HOT WORKING OF METALS

15.1 METAL FORMING

Metal forming is also known as mechanical working of metals. Metal forming operations are frequently desirable either to produce a new shape or to improve the properties of the metal. Shaping in the solid state may be divided into non-cutting shaping such as forging, rolling, pressing, etc., and cutting shaping such as the machining operations performed on various machine tools. Non-cutting or non machining shaping processes are referred to as mechanical working processes. It means an intentional and permanent deformation of metals plastically beyond the elastic range of the material. The main objectives of metal working processes are to provide the desired shape and size, under the action of externally applied forces in metals. Such processes are used to achieve optimum mechanical properties in the metal and reduce any internal voids or cavities present and thus make the metal dense.

Metals are commonly worked by plastic deformation because of the beneficial effect that is imparted to the mechanical properties by it. The necessary deformation in a metal can be achieved by application of mechanical force only or by heating the metal and then applying a small force. The impurities present in the metal are thus get elongated with the grains and in the process get broken and dispersed through out the metal. This also decreases the harmful effect of the impurities and improves the mechanical strength. This plastic deformation of a metal takes place when the stress caused in the metal, due to the applied forces reaches the yield point. The two common phenomena governing this plastic deformation of a metal are (*a*) deformation by slip and (*b*) deformation by twin formation. In the former case it is considered that each grain of a metal is made of a number of unit cells arranged in a number of planes, and the slip or deformation of metal takes place along that slip plane which is subjected to the greatest shearing stress on account of the applied forces. In the latter case, deformation occurs along two parallel planes, which move diagonally across the unit cells. These parallel planes are called twinning planes and the portion of the grains covered between them is known as twinned region. On the macroscopic scale, when plastic deformation occurs, the metal appears to flow in the solid state along specific directions, which are dependent on the processing and the direction of applied forces. The crystals or grains of the metal get elongated in the direction of metal flow. However this flow of metal can be easily be seen under microscope after polishing and suitable etching of the metal surface. The visible lines are called fibre flow lines. The above deformations may be carried out at room temperature or higher temperatures. At higher temperatures the deformation is faster because the bond between atoms of the metal grains is reduced. Plasticity, ductility and malleability are the properties of a material, which retains the deformation produced under applied forces permanently and hence these metal properties are important for metal working processes.

Plasticity is the ability of material to undergo some degree of permanent deformation without rupture or failure. Plastic deformation will take place only after the elastic range has been exceeded. Such property of material is important in forming, shaping, extruding and many other hot and cold working processes. Materials such as clay, lead, etc. are plastic at room temperature and steel is plastic at forging temperature. This property generally increases with increase in temperature.

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

Malleability is the ability of the material to be flattened into thin sheets without cracking by hot or cold working. A malleable material should be plastic but it is not essential to be so strong. The malleable materials commonly used in engineering practice in order of diminishing malleability are lead, soft steel, wrought iron, copper and aluminium. Aluminium, copper, tin, lead, steel, etc. are recognized as highly malleable metals.

15.2 RECRYSTALISATION

During the process of plastic deformation in metal forming, the plastic flow of the metal takes place and the shapes of the grains are changed. If the plastic deformation is carried out at higher temperatures, new grains start growing at the location of internal stresses caused in the metal. If the temperature is sufficiently high, the growth of new grains is accelerated and continuous till the metal comprises fully of only the new grains. This process of formation of new grains is known as recrystallisation and is said to be complete when the metal structure consists of entirely new grains. That temperature at which recrystalisation is completed is known as the recrystallisation temperature of the metal. It is this point, which draws the line of difference between cold working and hot working processes. Mechanical working of a metal below its recrystalisation temperature is called as cold working and that accomplished above this temperature but below the melting or burning point is known as hot working.

15.3 HOT WORKING

Mechanical working processes which are done above recrystallisation temperature of the metal are know as hot working processes. Some metals, such as lead and tin, have a low recrystallisation temperature and can be hot-worked even at room temperature, but most commercial metals require some heating. However, this temperature should not be too high to reach the solidus temperature; otherwise the metal will burn and become unsuitable for use. In hot working, the temperature of completion of metal working is important since any extra heat left after working aid in grain growth. This increase in size of the grains occurs by a process of coalescence of adjoining grains and is a function of time and temperature. Grain growth results in poor mechanical properties. If the hot working is completed just above the recrystallisation temperature then the resultant grain size would be fine. Thus for any hot working process the metal should be heated to such a temperature below its solidus temperature, that after completion of the hot working its temperature will remain a little higher than and as close as possible to its rccrystalisation temperature

15.4 EFFECT OF HOT WORKING ON MECHANICAL PROPERTIES OF METALS

1. This process is generally performed on a metal held at such a temperature that the metal does not work-harden. A few metals e.g., Pb and Sn (since they possess low crystallization temperature) can be hot worked at room temperature.
2. Raising the metal temperature lowers the stresses required to produce deformations and increases the possible amount of deformation before excessive work hardening takes place.
3. Hot working is preferred where large deformations have to be performed that do not have the primary purpose of causing work hardening.
4. Hot working produces the same net results on a metal as cold working and annealing. It does not strain harden the metal.
5. In hot working processes, compositional irregularities are ironed out and non-metallic impurities are broken up into small, relatively harmless fragments, which are uniformly dispersed throughout the metal instead of being concentrated in large stress-raising metal working masses.
6. Hot working such as rolling process refines grain structure. The coarse columnar dendrites of cast metal are refined to smaller equiaxed grains with corresponding improvement in mechanical properties of the component.
7. Surface finish of hot worked metal is not nearly as good as with cold working, because of oxidation and scaling.
8. One has to be very careful as regards the temperatures at which to start hot work and at which to stop because this affects the properties to be introduced in the hot worked metal.
9. Too high a temperature may cause phase change and overheat the steel whereas too low temperature may result in excessive work hardening.
10. Defects in the metal such as blowholes, internal porosity and cracks get removed or welded up during hot working.
11. During hot working, self-annealing occurs and recrystallization takes place immediately following plastic deformation. This self-annealing action prevents hardening and loss of ductility.

15.5 MERITS OF HOT WORKING

1. As the material is above the recrystallisation temperature, any amount of working can be imparted since there is no strain hardening taking place.
2. At a high temperature, the material would have higher amount of ductility and therefore there is no limit on the amount of hot working that can be done on a material. Even brittle materials can be hot worked.
3. In hot working process, the grain structure of the metal is refined and thus mechanical properties improved.

4. Porosity of the metal is considerably minimized.
5. If process is properly carried out, hot work does not affect tensile strength, hardness, corrosion resistance, etc.
6. Since the shear stress gets reduced at higher temperatures, this process requires much less force to achieve the necessary deformation.
7. It is possible to continuously reform the grains in metal working and if the temperature and rate of working are properly controlled, a very favorable grain size could be achieved giving rise to better mechanical properties.
8. Larger deformation can be accomplished more rapidly as the metal is in plastic state.
9. No residual stresses are introduced in the metal due to hot working.
10. Concentrated impurities, if any in the metal are disintegrated and distributed throughout the metal.
11. Mechanical properties, especially elongation, reduction of area and izod values are improved, but fibre and directional properties are produced.
12. Hot work promotes uniformity of material by facilitating diffusion of alloy constituents and breaks up brittle films of hard constituents or impurity namely cementite in steel.

15.6 DEMERITS OF HOT WORKING

1. Due to high temperature in hot working, rapid oxidation or scale formation and surface de-carburization take place on the metal surface leading to poor surface finish and loss of metal.
2. On account of the loss of carbon from the surface of the steel piece being worked the surface layer loses its strength. This is a major disadvantage when the part is put to service.
3. The weakening of the surface layer may give rise to a fatigue crack which may ultimately result in fatigue failure of the component.
4. Some metals cannot be hot worked because of their brittleness at high temperatures.
5. Because of the thermal expansion of metals, the dimensional accuracy in hot working is difficult to achieve.
6. The process involves excessive expenditure on account of high cost of tooling. This however is compensated by the high production rate and better quality of components.
7. Handling and maintaining of hot working setups is difficult and troublesome.

15.7 CLASSIFICATION OF HOT WORKING PROCESSES

The classification of hot working processes is given as under.

1. Hot rolling
2. Hot forging
3. Hot extrusion
4. Hot drawing

5. Hot spinning
6. Hot piercing or seamless tubing
7. Tube Forming and
8. Hot forming of welded pipes

Some of the important hot working processes are described as under.

15.8 PRINCIPAL HOT WORKING PROCESSES

15.8.1 Hot Rolling

Rolling is the most rapid method of forming metal into desired shapes by plastic deformation through compressive stresses using two or more than two rolls. It is one of the most widely used of all the metal working processes. The main objective of rolling is to convert larger sections such as ingots into smaller sections which can be used either directly in as rolled state or as stock for working through other processes. The coarse structure of cast ingot is convened into a fine grained structure using rolling process as shown in Fig. 15.1. Significant improvement is accomplished in rolled parts in their various mechanical properties such as toughness, ductility, strength and shock resistance. The majority of steel products are being converted from the ingot form by the process of rolling. To the steel supplied in the ingot form the preliminary treatment imparted is the reduction in its section by rolling as shown in figure. The crystals in parts are elongated in the direction of rolling, and they start to reform after leaving the zone of stress. Hot rolling process is being widely used in the production of large number of useful products such as rails, sheets, structural sections, plates etc. There are different types of rolling mills, which are described as under.

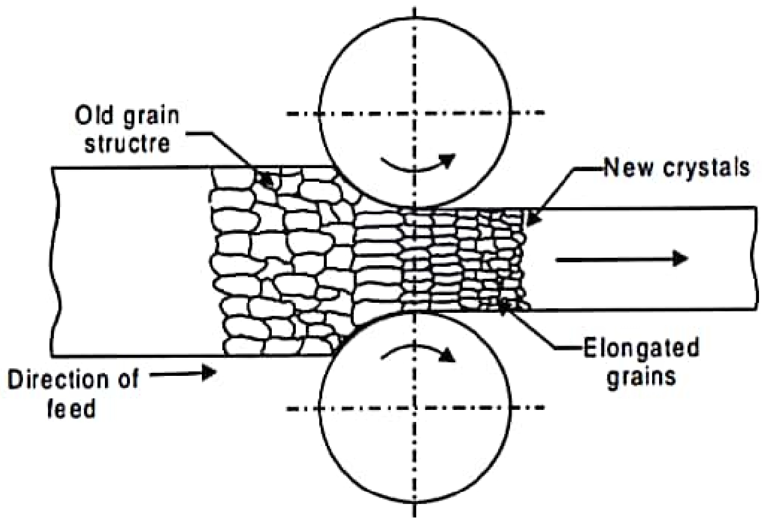

Fig. 15.1 Grain refinement in hot rolling process

15.8.1 Two-High Rolling Mill

A two-high rolling mill (Fig 15.2(a)) has two horizontal rolls revolving at the same speed but in opposite direction. The rolls are supported on bearings housed in sturdy upright side frames called stands. The space between the rolls can be adjusted by raising or 1owering the upper roll. Their direction of rotation is fixed and cannot be reversed. The reduction in the thickness of work is achieved by feeding from one direction only. However, there is another type of two-high rolling mill, which incorporates a drive mechanism that can reverse the direction of rotation of the rolls. A Two- high reverse arrangement is shown in Fig. 15.2(b). In a two-high reversing rolling mill, there is continuous rolling of the workpiece through back-and-forth passes between the rolls.

15.8.2 Three-High Rolling Mills

It consists of three parallel rolls, arranged one above the other as shown in Fig. 15.2(c). The directions of rotation of the upper and lower rolls are the same but the intermediate roll rotates in a direction opposite to both of these. This type of rolling mill is used for rolling of two continuous passes in a rolling sequence without reversing the drives. This results in a higher rate of production than the two-high rolling mill.

15.8.3 Four-High Rolling Mill

It is essentially a two-high rolling mill, but with small sized rolls. Practically, it consists of four horizontal rolls, the two middle rolls are smaller in size than the top and bottom rolls as shown in Fig. 15.2(d). The smaller size rolls are known as working rolls which concentrate the total rolling pressure over the workpiece. The larger diameter rolls are called back-up rolls and their main function is to prevent the deflection of the smaller rolls, which otherwise would result in thickening of rolled plates or sheets at the centre. The common products of these mills are hot or cold rolled plates and sheets.

15.8.4 Cluster Mill

It is a special type of four-high rolling mill in which each of the two smaller working rolls are backed up by two or more of the larger back-up rolls as shown in Fig. 15.2(e). For rolling hard thin materials, it may be necessary to employ work rolls of very small diameter but of considerable length. In such cases adequate support of the working rolls can be obtained by using a cluster-mill. This type of mill is generally used for cold rolling work.

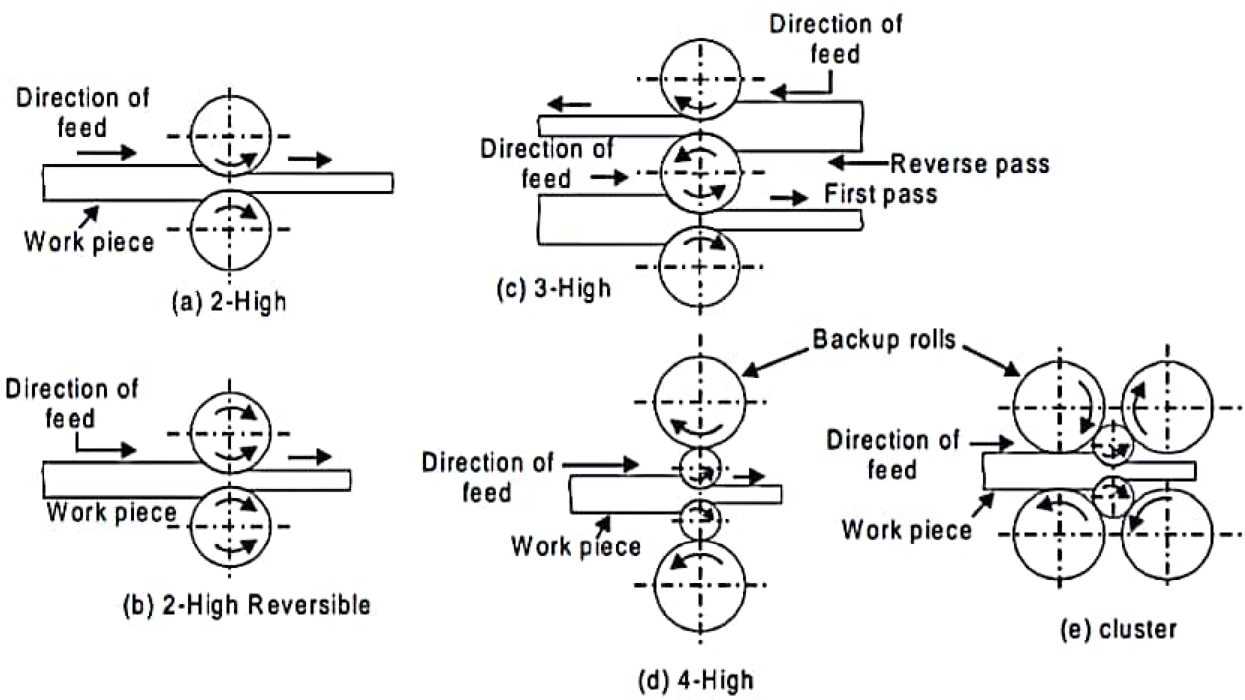

Fig. 15.2 Hot rolling stand arrangements

15.8.5 Continuous Rolling Mill

It consists of a number of non reversing two-high rolling mills arranged one after the other, so that the material can be passed through all of them in sequence. It is suitable for mass production work only, because for smaller quantities quick changes of set-up will be required and they will consume lot of time and labor.

15.8.6 Applications of Rolling

In the rail mill (Fig. 15.2(f)), the heavier structural sections and rails are made. Rolling mills produce girders, channels, angle irons and tee-irons. Plate mill rolls slabs into plates. The materials commonly hot rolled are aluminium, copper magnesium, their alloys and many grades of steel.

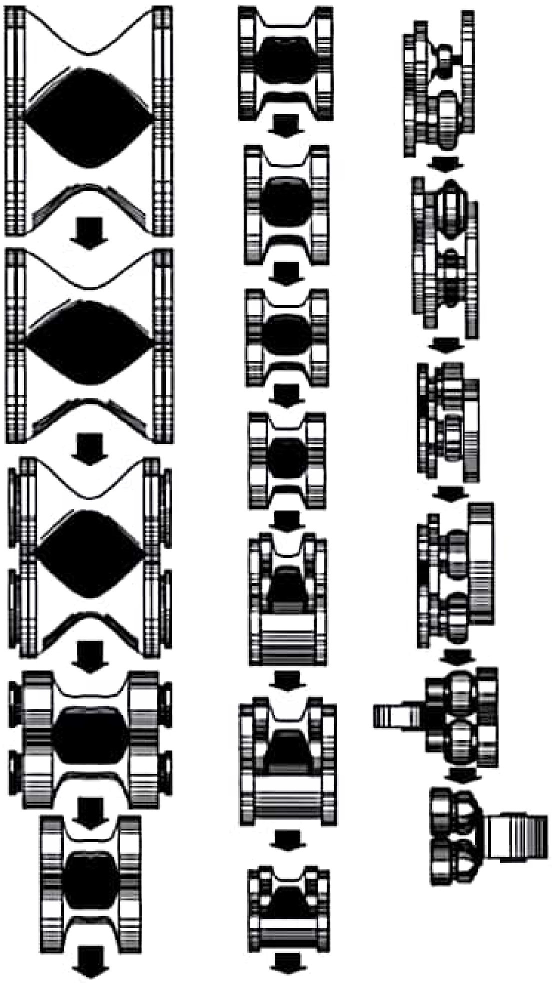

Fig. 15.2(f) Hot rolling stand arrangements

15.9 Hot Piercing or Seamless tubing

Hot piercing is also known as seamless tubing or roll piercing process. The process setup is shown in Fig. 15.3. It is used for making thin-walled round objects. Seamless tube forming is popular and economical process in comparison to machining because it saves material wasted in boring of parts.

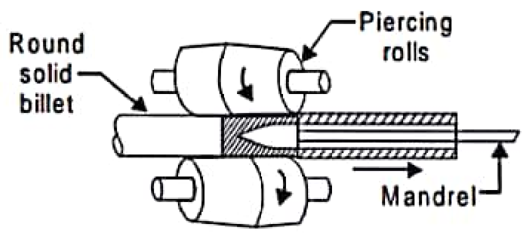

Fig. 15.3 Hot piercing or seamless tubing

Hot pircing includes rotary piercing to obtain formed tube by piercing a pointed mandrel through a billet in a specially designed rolling mill. The rotary piercing can be performed either on a two-high rolling mill or on a three-high rolling mill. In the former, the two rolls are set at an angle to each other. The billet under the rolls is deformed and a cavity formation is initiated at the centre due to tensile stressing. The carefully profiled shape of the mandrel assists and controls the formation of cavity. In a three-high rolling mill, the three shaped rolls are located at 1200 and their axes are inclined at a feed angle to permit forward and rotary motion of the billet. The squeezing and bulging of the billet open up a seam in its center pass makes a rather thick-walled tube which is again passed over plug and through grooved rolls in a two-high roll mill where the thickness is decreased and the length is increased. While it is still up to a temperature, it is passed on to a reeling machine which has two rolls similar to the piercing rolls, but with flat surfaces. If more accuracy and better finish are desired, the run through sizing dies or rolls. After cooling, the tubes are used in a pickling bath of dilute sulphuric acid to remove the scale.

15.10 HOT EXTRUSION

It is the process of enclosing the heated billet or slug of metal in a closed cavity and then pushing it to flow from only one die opening so that the metal will take the shape of the opening. The pressure is applied either hydraulically or mechanically. Extrusion process is identical to the squeezing of tooth paste out of the tooth paste tube. Tubes, rods, hose, casing, brass cartridge, moulding-trims, structural shapes, aircraft parts, gear profiles, cable sheathing etc. are some typical products of extrusion. Using extrusion process, it is possible to make components, which have a constant cross-section over any length as can be had by the rolling process. The intricacy in parts that can be obtained by extrusion is more than that of rolling, because the die required being very simple and easier to make. Also extrusion is a single pass process unlike rolling. The amount of reduction that is possible in extrusion is large. Generally brittle materials can also be easily extruded. It is possible to produce sharp corners and re-entrant angles. It is also possible to get shapes with internal cavities in extrusion by the use of spider dies, which are explained later.

The extrusion setup consists of a cylinder container into which the heated billet or slug of metal is loaded. On one end of the container, the die plate with the necessary opening is fixed. From the other end, a plunger or ram compresses the metal billet against the container walls and the die plate, thus forcing it to flow through the die opening, acquiring the shape of the opening. The extruded metal is then carried by the metal handling system as it comes out of the die.

The extrusion ratio is defined as the ratio of cross- sectional area of the billet to that of the extruded section. The typical values of the extrusion ratio are 20 to 50. Horizontal hydraulic presses of capacities between 250 to 5500 tonnes are generally used for conventional extrusion. The pressure requirement for extrusion is varying from material to material. The extrusion pressure for a given material depends on the extrusion temperature, the reduction in area and the extrusion speed.

15.10.1 Methods of Hot Extrusion

Hot extrusion process is classified as

1. Direct or forward hot extrusion
2. Indirect or backward hot extrusion
3. Tube extrusion

Different methods of extrusion are shown in Fig. 15.4. Each method is described as under.

15.10.1.1 Direct or Forward Hot Extrusion

Fig. 15.4 (a) shows the direct extrusion operational setup. In this method, the heated metal billet is placed in to the die chamber and the pressure is applied through ram. The metal is extruded through die opening in the forward direction, i.e. the same as that of the ram. In forward extrusion, the problem of friction is prevalent because of the relative motion between the heated metal billet and the cylinder walls. To reduce such friction, lubricants are to be commonly used. At lower temperatures, a mixture of oil and graphite is generally used. The problem of lubrication gets compounded at the higher operating temperatures. Molten glass is generally used for extruding steels.

15.10.1.2 Indirect or Backward Hot Extrusion

Fig. 15.4 (b) shows the indirect extrusion operational setup. In indirect extrusion, the billet remains stationary while the die moves into the billet by the hollow ram (or punch), through which the backward extrusion takes place. Since, there is no friction force between the billet and the container wall, therefore, less force is required by this method. However this process is not widely used because of the difficulty occurred in providing support for the extruded part.

15.10.1.3 Tube Extrusion

Fig. 15.4 (c and d) shows the tube extrusion operational setup. This process is an extension of direct extrusion process where additional mandrel is needed to restrict flow of metal for production of seamless tubes. Aluminium based toothpaste and medicated tubes are produced using this process.

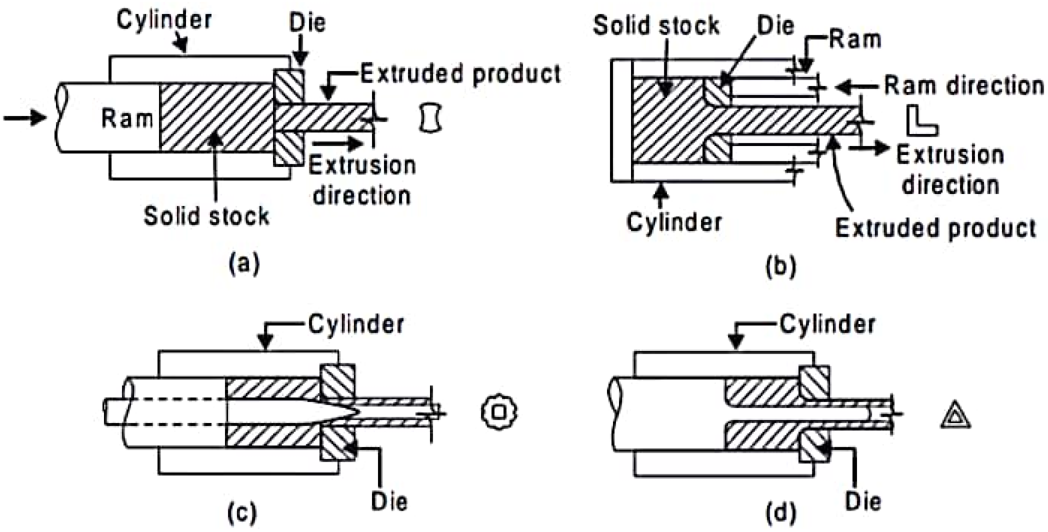

Fig. 15.4 Method of hot extrusion

15.11 HOT DRAWING

Drawing is pulling of metal through a die or a set of dies for achieving a reduction in a diameter. The material to be drawn is reduced in diameter. Fig. 15.5 is another method used in hot drawing or shaping of materials where the heated blank is placed over the die opening the punch forces the blank through the die opening to form a cup or shell. The multiple dies are also used to accomplish the stages in drawing process. Kitchen utensils and components of food processing industries are manufactured by this process.

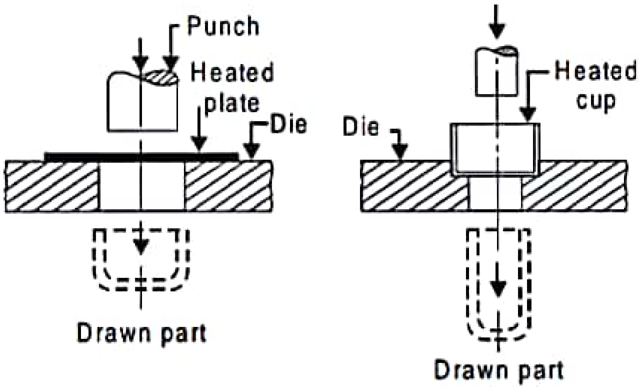

Fig. 15.5 Hot drawing

15.12 HOT SPINNING

Hot spinning is a process in which pressure and plastic flow is used to shape material. Spinning may be either hot or cold and is generally carried over a spinning lathe. In both cases, the metal is forced to flow over a rotating shape by pressure of a blunt tool as shown in Fig. 15.6. The amount of pressure of the blunt tool against the disc controls the generated heat, which helps in forming processes.

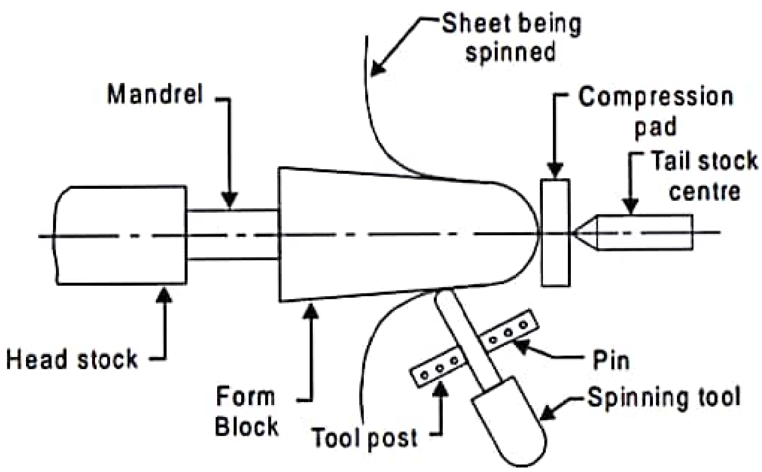

Fig. 15.6 Hot spinning