7

MECHANICAL WORKING OF METALS

7.1 INTRODUCTION

Subsequent to casting, further shaping 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" or "non-chipping shaping" such as forging, rolling, pressing, etc., and "cutting shaping" or "chipping shape giving" including the machining operations of various machine tools. Non-cutting shaping are referred to as *mechanical working processes*.

Mechanical working of a metal is simply plastic deformation performed to change dimensions, properties, and/or surface condition by means of mechanical pressure. Mechanical working may be either *hot working* or *cold working* depending on temperature, and strain rate such that recovery processes take place simultaneously with the deformation. Plastic deformation above recrystallization temperature, but below the melting or burning point, is hot work. Some metals, such as lead and tin, have a low recrystalline range and can be hot-worked at room temperature, but most commercial metals require some heating. Plastic deformation below the recrystallisation temperature is cold work. Although normal room temperatures are ordinarily used for cold working of steel, temperatures up to the recrystallisation range are sometimes used. In cold working, recovery processes are not effective. It is, therefore, important to realize that the distinction between hot working and cold working does not depend upon any arbitrary temperature, but also on the recrystallisation temperature of deformation.

7.2 HOT WORKING

Hot working is the initial step in the mechanical working of most metals and alloys. Hot working combines the working and annealing processes by deforming metal above the recrystallisation temperature at which new grains are formed. Since most metals and alloys have relatively high recrystallisation temperatures, they must be worked at high temperatures. Each metal, of course, has a characteristic hot-working temperature range over which hot working may be performed. The upper limit of working temperature depends on metal composition, prior deformation, and impurities within the metal. Obviously, the upper limit for working must be somewhat below the melting or burning point. The *finishing temperature*, however, is usually just above the minimum recrystallisation temperature at which reheating is desired before further hot working.

In addition to mere change of shape, hot working has profound effects on metal characteristics or properties. These are listed under Table 7.1. The changes in structure from hot working improve mechanical properties such as ductility, toughness, elongation percentage, reduction of area percentage, and resistance to shock and vibration.

However, there are certain disadvantages to hot working. The major disadvantages are also described under Table 7.1.

The principal methods of hot working are as follows :

1. Rolling
2. Piercing
3. Drawing
4. Spinning
5. Extruding
6. Forging

7.3 HOT ROLLING

Rolling is the most rapid method of forming metal into desired shapes by plastic deformation in between rolls. The crystals are elongated in the direction of rolling, and they start to reform after leaving the zone of stress, but in cold-rolling they retain substantially the shape given to them by the action of the rolls.

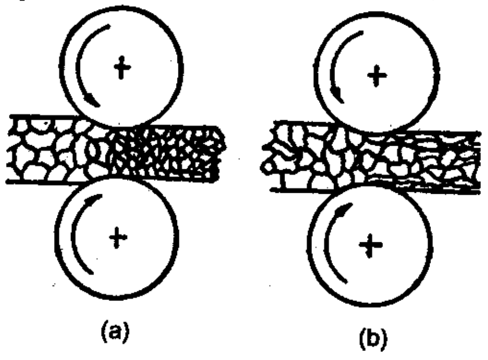

Figure 71. Rolling
(a) Hot rolling, (b) Cold rolling

In deforming metal between rolls, the work is subjected to high compressive stresses from the squeezing action of the rolls and to surface shear stresses as a result of the friction between the rolls and the metal. The frictional forces are also responsible for drawing the metal into the rolls.

In the hot rolling process, metal in a hot plastic state is passed between two rolls revolving at the same speed but in opposite direction

(Fig. 7.1). As the metal passes through the rolls, it is reduced in thickness and increased in length. The forming of bars, plates, sheets, rails, and other structural sections (Fig. 7.2) requires many passes through plain or grooved rolls (Fig. 7.3)

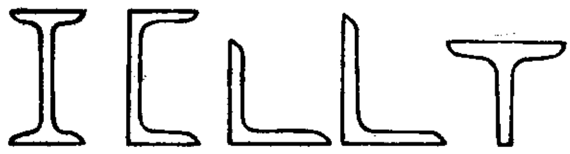

Figure 7.2 Rolled-steel selection
(a) Beam section, (b) Channel section, (c) Equal angle, (d) Unequal ange, (e) T-section.

Fig. 7.3 illustrates number of passes and sequence in reducing the cross-section of a billet to round bar stock. The process starts with the reduction of ingots which have been heated in soaking pits to the desired rolling temperature. This ingot will be about 1.5m long, slightly tapering and approximately square in cross-section, sizes varying from about 300 mm to 500 mm square. The ingots are rolled on blooming mills between two grooved rollers (Fig. 7.4), where these are reduced to blooms. A bloom is a piece of steel usually 200 mm to 300 mm square and about 3.5 m to 5.5 m in length. The space between the rolls can be adjusted and the direction of rolling can be reversed for alternate trips. On each side of the mill are motor-driver roller-conveyors on which the hot ingot is moved to and from the rolls. During rolling at the blooming mill, the ingot is frequently turned 90° so that all surfaces of the ingot are in contact with the rolls, and devices known as "manipulators" are provided to turn the ingot. Blooming mill is often called the "mother mill" because all ingots pass through it.

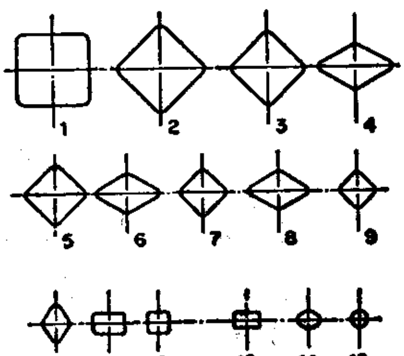

Figure 7.3 Number of passes through rollers

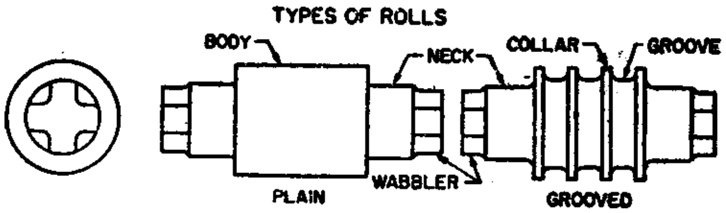

Figure 7.4 Types of rolls

A set of rolls and the housings in which they are mounted are known as a *stand*. When stands are placed one in front of another, this arrangement is known as a continuous mill. When there are only top and bottom rolls the mill is called a "two-high" mill. If three rolls are mounted so that rolling may be done between the top, or bottom roll, and the centre one, it is called a "three-high" mill. Likewise, a "four-high mill" has four rolls. A *cluster mill* consists of two working rolls of smaller diameter and four or more back-up rolls of larger diameter. These are illustrated in Fig. 7.5. Rolls are made of cast steel with or without alloys. Finishing rolls are usually made of chilled cast iron.

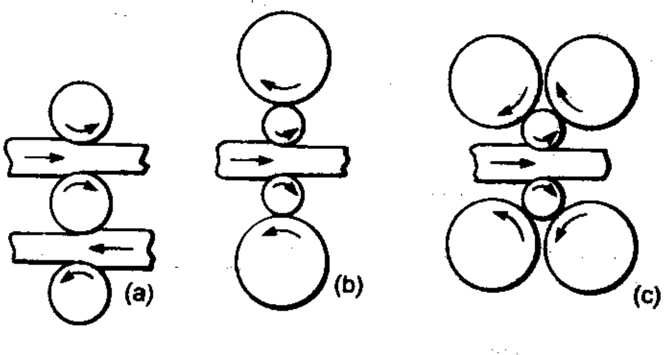

Figure 7.5 Rolling operation
(a) Three-high roll, (b) Four-high rolls, (c) cluster roll

When the metal is to be used for bars, blooms are reduced in size to billets by passing through a continuous series of rolls known as a ***billet mill***. The billet, which has dimensions between 50 mm and 150 mm square, is then cut into shorter lengths which are reheated for further rolling in the bar mill.

The blooming mill also feeds the rail mill with blooms and the plate mill with slabs. Slabs are flat rectangular pieces of steel 50 to 100 mm thick. In the rail mill, the heavier structural sections and rails are made. So it is from this mill that girders, channels, angle irons, and tee-irons are obtained, and the plate mill rolls slabs into plates.

The materials, commonly hot rolled are aluminium, copper, magnesium, their alloys and many grades of steel.

7.4 PIERCING OR SEAMLESS TUBING

Piercing is employed to produce seamless tubing which is the natural form from which is made any thin-walled round objects. Seamless tubing is a popular and economical raw stock for machining because it saves drilling and boring of parts. The process of making hot-pierced tubing consists of passing a hot-rolled billet between two conical-shaped rolls and over a mandrel which assists in the piercing and controls the size of the hole as the billet is forced over it as depicted in Fig. 7.6.

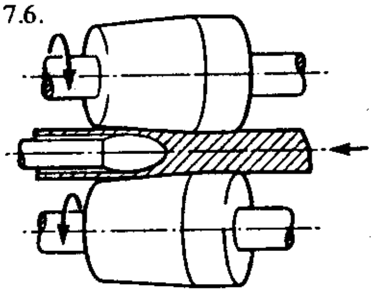

Figure 7.6 Tube piercing

The solid billet is uniformly heated to about 1100° C, and the piercing action is actually started previous to placing it between the rolls by drilling, punching, or piercing with oxygen a hole to about 25 mm deep. It is then pushed into the two piercing rolls which impart axial as well as rolling movement to the billet and force it over the mandrel. The alternate squeezing and bulging of the billet open up a seam in its center. The first pass makes a rather thick-walled tube, which is again passed over a tapered plug and through grooved rolls in a two-high mill where the thickness is decreased and the length is increased. While it is still up to a working temperature, it is passed onto a reeling machine which has two rolls similar to the piercing rolls, but with flat surfaces. The reeler further straightens and sizes the tubes. If more accuracy and better finish are desired, the tube may run through sizing dies or rolls. After cooling, the tubes are usually placed in a pickling bath of dilute sulphuric acid to remove the scale and oxide.

7.5 DRAWING

Drawing is pulling the metal through a die or a set of dies to achieve a reduction in a diameter. The material to be drawn is reduced in diameter for a short distance at one end by swaging, to permit it into the die orifice and gripped in the jaws. The process requires a very large forces in order to pull the metal through the die. To reduce the frictional force between the die and the metal the die is kept well lubricated. Also refer wire drawing in section 7.11.

7.6 DEEP DRAWING

Deep drawing is defined as a process for the making of cup-shaped parts from flat sheet-metal blanks. The blank is first heated to provide necessary plasticity for working. The heated blank is then placed in position over the die or cavity as shown in Fig. 7.7. The punch descends and pushes the metal through the die to form a cup. So this process is also known as *cupping*.

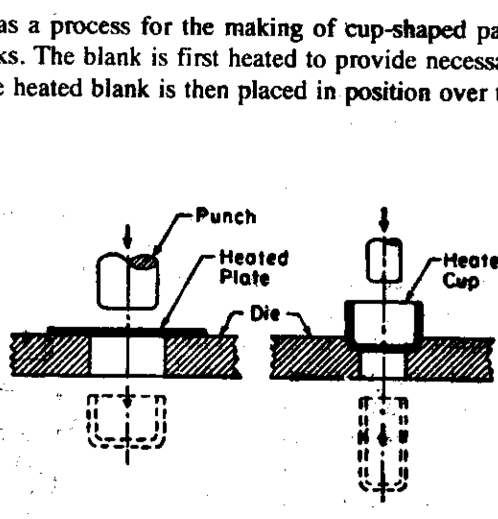

Figure 7.7 **Deep drawing**

The process may be continued through a series of successively smaller dies and punches to obtain cup-shaped pieces of the desired size and wall thickness. On many occasions, several dies of successively decreasing diameter is set up on a bench known as ***hot-draw bench***.

Seamless tubing and cylinders made in this way are used primarily for thick-walled cylindrical tanks.

7.7 HOT SPINNING

Parts that have circular cross-sections can be made by spinning them from sheet metal. The principle of metal spinning is illustrated in Fig. 7.8. A heated circular blank of sheet metal is lightly held against a chuck by the pressure of a freely rotating pad on the lathe tail stock. This chuck may be made of plaster, wood, or metal and is revolved on the spindle of a lathe. A rounded stick or roller is pressed against the revolving piece and moved in a series of sweeps. This displaces the metal in several steps to conform to the shape of the chuck. Once the operation is started, considerable frictional heat is generated which aids in maintaining the metal at a plastic state.

Spinning is a highly specialized art. To avoid excessive thinning of the metal, the pressure of the forming tool (rounded stick) should be directed sometime backward toward the tail stock as well as forward toward the headstock. During "spinning on air" (not against the chuck), with large parts made from relatively thin metal, a hardwood bar is commonly used as a back-up support opposite the spinning tool to avoid wrinkling at the outer edge.

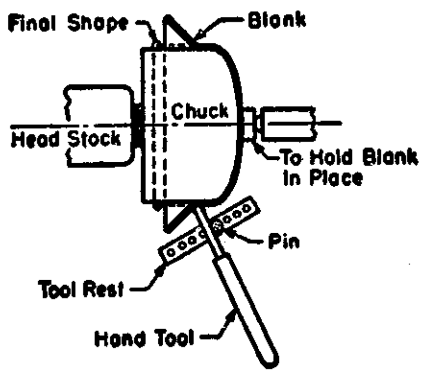

Figure 7.8 Hot spinning

7.8 EXTRUSION

Extruding is a process in which a heated billet or slug of metal is forced by high pressure through an orifice that is shaped to provide the desired form to the finished part. An everyday analogy is the squeezing of toothpaste from a collapsible tube. Because of the large forces required in extrusion, most metals are extruded hot under conditions where the deformation resistance of the metal is low. However, cold extrusion is possible for many metals and is rapidly taking an important commercial position. Most commercial metals and their alloys, such as steel, copper, aluminium, magnesium, and nickel, are directly extruded at elevated temperatures. Rods, tubes, moulding trim, structural shapes, brass cartridges, lead-covered cables, aircraft parts, flooring strips, and many hardware items such as window sash, door trim, etc., are typical products of extrusion.

The reaction of the extrusion billet with the container and die results in high compressive stresses which are effective in reducing the cracking of the materials during primary breakdown from the ingot. This is an important reason for greater use of extrusion in the working of metals difficult to form, e.g., stainless steels, nickel-base alloys, and molybdenum.

Most hot extrusion is done on horizontal hydraulic presses especially constructed for this purpose. Common sizes are rated from 250 to 5500 tonnes. Temperatures of billets are 350°C to 425°C for magnesium, 425°C to 475°C for aluminium, 650°C to 1300°C for copper alloys, and 1200°C to 1300°C for steel. Pressure normally vary from 4998 to 7038 kgf per sq cm (69×10^7 N/m^2). Lubrication of the extrusion chamber, die, and ram is necessary and is ordinarily achieved by mopping with oil supported graphite. Vegetable oils are better than petroleum oils for this purpose. The extrusion of steel at high temperatures is most successfully done by using glass which, at the temperatures involved, acts as a lubricant. Metal is extruded in a number of basic ways as follows:

Direct or forward extrusion. Direct extrusion illustrated in Fig. 7.9 employs a press-operated ram and a cylinder or container into which the workpiece is placed for confinement. A dummy block is used between the ram and the hot metal. With application of ram pressure, the metal first plastically fills the cylindrical shape, and it is then forced out through the die opening until a small amount remains in the container. It is then sawed off next to the die and the butt end removed.

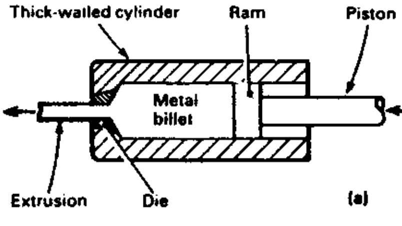

Figure 7.9 Direct extrusion

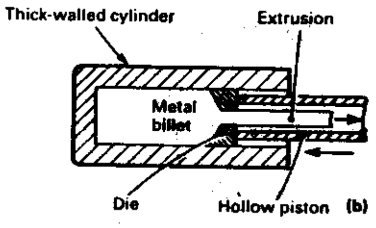

Figure 7.10 Indirect extrusion

Indirect or backward extrusion. Indirect extrusion is similar to direct extrusion except that the extruded part is forced through the hollow ram as shown in Fig. 7.10. It involves no friction between the metal billet and container walls, because the billet does not move the container. Compared with direct extrusion, less total force is required, but the equipment used is mechanically more complicated in order to accommodate the passage of the extruded shape through the centre of the hollow ram.

Tube extrusion. It is a form of direct extrusion but uses a mandrel to shape the inside of the tube. After the heated billet is placed inside the container, the die containing the mandrel is pushed through the billet. The ram then advances and extrudes the metal through the die and around the mandrel as shown in Fig. 7.11

Impact extrusion. Extrusions are also made by striking slugs of metal and forming them by high impact. This is essentially a cold working operation, and is described in Sec. 7.14.

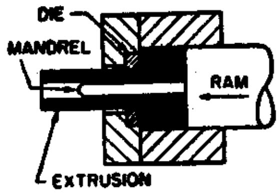

Figure 7.11 Tube extrusion

7.9 COLD-WORKING

The working of metals at temperatures below their re-crystallization temperature is defined as cold-working. Sometimes this working temperature is well above room conditions as in cold finishing of hot-rolled products. Most of the cold-working processes, however, are performed at room temperature.

When materials is cold-worked the resulting change in material shape brings about marked changes in the grain structure. The effect of cold-working on the structure of steel is to distort or elongate the grain in the direction of the flow of metal. Much greater pressures are needed for cold-working than for hot-working. The metal, being in a more rigid state, is not permanently deformed until stress exceeding the elastic limit is passed. Severe stress, known as residual stress is, therefore, set up inside the metal during cold-working. This effect of cold-working is reduced or minimized by heating the metal into the re-crystallization or annealing range, and finally the metal is brought to its original condition. This sequence of repeated cold-working and annealing is frequently called the *cold-work-anneal cycle*.

It is customary to produce cold-worked products like strip and wire in different *tempers*, depending upon the degree of cold reduction following the last anneal. The cold-worked condition is described as the annealed (soft) temper, quarter-hard, half-hard, three-quarter hard, full-hard, and spring temper. Each temper condition, indicates a different peicentage of cold reduction following the annealing treatment.

Cold-working is employed chiefly as a finishing operation, following the shaping of the metal by hot-working. It also controls the mechanical properties of steel in a large measure. It increases the tensile strength, yield strength and hardness of steel, but lowers its ductility. The increase in hardness resulting from cold-working is described as*work-hardening*.

In general, cold-working produces the following effects :

1. Internal stresses are set up which remain in the metal unless they are removed by proper heat-treatment.
2. A distortion of the grain structure is created.
3. Strength and hardness of the metal are increased but ductility is decreased.
4. Smooth surface finish is produced.
5. Accurate dimensions of parts can be maintained.

The principal methods of cold-working are as follows :

1. Rolling.
2. Forging.
3. Drawing.
4. Bending.
5. Spinning.
6. Extruding.
7. Squeezing.
8. Peening.
9. Sizing, coining, hobbing.

7.10 COLD-ROLLING

Bars of all shapes, rods, sheets, and strips are commonly finished by cold-rolling. Foil is made of the softer metals in this way. Two main reasons for cold-rolling metals are to get smooth bright surface finish and improved physical properties. If the object is only to give a clean, smooth finish to the metal, only a superficial amount of rolling will be needed. On the other hand, where it is desirable that the tensile strength, stiffness, and hardness be increased substantially, and that the section thickness be appreciably reduced, then higher roll pressures and deeper kneading are necessary. Cold-rolling also improves machinability by conferring the property of brittleness, a condition which is conducive to smooth tool finishes and well-broken chips.

As a preliminary step to the cold-rolling operation, sheets, strips etc. of hot-rolled steel are immersed in an acid solution to remove the scale and washed in water and then dried. The cleaned steel is passed repeatedly through set of rolls thereby producing a slight reduction in each pass until the required thickness is obtained.

7.11 COLD-DRAWING

Drawing operations involve the forcing of metal through a die by means of a tensile force applied to the exit side of the die. Most of the plastic flow is caused by the compressive force which arises from the reaction of the metal with the die. Usually the metal has a circular symmetry, but this is not an absolute requirement.

Rods, tubes and extrusions are often given a cold-finishing operation to reduce the size, increase the strength, improve the finish, and provide better accuracy. In general, the preparatory step in cold drawing of bars, tubes that have been hot-rolled is that of removing all traces of scale. This is best done by immersing them in a vat of dilute sulphuric acid from 15 to 30 minutes, removing, and washing in fresh water. After the scale is removed, the material is washed in lime to remove the acid. The lime, plus soap or oil, acts as a good drawing lubricant.

Wire drawing. All the wire that is available is produced by cold-drawing through dies. As in the case of cold rolling, the raw material for drawing is rolled bar from hot rolling mill. The size of rod varies from about 6 to 19 mm in diameter, depending upon the size of the finished wire. When required for drawing into wires this may be in coils several hundred meters in length.

Dies are made of chilled cast iron, hardened alloy steel, cemented tungsten carbide, and diamonds. The selection of the die material depends upon the composition of the wire as well as upon the size of the wire and the finish required. In passing through the dies, the steel is severely cold worked and must be annealed. To soften the wire, it is passed through a furnace where it is heated to a temperature in the vicinity of, or slightly lower than, the critical range.

Both *single-drafts* or *continuous-drawing* processes may be used. In the first method, the drawing operation is started by pointing the end of the rod and pushing it through the tapered hole in the die as shown in Fig. 7.12. The end is gripped by tongs and sufficient wire is pulled through the die so that the wire can be attached to a power-operated reel. The reel is then rotated to draw the wire through the die at the desired rate. In single-draft method, the wire is drawn several times through a single die until the necessary reduction has been obtained. In view of the enormous pressure between the die and rod

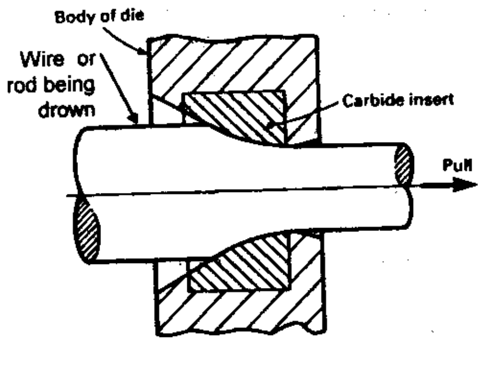

Figure 7.12 Wire drawing process

being drawn, it is necessary to lubricate the area of contact. In continuous-drawing, the wire is fed through several dies and draw-blocks are arranged in series to obtain the necessary reduction.

Tube drawing. This method produces tubes having smaller diameters or thinner walls than can be obtained by hot rolling. This is also used to get dimensional accuracy, smooth surface, and improved physical properties of tubes already made by hot rolling process.

Cold-drawing seamless tubing is similar to the corresponding process in solid bar stock. Hot-rolled tubing must first be treated by pickling and washing to remove all scale and then covered with a suitable lubricant. One end of the tube is reduced in diameter to permit it to enter the die, and a mandrel that has an outside diameter smaller than the workpiece inside diameter is passed through the tube stock. In drawing through with the tongs, in inside and outside, diameters of the tube plastically conform to the diameters of the mandrel and die, respectively. Light finishing requires only a single pass, while deep reduction necessitates two or more passes of the tube through the die.

7.12 COLD BENDING

Bending is the process by which a straight length is transformed into a curved length. It is one of the most widely used forming process for changing plates (or sheets) into drums, curved channels etc. Bars, rods, wires, tubing and structural shapes as well as sheet metal are bent to many shapes in cold conditions through dies. In all metal bending, the metal stressed beyond the elastic limit is in tension on the outside and in compression on the inside of the bend. Stretching of the metal on the outside makes the stock thinner. Bending a flat strip of metal is commonly done by roll forming.

Roll forming. There are two main types of roll forming ; one uses continuous-strip material for high-production work ; the other uses sheet and plate stock. Materials used for roll forming include carbon steel, stainless steel, bronze, brass, copper, zinc, and aluminium. Among its many products are metal window and screen frame members, bicycle wheel rims, furnace, jacked rings, trolley rails. Much of the present-day tubing is roll-formed cold and then resistance welded.

Continuous roll forming utilizes a series of rolls to gradually change the shape of the metal. As the metal passes between the rolls in a fast-moving continuous strip, the cross-sectional shape is changed to the desired shape. The forms are almost limitless in variation. The intricacy of the shape, the size of the section, the thickness, and the type of material will determine the number of rolls required.

Bending rolls are used for bending sheet and plate stock into cylindrical shapes. A roll-bending machine is made up of three rolls of the same diameter, two of them being held in a fixed position and one being adjustable. As a metal plate enters and goes through the rolls, its final diameter is determined by the position of the adjustable rolls. After the part is removed from the rolls, it is placed in a fixture to close the gap prior to welding. Bending-roll machines range in size from those that are able to roll heavy steel plate 25 mm thick, to small bench models used for light-gauge sheet metal work.

7.13 COLD-SPINNING

Cold-spinning is the operation of shaping very thin metal by pressing it against a form while it is rotating. The method is exactly similar to hot spinning described in Sec. 7.7, except the condition of metal. In cold-spinning the metal is worked at room temperature.

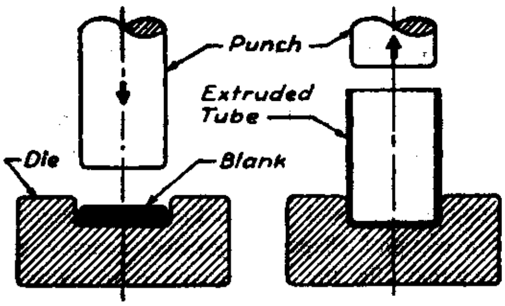

Figure 7.13 Cold extrusion

Equipment required for spinning comprises a lathe, forming tools, and a metal or wood former to suit the shape required. A circular blank is cut and positioned against the former by a follower. A round-nose tool is used and while the lathe rotates the blank is forced to the shape of the former. The process works the material considerably, and thinning of the metal can result. Lubricants such as soap, bees-wax, white lead, and linseed oil are used to reduce the tool friction. Cold-spinning process is frequently used in the making of bells on musical instruments and also for light fixtures, kitchen-ware, reflectors, funnels, and large processing kettles.

7.14 COLD-EXTRUSION

The principle of cold extrusion is exactly similar to that of hot extrusion. Of the various processes of extrusion, impact extrusion is essentially a cold-extrusion method.

Impact extrusion. Impact extrusion is limited primarily for making small workpieces from the more ductile metals. The process is illustrated in Fig. 7.13. The work material is placed in position into a blind die and a ram punch with clearance is forced into the die, causing the metal to flow plastically around the punch. The outside diameter of the tube is the same as the diameter of the die, and the thickness is controlled by the clearance between the punch and die. The extruding force is usually supplied by a mechanical press. Collapsible medicine tubes and toothpaste tubes are made in this way.

7.15 SQUEEZING

Squeezing is a quick and widely used way of forming ductile metals. Of the different processes of squeezing, *cold heading* and *rotary swaging* are very common.

Cold heading. Cold heading is a cold forging process, used primarily for the manufacture of bolts, screws, rivets, nails and similar items. Materials in bar form is fed into the machine, where it is cut to length, held in a pair of jaws, and subjected to two or three blows to rough form the head. For complex shapes, or greater accuracy, the part is then repositioned in another die for final shaping or sizing. Bolt making machines combine thread rolling with cold heading to produce a complete bolt. A material to be cold headed must be ductile.

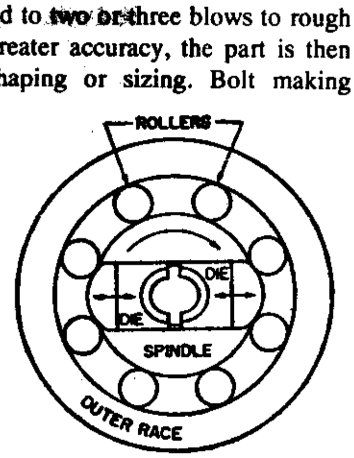

Figure 7.14 Rotary swaging

Thread rolling is a mass-production method for producing threads. It is a cold-working process, and is usually designed for automatic operation. The rolls have the thread form cut on their surface. The rolls rotate and are fed into the blank under pressure ; metal flows into the die shape forming a thread. The threading dies may be in the form of flat plates. These have a reciprocating action, the blank being rolled between them to form the thread.

Rotary swaging. Rotary swaging is the process used to reduce the cross-sectional area of rods and tubes. Swaging is often accepted of as a cold-forging operation, because the metal-forming takes place under the hammering blows of die sections. The swaging machine consists mainly of a hollow spindle which carries the die sections and rollers as shown in Fig.7.14.

The die is inserted in the slot in a spindle, rotated, and forced together repeatedly by the rollers around the periphery, as much as several thousand times a minute, forming taper on the work.

7.16 PEENING

This method is employed to set up a superficial state of surface compressive stress, causing the interior of the member to assume an opposite tensile stress. Because fatigue generally occurs from surface cyclically loaded in tension, the useful lives of such members are frequently extended by shot peening. This method is sometimes employed to achieve an ornamental effect.

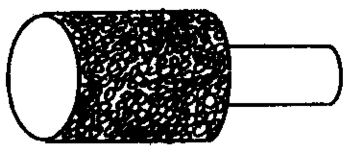

Figure 7.15 Shot peening

Shot peening is done by blasting or hurling a rain of small shot at high velocity against workpieces to cause slight indentations. Figure 7.15 shows shot peenig action on a job.

7.17 SIZING, COINING AND HOBBING

Parts of malleable iron, forged steel, powdered metals, aluminium, and other ductile nonferrous metals are commonly finished to thickness by squeezing an operation called *sizing*. A special die is needed for almost every job, but each piece can be sized in a fraction of the time of machining. Thus, sizing is economical wherever applicable in high production industries.

Operations like sizing have been called *coining*, but coining more truly involves the impression and raising of images or characters from a punch and die into the metal. The metal is made to flow, and the designs on opposite sides of a coined piece are not necessarily related as in embossing. Hard money is probably the best known product of coining.

Hobbing or *hubbing* is a method of making moulds for the plastic and die-casting industries. A punch called the *hob* or *hub*, is machined from tool steel to the shape of the cavity, heat treated for hardness, and polished. It is then pressed into a blank of soft steel to form the mould. A prime advantage of this method is that one hob properly applied can make a number of cavities in one mould or in a series of mould.

Sizing, coining, hobbling, etc., are illustrated in Fig. 7.16

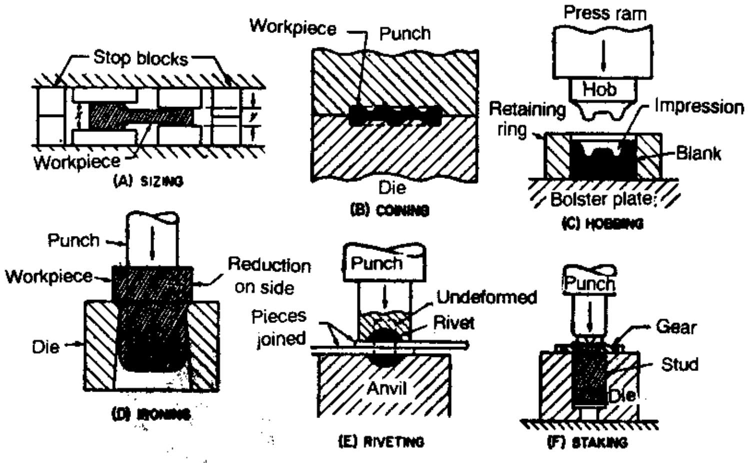

Figure 7.16 Some common metal-squeezing operations

7.18 ELECTRO–HYDRAULIC FORMING

Electro–hydraulic forming is an unconventional forming process. In this process a high intensity shock wave is generated by discharging stored electrical energy across electrodes submerged in an electrolyte. A potential

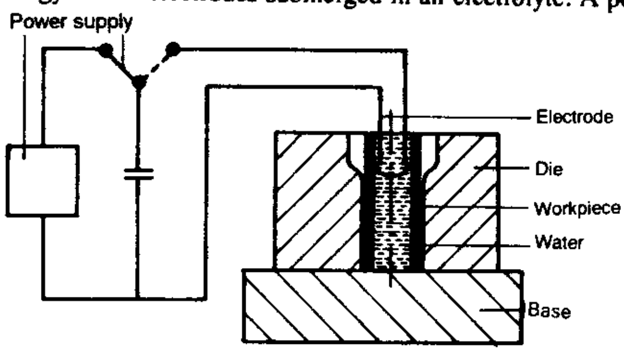

Fig. 7.17 Electro–hydraulic forming set-up

difference of 30 kV is discharged through a wire 1 mm diameter which is immersed in water. The vapouring action of the wire due to intense heat generation in turn creates high pressure shock wave. The process can be used for bulging, forging, drawing, blanking and piercing. Fig. 7.17 shows the ser-up.

TABLE 7.1 METALLURGICAL ADVANTAGES OF HOT-WORKING OVER COLD-WORKING PROCESSES

	Hot-working	*Cold-working*
1.	Hot-working is done at a temperature above recrystallization temperature. It can therefore be regarded as a simultaneous process of deformation and recovery.	Cold working is done at a temperature below recrystallization temperature. So no appreciable recovery can take place during deformation.
2.	Hardening due to plastic deformation is completely eliminated, by recovery and recrystallization. This is true, however, only if the rate of crystallization is higher than that of deformation.	Hardening is not eliminated since working is done at a temperature below critical temperature and this is always accompanied by work-hardening.
3.	Mechanical properties such as elongation, reduction of area, and impact values are improved. Ultimate tensile strength, hardness, and resistance to corrosion, are not affected by hot-working if this is properly done.	Cold-working decreases elongation, reduction of area, and impact values, while it increases ultimate tensile strength, yield point, fatigue strength, and hardness. But resistance to corrosion is decreased by cold-working. If severely worked, yield point may coincide with ultimate tensile strength.
4.	Refinement of crystals occurs.	Crystallization does not occur. Grains are only elongated and/or distorted. The extent of distortion depends on the degree of cold-working.
5.	Breaks up brittle film of hard constituents, and promotes uniformity of materials by facilitating diffusion of constituent alloys.	Uniformity of materials is lost and the properties are affected.
6.	Cracks and blow holes are welded up.	Possibility of crack formation and its propagation is great
7.	Internal of residual stresses are not developed in the metal.	Internal and residual stresses are developed in the metal.

7.19 METALLURGICAL ASPECTS

After a brief discussion of almost all important mechanical working processes, it can be concluded that hot-working have greater advantage over cold-working processes, particularly from metallurgical stand-point. This can be viewed from Table 7.1.

REVIEW QUESTIONS

1. What is mechanical working, and what use is made of it any why ?
2. Discuss the advantages and limitations of hot- and cold-working.
3. Show by sketch the various roll arrangements used in rolling mills.
4. Describe and specify the merits of different kinds of rolling mills.
5. What are the forms a steel goes when rolled into structural shapes?
6. Why are a number of passes required to roll a steel bar ?
7. What are the advantages of extrusion over other shaping processes ? State the main applications of hot extrusion.
8. Explain briefly with neat sketches different processes of extrusion. Discuss their relative merits and demerits.
9. Explain briefly with neat sketch the process of wire drawing.
10. How are collapsible tubes produced ?
11. What is impact extrusion ?
12. What are some of the applications of cold extrusion ?
13. How is seamless tubing pierced ?
14. Describe the process of hot and cold spinning stating their advantages and specific uses.
15. Describe the following processes with their specific uses and limitations : (a) cold-drawing, (b) cold-bending, (c) cold-heading and rotary swaging.

8

SMITHING AND FORGING

8.1 INTRODUCTION

Smithing is the act or art of working or forging metals, as iron, into any desired shape. In this process relatively small sized jobs are heated in an *open fire* or *hearth* and subsequently hammered to get the desired shape. The shop in which the work is carried out is known as the smithy or smith's shop, and the various operations are performed by means of hand hammers or small power hammers.

Forging refers as the process of plastically deforming metals or alloys to a specific shape by a compressive force exerted by some external agency like hammer, press, rolls, or by an upsetting machine of some kind. The portion of a work in which forging is done is termed the forge and the work is mainly performed by means of heavy hammers, forging machines, and presses. Forging processes are among the most important manufacturing techniques since forged are used in the small tools, rail-road equipment, automobile, and aviation industries.

8.2 FORGING MATERIALS

In all plastic deformation processes such as in forgings, the work piece calls for materials that should possess a property described as ductility that is, the ability to sustain substantial plastic deformation without fracture even in the presence of tensile stresses. If failure occurs, it occurs by the mechanism of ductile fracture and is induced by tensile stresses. A material of a given ductility may fare very differently in various processes, depending on the conditions imposed on it. Therefore, it is proper to think of a more complex property called *work-ability* in plastic deformation processes, and *forgeability* in forging processes. All one can say is that wrought alloys must possess a minimum ductility that the desired shape should possess.

FORGEABLE METALS

While all ductile materials can be forged, forgeability of a metal at the forging temperature depends upon the crystallographic structure, the melting point, yield strength, strain rate, and dry friction.

The metal or alloy to be forged is usually purchased as hot rolled bars or billets with round or rectangular cross sections. The following materials are ranked in order of increasing forging difficulties:

1. Aluminium alloys (GF)
2. Magnesium alloys (GF)
3. Copper alloys (GF)
4. Carbon/low-alloy steels (GF)
5. Marten. stainless steels (SD)
6. Maraging steels (SD)
7. Austen.. stainless steels (SD)
8. Nickel alloys (SD)
9. Titanium alloys (D)
10. Iron –base super alloys(D)
11. Cobalt-base super alloys(D)
12. Tantalum alloys (D)
13. Tungsten alloys (VD)
14. Beryllium (VD)

The forgeability of the above mentioned materials are categorized as good (GF), somewhat difficult (SD), difficult (D), and very difficult (VD) and has been indicated in the brackets.

FORGEABILITY

The basic lattice structure of metals and their alloys seem to be a good index to their relative forgeability or workability. Forgeability increases with temperature up to a point at which a second phase, e.g., from ferrite to austenite in steel, appears or if grain growth becomes excessive. Certain mechanical properties also influence forgeability. Metals, which have low ductility, have reduced forgeability at higher strain rates, whereas highly ductile metals are not so strongly affected by increasing strain rates. The product designer has a wide variety of metals or alloys from which to choose the materials for forged parts. Most forging grades of ferrous or non-ferrous alloys are selected based on their inherent property levels as bar or billet materials, usually after heat treatments are performed. The forging process tends to improve some of the mechanical properties, such as impact toughness, fatigue strength, and tensile ductility, which are dependant on the grain flow patterns developed during forging. Some alloys are relatively easy to forge and may be used to make components with very intricate features. Grades that are more difficult to forge require distinct design approaches. Forgeability, thus, can be defined as *" the relative ability of a material to deform without rupture."*

8.3 HEATING DEVICES

The stocks that needed heating for optimizing product requirement or specifications are heated to the correct forging temperature in a smith's hearth or in a furnace located *near* the forging operations. Gas, oil or electric-resistance furnaces or induction heating classified as *open* or *closed hearths* can be used. Gas and oil are economical, easily controlled, and mostly used as fuels. The formation of scale, due to the heating process, specially on steel creates problems in forging. A non-oxiding atmosphere should, therefore, be maintained for surface protection. New styles of gas-fired furnaces have been developed to reduce scaling to minimum. Electric heating is the most modern answer to scaling, and it also heats the stock more uniformly. In some cases, coal and anthracite, charcoal containing no sulphur and practically no ash are the chief solid fuels used in forging furnaces. However, fuels must have a calorific value of at least 1,400 to 1,500 large calories (5,600 to 6,000J). Petroleum sometimes serves as an excellent fuel.

Forge furnaces are built so as to ensure a temperature upto 1350°C in their working chambers. They should be sufficiently large to allow proper combustion of the fuel, and to obtain uniform heating of the workpiece. Each heating furnace consists of the following parts : firebox, working chamber, chimney, flues, recuperator or regenerator, and various auxiliary arrangements. Several types of furnaces are used for heating the workpiece and some of them are briefly described below.

BOX OR BATCH TYPE FURNACES

These are widely employed in forging shops for heating small and medium size stock because they are the least expensive. There is a great variety of design of box-type furnaces, each differing in their location of their charging doors, firing devices and methods employed for discharging their products. These furnaces are usually constructed of a rectangular steel frame, may be 2400 mm wide by 1200 mm deep, lined with insulating and refractory bricks. One or more burners for gas or oil are provided on the sides. The workpieces are placed side by side inside a low 'slot' through which the furnace operator reaches with tong. This is, therefore sometimes called *slot-type furnace*. However, usually two people tend all types of furnaces, one feeding in the cold stock and other bringing heated stock to the forge operator.

ROTARY–HEARTH FURNACE

These are doughnut shaped and are set to rotate slowly so that the stock is heated to the correct temperature during one rotation. These are also heated by gas or oil.

CONTINUOUS OR CONVEYOR FURNACES

These are used of several types if only one end of the work must be heated, though they also will heat complete stock. Especially for larger stock, a pusher furnace may be used. This has an air or oil-operated cylinder to push stock end-to-end through a narrow furnace. The pieces are charged at one end, are conveyed through the furnace, and are moved at the other end at the correct temperature for forging.

INDUCTION FURNACES

In induction furnaces the stocks are passed through induction coils in the furnaces. These furnaces are becoming very popular because induction greatly decreases scale, can often be operated by one person, requires less maintenance than oil–or gas–fired furnaces, and is faster. Delivery to the forging machine operator can be effected by slides or automatic handling equipment.

RESISTANCE FURNACE

Resistance furnaces are faster than induction furnaces, and are often automated. In resistance heating the stock is connected into the circuit of a step-down transformer. Fixtures must be made for holding each different length, shape, and diameter of stock. However, the fixtures are often quite simple, and some can be adjusted to handle a 'family' of parts.

OPEN FIRE AND STOCK FIRE

In a forge, the fire itself plays an important part on the efficient heating of the stock. The fire must be deep and kept well banked. A fire which is thin and spread all over the hearth is useless for forging. Further it must be kept clean, i.e., free from excess dust or clinkers. The placing of the work in the fire is also important. Work which is laid on top of the fire will get hot underneath and remain colder on the top because it is exposed to the atmosphere, and uneven heating will result. In the same way, work which is placed low in the fire but at the same time against the tuyere will become hot on one side, but will have a blast of cold air blowing against it, from the tuyere, on the other side. The correct position is in the hearth of the fire.

Two methods of firing a smith's forge in common use are : (1) open fire, and (2) stock fire.

Open fire. Open fire, sometime called loose fire, is convenient for all general work. This is made up in the hollow space in front of tuyere nozzle with coke left from the last fire, covered with green coal (Fig. 8.1). As the fire burns away coke from the top and sides is drawn into the centre, and its place is taken by more green coal taken from the supply maintained on the front place of the forge or taken from the outside. The work must be covered with a layer of coal, and to obtain a flame at a single spot, the coal should be slightly damped with water and pressed down with a flat shovel.

In the spot where the flame is desired, the coal should be loosened with a pocker. To ensure uniform heating of work on all sides it must be turned round from time to time.

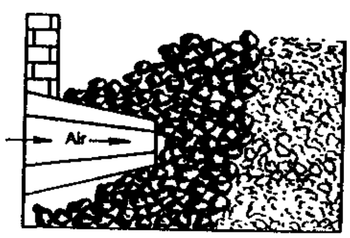

Figure 8.1 Open fire

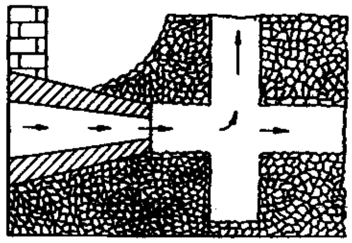

Figure 8.2 Stock fire

Stock fire. A stock fire (Fig.8.2) is intended to last for several hours, and is especially useful in dealing with large pieces, when a heat may have to be kept up for some time. Another advantage with the stock fire is that the work may be turned in all directions to ensure uniform heating of the job. Stock fire is made up round a block of the size desired, which is placed near the tuyere nozzle and upon coal damped with water that is closely built into the form of a mound or "stock". Fine coal or pulverized coal is suitable for use in stock fire. The block is then withdrawn from the bed of the hearth with a turning force to prevent the stock from being broken, and a tunnel is thus formed with an opening at the top. The fire is lighted in the hollow space. From the bottom of the tunnel a small amount of coal is removed and a cavity is formed in the place into which clinker may fall. Here the work is heated, being carefully covered with freshly-coked fuel from time to time as the fire burns away.

8.4 FORGING TEMPERATURE

For forging, a metal must be heated to a temperature at which it will possess high plastic properties both at the beginning and at the end of the forging process. For instance, the temperature to begin the forging for soft, low carbon steels is 1,250 to 1,300°C, the temperature to finish forging is 800 to 850°C. The respective temperatures for hard, high-carbon and alloy steels are 1,100 to 1,150°C and 825 to 875°C. Wrought iron is best forged at a temperature little below 1,300°C. Nonferrous alloys like brass and bronze are heated to about 600 to 950°C, and aluminium and magnesium alloys to about 350 to 500°C.

If the forging operation is finished at a lower temperature, this leads to cold hardening and cracks. With excessive heating the forgings suffer oxidization and much metal is wasted. The blanks should be heated uniformly all over and at a definite rate.

The temperature of heating steel for hand forging can be estimated by the *heat colour* which is the colour of the light emitted by the heated steel. The heat colour disappears when the steel cools down. For more accurate determinations, *optical pyrometers* are used. Surface colours for iron and steels at various temperatures are given in Table 8.1.

TABLE 8.1 SURFACE COLOURS FOR IRON AND STEEL

Color	*Temperature (approximate) in °C*
Faint red	500
Blood red	650
Cherry red	750
Bright red	850
Salmon	900
Orange	950
Yellow	1050
White	1200

FINISHING TEMPERATURE OF FORGING

The temperature at which the hammering of a forging is left off has an important influence on the properties of the forging. When steel is heated well above the upper critical temperature, the grain begins to grow in size, and they will continue to grow as the temperature is increased. During forging, however, its grains are broken up and become finer. If the final forging temperature is high (above 910°C), the grains will grow during the process of cooling in the air; the cold forging will then have a coarse-grained structure and low mechanical properties. If forging is finished at low temperature (below 910°C), the grains will not grow when the steel is cooled owing to the low temperature. The cold forging will then possess a fine-grained structure and high mechanical properties. If steel is hammered when it is below the lower critical temperature (about 723°C) it will be cold worked and may be given small hair cracks. Thus, if the forging of a piece of steel is finished within a temperature interval of 910 to 723°C, depending on its grade, the forging must be completed at a temperature at which further growth of the grain will not take place.

8.5 HAND TOOLS AND APPLIANCES

The tools and appliances used and their applications in numerous forging operations are described below.

The anvil. The anvil (Fig.8.3) forms a support for blacksmith's work when hammering. The body of the anvil is made of mild steel with a tool steel face welded on the body, but the beak or horn used for bending curves is not steel faced. The round hole in the anvil called *pritchel hole* is used for bending rods of small diameter, and as a die for hot punching operations. The square or *hardie hole* is used for holding square shanks of various fittings.

Anvils vary up to about 100 to 150 kg and should stand with the top face about 0.75 m from the floor. This height may be attained by resting the anvil on a cast iron or wooden base.

The swage block. This forgeshop tool (Fig. 8.4) is used for mainly squaring, sizing, heading, bending and forming operations. It is 0.25 m or more wide and may be used either flat or edgewise in its stand.

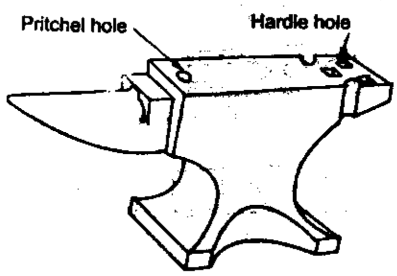

Figure 8.3 The anvil

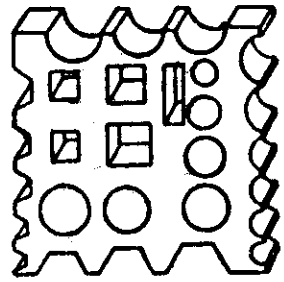

Figure 8.4 The swage block

Hand hammers. Two kinds of hammers are used in hand forging: (1) the hand hammer used by the smith himself, and (2) the sledge hammer used by the striker (Fig. 8.5)

Hand hammers may be classified as : (a) ball peen hammer, (b) straight peen hammer, and (c) cross peen hamm . Hammer heads are made of cast steel, the ends hardened and tempered. The striking face is slightly convex. The weight of a hand hammer varies from about 0.5 to 2 kg while the weight of a sledge hammer varies from 4 to 10 kg. Hand hammers have been fully described in Article 14.3.

Tongs. The work to be forged is generally held with tongs. The tongs generally used for holding work are (Fig. 8.5) :

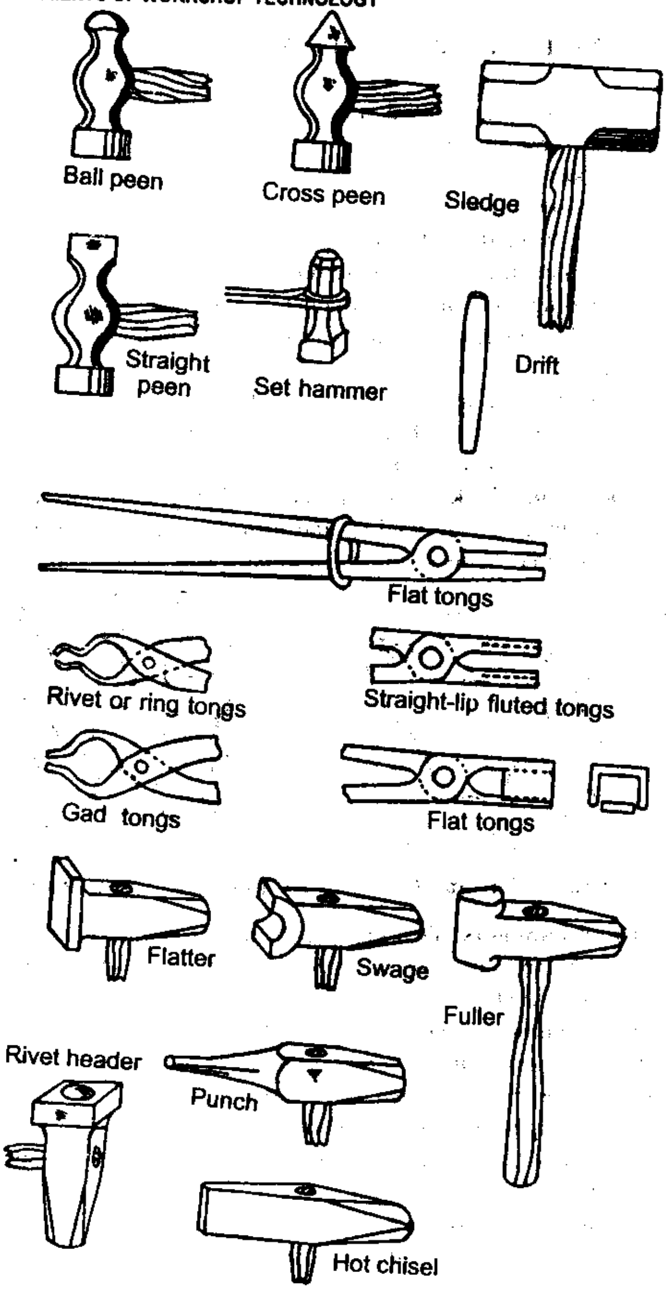

Figure 8.5 Forging tools