulic or a combination of the two and the pressure used is from 100 to 1000 MN/m^2.

12.6 PRESINTERING

Presintering is the process of heating the green compact to a temperature below the sintering temperature. This is done to remove the lubricants and binders added during blending and to increase the strength of the compact. All metals do not require presintering. But some metals like tungsten carbide are easily machined after presintering. After sintering they become so hard that they cannot be machined.

12.7 SINTERING

After being compacted into a briquette having the shape of the finished workpeice, the cold-welded aggregate of metal particles is heated in a furnace to a temperature close to the melting point of the basic metal which goes into the mixture. This is carried out in controlled atmosphere furnaces. It may also be carried out under protective gas normally hydrogen or in a vacuum if the material tends to react with the protective gas. The heating causes the metal particles to sinter, that is, a proportion of them partly melt and by so doing cement the remaining particles together in a cellular structure. From the economic point of view, the sintering time should be as short as possible, but the time must be long enough to obtain the required properties in the workpiece.

Sintering is performed to achieve all possible final strength and hardness needed in the finished product. The three most important variables governing the sintering process are temperature, time and sintering atmosphere. The workpiece dimensions change during sintering. Such changes may be either a shrinkage or growth. In general, bronze tends to expand and iron and brass to contract. The whole process of powder metallurgy including compacting is shown in Fig 12.2.

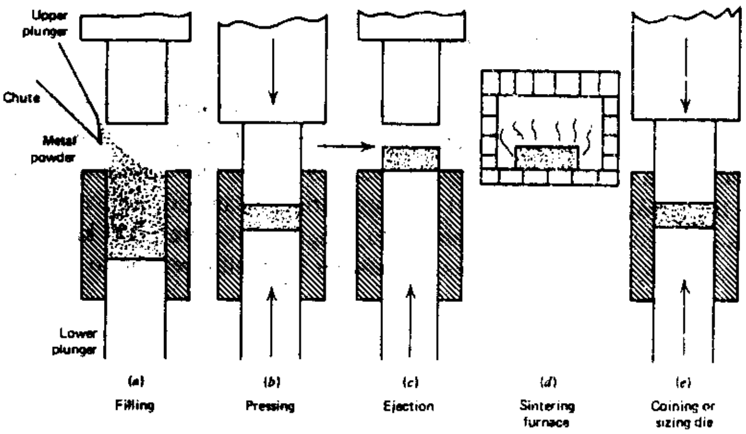

Figure 12.2 Powder metallurgy process including compacting

12.8 SECONDARY OPERATIONS

Many powder-metal parts may used in the "as sintered" condition. However, when the desired surface finish, tolerance of metal structure cannot be obtained by the previous methods, additional finishing operations must follow.

Of the various operations, sintering is usually followed by a *sizing* operation and perhaps by some *machining*. The sizing stage may be effected by a punch and die set-up on a press, by *coining* or by *broaching*.

When self-lubricating properties are desired, the sintered parts are ***impregnated*** or saturated with oil, grease, wax or other lubricating materials. The lubricant is retained in the part by the capillary action, until external pressure or heat of friction draws it to the surface.

In some cases *infiltration* is needed to provide increased strength, hardness and density not obtainable by straight sintering.

Sometimes *plating* is done for two objectives– pleasing appearance and protection from corrosion. The procedures for plating powdered metal parts are quite different from those used for wrought or cast metal parts. In powdered metal parts, porosity must be eliminated before the part is plated. After the porosity has been eliminated regular plating procedures can be used.

Heat treatment is done on powder-metal parts to improve grain structure, strength and hardness.

12.9 ISOSTATIC PRESSING

Isostatic pressing is a relatively new development for powder metallurgy. In isostatic pressing, prepared metal powder is placed inside a flexible mould. A vacuum is created in the mould and it is then sealed. The mould along with the powder is then placed in a pressurised chamber into which gas or oil is pumped through the chamber to generate pressure 3000 kgf/cm^2 or more. The pressure compresses the powder from all direction to give it the required shape.

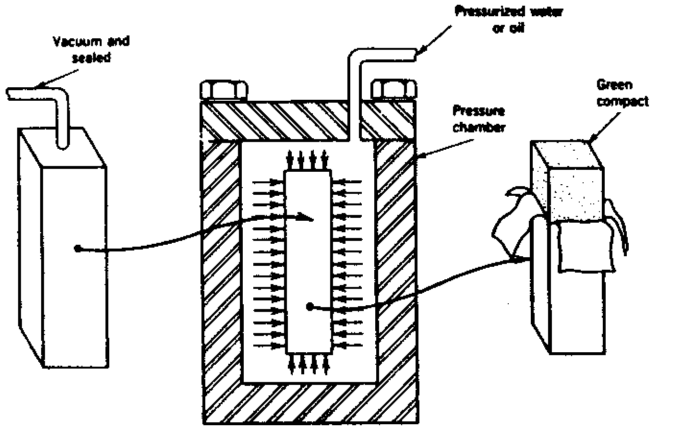

Figure 12.3 Isostatic pressing

There are two types of isopressing ; (1) cold isostatic pressing (CIP) and (2) Hot isostatic pressing (HIP).

In CIP, the metal powder is placed in a elastomeric material (an elastomer posses rubbery qualities such as high resilience and extensibility) and high pressure is applied at room temperature inside the pressure chamber. Water or oil is the pressure medium. The parts are removed and sintered.

In HIP, the pressure is generated by an inert gas like helium or argon. The gas is reclaimed after every charge. However, in both the methods tooling cost is high in comparison to die-compacting method.

12.10 METAL INJECTION MOULDING

Metal Injection Moulding (MIM) is a mass production technique to produce intricately shaped metallic components. A variety of metal co-injection moulded components has been produced using several model material systems. This means that one type of material can provide the required surface characteristics, such as corrosion or wear resistance, with a cheaper material forming the core of the components. (eg. iron as core and stainless steel as skin). Fig. 12.4 shows the steps of processing. These are :

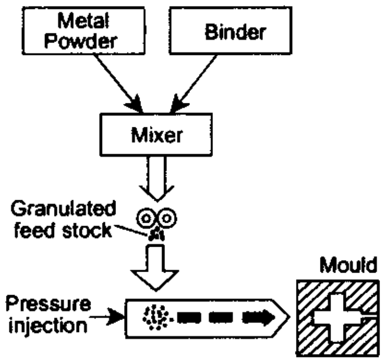

Figure 12.4 Steps in MIM

1. **Feed stock mixing :** Metal powder is blended with a binder consisting of wax and polymer at about 160°C and subsequently cooled and granulated to pellets.
2. **Moulding :** At about 160°C, the pellets are rammed into the mould at a pressure of 120 MPa to for the green moulding.
3. **Debinding :** Hot air is passed over the components to remove binding materials, resulting in brown metal mouldings.
4. **Sintering :** The porous components are heated to 1600°C (for ferrous metal/alloys) at very low pressure (10^{-3} MPa). The particles melts/fuse together excluding air/trace of binders resulting in white *shiny* parts.

12.11 PRODUCTS OF POWDER METALLURGY

The range of articles and products now manufactured by the process is very wide and varied and is steadily increasing. the range can be readily perceived from the following incomplete list :

High-production parts such as gears, cams, pawls, actuating levers ; parts of cars, aircraft, gas turbines, electric clocks, sewing machines, refrigerators and vacuum cleaners ; parts of guns ; porous metal bearings and porous metal applications of filters, gas diffusers ; welding rod containing a powdered flux ; diamond-impregnated wheels, commutator segments, contacts and other electric engineering articles such as filament of electric bulbs, radio valves, X-ray tubes, etc. ; magnetic materials and articles ; bi-metallic strips ; manufacturing of hard-carbide alloys for cutting tools and drawing dies and various composites.

Porous and "self-lubricating" bearings. Porous bearings, impregnated with upto 40 per cent of oil, constitutes the largest volume of powder metallurgy production; while filters, with pores as small as 0.002 mm, are produced easily and economically.

It is well known that anti-friction alloys are characterized by the presence of hard and soft structural components. In porous bearings the pores are the softer "structural element", while the basic metal harder. The forms of antifriction bearings now produced on an industrial scale are : bronze and bronze-graphite with a porosity of 20 to 30 per cent ; iron with a porosity of 20 to 30 per cent ; iron-copper and iron-copper-graphite ; porous aluminium-iron-graphite and aluminium-copper-graphite.

Porous bearings have a number of advantages compared to other bearings. Porous bearings "run in" excellently and are simple in use. In addition, they are cheap and silent in operation.

As stated earlier, porous bearings can be impregnated with oil and therefore posses the property known as "self-lubrication". The self-lubrication of porous bearings is based on the fact that during operation, as the bearing heats up, the oil held in the voids and very small channels of the materials by capillary forces, is gradually forced out and forms a lubricating film on the working surface. When the bearing is stopped and allowed to cool down the oil is partially sucked back into the voids. There is therefore fluid friction and not semi-dry friction when starting or at low speeds of rotation. At low loads the lubricants contained in the voids or pores of the bearings itself is sufficient for the several month's operation. The consumption of the oil as compared with other bearings requiring lubricants from outside is therefore extremely low since there is no wastage.

The addition of graphite to iron or brass powder considerably improve the anti-friction properties of porous bearings. Graphite increases the resistance to wear, improves the bearing's ability to 'run in' and also increases its resistance to pitting.

Against these advantages, porous bearings made of iron powder is not recommended at high loads as the total supporting surface of porous bearings in comparison with cast ones is considerably less.

12.12 ADVANTAGES OF THE PROCESS

The following advantages of the powder metallurgy process are noteworthy.

1. Although the first cost of metal powder is high, there is no loss of material. The components can be produced clean and bright, ready for use.
2. Perhaps the greatest advantage possessed by the process is the case in which the composition of the product can be controlled. Besides, the material does not run the risk of contamination with any unwanted substance.
3. Close dimensional tolerances can be maintained especially if a sizing operation is used.
4. Nonmetallic substances can be introduced as required and in any proportion to get the desired properties.
5. A wide range of properties such as density, porosity and particles size can be obtained for particular applications.
6. It is possible to unite materials that cannot be alloyed in the usual sense or would not yield the desired characteristics if they were joined mechanically.
7. The process is also of advantage in the production of magnetic cores having special desirable properties.
8. A considerable decrease in production time and consequently high production rate may be achieved by adaptation of the process, since this is automated.
9. Highly skilled labour is not required.
10. The process facilitates saving in material as there is no waste during fabrication.
11. Composition, structure and properties can be controlled more easily and closely than any other fabricating processes. The components can be produced clean and bright, ready for use.

12.13 DISADVANTAGES AND LIMITATIONS

The drawbacks of powder metallurgy, which render its use difficult and restricted, ought to be mentioned alongside its advantages. The drawbacks are :

1. Pure metal powders are very expensive to produce.
2. The size of parts produced is limited because of the large presses needed to obtain the compressing pressures resulting in increased tool and press costs.
3. The lack of simple methods of obtaining alloy powders– of steels, bronzes, brasses, etc.

4. The strength properties of the finished articles are usually lower than those of a similar article produced by conventional means.
5. Articles made out of metal powders possess, as a result of their porosity and increased tendency to oxidation throughout the whole body and only on the surface of the article.
6. Powder metallurgy products possess comparatively poor plastic properties (impact strength, elongation).
7. Die design limitations limit the type of shapes that can be produced.
8. Since the dies are very expensive, the process is not practical (economical) unless quantities of at least a few thousand pieces are manufactured.

12.14 DESIGN CONSIDERATION

In the design of parts for powder metallurgy, the following points require special mention :

1. Holes should not be made in the direction of pressing.
2. Production of very small holes through pressing should be avoided as far as possible.
3. Threads, knurlings and other similar shapes should not preferably be formed by compacting. They should be produced by machining.
4. Abrupt changes in section thickness and narrow and deep sections should be avoided as far as practicable.
5. Very close dimensional tolerances in the direction of pressing should be avoided.

REVIEW QUESTIONS

1. What is meant by "powder metallurgy" ? Describe briefly the methods by which powders suitable for powder metallurgy can be produced.
2. What are the effects of sintering on the powder compact produced by pressing ?
3. Outline the advantages of (a) presintering and (b) coining or sizing on metal compacts.
4. Explain the objectives of powder compaction and list important products of powder metallurgy.
5. State briefly the process of making a powder metallurgy product having improved properties.
6. List and discuss the advantages and limitations of powder metallurgy process.
7. Why it is necessary to use lubricants in the press compaction of powders? State and explain the advantages of porous and self-lubricating bearings over the standard sleeve bearings.
8. Describe in brief metal injection moulding process.

13

PLASTICS AND THEIR PROCESSINGS

13.1 INTRODUCTION

In general, the term "plastic" is applied to all materials capable of being modeled or moulded. However, the meaning of the word today has changed or been limited to a group of materials which, when heated, can be formed into a variety of useful articles by moulding, casting or extrusion.

Plastics have been increasingly accepted for modern engineering application due to the fact that plastics are attractive materials and offer advantages in weight, cost, moisture, strength and chemical resistance, toughness, abrasive resistance, strength, appearance, insulation (both thermal and electrical), formability and machinability.

13.2 TYPES OF PLASTICS

The great majority of plastics are organic substances or resins, usually containing oxygen, carbon, hydrogen, nitrogen and sometimes other elements. Technically, these organic compounds are called *polymers*. *Poly* means many and *mer* means a unit or part. The basic structural units of plastics are referred to as *monomers*. These are molecules consisting of carbon atoms with attached ribs of other atoms such as hydrogen, chlorine and fluorine. These ribs determine to a large extent the intrinsic properties of the plastic. However, these structural units, monomers, are joined end to end to produce long chain like molecules known as polymers. The process by which polymers are formed into long chain like formations is a chemical reaction known as *polymerization*. These chains or giant molecules have become heavy enough to become solid plastic.

By virtue of their thermal characteristics, plastic usually are divided into two groups, thermoplastic or thermosetting. A brief description of some of the principal plastic resins, their properties and their applications is given under the headings thermoplastics and thermosetting plastics.

THERMOPLASTICS

Thermoplastics are linear polymers, the molecules of which are synthesized in the shape of long threads. They undergo no chemical change in the moulding operation and is often with the application of heat and harden upon cooling. They can be reshaped while in the softened state and they will reharden ; thus the scrap can be used again. They may become too soft to use at temperatures from 66 to 315°C. Since they become increasingly softer with increase temperature, certain members of the thermoplastic family are liable to permanent distortion under mechanical strain at relatively low temperature. They may flow to an appreciable extent under load at room temperature. Most of the plastics in use today are thermoplastics. Table 13.1 lists some of the mechanical properties of thermoplastics.

TABLE 13.1 PROPERTIES OF THERMOPLASTICS

Polymer	*Tensile strength*	*Compressive strength*	*Machining properties*	*Chemical resistance*
Nylon	Excellent	Good	Excelent	Good
P.T.F.E. (Poly-tetra-fluoro-ethylene)	Fair	Good	Excelent	Outstanding
Polypropylene	Fiar	Fair	Excellent	Excellent
Polysterene	Excellent	Good	Fair	Fair
P.V.C. (rigid) (poly-Vinyle-chloride)	Excellent	Good	Excellent	Good
P.V.C. (flexible)	Fair	Poor	Poor	Good

Compressive strength : *Excellent* indicates 21.5 kgf/mm² (210 N/mm²)
: *Poor* indicates 3.6 kgf/mm² (35 N/mm²)

Tensile strength : *Excellent* indicates 5.6kgf/mm²(55 N/mm²)
: *Poor* indicates 2.2 kgf/mm² (21 N/mm²)

The cellulosics. The family of cellulosics comprises a wide variety of materials such as cellulose acetate, cellulose nitrate, cellulose acetate butyrate, cellulose propionate, etc. The cellulosics are prepared from various treatments of wood fibres and cotton.

The cellulosics have good strength, toughness, transparency, surface gloss, chemical resistance and mouldability from various grades. Cellulose acetate is the most easily worked of all plastics. It can also be made in solid form for moulded parts such as toys, cutlery handles, electrical parts, knobs, packaging, etc. In the sheet form cellulose acetate has become the household term "cellophane". It is also made as an electrical insulating tape. Cellulose nitrate, well known in the trade name of "celluloid" is available in a wide variety of beautiful colours. It is still very familiar in spectacle frames, fabric coatings, etc.

Nylons (polyamides). Nylons is now a generic name. Polyamide resins are also sold as Nylatron, Nylafil, Plaskon and Zytel. Nylon was originally introduced in the market in the form of fibres and fabrics. In recent years, nylon has been successfully moulded, extruded, formed into sheet and film and cast to prepare bearings, gears, drawer slides, machine slides, and roller besides the many varieties of filaments used in clothing, rope, brush bristles, etc. Its outstanding features are a low coefficient of friction and its resistance to heat, abrasion and chemicals. It is strong, tough and light weight. It is not recommended for exposure to ultraviolet light, hot water or alcohols, Nylon absorbs water up to 2% at high humidity, with some expansion resulting.

Polyethylene resins. Polyethylene leads all plastics in the volume of resin used each year. They are produced in three types: low, intermediate and high density. All three types have in common the properties of toughness, resistivity to solvents, alkalies, excellent dielectric properties, good colourability, very low moisture absorption and relatively low cost. The polyethylenes are blow and injection-moulded, extruded into a very wide range of products which include housewares such as bowls, plates, dishpans, paint-brush handles, flexible tubing, bags for packaging vegetables, hardware, squeeze bottles, etc.

Polystyrene. This is number two in the total volume of resins used. It is a crystal clear, odourless, tasteless plastic with a high gloss. Most grades are quite brittle and unless modified will hold static electricity. Polystyrene has an excellent tensile strength, but it can be used only upto 66 to 90°C. It is easily produced in any form, by most processes, and easily can be joined by the cementing. It is used for bottles, low cost picnic utensils, model kits, signs, toys, etc. in a wide choice of colours. *Expanded foam* in slabs or beads is a leading use of polystyrene.

Polypropylene. Polypropylene is an excellent insulator and is stiffer than polyethylene. It can be moulded or extruded into sheet, film or pipe. It is used for automobile accelerator pedals, luggage and hospital equipment. They have unlimited colourability.

Polycarbonate. This is a new plastic material that is probably better known by its trade name Lexan, Merlon and Polycarbafil. It is easy to handle for moulding, extrusion and machining. It can be nailed and riveted without cracking.

Polycarbonates, due to their toughness, make excellent safety glass for street lamps, windows and machine guards. They keep their toughness and strength at temperature from −138 to 120°C. In thickness over 1.25 mm, they do not support combustion. Polycarbonates are crystal clear or can be prepared to any colour. They are used for housings for shavers, power tools, household equipment and blow-moulded bottles.

Acrylic resin. The full name is polymethyl methacrylate and it is better known as Acrylic Plexiglas or Lucite. This beautifully clear, easily shaped plastic is most widely used in sheet form for signs of all kinds. Rods and tubes are cast in glass or metal cylinders or extruded. Acrylics can also be injection moulded.

Acrylics will "pipe" light and are used in fibre optics and edge-lighted dials. It is tough but easily scratched. It is now widely used for outdoor signs, contact lenses, brush backs, transparent bowls, drink dispensers, etc.

Acetal (polyacetal). This is one of the newer plastics perhaps better known by its trade name of Derlin. It has been developed as a material for mechanical parts including sprinkler nozzles, handles, gears, housings etc. At present this is widely used for stereo tape cartridges, toys, furniture casters and cigarette lighter cases. It has good tensile strength, resistance to temperature (115°C), low friction characteristics, resistance to most solvent and low moisture absorption.

Vinyl Plastics. This is the general name of a large group of plastics usually *polyvinyl–chloride* (P.V.C) is the most frequently used of this group. This is a very clear, transparent plastics, easily coloured, resistant to most chemicals and very water-repellant. It can stand outdoor exposure and is quite abrasion resistant, but it has a low tensile strength.

PVC can be extruded as wire insulation, chemical tubing and refrigerator door gaskets. Coating of fabrics of all kinds for industrial uses (such as tents and tarpaulin-type cover) is a major use of PVC.

THERMOSETTING PLASTICS

Thermosetting plastics are made from chains which have been linked together, referred to as *cross-linked*. These have a three dimensional network of molecules and will not soften when heated. They are practically insoluble, fireproof and usually hard and brittle. These plastics cannot be reused.

Epoxy resins. Epoxy resin is one of the newcomers to the plastic field. It is cured or cross-linked by the addition of a hardener. Epoxies have excellent chemical resistance and electrical insulating properties. Their working temperature is from 150°C to 260°C with fillers and additives.

Coatings made from these resins combine the properties of toughness, flexibility, adhesion and chemical resistance to a degree not found in other coating materials. Epoxy adhesives are now finding applications in aircraft, automobiles and in the home.

TABLE 13.2 PROPERTIES OF THERMOSETTING PLASTICS

Polymer	*Tensile strength*	*Compressive strength*	*Machining properties*	*Chemical resistance*
Epoxy Resin (glass fibre filled)	Outstanding	Excellent	Good	Excellent
Melamine Formaldehyde (asbestos filled)	Good	Fair	Fair	Good
Phenol formaldehyde (bakelite)	Good	Fair	Fair	Fair
Polyester (glass fibre filled)	Excellent	Good	Fair	Fair
Silicone (asbestos filled)	Outstanding	Fair	Good	Fair

While epoxy adhesive are well known, these plastics are also used as casting for pipe fittings, electrical and other equipment. These are also used in both low-pressure and high pressure laminates such as printed-circuit boards, boat bodies, etc.

Amino Resins. The two important groups of amino resins are the *urea-* and *melamine-formaldehyde* resins. Both are used as adhesives in making plywood and melamine is laminated with cloth to make table and counter tops. The melamine can be moulded into very hard, scratch-resistant dinnerware, business machine housings, electric switch cover plates, radio cabinets, etc. The urea compounds are less water resistant but better electrical insulators.

Phenolics. Phenol and formaldehyde combine in the presence of a catalyst to produce phenolic resins. These are hard, brittle, heat-resistant thermosets widely known in the trade name of **Bakelite**. They are inexpensive, excellent insulator and have heat-distortion temperatures upto 180°C and working temperatures upto 260°C. They are often used with a wide variety of fillers.

These may be moulded or cast and they are also used as coatings and in adhesive applications.

Silicones. Silicones are chemical hybrid, a cross between organic and inorganic materials. Silicone-base polymers possess a combination of properties that make them valuable for a large group of industrial products including greases, oils, adhesives, resin and rubber compounds.

Special silicone fluids are fast becoming an ingredient in cosmetics. The silicones are also useful in furniture, auto, shoe, glass and silver polishes. Silicone resins can be processed by extrusion, transfer moulding, casting and compression moulding.

13.3 ELASTOMERS

Elastomers are polymers which are less tightly bound together. They exhibit the unique property of high elasticity, stretching five to ten times their original length on loading in tension and reverting back to their original dimensions on release of the load. Structurally they are noncrystalline polymers at room temperature and are *intermediate* between long-chain molecules and three dimensional networks. The best known elastomer is *natural rubber* and the raw material is *latex*, a viscous milky fluid which contains a linear polymer of polyisoprene. Other examples are silicone, urethane and chlorinated polyethylene.

Most elastomers are manufactured into the requisite shape by cross-linking after moulding. Thus, sulphur is used to *vulcanize* rubber at elevated temperatures. Some of the newer elastomers have a dual behaviour : they acquire thermoplastic properties on heating but behave as elastomers after cooling.

However, elastomers are used for gaskets, moulds, foam, mattresses and insulation.

13.4 MATERIALS FOR PROCESSING PLASTICS

Most plastic resins have to be combined, compounded or otherwise chemically treated with processing materials before they are ready for processing. Thorough *mixing* of ingredients is vital for all classes of polymers and special equipment has been developed for the purpose. One of the following additions are usually employed.

1. *Plasticizers.* Organic solvents, resin and even water are used as plasticizers. These substances act as internal lubricants improving flow of and giving toughness and flexibility to the material. Plasticizers are also used to prevent crystallization by keeping the chains separated from one another. For example vinyles are generally hard and brittle materials. By adding a plasticizers they can be made soft and flexible.
2. *Fillers.* Typical fillers which include wood flour, asbestos fibre, glass fibre, cloth fibre, mica, slate powders, may be added in high proportions to many plastics essentially to improve strength, dimensional stability and heat resistance.
3. *Catalyst.* These are usually added to promote faster and more complete polymerization. As such they are also called *accelerators* and *hardeners.*
4. *Initiators.* As the name indicates, the initiators are used to initiate the reaction, i.e., to allow polymerization to begin. They *stabilise* the ends or reaction sites of the molecular chains. H_2O_2 is a common initiator.
5. *Dyes and pigments.* Pigments and dyes, when added, give plastics their brilient colours. The colouring is important as it provides sales appeal. The colourants must be able to disperse evenly throughtout the molten plastics and must have heat stability.
6. *Blowing agents.* A plastic re in such as polystyrene is foamed by injecting an inert gas (nitrogen/argon) before the molten material is forced into the mould. The process creates a porous interiors. The familiar disposable cups are examples.
7. *Modifiers.* The modifiers are added to improve mechanical properties/characetristics of the base resin.
8. *Antioxidants.* Antioxidants added to plastics provide resistance to ultraviolet rays. They also impart melt-flow retention for easy moulding.

PROCESSING PLASTICS

In processing plastics, either thermoplastic or thermosetting, only a limited number of processes are available. Each process is able to impart some desired form to the plastic. Common production processes are moulding, calendering, thermoforming, casting and fabricating processes.

13.5 MOULDING PROCESSES

Moulding processes correspond to casting and bulk-deformation processes in metals. These are based on the fact that when the plastic is heated it will soften to a viscous liquid that can be forced into a mould of desired shape, where it solidifies.

COMPRESSION MOULDING

Compression moulding is essentially a forging process, performed in a heated die that forms a premeasured quality of the polymer. The process is most widely used for the forming of the thermosetting plastics.

The basic procedure for compression moulding, illustrated in Fig. 13.1. consists of placing a measured amount of powder or a compressed preform (called the *charge*), into the open mould cavity, closing the mould and then applying heat and pressure through a downward-moving die (called the *force, plug, or core*) to the material until it softens and is forced fill the mould cavity. In the closed mould, a chemical reaction or polymerization, that cross-links the polymer chains takes place and the material hardens into the required shape. Heat for polymerization or curing is supplied through the walls of the cavity by steam or electricity.

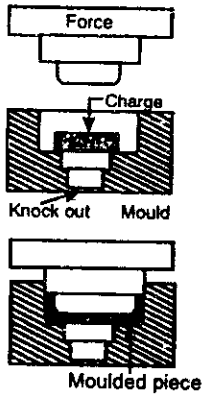

Figure 13.1 Compression moulding (positive)

Moulding pressures (hydraulic) may be as low as 0.35 kgf/mm^2 (3.5 MPa) for polyester and epoxy but most thermosets require 1.4 to 4.2 kgf/mm^2 (13.8 to 41.4 MPa), depending largely on the filler or plasticizer used. Moulding temperatures are from 1,100 to 2,200°C depending on the plastic, filler, etc.

The complete cycle may take from 10 sec, for small parts under 2.5 mm thick to 5 or 10 min for large, thicker parts. This curing time may be reduced as much as 50% by pre-heating the charge.

Compression moulding may be of the *positive-type, semi-positive-type,* or the *flash type*. In the latter, some of the material is allowed to escape, usually along the moving-die perimeter, over a land or cut-off area, in the form of a thin *flash* or *fin* which is finally trimmed off. A mould of this type gives closer tolerances and is usually cheapest to make.

Cold Moulding. Although compression moulding is mostly done hot, some cold moulding is done. A powder or fibres (often of refractory materials) are mixed with a binder and compacted in a cold die. These procedures are followed by *curing* in a separate oven. This method is not suitable where close tolerance and good surface finish is required.

TRANSFER MOULDING

Transfer moulding, also called *extrusion or gate moulding*, is the process of forming articles in a closed mould, where the fluid plastic material is conveyed into the mould cavity under pressure from outside of the mould.

The material, often a preheated preform, is placed in a heated *transfer pot*. As soon as the material is sufficiently softened, the plunger forces the almost fluid plastic through the *orifice* (sprue) into the closed mould where final cure takes place. Pressures used are 50 to 100% higher than those used for compression moulding ; thus better details and higher strengths are possible. Fig. 13.2 shows the mechanism of transfer moulding.

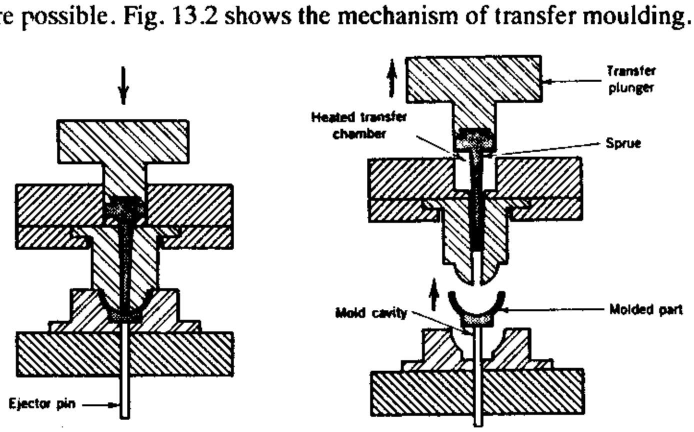

Figure 13.2 Transfer moulding

INJECTION MOULDING

Injection moulding is the most widely used method of producing parts of thermoplastic and more recently, thermosetting resins as well. The process (Fig. 13.3) resembles the hot-chamber die-casting of metals : the die, split to allow removal of the solidified product, is kept shut with an appropriate press force and ejectors are provided for removing the moulded component. The difference between metals and plastics lies in the supply of the polymer, which is usually fed in a solid form, pellets or powder, through a *hopper* to a *injector screw*, the die-end of which is surrounded with heaters that gradually brings the polymer to the required temperature. There the material is softened.

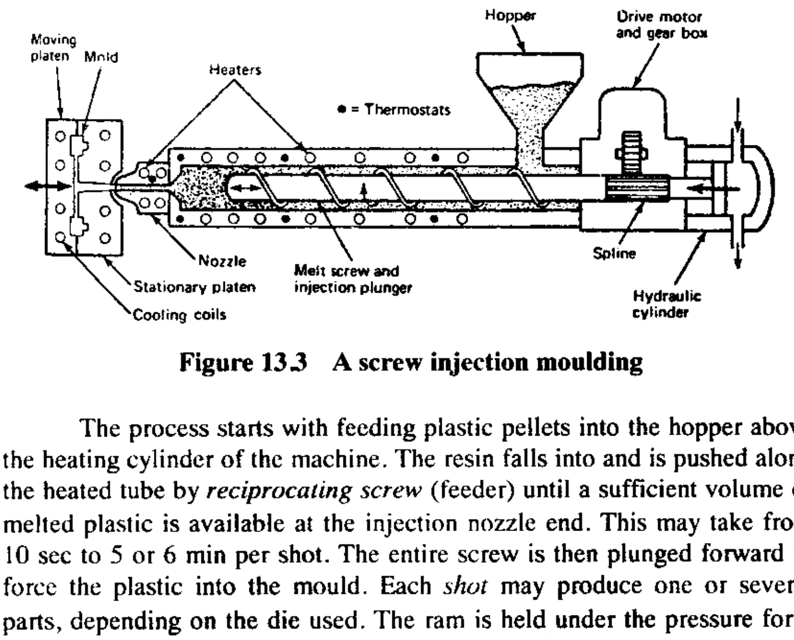

Figure 13.3 A screw injection moulding

The process starts with feeding plastic pellets into the hopper above the heating cylinder of the machine. The resin falls into and is pushed along the heated tube by *reciprocating screw* (feeder) until a sufficient volume of melted plastic is available at the injection nozzle end. This may take from 10 sec to 5 or 6 min per shot. The entire screw is then plunged forward to force the plastic into the mould. Each *shot* may produce one or several parts, depending on the die used. The ram is held under the pressure for a few seconds so that the moulded part can solidify (cool). It then retracts slightly and the mould opens. Knock-out pins eject the moulded piece. The sprue and runners are trimmed off, usually in a separate trimming press.

The addition to reciprocating screw machine, there are also conventional *single-stage plunger type*, and *two-stage plunger-* or *screw-plasticizer type* machines.

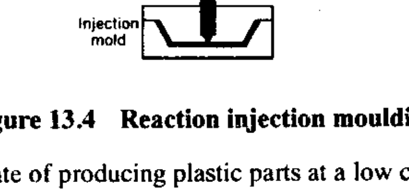

Figure 13.4 Reaction injection moulding

Injection moulding provides the highest production rate of producing plastic parts at a low cost.

The time required per shot will vary with the material and size of the mould, but 300 to 400 shots per hour in a fully automatic equipment are not uncommon.

Jet Moulding. A modified version of the injection moulding is also used and the process is also known as jet moulding. By this process the plastic is preheated to about 93°C in the cylinder surrounding to nozzle. It is then further heated as the plunger forces the resin through the nozzle. After the mould has been filled, the nozzle is cooled by running water to prevent polymerization of the remaining. matérial.

Reaction injection moulding. It is a newer development of injection moulding. In this process two resins (monomers) are injected together in the mould. Just before they enter in the mould, A chemical reaction takes place between the resins at low heat and a polymer is created at that moment. This process does not require heat before moulding. Fig. 13.4 shows the process.

EXTRUSION

Extrusion means the continuous flow of material through a die. Extrusion moulding is used mostly for the production of sheet, tube bar and typical applications in thermoplastic materials. Granulated powder made of such materials as vinyl resins, cellulose derivatives, nylon, polyethylene and polypropylene make up the materials used in the process.

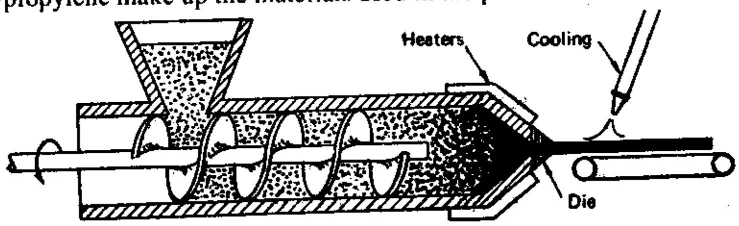

Figure 13.5 Continuous extrusion

Plastic extrusion machine (Fig. 13.5) consists of a hopper into which the powder or pellets are fed into a heated cylinder, the screw feeding mechanisms, a nozzle and the die assembly. The rotating screw carries the heated plastic forward and forces it through heated die orifice of the required shape. As it leaves the die, it is gradually cooled by carrying it through cooling media while resting on a conveyor, It is then wound into coils or cut to desired lengths.

There are advantages to the extrusion process. The tooling is low-cost compared to injection moulding. Material thickness can be accurately controlled. In addition, production rates are high and intricate profiles can be produced.

13.6 CALENDERING

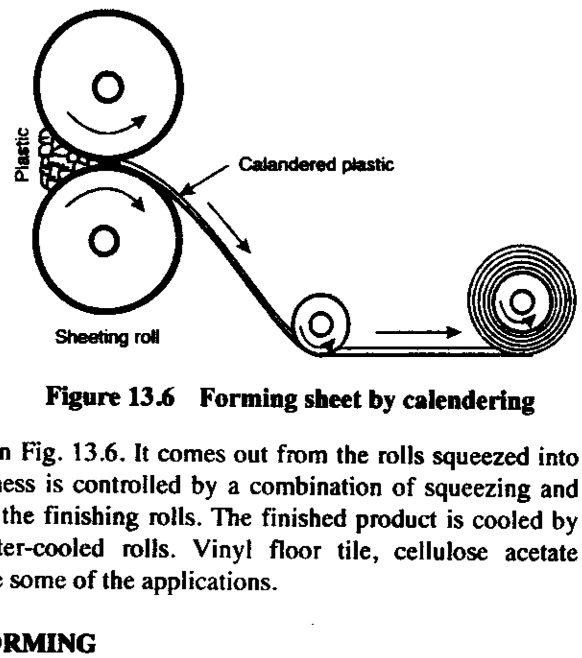

Figure 13.6 Forming sheet by calendering

An important method of making film and sheet is known as calendering. In this process the plastic compound (composed of resin, filler, plasticizer and colour pigment) is passed between a series of heated rollers as illustrated in Fig. 13.6. It comes out from the rolls squeezed into film or sheet. Thickness is controlled by a combination of squeezing and altering the speed of the finishing rolls. The finished product is cooled by passing through water-cooled rolls. Vinyl floor tile, cellulose acetate sheeting and films are some of the applications.

13.7 THERMOFORMING

Thermoforming sometimes called *vacuum forming*, is the shaping of hot sheets or strips of thermoplastic materials into a desired shape either by mechanical or pneumatic methods. The sheets of plastic used in the thermoforming process are produced by either extrusion, calendering or pressing. Thickness of the sheets tat are processed range from 0.125 to 3.2 mm or even greater.

The basic process is quite simple. A piece of plastic sheet is clamed into a frame. The plastic is heated, usually with electric heaters, until it begins to sag. Vacuum, air or mechanical pressure is then applied through small holes in the mould and the plastic is rapidly pulled tightly against the mould creating close profile conformity. The frame is raised, the part is removed and then trimmed in a punch press. The mould may have several shapes, for the same part or for different parts.

In vacuum forming (Fig. 13.7*b*), the sheet is clamped in a stationary frame and the heated sheet is vacuum-drawn into the mould.

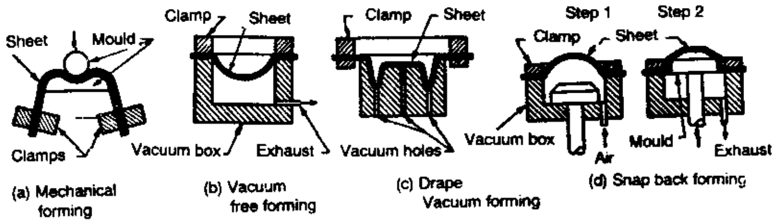

Figure 13.7 Thermoforming (methods of forming sheets)

A male mould is used in *drape vacuum forming* and a moveable frame or clamp drapes a heat-softened sheet over the male mould before vacuum is pulled (Fig. 13.7*c*). A more complex shape can be developed by this method.

In the *vacuum snap back* process (Fig. 13.7*d*), in the first step, vacuum is produced in the chamber and the sheet is drawn down into the cavity. The male plug descends and clamps against the chase which holds the sheet. In the second step, vacuum is applied to male plug and the material is drawn to the mould. Deep drawn parts with generous tapers and corners with large radii are possible with this technique.

Among the items made by thermoforming process are small jelly containers used in restaurants, luggage, refrigerator inner panels lighting fixture, helmets and containers for packing.

BLOW MOULDING

Blow moulding is a process of placing a softened thermoplastic closed-end tube (parision) and applying air pressure to inflate it.

In operation, the heated parison is continuously extruded, cut to the proper length and sealed at one end, gripped in the two-piece mould and then air is injected to force the plastic against the walls of the water-cooled mould. The part cools and then the mould is opened and the part is removed (Fig. 13.8)

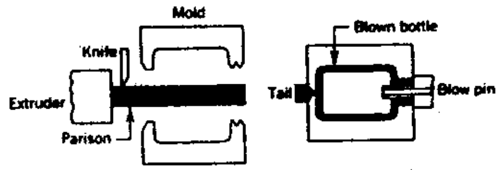

Figure 13.8 Stages in blow moulding

Production methods range from simple manual operations to relatively complicated automatic ones. Blow moulded products include bottles, floats, automobile heater ducts and similar articles.

13.8 CASTING

Casting, that is, pouring a liquid into a mould *without pressure,* can be done with several plastics. When there is not sufficient justification for making expensive dies, the casting process is generally used.

Open moulds into which the liquid resin, mixed with a catalyst or hardener, is poured can be used for most plastics.

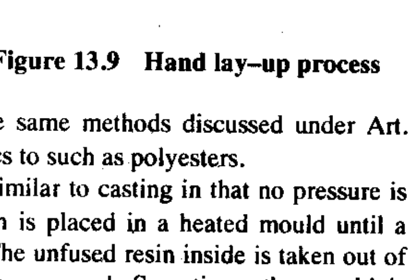

Figure 13.9 Hand lay–up process

Centrifugal casting, using the same methods discussed under Art. 11.27 can be used with several plastics to such as polyesters.

Shell moulding is somewhat similar to casting in that no pressure is used. In this process, powdered resin is placed in a heated mould until a layer fuses to the desired thickness. The unfused resin inside is taken out of the mould and the hollow moulding removed. Sometimes the mould is rotated in what is called *rotational moulding.*

Slush moulding is similar to shell moulding. It employs a thermoplastic-resin slurry or "slush" which is poured into a preheated mould. The heat causes the slurry to set in a viscous layer of the desired wall thickness.

Both shell and slush moulding produce thin-walled products such as toys and gloves.

Hand Lay-up is a simple method to form plastic materials into a required shape. Special shapes like boats, tanks and big-sized parts of plastics are produces by this method. First a mould of desirable shape is prepared. The mold is covered by fibre mats of desired thickness and plastic resin (such as epoxy) is draped over the mould and allowed to harden. Fig 13.9 shows the process.

13.9 LAMINATING AND REINFORCING

Laminates refer to a variety of materials bonded together by heat and pressure to form a single piece. Most laminated plastics consist of sheets of wood, asbestos, fabric and other special materials. These materials are impregnated or coated with resin and then processed by applying heat and pressure to form the product. Since the amount of heat and pressure varies, we have the terms *high-pressure* and *low-pressure laminates.*

High-pressure laminates, compressed at over 70 kgf/cm^2 (6.8 MPa) and heated to around 150°C, are available as sheets, rods, and tube in stranded sizes and are fabricated in special shapes. Several trade names are Formica, Micarta and Limicoid.

Low-pressure laminates or *reinforced plastic mouldings* are those that require much lower pressure than that required for high-pressure laminates. The most common reinforcing material is glass in the form of fabric or fibres, but others are asbestos, boron, cotton and nylon fibres. The mouldings include such products as storage bins, loudspeaker horns, machinery housings, aircraft panels.

13.10 FOAMED PLASTICS

Foamed plastics have become important in many applications, because *discrete porosity* improves buoyancy and elasticity and acoustical, heat and electrical insulating properties, while *interconnected porosity* makes the structure absorbent. Porosity is included with *foaming agents* which may be *chemical* (substances that decompose to release a gas such as nitrogen) or *physical* (liquids that evaporate or gases that expand). They can be added to both thermosetting and thermoplastic compounds. The plastics used in the foam form are polystyrene and polyurethane, usually referred to as urethane. Polypropylene, phenolic, silicone and epoxy are also used.

Foamed plastics are widely used in making mattresses, automobile dash boards and seat cushions, boards, sheets and rods, etc. These are generally made by extrusion or injection moulding.

13.11 FASTENING AND MACHINING PLASTICS

Fastening of plastics to plastics, metal or wood may be done by rivets, bolts or screws. Plastics are often the base for adhesives and can be secured to themselves and to metal by "glueing" or cementing.

One most commonly used method of joining plastic parts together is by *localized heating*. This can be done by hand with a torch or by more automatic methods.

All except highly inflammable thermoplastic can be welded by heat softening and pressing together surfaces to be joined. *Common welding methods* are : (1) hot-gas, (2) heated tool, (3) friction and (4) ultrasonic welding.

Machining of plastics can be satisfactorily performed with conventional machine tools employed for machining metals. However, there are some principles of machining that apply to plastics alone because the properties of plastics are different from those of metals. Furthermore, plastics have a greater thermal expansion rate and soften and distort at temperatures well below those of metal. This behaviour of plastic imposes certain precautions which include keeping the work cool to avoid sticking or excessive expansion or deflection. Air-, water- and oil-coolants are commonly used for cutting plastics. Coolants with a 10% solution of water soluble oil are best, but that do not discolour the plastic or do not present a cleaning problem can be used. Many plastics are resilient (bounce back), so cuts must be made with very sharp tools. Sharp tools also avoid too much heat.

Cutting tools should be high speed steel, but hard and wear-resistant nonferrous alloy, cemented carbide or sintered oxide tools are necessary to cut plastics with abrasive fillers. Tools should be set with zero or slight negative rake and should have a scraping instead of a cutting action that will keep the material from chipping out. In general, tool angles can be similar to those used in machining copper and brass.

TABLE 13.3 CUTTING TOOL ANGLES. SPEEDS AND FEEDS FOR MACHINING PLASTICS

Material		*Nylon*	*P.T.F.E.*	*Polystyrene*	*P.V.C. (rigid)*	*Phenolic laminate*
Rake		0 to – 10°	0 to – 5°	0 to – 5°	0 to – 10°	0 to – 30°
Clearance		20° – 30°	20° – 30°	20° – 30°	20° – 30°	15°
Turning	C. Speed (m/s)	2.5 to 5.0	1.0 to 2.5	1.5 to 5.0	2.5 to 5.0	1
	Feed (mm/rev)	0.1 to 0.25	0.05 to 0.25	0.05 to 0.25	0.25 to 0.75	0.1 to 0.25
Milling	C. Speed (m/s)	5	5	5	5	7.5
	Feed (mm/rev)	upto 4	upto 4	upto 4	upto 4	upto 4
Drylling	C. Speed (m/s)	2 to 5	125 to 5	0.5 to 10	2.5 to 30	3.5 to 50
	Feed (mm/rev)	0.1 to 0.38	0.1 to 0.38	0.2 to 0.38	0.05 to 0.13	0.1 to 0.25

Machine tools can work to as close tolerances in cutting plastics as with many materials, but in some cases a small tolerance is of no use because the plastic will not retain a size. However, to maintain close tolerances, it is necessary to anneal at the time of machining. This is especially true when considerable material is to be removed and there is likelihood of stress build-up.

Table 13.3 gives a guide for cutting tool angles, speeds for common thermoplastic and thermosetting plastics.

13.12 DESIGN CONSIDERATIONS

In designing a part to be made of plastic, many of the rules and their reasons given for casting and moulding of metal apply to the moulding of plastics. The proper method of moulding is determined by the plastic material being processed ; the number of parts to be produced within a given time ; the size, geometry and tolerance requirements of the design ; and inserts to be moulded into the piece. However, some general guides that apply to almost all methods of processing plastics are :

1. Taper is essential to remove parts from the mould without injury to it. A taper of 3° is considered standard for plastic.
2. Thick sections should be avoided for greater economy and faster cooling and quick moulding.
3. Thick and thin sections under one surface should be avoided because the thicker one shrinks more and causes noticeable heat sinks.
4. Plastic walls must not be too thin or weak.
5. Transition between thick and thin sections should be gradual to promote uniform cooling and to avoid stress concentration.
6. Ribs, beads and flanges should be used to add additional strength to the article, but they should be provided with sufficient draft.
7. Sharp corners should always be avoided as in the metal castings.
8. Adequate radii and fillets should be provided to eliminate sharp edges and corners wherever possible. The radius or fillet should be at least 25% of wall thickness and never less than 0.794 mm.
9. Holes should be cored wherever possible to avoid machining; but smaller holes are best drilled and small threads of reasonable strength are best provided by *metal inserts.*
10. Inserts, if used, should be strong enough to sustain mould pressure. The wall thickness around the insert must be

sufficiently heavy to avoid cracking.

11. Due allowance for shrinkage must be provided.
12. A working tolerance of ±0.125 mm is practical in mould construction. Tolerances of ±0.0050 mm can be readily be held but at an increase of 15 to 20 percent in cost.

REVIEW QUESTIONS

1. What are plastics ? Name two broad classifications of plastics. Distinguish between them. Explain the term "polymerization".
2. What raw materials are used to produce plastic compounds ?
3. Name five common thermoplastic and four common thermosetting plastics and give several uses of each.
4. Describe the plastic processing methods with the help of neat sketches, wherever possible: (a) Compression moulding (d) Slush moulding (b) Transfer moulding (e) Calendering (c) Injection moulding (f) Blow moulding
5. What types of items are manufactures by the extrusion process ? How does extrusion differ from injection moulding ?
6. Why is the thermoforming a valuable method for the plastic manufacturer ?
7. What are the common methods used for forming plastic sheet ?
8. Distinguish between high-pressure laminating and low-pressure laminating processes.
9. What are foamed plastics and state how foaming is done ?
10. State how joining and machining of plastics are carried out.
11. What are the major considerations in the design of plastic parts ?

14

BENCH WORK AND FITTING

14.1 INTRODUCTION

In engineering, particularly in heavy and medium engineering, even to-day, with the use of automatic machines, bench work and fitting have important roles to play to complete and finish a job to the desired accuracy. Although majority of the work can be finished to fairly good degree of accuracy in a reasonable time through various machining operations they still require some operations to be done on them to finish the job by hand. Much of the raw materials go into the machine shop and re-appear as a finished component ready for assembly ; some parts need both machining and then a certain amount of work in fitting ; other parts are entirely made and fitted on the bench.

The term "bench work" generally denotes the production of an article by hand on the bench. "Fitting" is the assembling together of parts and removing metals to secure the necessary fit, and may or may not be carried out at the bench. It is seen that there is no clear dividing line between these two terms, and in most cases they are both concerned, and the terms are used rather loosely.

However, all these two types of work require the use of a large number of tools and equipments and involve a number of operations to finish the work to the desired shape and size. The operations commonly used in bench and fitting work may be classified as :

1. Chipping.	6. Marking.
2. Filing.	7. Drilling.
3. Scrapping.	8. Reaming.
4. Grinding.	9. Tapping.
5. Sawing.	10. Dicing.

14.2 VICES

The vice is the most common tool for holding work. Various types of vices are used for various purposes. They include bench vice, leg vice, pipe vice, hand vice, pin vice and toolmaker's vice.

Bench vice. The most commonly used is the engineer's parallel-jaw bench vice, sometimes called fitter's vice (Fig. 14.1). It must be firmly fixed to the bench with coach screws, or with nuts and bolts. The vice essentially consists of cast iron body, a fixed jaw, a movable jaw—both made of cast steel, a handle, a square-threaded screw, and a nut—all made of mild steel. Separate cast steel plates known as jaw plates are fixed to the jaws by means of set screws and they can be replaced when worn. The holding faces of the jaw plates have teeth for holding the work firmly but this has some disadvantage for soft metal which may be damaged when firmly held between the faces. Protective grips or 'clamps' which can be made of lead, fibre, tin-plate, etc. are, therefore, usually fitted over the jaws to prevent the serrations damaging the surface of the finished work. The movement of the vice is caused by the movement of the screw through the nut fixed under the movable jaw and the screw is provided with a collar inside to prevent it from coming out of the jaw when revolved.

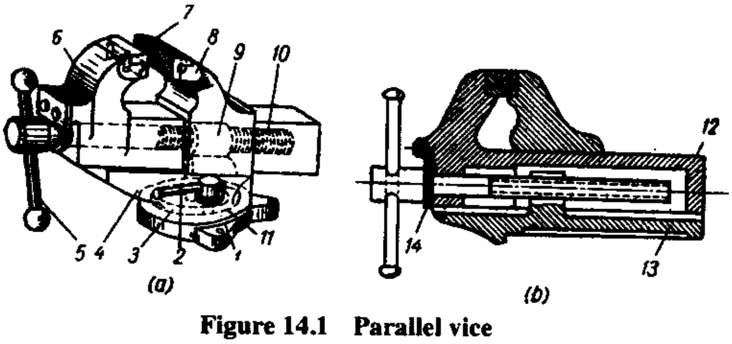

Figure 14.1 Parallel vice

(a) Swivel parallel vice, (b) Plain parallel vice,
1. Stationary support disk, 2. Turning lever, 3. Swivel plate, 4. Base plate, 5. Handle, 6. Movable jaw, 7. Jaw plates, 8. Fixed jaw, 9. Fixed nut, 10. Clamping screw, 11. Circular slot, 12. Prismatic shank, 13. Base, 14. Coupling plate

The size of a vice is known by the width of its jaws. The width suitable for common work varies from 80 to 140 mm, the maximum openings being 95 and 180 mm.

Leg vice. The leg vice is used by blacksmiths but it is also suitable for heavy hammering, chipping, and cutting in fitter's work. The vice is secured to the top of bench by a strap which is fastened to a plate bolted to the bench top. The leg of the vice is fastened to the bench leg with staples and its ends fit into a hole in the floor. This construction of the vice makes it suitable for heavy work. One disadvantage of this type is that the jaws come together like the arms of a letter "V", and therefore don't provide such a firm grip as the parallel jaw type.

Pipe vice. The pipe vice shown in Fig. 14.2 is used for holding round section metal, tubes, pipes, etc. In this case, the screw is vertical and the movable jaw works vertically. It grips the work at four points on its surfaces.

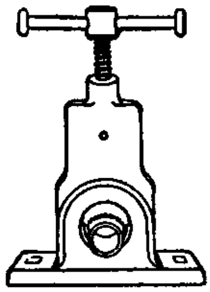

Figure 14.2 Pipe vice

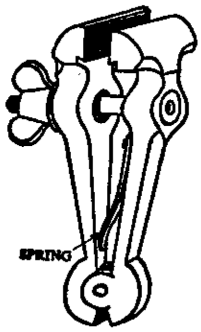

Figure 14.3 Hand vice

Hand vice. The hand vice is used for gripping screws, revets, keys, small drills and other similar objects which are too small to be conveniently held in the bench vice. This is made in various shapes and sizes. The length varies from 125 to 150 mm and the jaw width from 40 to 44 mm.

A typical hand vice is shown in Fig. 14.3. It consists of two legs made of mild steel which hold the jaws at the top and are hinged together at the bottom. A flat spring held between the legs tends to keep the jaws open. The jaws can be opened and closed by a wing nut which moves through a screw that is fastened to one leg and passes through the other.

Pin vice. The pin vice is used for holding round material of small diameter such as wire and pins, during working. It also forms a very useful handle for small files. This is illustrated in Fig. 14.4. It consists of a handle and a tapered nose covering a small collet chuck at its end. The chuck carries the jaws which are operated by turning the handle.

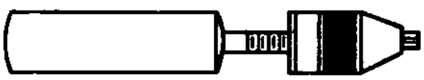

Figure 14.4 Pin vice

Toolmaker's vice. The toolmaker's vice as shown in Fig. 14.5 is particularly useful for holding small work which requires filing or drilling, and for such work as laying out small jobs on the surface plate. It is made of mild steel.

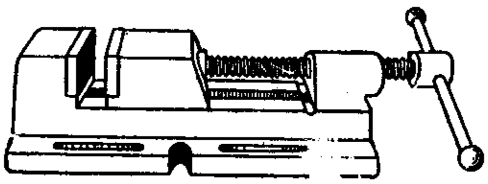

Figure 14.5 Toolmaker's vice

Care of vices. Vices should be kept clean and free from dust and metal chips, using a brush. Occasionally, the thread and the nut should be oiled. The vice should never be used as an anvil, and a hammer or other means must not be used to move the handle. It will only bend the handle and spoil the screw threads.

The serrated jaws are covered with soft metal clamps when finished work is held. When it is necessary to hold a screw or bolt in the vice a length of soft wire should be wound into the vee of the thread for protection. For holdirg tubing, temporary wooden "V" blocks are used.

14.3 HAMMERS

Hammers are used to strike a job or a tool. They are made of forged steel of various sizes (weights) and shapes to suit various purposes. A suitable range would be from 0.11 to 0.33 kg for light work such as clinching small rivets and dot punching, 0.45 kg for chiselling, 0.91 kg for heavier work such as chipping, the popular sizes for bench work being 0.33 and 0.45 kg.

A hammer consists of four parts namely *peen, head, eye and face* as shown in Fig. 14.6. The eye is normally made oval or elliptical in shape and it accommodates the *handle* or *shaft*. The end of the handle which fits into the eye is spread or split by forcing a metal wedge into it to prevent the hammer head from flying off the handle during striking. The handle is made of elastic wood or bamboo and is so shaped and sized that when gripped it gives an easy feel to the hand. This "feel" is known as the "balance" of the hammer. A well balanced hammer "feels" just right when the handle is grasped at the correct point. The face is hardened and polished well, and is slightly convex, instead of flat to avoid spoilage of the surface of the metal to be hammered by the sharp edge of the flat surface. on an average, the handle should be 250 to 325 mm long. The length of handles for light hammers is 200 to 260 mm, that for heavy hammers is 380 to 450 mm.

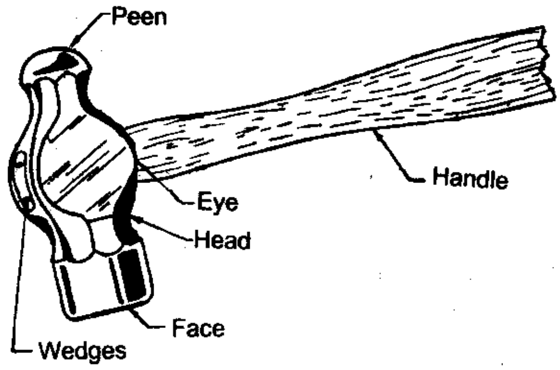

Figure 14.6 Hand hammer

Hammers are classified, according to the shape of the peen, as ball peen, cross peen and straight peen hammers.

Ball peen hammer. This is most common form of hammer and is sometimes called engineer's hammer, or chipping hammer. The peen has a shape of a ball which is hardened and polished. This is hammer is chiefly used for chipping and riveting. The size of this hammer varies from 0.11 to 0.91 kg (IS : 841-1957).

Cross peen hammer. This is similar to ball peen hammer in shape and size except the peen which is across the shaft or eye. This is mainly used for bending, stretching, hammering into shoulders, inside curves, etc. The size varies from 0.22 to 0.91 kg (IS : 841-1957).

Straight peen hammer. This hammer has a peen straight with the shaft, i.e. parallel to the axis of the shaft. This is used for stretching or peening the metal. The size varies from 0.11 to 0.91 kg.

Soft hammer. where is necessary to strike metal a blow with the minimum damage to the surface, a soft-hammer, called *mallet,* is used. Mallet heads go by the numbers or by the diameter of the head. They are made of raw hide, hard rubber, copper, brass, lead or most commonly—of wood.

14.4 CHISELS

Cold chisels are used for cutting and chipping away pieces of metal and are made of carbon steel usually rectangular, hexagonal or octagonal cross-section. They are forged to shape, roughly ground, and then hardened and tempered. Afterwards the edge is ground sharp to the correct cutting angle, care being taken not to overheat the steel and draw the temper. The making of cold chisel, its hardening and tempering are described in Art.8.7. The cutting angle given to the chisel is determined mainly by the nature of the metal to be chipped. It varies between 35 and 70°, the less acute angles being for the harder and tougher metals.

Table 14.1 will give the cutting angle of chisel for chipping various metals :

TABLE 14.1 CUTTING ANGLE OF CHISEL (*IS : 402-1964*)

Type of chisel	*Material to be cut*			
	Steel	*Cast iron*	*Copper and brass*	*Zinc and Aluminium*
Flat	70°	60°	45°	35°
Cross-cut	70°	60°	45°	35°
Diamond point	60°	60°	60°	60°
Half-round nose	45°	45°	45°	45°

The chisel is subdivided into cutting edge, shank and head, and this is generally specified by the length, and width of the cutting edge ; and particularly by the width of the cutting edge. A 25 mm cold chisel means a chisel with a 25 mm wide cutting edge. The shape of its cutting edge is also required to completely specify a chisel. The five most common types are the flat, the cross-cut, the diamond pointed, the half round and the side chisel. Apart from the cutting angle, other angles that can be specified for a chisel are : 1. rake angle, 2. forging angle, and clearance angle. Fig. 14.7 shows various angles of a chisel.

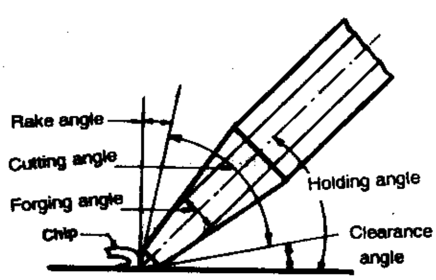

Figure 14.7 Chisel in operation

The rake angle is the angle which is made by the upper taper surface of the chisel point and a line perpendicular to the point of metal surface which the tip touches. The clearance angle is dependent of the way the operator drives it and this angle is kept more than 10° for proper digging the metal. Forging angle is kept around 25° to 30°.

Flat chisel. The flat chisel as shown in Fig.14.8 is the most common of all the chisels used in engineering. It is the chisel which is used for most of the general chipping operations. It may be used for removing surplus metal from surfaces of jobs.

The flat chisel should be drawn down to the shape shown in the diagram. The cutting edge should be slightly curved as shown as this will prevent the corners digging in when it is being used.

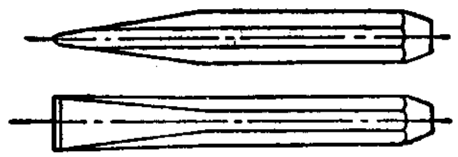

Figure 14.8 Flat chisel

The length of a flat chisel varies from 100 to 400 mm, while the width of the cutting edge varies from 16 to 32 mm (*IS : 402-1964*).

Cross-cut chisel. The cross-cut chisel (Fig.14.9) or *cape chisel* as it is sometimes called, is used for cutting grooves in large surfaces previous to using the flat chisel, and is also used in cutting key ways in wheels and shafts.

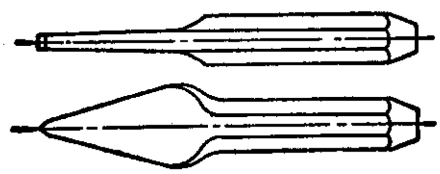

Figure 14.9 Cross-cut chisel

The cutting edge is slightly wider than the supporting metal to provide clearance. Length of this chisel varies from 100 to 400 mm, and width of the edge varies from about 4 to 12 mm (*IS : 402-1964*).

Half-round chisel. A half-round chisel is shown in Fig.14.10 and is particularly useful for cutting oil-ways or grooves in bearing, bosses and pulleys, etc. They are also used for setting-over pilot holes. When a hole is to be drilled a smaller or pilot hole is drilled first.

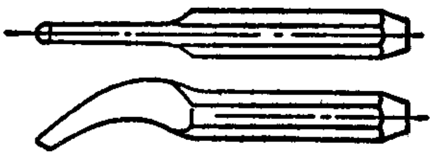

Figure 14.10 Half round chisel

The shank is reduced to a half-round taper, which is bevelled at the end to give a circular edge. Length varies from 150 to 250 mm and width of the cutting edge from 2 to 16 mm (*IS : 402-1964*).

Diamond-point chisel. The diamond-point chisel as shown in Fig.14.11 is used for cutting vee grooves, cleaning corners and squaring small holes.

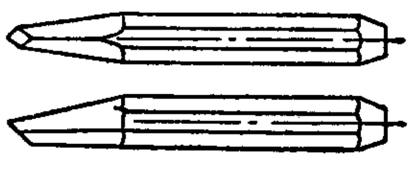

Figure 14.11 Diamond-point chisel

The chisel is drawn to a square section. The end is ground off at an angle producing the "diamond" shape. Length of this chisel varies from 100 to 400 mm and width of the cutting edge from 6 to 16 mm (*IS : 402-1964*).

Side chisel. A side chisel is shown in Fig.14.12. This is particularly useful in chipping and removing the surplus metal in cotter ways and slots, which may have to be cut by hand after having been drilled.

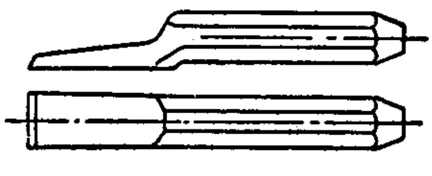

Figure 14.12 Side chisel

The shank of this chisel is bent out a little sideway, and then vertically down again.

14.5 CHIPPING

Chipping is the process of removing thick layers of metal by means of cold chisels. In chipping work, the lob is firmly held in a vice and the metal is removed by striking the chisel on to the surface of the workpiece by a hammer. When chipping, the chisel should be held chiefly with the second and third fingers, the index being relaxed. The hammer shaft should be grasped at the end, and when in use should be brought up square with the body and nearly to the shoulder to ensure sufficient power in the blows. The angle the chisel should be held at in relation to the work depends to some extent upon its cutting angle, but can be best determined by actual practice. This should be at such an angle with the work that an even chip of right depth can be obtained at ease.

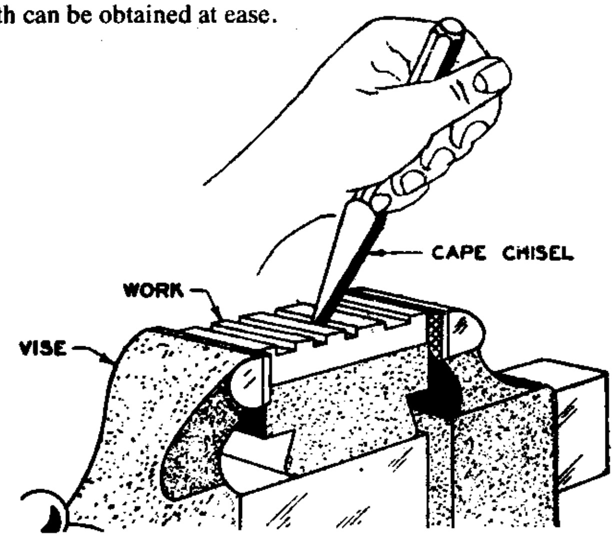

Figure 14.13 Chipping by a cross-cut chisel

If the surface to be chipped is too long it is advisable to cut grooves along the whole surface by a cross-cut chisel as shown in Fig. 14.13 and then chip away the rest of the metal. In removing large volume of metal frequent lubrication of the cutting edge will be necessary to ensure long tool life and to make the cutting action quicker and smoother. While chipping, the operator should always keep his eyes on the cutting edge of the tool and not on its head. The process includes cutting key ways, forming grooves, slots, oil channels, etc.

14.6 FILES

The most widely used hand tool to be found in an engineering workshop is the file. A file is a hardened piece of high grade steel with slanting rows of teeth. It is used to cut, smooth, or fit metal parts. It cuts all metals except hardened steel.

A file consists of the following parts as shown in Fig. 14.14. The *tang* is the pointed part which fitted into the handle. The *point* is the end opposite the tang. The *heel* is next to the handle. The *safe edge* or *side* of a file is that which has no teeth.

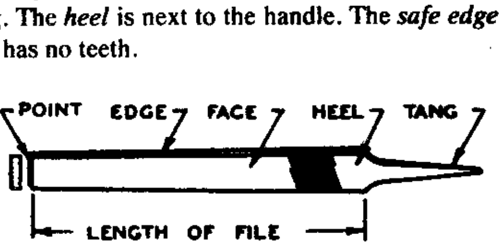

Figure 14.14 Different parts of a file

Files are classified and named according to the three principal factors—sizes, type or cut of teeth, and sectional form.

Size. The size of a file is its length. This is the distance from the *point* to the *heel*, without the tang. Files for fine work are usually from 100 to 200 mm and those for heavier work from 200 to 450 mm in length.

Cut of teeth. Cuts of files are divided into two groups as shown in Fig. 14.15. These groups are : (1) single-cut (2) double-cut.

On *single-cut* files the teeth are cut parallel to other across the file at an angle of about 60^0 to the centre line of the file. Such files are frequently termed as "flats" and are chiefly used on very hard metal. *Double-cut* files have two sets of teeth, the over-cut teeth being cut at about 60° and the up-cut at 75 to 80° to the centre line.

Single-cut and double-cut files are further divided according to the coarseness or spacing between the rows of the teeth. In descending order of roughness they are listed as :

1. Rough (R)
2. Bastard (B)
3. Second cut (SC)
4. Smooth (S)
5. Dead smooth (DS)
6. Super smooth (SS)

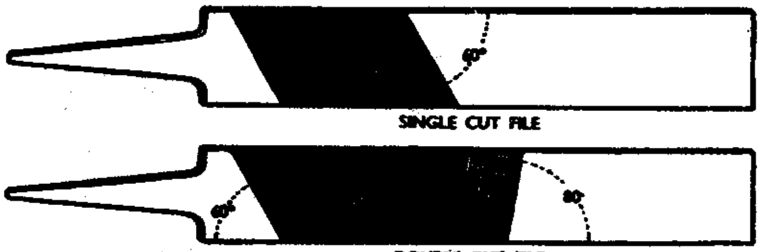

Figure 14.15 Single-cut and double-cut of a file

Table 14.2 will give a fair idea of the number of teeth or cut in each of the above grades over a length of 10 mm. It will be seen from the table that the **coarseness of a file changes with its length.** The larger the file, the coarser it is. Thus, a rough cut, on a small file may be as fine as a second-cut on a lager file.

TABLE 14.2 GRADE OF CUT IN A FILE

	Usual nominal lengths in mm							
Type of cut	100	150	200	250	300	350	400	450
	Number of cuts over a length of 10 mm							
Rough	10	8	7.1	6.3	5.5	5.3	4.8	4.5
Bastard	18	13	11	10	9	8	7	6
Second cut	21	17	16	15	14	13	12	11
Smooth	30	24	22	20	19	18	16	15
Dead smooth	35	33	31	30	28	—	—	—
Super smooth	63	49	45	40	—	—	—	—

Rough cuts are used for soft metals. They are often used for trimming the rough edges of castings of softer metals. Bastard is the standard cut used for general shaping work. Second cut is an excellent file for harder metals and gives a good finish for many pieces of fitting work. Other cuts are used to give a high degree of accuracy with a very high finish.

Shapes. The shape of a file is its general outline and *cross-section*. Files are made in hundred of shapes. Fig. 14.16 show the most commonly used shapes. They are :

Flat file : This is tapered in width and thickness, and one of the most commonly used files for general work. They are always double-cut on the faces and single-cut on the edges.

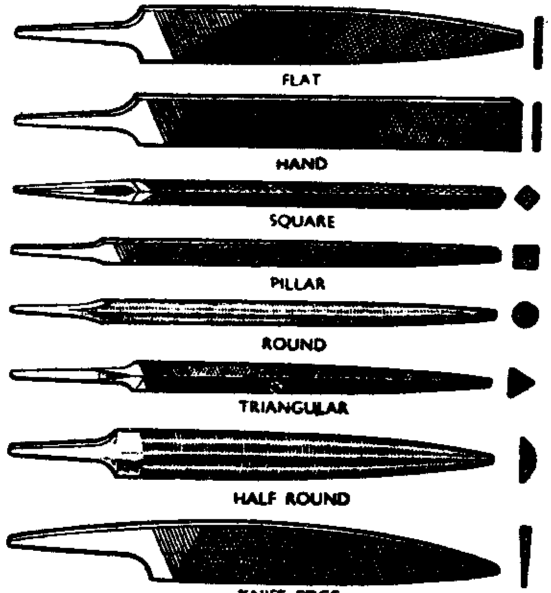

Figure 14.16 Shapes of file

Hand file : This is parallel in its width, and tapered in thickness. A hand file is used for finishing flat surfaces. It has one edge (i.e. it is uncut) and therefore, is useful where the flat file cannot be used. They are always double-cut.

Square file : This is square in cross-section, double-cut, and tapered towards the point. This is used for filling square corners, enlarging square or rectangular openings as splines and keyways.

Pillar file : Pillar files are double-cut, narrow and of rectangular section. It has one safe edge, and is used for narrow work, such as keyways, slots and grooves.

Round file : They are round in cross-section and usually tapered, when they are termed rat-tailed. When parallel they are described as parallel round. Round files are used for filing curved surfaces and enlarging round holes and forming fillets. They may be single-cut or double cut .

Triangular file : Three square or triangular file is tapered, double-cut, and the shape is that of an equilateral triangle. They are used for rectangular cuts and filing corners less than 90^0

Half-round file : This is tapered double-cut and its cross section is not a half circle but only about one-third of a circle. This file is used for round cuts and filing curved surfaces.

Knife edge file : This is shaped like a knife, tapered in width and thickness and double-cut. They are used filing narrow slots, notches, and grooves.

There are a number of other types of file in less common use. They are all used for special purposes and not in general use. They are wording file, needle file, riffier, etc. *A wording file* is a thin flat file having fine cut teeth, about 100 mm long. This is widely employed for all kinds of fine work. *A needle file* is made in sizes from 100 to 200 mm, of various shapes and cuts. They are extremely delicate and are used for fine work. *Rifflers* are curved upwards at the ends into an arc. They are used to reach the bottom of a sinking and for filing the insides of castings.

Specification. When ordering a file following informations should be given :

1. Length, say, 100 mm.
2. Shape, say, flat
3. Single or double cut
4. Roughness, say, bastard

14.7 FILING

Filing is the most important operation that a metal worker has to learn. Filing is usually an after-treatment and usually done after chipping. It serves to remove the burr from the cuts and clean the face of the cuts, and to finish the final shape of a workpiece. In general no more than 0.6 mm tooling allowance should be left for filing. Filing allows work to be made accurate to 0.05 mm, in some cases to 0.02 mm, and even to 0.01 mm.

Working with the file requires some skill. Normally the work is held in a vice and should be level with the operator's elbow. He should place his left foot in the direction of the file stroke, and his right foot should be placed at an angle of 90^0 in relation to his left foot.

The proper handling of the file is also an important condition for satisfactory filing work. In principle, the worker should grip the file handle with his right hand, which is to guide the file. When working with large files, the ball of the left thumb should be placed on the end of the file blade which is clasped by the fingers. The left hand exerts an increasing pressure on the file in the forward motion. This is shown in Fig. 14.17. The right hand is to guide the stroke also when working with medium-size files, while thumb and forefinger of the left hand exert the necessary pressure. For very light work with small files it is better to point the first finger along the top of the handle to give more sensitive control and file is pressed against the workpiece with several fingers of the left hand.

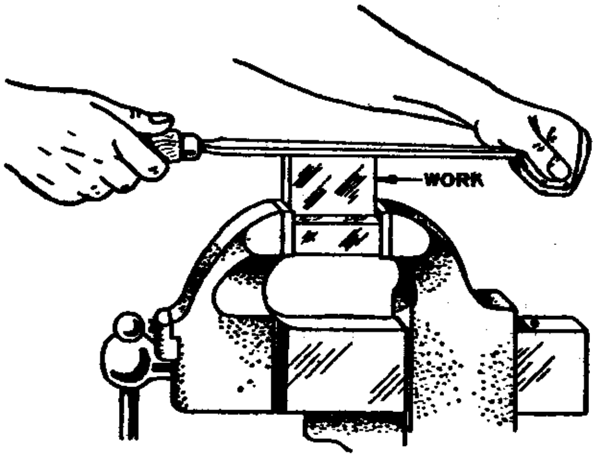

Figure 14.17 Filing a job

It should be noted that the file cuts only on the forward stroke, hence if required the file can be lifted off the work for the return stroke. As a rule, however, the file is allowed to remain on the work during the return stroke, but the pressure from the left hand is released. Filing should always be carried out with the file making the longest possible strokes so that all the teeth of the file receive even wear. The file should also be moved across the work with slow steady strokes (50 to 60 per cent minute), taking care to keep it horizontal, and covering the whole of the filing area at each stroke.

Methods of filing. Generally speaking, there are three main methods of using a hand-flat file :

In *cross-filing* the file strokes run alternately from the right and from the right to the left as shown in Fig. 14.18. This is the commonest form of filing and the one used for general shaping. In this method the possibility of rounding is minimized, and the score marks made in the work by the file teeth are criss-crossed so that maximum amount of metal is removed. The aim in cross-filing is always to move the whole of the file surface across the whole of the work surface in one stroke.

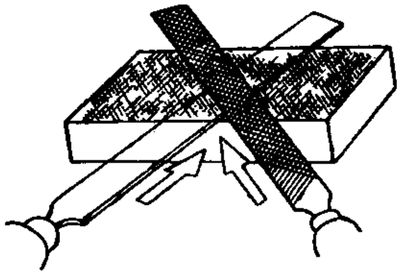

Figure 14.18 Cross-filing

In *straight-filing* the file is pressed forward approximately at right angles to the length of the work. On the back stroke, the file should be lifted clear of the work in order not to blunt the teeth straight-filing is specially useful on long and narrow piece of work whose width is less than that of the file.

In *draw-filing* the handle of the file is not held. Instead, both bands are placed to close together on the blade as shown in Fig. 14.19. The file is placed at right angles across the work while the hands, and especially the thumbs, grip the file and move it up and down the length of the metal. It does not move much material, but a smoother cutting action is achieved than with cross or straight-filing.

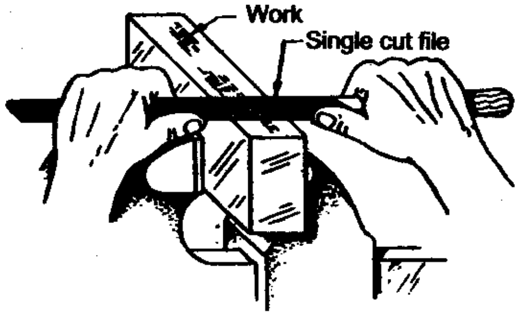

Figure 14.19 Draw -filing

Care of files. Files are very brittle and should be placed thoughtfully in the bench well in such a way that they do not rub or knock against other tools, especially those of cast steel. Similarly, the file should never be used on hardened steel, or hard surface scale such as cast iron skin, or allowed to strike against the hardened vice jaws. When not in use, the files are protected from rust by coating them lightly with machine oil. Before using the file, the oil should be removed with carbon tetrachloride or caustic soda. Make sure that the handle is firmly fixed to the file.

New files are generally first used on copper, brass, and later on wrought iron and mild steel. Filing , especially the filing of soft metals, causes the file teeth to become clogged with particles of metal. This is known as pinning and, unless the obstructions are removed they will make deep scores across the work and also the file will be unserviceable. Vigorous rubbing with a *file brush* or *file card* down the lines of the teeth will clean the file. After brushing the file, chalk may be rubbed into the teeth. Rubbing the file teeth with chalk will help to prevent pinning.

Worn files may be reused to a certain extent by dipping in hydrochloric acid but of course there is a limit to the number of times this etching process can be carried out. Worn files are useful for making scraper, punches chisels, etc. They are also useful on the soldering bench when re-tinning soldering irons.

14.8 SCRAPER

Scraping means shaving or paring off thin slices or flakes of metal to make a fine, smooth surface. This is done with tools called scrapers which have very hard cutting edges. The material is a good quality forged steel and the cutting edge is usually left very hard. Old files make excellent scrapers. The teeth of the file must first be ground off on all sides. They are then heated and bent to the desired shape and ground to have the cutting edge, followed by hardening and tempering. Scrapers are fitted with short, round handles that fit handle snugly.

Since a scraper removes very thin chips, the scraping allowance should be small. These allowances depend upon the width and length of the surface to be scraped or on the diameter and length of the hole to be scraped. Table 14.3 gives the allowances for scraping the plane surfaces and holes.

Scraper are made in a variety of lengths from 100 mm upwards and in many shapes, as shown in Fig. 14.20, depending on the work to be done. These are : triangular, and' half round.

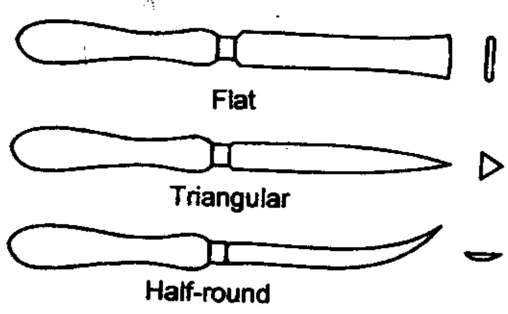

Figure 14.20 Types of scraper

Flat scraper. The flat scraper is the most common and also the most easily made. The cutting edge is at the end. It should be curved a little looking at the broad side. This is done to keep from taking too broad a cut and to prevent the corners of the scraper from coming in contact with the surface being scraped and marking deep scratches. A flat scraper is used for producing a perfectly flat surface. Flat single-ended scrapers vary in length from 100 to 250 mm, double-ended scrapers having no handles can be 350 to 400 mm long. Scrapers for rough work are 20 to 30 mm wide. For accurate work they are made 16 to 20 mm wide, and for extra-accurate work 5 to 10 mm wide. The thickness at the cutting end varies from 1 to 3.5 mm. The lip angle of scrapers for rough scraping is 60 to 75 degrees, for finish scraping 90 degrees.

TABLE 14.3 PLANE SURFACE SCRAPING

Surface width, mm	*Scraping allowance (mm) for the surface lengths (mm)*				
	100-500	500-1000	1000-2000	2000-4000	4000-6000
Upto 100	0.10	0.15	0.15	0.25	0.30
100-500	0.15	0.20	0.25	0.30	0.40

Triangular scraper. The triangular scraper has three cutting edges and is made from a triangular file. It is used to scrape round or curved surfaces and to remove sharp corners and burrs. The blade is usually 150 mm long.

Half-round scraper. A half-round scraper is, in shape, like a half-round file. In fact, they are often made from old half-round files. They are used to scrape round or curved surfaces. The length of the blade from the handle should be at least 150 mm.

Care of scraper. Scrapers have very sharp cutting edges. When, not in use, therefore, these scrapers should be stored so that the blades are protected from damage. Either it should be kept in a special case or wrapped in a piece of cloth. If the edges of the scraper requires sharpening, the blade must be ground on the grinding wheel and then finished on the oilstone.

14.9 SCRAPING

Scraping is used for obtaining a truer flat surface than can be produced by machining or filing. So scraping often follows filing. Having got the surface of the block reasonably flat with the file, the block should first be tested on the surface plate, which is of cast iron and has a perfectly flat upper surface.

The top of the surface plate is covered with a very thin film of *Prussian blue*. *Red lead* may be used instead of Prussian blue. The surface to be scraped is then laid on the surface plate and moved back and forth.

Thus the high spots on the work will be marked with Prussian blue. If a thick coat is put on the surface plate, the low spots on the work will be marked as well as the high ones. The high spots are scrapped down, the scraper being worked with a small circular motion. The work is wiped clear of scrapings before each testing . The process is repeated until the colour is spread evenly over the surface.

During scraping the handle of the scraper is held in the right hand with the first finger extended. The left hand is placed on the lower end of the scraper and controls the cutting action.

For scraping cylinder surface of a bearing either the curved or triangular scraper is used, with the handle in the right hand and the left controlling the cutting edge.

Frosting or flowering. This is a finish which is an imitation of frost, patch work, or checker-board design. frosting is made by scraping off high spots as explained above. Strokes should be very short about 6 to 12 mm and the direction should be changed after each marking. This is intended only to give a better appearance as it does not in anyway increase the accuracy.

14.10 GRINDING AND POLISHING

Grinding is the process of removing mental usually 0.25 to .50 mm in most operations, by the use of grinding wheel. It may be used to finish almost any surface, which has been previously rough shaped by some other method or to remove the surplus from material which is too hard to be worked by other methods. The accuracy in grinding is in the order of 0.000025 mm.

The work for grinding is held pressed against the wheel which revolve at a high speed and the metal gets reduced by abrasion. A grinding is made up of particles of hard substance called the *abrasive*. Embedded in a matrix called the *bond*. These abrasives form the cutting points in a wheel and are termed as *grains*. There are two kinds of abrasives : (1) natural and (2) artificial. *Emery* and *corundum* are two natural abrasives, while *carborundum* and *aloxite* are artificial abrasives. They are described in Vol. II.

A surface grinder having an emery wheel is generally used in a fitting shop. It is very useful in removing waste metal and sharpening drills, chisels, and other cutting tools. The hardness or softness of the wheel is dependent on the amount and kind of the bonding material used. Generally, hard wheels of aloxite are used for grinding soft materials and soft wheels of carborundum for grinding hard materials. When heavy reduction is necessary, coarse-grained wheel is used but for light reduction a fine-grained one may be employed. Wet grinding, which provides a large amount of coolant over the work, wheel face. and sides is generally employed. This dissipates the heat normally generated during grinding, promotes long wheel life, and produces high finish.

The cutting face of a grinding wheel must be kept in a true, clean, sharp condition, to obtain efficient cutting. *Glazed* and *loaded* wheels are reconditioned by dressing with suitable dressers. "Dressing" is the periodical cleaning of the grinding surface which becomes blunt or glazed.

Polishing is the process of making a flat, scratch-free, mirror-like finish. The polishing procedure generally consists of rough grinding, intermediate grinding, rough polishing, and fine polishing. The first step is carried out on an emery surfacer or similar grinder to remove deep cut off marks. The intermediate grinding is done with fine emery or silicon carbide (Carborundum) papers decreasing in grit size in three to four stages to remove grinding marks. Emery papers are graded from "fine' to "coarse", the numbers being from 0 to 4. Each succeeding paper will produce a finer scratch on the surface of the material. This operation may be done by hand or mechanically, using rotating disks.

Fine polishing in ordinary work is usually done by No.2 or e emery cloth. This may be wrapped round either a flat file or conveniently shaped block of wood or metal. The motion in polishing should always be straight and the strokes should cover the whole length of the surface being polished. After the first grade of emery cloth has completed its work a finer grade should be submitted and so on until the desired finish is obtained. The final applications may be assisted by use of oil on the emery cloth, or for a very high finish, ordinary metal polish alone may be used with the cloth. A silicon-carbide cloth may be used with greater advantage but this is more expensive than emery cloth.

14.11 HACKSAW

The hacksaw is used for sawing all metal except hardened steel. A hand hacksaw consists of a *frame, handle, prongs, tightening screw* and *nut,* and *blade* as shown in Fig. 14.21. The frame is made to hold the blade tightly. They are made in two types : The *solid frame* in which the length cannot be changed and the *adjustable frame* which has a back that can be lengthened or shortened to hold blades of different length.

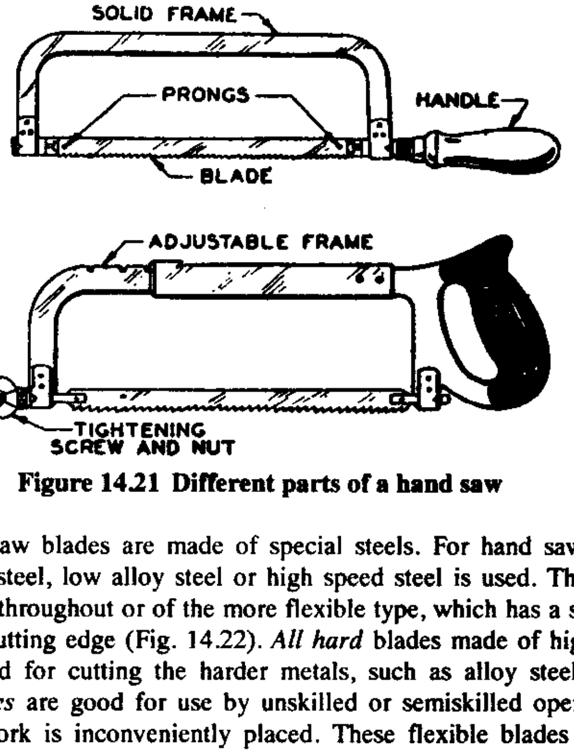

Figure 14.21 Different parts of a hand saw

Hacksaw blades are made of special steels. For hand saws either high carbon steel, low alloy steel or high speed steel is used. The blades may be hard throughout or of the more flexible type, which has a soft back and a hard cutting edge (Fig. 14.22). *All hard* blades made of high speed steel are used for cutting the harder metals, such as alloy steels, while *flexible blades* are good for use by unskilled or semiskilled operators or where the work is inconveniently placed. These flexible blades are less liable to break and are used for general work. Blades are measured by the ; (1) length, (2) width, (3) thickness, and (4) pitch of teeth.

The length of the blade is the distance between the centres of the holes at each end. For hand operation, the common lengths are 250 and 350 mm, widths are 13 and 16 mm, and thickness are 0.63 and 0.80 mm respectively (*IS : 2594*). According to the distance between two corresponding points on adjacent teeth, the saw may have a coarse, medium or fine pitch. A coarse teeth saw has 1.8 mm pitch, medium teeth saw, and 1.4 mm pitch and fine teeth saw 1.0 mm pitch. For general work the blade and fine teeth saw, 1.0 mm pitch For general work the blade with 1.8 mm and 1.4 mm pitch is used. Generally, soft metals, plastic, and synthetic materials are

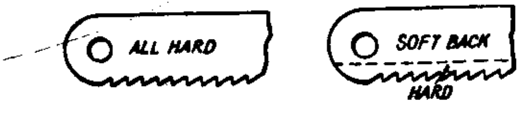

Figure 14.22 All hard and flexible type of blade

being cut by coarse-tooth saw ; tool steel, medium-hard steel, hard light alloys, copper alloys, and thicker sections or tubes are cut by medium tooth saws ; materials of small thickness are cut by fine-tooth saws.

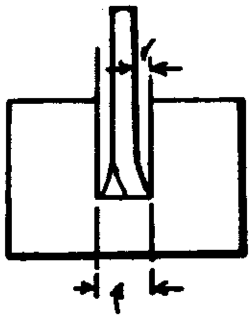

Figure 14.23 Clearance of saws

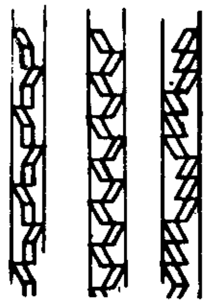

Figure 14.24 Various settings of teeth
(a) Raker, (b) Alternate, (c) Wavy

The points of the teeth are bent to cut a wide groove and provide clearance as shown in Fig. 14.23 for the blade to prevent "binding". This binding of the teeth to the sides is called the set of the blade.

The setting is done in three ways ; (1) raker, (2) alternate, and (3) wavy (undulated)

In raker setting one tooth is bent on one side the next is kept flat and the third on the opposite side of the first. In alternate setting one tooth of the blade is bent on one side while the often on the opposite side. In wavy type of setting, the teeth-arrangement looks like a wave. Figure 14.24 shows the setting.

Power hacksaw. The power hacksaw is very similar to the hand hacksaw with the addition of a suitable driving mechanism. The drive is given either by a belt from a line shaft or by an enclosed motor. Suitable mechanisms are provided whereby the length of the stroke and the weight applied may be varied. On many metals cutting fluid is used during the sawing and this is pumped on to the blades while the machine is working.

This machine uses a much heavier blade than that in a hand hacksaw and can cut diameters up to 150 mm or more. The length varies from 300 to 600 mm, width from 20 to 50 mm, thickness from 0.8 to 2.5 mm, and pitch from 1.4 to 6.3 mm (*IS : 2594*). The machine is so made that it stops automatically when the cut is finished. Another advantage with the power hacksaw is that an unskilled operator can work on these machines and the metal is cut accurately to length but this has the disadvantage that it can only be used for the simplest of sawing operations.

14.12 SAWING

Hacksawing (Fig. 14.25) is the quickest method of severing. shaping, and slotting cold metal. The work to be sawn should be held tightly in the vice. As a rule, the workpiece must be held in such a way that the marking line is situated a few millimeters to the left of the vice jaws. The blade is hung on two slightly hooked pegs projecting from pins which fit into each end of the frame. The blade is made tight by screwing a wing nut on the leading pin. The blades are fixed with the teeth facing forward for work on the forward stroke.

Placing the saw on the work with the right hand on the handle and the left hand on the other end of the saw frame firmly, the sawing should begin with a backward stroke. The pressure is applied on the forward stroke and a little lift is necessary on the return stroke, because the blade cuts only on the forward stroke. The saw must be guided with particular care as long as the saw blade is still sliding in a saw kerf not yet sufficiently deep . If the saw kerf is not yet available when sawing is started, the saw tends to deviate from the desired direction. At this initial stage, wrong cuts or ugly scratches may originate to the left or to the right of the desired kerf. Clean starting cuts can be achieved by first filing a notch close to the working line (a distance of about 0.5 mm therefrom) on the side of the piece which will fall off, using a triangular file to this end. Then the saw will be able to enter the material with some guidance. Further be sure to begin sawing with short strokes and to apply the saw in a position somewhat inclined to the workpiece. Make almost all the blade do the cutting and make about 50 strokes per minute.

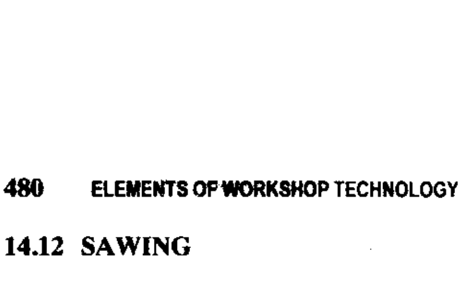

Figure 14.25 Sawing

Sawing of tubes. Tubes are never sawn in one go. First file a notch and then saw into the tube down to a point near the inner wall ; then turn the tube forwardly to such an extent that the saw will still be guided by the saw kerf. Then resume sawing and again cut to a point shortly before the inner wall is reached, then turn the tube through an appropriate angle and repeat this procedure, until the tube is divided.

14.13 MARKING TOOLS

In addition to the measuring instruments described in a later chapter, the following tools are used for marking :

1. Surface plate.	4. V-block.
2. Scriber.	5. Angle plate.
3. Punch.	6. Try-square.

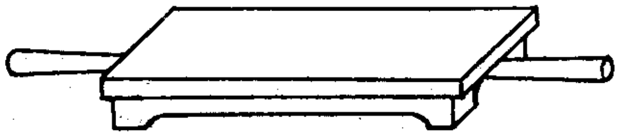

Figure 14.26 Surface plate

14.14 SURFACE PLATE

The surface plate as shown in Fig. 14.26 is used for testing the flatness of work itself and is also used for marking-out work. This is used for small pieces of work while the *marking-out table* is used for larger jobs.

Surface plates are made of grey cast iron and of solid design or with ribs. They should be well and reflection-free illuminated and rest horizontally on a firm support, the working height being about 800 mm from the floor. These plates may be of the following types 1.5x5m ; 1.5x3m ; 2x2m and 2x4m. The marking-out surface must be protected from rust and dirt and wiped clean and smeared with grease or oil after use. They are made in two grades of accuracy *A* and *B grade*. A surface plates are scraped to within 0.005 mm of flatness while grade *B* plates are 0.02 mm of flatness.

14.15 SCRIBER

The scriber as shown in Fig. 14.27 is a piece of hardened steel about 150 to 300 mm and 3 to 5 mm in diameter pointed one or both ends like a needle. It is held like a pencil to scratch or scribe lines on metal. The bent end is used to scratch line in places where the straight end cannot reach. The ends are sharpened on an oilstone when necessary.

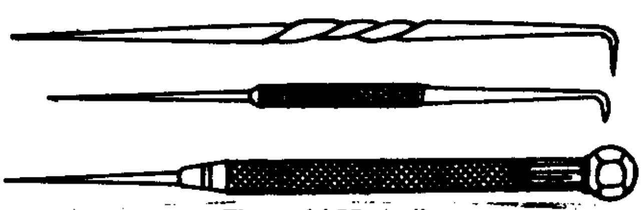

Figure 14.27 Scriber

14.16 PUNCH

A punch is used in a bench work for marking out work, locating centres, etc. in a more permanent manner. Two types of punches are used : (1) prick punch, and (2) centre punch. The prick punch (Fig.14.28) is a sharply pointed tool. The tapered point of the punch has an angle of usually 40°. It is used to make small punch marks on layout lines in order to make them last longer.

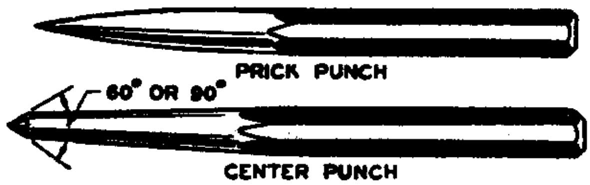

Figure 14.28 Punch

The *centre punch* looks like a prick punch. Its point has an angle more obtuse than that of the prick punch point, this angle usually being 60°. The centre punch is used only to make the prick-punch marks larger at the centres of holes that are to be drilled, hence the name centre punch. A strong blow of the hammer is needed to mark the point.

In its body portion the punch is a steel rod 90 to 150mm long and 8 to 13mm in diameter.

14.17 V-BLOCK

The V-block is a block of steel with V-shaped grooves (Fig. 14.29). Roundly shaped work pieces which are to be marked or drilled are placed on V-supports. In this way they are firmly supported in a horizontal position and cannot rotate easily. V-blocks of the following sizes are found to be most useful : length from 50 to 250 mm width and height from 50 to 100 mm. For long cylindrical work, several blocks of the same size are used as set.

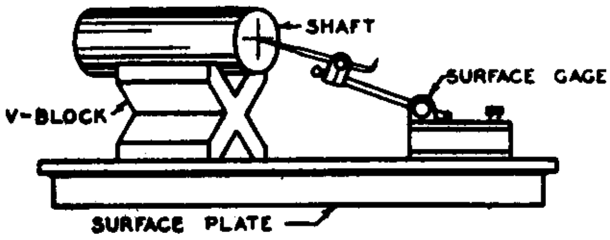

Figure 14.29 Use of a V-block

14.18 ANGLE PLATE

The angle plate which is made of grey cast iron has two plane surfaces at right angles to each other. This is used in conjunction with the surface plate for supporting work in the perpendicular position. It has various slots in it to enable the work to be held firmly by bolts and clamps.

14.19 TRY-SQUARE

The try square as shown in Fig. 14.30 is made in one piece, both *blade* and *beam*. This is used when it is necessary to get another edge or surface exactly at right angles to an already trued edge or surface and also for laying out work. The squares of any square may be tested by placing the beam of the square against a straight edge with the blade resting on a smoother surface. While in this position a line may be scribed along the edge of the blade.

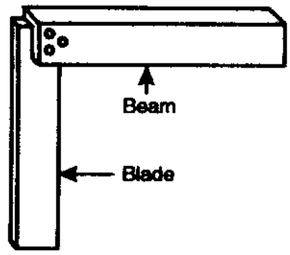

Figure 14.30 Try square

14.20 MARKING OUT

Marking out consists of marking on the job a series of definite lines or positions. These lines act as a guide to the fitter who will have to work on the job after it has been marked out. All marking should be done with reference to true edges or surfaces, preferably two at right angles or with reference to certain datum lines. The position of these edges, or the position of the datum lines, may be determined from the drawing which is necessary for each job.

The surfaces of work to be marked out are usually treated with chalk, or with copper sulphate solution which leaves a thin film of copper on iron and steel. After the coat is dried the work is positioned for marking out. The work is held either in a V-block if it is round, or laid in a surface plate if it is flat.

Horizontal and vertical lines are scribed over a vertical surface by a scribing block. The work is supported against an angle -pate which keeps the surface of the work to be marked at right angles to the surface of the surface plate used in conjunction with the angle plate. Horizontal lines are first scribed. Vertical lines may then be drawn by turning the job through 90^0 and using a scriber. A horizontal or vertical line can also be scribed by a try-square, provided a true surface on the edge of the job to be marked is available.

The center on the end of a round bar may be found in several ways. The hermaphrodite caliper may be used to scribe four arcs with the bar held in a vice. The centre head of a combination set may be used to find the centre of a round piece of metal. The centre of a round bar may also be found with a surface gauge. The centre of a flat circular hole can be found by means of a divider. Angles can be marked by a combination square or a combination set.

Boundary marks, which later are to be cut away, are made permanent by light dot punching along their holes are marked by cross-lines, centre punched of the junction.

The position of larger holes are marked by a centre punch mark and two concentric rings, one to the required diameter and the other slightly larger (Fig. 14.31). When the material has been removed, the outer circle remains as a reference line for final comparisons.

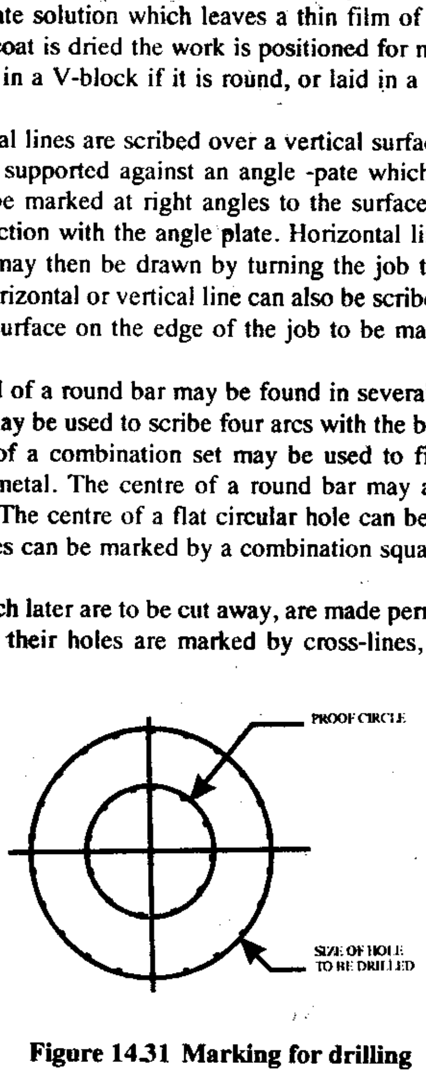

Figure 14.31 Marking for drilling