CHAPTER

19

MECHANICAL WORKING OF METALS

19.1 INTRODUCTION

By the term **'Mechanical Working'** of metals we mean an intentional deformation of metals *plastically*, to provide it the desired shape and size, under the action of externally applied forces. 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 phenomena governing this plastic deformation of a metal are (1) **Deformation by Slip**, and (2) **Deformation by Twin Formation**. In the first case it is considered that each *grain* of a metal comprises 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 second case, **deformation** occurs along two *Parallel Planes* which run 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**. Both the above deformations may be effected at room temperature or higher temperatures. At higher temperatures the *deformation* is quicker because the *bond* between atoms of the metal grains is reduced. All these aspects have already been discussed in detail in Chapter 4.

During the above deformations the metal is said to **Flow**, called the **Plastic Flow** of the metal, and the shapes of the grains are changed. If the deformation is carried out at higher temperatures, new grains start growing at the locations of internal stresses caused in the metal by *slip* or *twin formation*. When 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*. The *temperature* at which this process is completed is known as the **Recrystallisation Temperature** of the metal, and it is this point which differentiates *cold working* from *hot working*. Mechanical working of a metal below its recrystallisation temperature is called **Cold Working** and that accomplished above this temperature but below the melting or burning point is known as **Hot Working**.

19.2 HOT WORKING

As described above, **Hot Working** is accomplished at a temperature above the *recrystallisation temperature* of the metal. However, this temperature should not be too high to reach the *solidus* temperature, otherwise the metal will burn and become unsuitable for use. As a general rule it can be mentioned that 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 recrystallisation temperature. **Hot Working** of metals is generally accompanied by the following **advantages and disadvantages.**

Advantages

1. Larger deformation can be accomplished, and more rapidly, by hot working since the metal is in plastic state.
2. Porosity of the metal is considerably minimised.
3. Concentrated impurities, if any, in the metal are disintegrated and distributed throughout the metal.
4. Grain structure of the metal is refined and physical properties improved.
5. No residual stresses are introduced in the metal due to hot working.

Disadvantages

1. Due to high temperature a rapid oxidation or scale formation takes 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, which is a disadvantage when the part is put to service.

3. This weakening of the surface layer may give rise to a fatigue crack which may ultimately result in fatigue failure of the part.
4. Close tolerances cannot be maintained.
5. It involves excessive expenditure on account of high cost of tooling. This, however, is compensated by the high production rate and better quality of products.

19.3 PRINCIPAL HOT WORKING PROCESSES

The *Principal Hot Working Processes*, generally applied to various metals, are the following :

1. Hot rolling.
2. Hot forging.
3. Hot spinning.
4. Hot extrusion.
5. Welded pipes and tube manufacturing.
6. Roll piercing.
7. Hot drawing.

19.4 HOT ROLLING

The purpose 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. As a result of *rolling*, the coarse structure of cast ingot is converted into a fine grained structure and a marked improvement is accomplished in its various

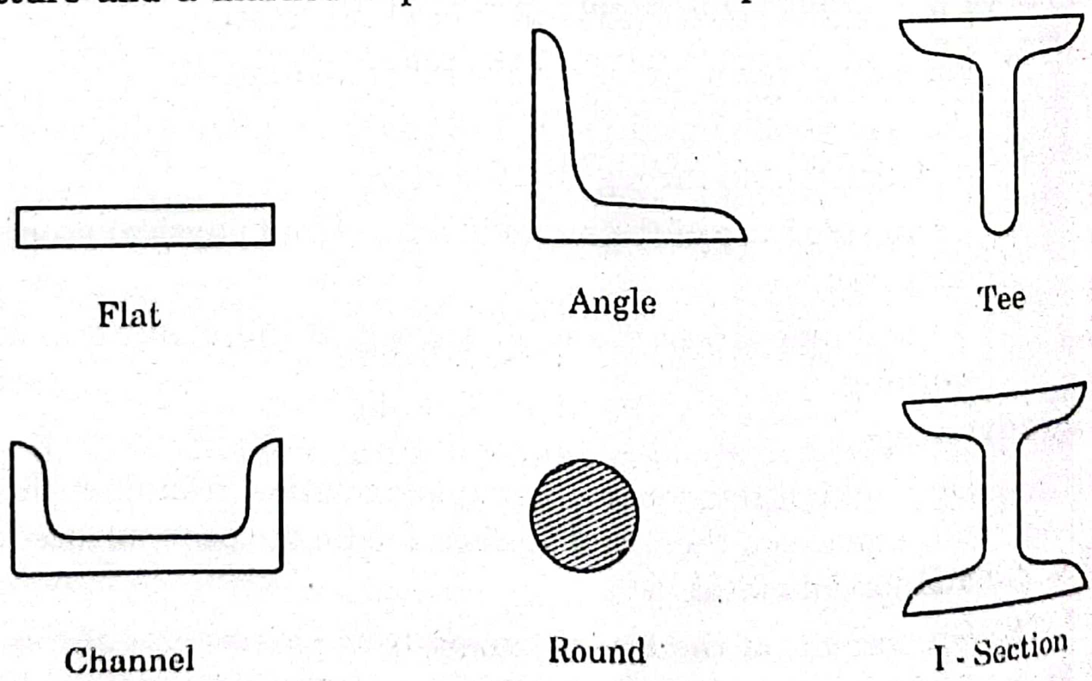

Fig. 19.1. Commonly used rolled steel sections.

physical properties such as strength, toughness, ductility and shock resistance. A large number of useful articles like structural sections, sheets, rails, plates and bars etc., are produced through rolling. Some commonly used **Rolled Steel Sections** are shown in Fig. 19.1.

The desired reduction in the cross section of the billet and the desired shape of the rolled section is not achieved in a single pass. It has to be rolled again and again several times before the desired shape and cross section of the rolled product is obtained. This is clearly illustrated in Fig. 19.2, which shows the *Sequence of Rolling* and the number of *passes* required to reduce the cross-section of a billet to a round steel bar.

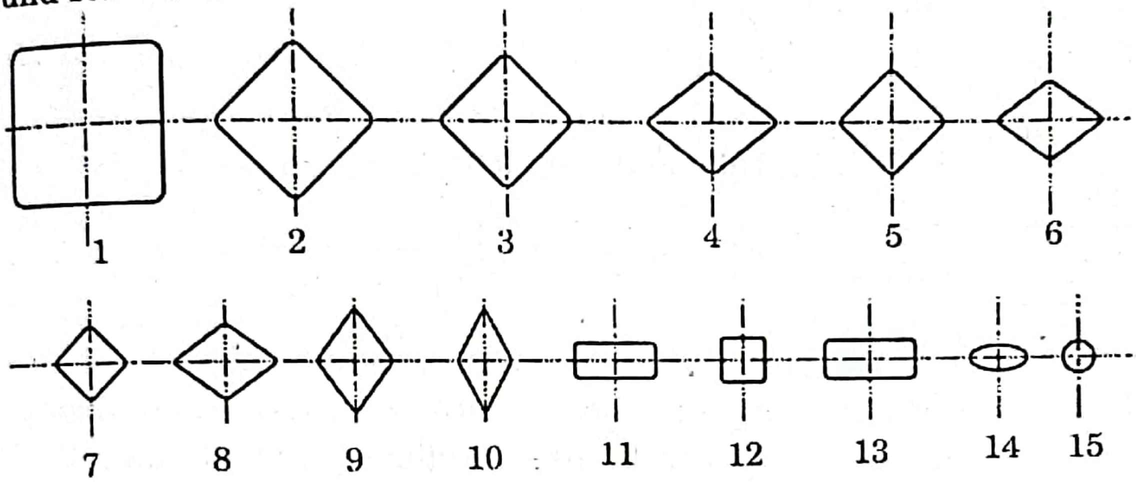

Fig. 19.2. Various stages of rolling and number of passes for converting a steel billet into a round bar.

In this process, the Ingots are first heated to the rolling temperature in **Soaking Pits** and then rolled in **Blooming Mills** to convert them into **Blooms**. Blooming mills carry mechanical *manipulators* to turn the hot ingot (billet) through 90° after every pass. This enables all the surfaces of the ingot to come in contact with the rolls. **Grooved rolls**, of the type shown in Fig. 19.10, are used on blooming mills for this process. Since the *Blooming Mill* is the first mill through which all the ingots are passed, before being rolled on other mills it is called the **Mother Mill**. The different types of mills, arrangement of rolls on them and their features are described later in this chapter.

19.5 PRINCIPLE OF ROLLING

The process of rolling basically consists of passing the hot ingot through two *rolls* rotating in opposite directions at a uniform peripheral speed. The space between the rolls is adjusted to conform to the desired thickness of the rolled section, and the same is always less than the thickness of the ingot being fed. The rolls, thus, squeeze the passing ingot to reduce its cross-section and increase its length.

The process is illustrated in Fig. 19.3, which shows the changes that take place in the *grain structure* of the metal as it passes through the rolls. As a result of *squeezing* the grains are elongated in the direction of rolling and the *velocity* of material at exit is higher than that at the entry. After crossing the *stress zone* the grains start refining. But this is the case only in *Hot Rolling*. In *Cold Rolling* they tend to retain the shape acquired by them during rolling.

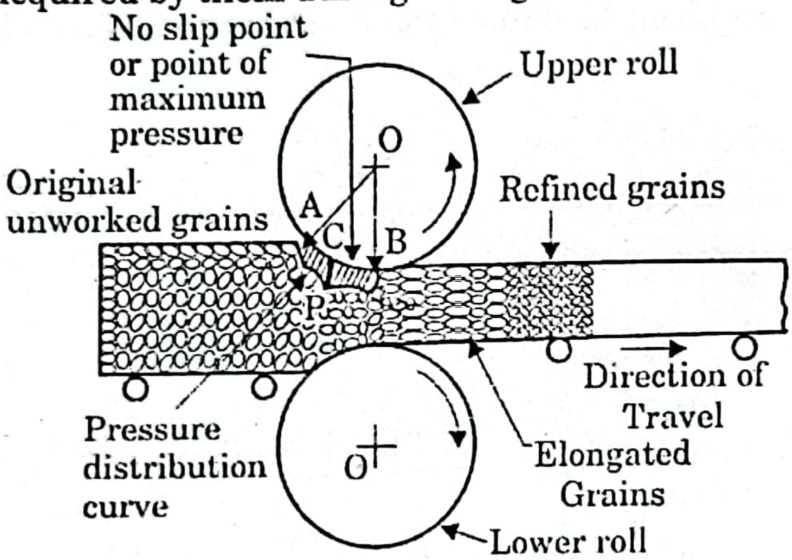

Fig. 19.3. The rolling process.

The *Rolls* are in contact with the passing metal piece over a sufficient distance, represented by the arc *AB* in the diagram. The angle *AOB* subtended at the centre of the roll by the arc *AB* is called the **Angle of Contact** or the **Maximum Angle of Bite**. It is the *friction* between the surfaces of the metal piece and the rolls which provides the required *grip* of the rolls over the metal piece to draw the latter through them. The greater the *coefficient of friction* the more the possible reduction.

The pressure exerted over the metal by the rolls is not uniform throughout, but varies as represented by the **Pressure Distribution Curve** in the diagram. It will be observed that it is minimum at both the extremities and maximum at a point somewhere within the curve. The line *CP*, representing the maximum pressure, is called the **Neutral or No Slip Line**, and the point *C* is known as **No-Slip Point** or the **Point of Maximum Pressure.** At this point the surfaces of the metal and the roll move at the same speed. Before reaching this point, *i.e.*, from *A* to *C* the metal moves slower than the roll and the frictional force acts in the direction to draw the metal piece into the rolls. After crossing the neutral point C, *i.e.*, from C to B, the metal moves faster than the roll surface, as if it is being extruded, and the friction opposes the travel, tending to hold the metal back. This results in setting up of *stresses* within the metal to obstruct its reduction.

The position of point C depends upon the diameter of rolls, extent of reduction and similar other operating conditions. As the **Arc of Contact** increases this point tends to move towards the exit point B, and when this arc becomes so big that the maximum *Angle of Bite AOB* becomes more than two times the *Angle of Friction* between the rolls and the work the point C coincides with B and then the rolls cannot draw the work through them.

19.6 ROLLING PARAMETERS AND THEIR EFFECTS

Before we actually discuss the action of **Rolling forces** it will be worthwhile to know a few important terms (see Fig. 19.4). Let t_1, l_1, b_1 and t_2, l_2, b_2 be the initial and final thickness, lengths and breadths of the metal piece respectively.

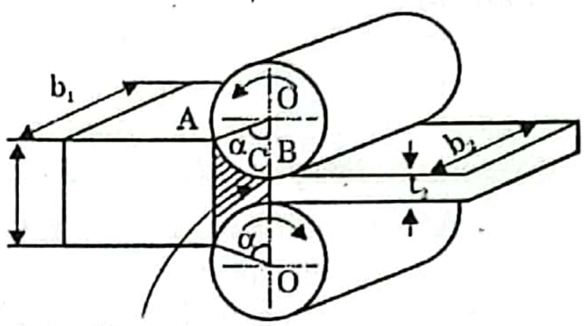

Fig. 19.4. Metal rolling process.

Absolute draught. It is the difference between the initial and final thicknesses of the metal being rolled.

i.e., $$\delta t = (t_1 - t_2) \text{ mm.}$$

Absolute elongation. It is the difference between the final and initial lengths of the metal piece being rolled.

i.e., $$\delta l = (l_2 - l_1) \text{ mm}$$

Absolute spread. It is the difference between the final and initial widths of the metal piece being rolled.

i.e. $$\delta b = (b_2 - b_1) \text{ mm}$$

Relative draught. It is the ratio of the absolute draught to the initial thickness of the metal piece, and is expressed as a percentage of the same.

i.e., $$R_t = \frac{\delta t}{t_1} = \frac{(t_1 - t_2)}{t_1} \times 100$$

Elongation coefficient. It is the ratio of the final length of the rolled strip to its initial length.

i.e. $$\mu_1 = \frac{l_2}{l_1}$$

But, we know that there is no change in the volume of the metal by rolling. Therefore,

$$t_1.b_1.l_1 = t_2.b_2.l_2$$

or $$\frac{t_1\, b_1}{t_2\, b_2} = \frac{l_2}{l_1} = \mu_1 \text{ (i.e. coefficient of elongation)}$$

Angle of Contact. It is the angle subtended at the centre of the roll by the arc of contact *AB*. Its value can be computed from the following relation :

$$\cos\alpha = 1 - \frac{\delta t}{D} \quad \text{[where } D \text{ is the diameter of the roll]}$$

Forces acting on the metal during Rolling

At the point of entry (or *bite*) the metal is under the action of two forces on its both sides facing the rolls. The forces are the Radial or **Normal force** *N* and **Frictional** or **Tangential** force *F* (Fig. 19.5).

But, $$F = \mu N$$

[where **μ** is the coefficient of friction]

Also, $$\frac{F}{N} = \tan\beta = \mu$$

[where β is the angle of friction]

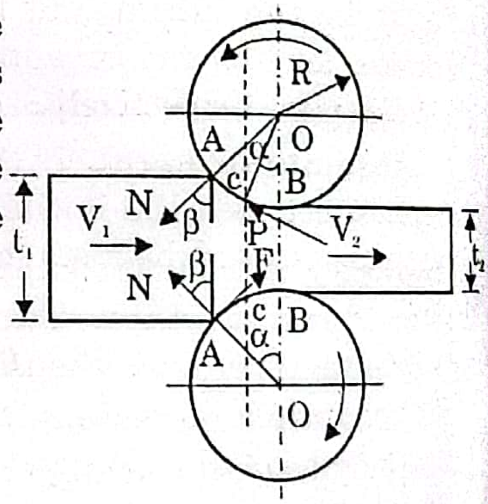

Fig. 19.5. Forces at bite in rolling.

Now, in order that the metal piece enters between the rolls it is necessary that :

μ > tan β or α > β

The maximum permissible value of *Angle of Contact* or *Bite* varies according to the materials of the metal piece and the rolls, rolling temperature and speed and the surface roughness of the rolls and the metal piece being rolled. Normally, the following values are adopted in practice :

2° – 10° For cold rolling of coiled sheet and strip.

15° – 20° For hot rolling of sheet and strip.

24° – 30° For the rolling of heavy billets and blooms.

As stated in the last article, the velocity (V_2) of the bar at the delivery point B is higher than that (V_1) at the point of entry A. Also, it is reckoned that on the point of No Slip or Critical Point 'C' the roll velocity V is equal to the velocity of strip at that point. The angle (γ) subtended at the centre of the roll by this point is called the **Angle of Noslip** or **Critical Angle.** The vertical cross-section through points, shown by dotted line in Fig. 19.5, is known as **Neutral Section, No-slip Section** or **Critical Section.** The portion of the *Deformation Zone* (Fig. 19.4) falling on the left of the *neutral section* is called the **Lagging Zone** and that on its right as **Forward Slip Zone.** The amount by which the *velocity* (V_2) of strip at delivery point is higher than the *peripheral velocity* (V) of the roll, is called **Forward Slip.** It is expressed as a percentage of *Roll Velocity* as follows :

$$\textbf{Forward slip} = \frac{V_2 - V}{V} \times 100$$

Its value normally varies from 3 to 10 percent and increases with the increase in roll diameter and coefficient of friction, and also with the reduction in thickness of the strip being rolled.

19.7 TYPES OF ROLLING MILLS

The different types of **Rolling Mills** are described below :

1. Two-high Mill. It consists of two heavy horizontal rolls, placed exactly one over the other. 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 lowering the upper roll. The position of the lower roll is fixed. Both the rolls rotate in opposite directions to one another, as shown in Fig. 19.6. Their direction of rotation is fixed and cannot be reversed. Thus, the work can be rolled by feeding from one direction only.

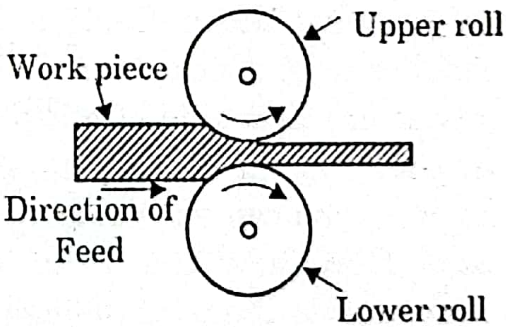

Fig. 19.6. A two high mill.

There is another type of **Two-high Mill** which incorporates a *drive mechanism* that can reverse the direction of rotation of the rolls. This facilitates rolling of the workpiece continuously through back-and-forth passes between the rolls. This type of rolling mill is known as a **Two-high Reversing Mill.** They are normally employed for the initial rolling of an ingot.

2. Three-high Rolling Mills. It consists of three horizontal rolls, positioned directly one over the other, as shown in Fig. 19.7. 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. All the three rolls continuously revolve in the same fixed directions and are never reversed. The work piece is fed in one direction between the upper and middle rolls and in the reverse direction between the middle and lower rolls. Many pieces may be passed through the rolls simultaneously. This results in a higher rate of production than the two-high mill. This mill may be used for *blooming, billet rolling* or *finish rolling*.

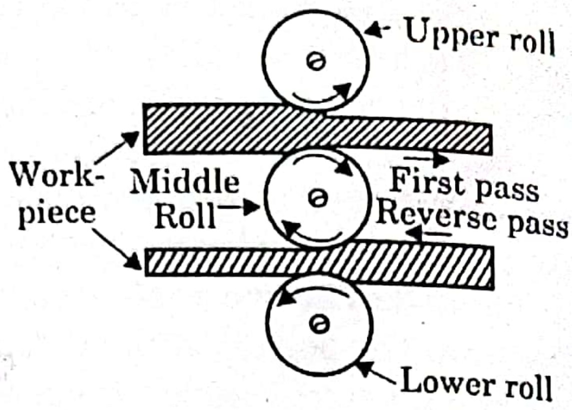

Fig. 19.7. Roll Positions in a three-high rolling mill.

3. Four-high rolling mill. It consists four *horizontal rolls*, two of smaller diameter and two of larger diameter, arranged directly one over the other as shown in Fig. 19.8. 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 *smaller rolls* are known as **Working Rolls** and they are the rolls which concentrate the total rolling pressure over the metal. These mills are generally used for subsequent rolling of *slabs*. The common products of these mills are hot or cold rolled sheets and plates.

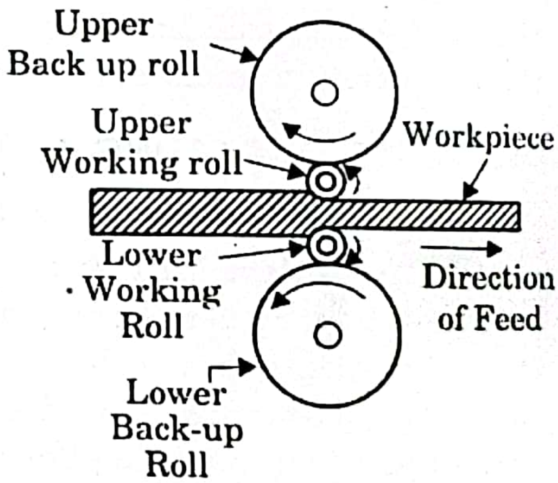

Fig. 19.8. Arrangement rolls in a four-high rolling mill.

4. Cluster mill. It consists of two *Working Rolls* of smaller diameter and four or more *Back-up Rolls* of larger diameter. The arrangement of rolls for this mill is shown in Fig. 19.9. The number of back-up rolls may go up as high as 20 or more, depending upon the amount of support needed for the working rolls during the operation. This type of mill is generally used for **cold rolling.**

5. Continuous rolling mill. It consists of a number of *non-reversing* **Two-high Mills** arranged one after the other, so that the material can be passed through all of them successively. The rolls of each successive *mill stand* rotate at a faster speed than that of the preceding rolls in order to accommodate the increasing length of the metal piece being rolled. This arrangement facilitates a very rapid production because the component passes continuously from one stand to the other until it reaches the final pass. But it is suitable for mass production work only, because for smaller quantities quick changes of set-up will be required and they will consume a lot of time and labour. As the speed of rolls on each successive stand varies it is necessary that their respective surface speeds should be properly calculated and adjusted.

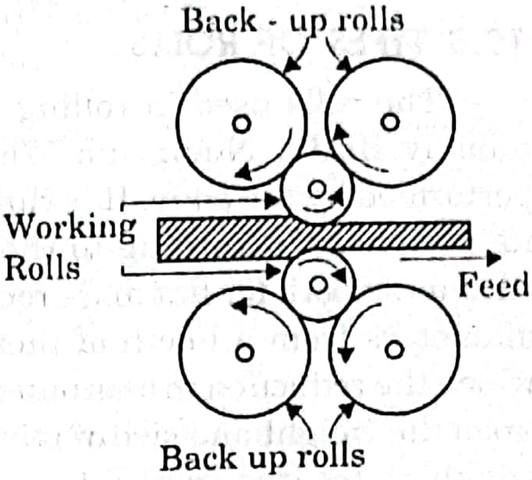

Fig. 19.9. Arrangement of rolls in a cluster mill.

6. Other types of rolling mills and their rolled products

The above **Rolling Mills** are known with various different names according to the types of operations performed and the products obtained from them. A few important names are described below :

(*i*) **Blooming Mills.** A rolling mill used for reducing ingots to **Blooms** is called a **Blooming Mill.** A ***Bloom*** is a square or rectangular piece of metal of which the cross-section ranges between 150 mm × 150 mm to 250 mm × 300 mm.

Billets. They are similar to blooms but have smaller cross-sections. Their sizes range from 50 mm × 50 mm to 150 mm × 150 mm. Generally other types of *Rolling mills* are used for producing billets than those used for blooming.

(*ii*) ***Slabing mills.*** The *Rolling Mills* used for producing *slabs* are known as **Slabing Mills.** Generally, *Two-high Reversing type* rolling mills are used for this purpose.

Slabs. Slabs are also metal pieces with rectangular cross-section having their thickness between 50 mm to 150 mm and width between 300 mm to 1500 mm.

(*iii*) **Primary and secondary mills.** *Blooming* and *slabing* mills are quite often known as **Primary Mills,** and those used for further rolling work as **Secondary Mills.** Primary and secondary rolling mills are also sometimes known as **Roughing and Finishing mills** respectively.

19.8 TYPES OF ROLLS

The rolls used in rolling mills essentially consist of three parts, namely **Body, Neck and Wabbler.** The main rolling operation is performed by the *body*. It is therefore made to have different shapes on its periphery, according to the desired shapes of the rolled products, such as smooth for flat and grooved for other sections. The *Rolls* vary in diameters from a few centimetres to about 1.5 metres. The extent to which the reduction in cross-section can be made in a single pass depends upon the weight and size of the Rolls. The *neck* is that part of the roll on which it rotates in the bearing. The *Wabbler* is the star-shaped construction at both ends of the roll which engages the hollow cylinder to connect it to the driving shaft to receive power. The advantage of providing the wabblers is that the main body of the roll is not directly connected with the driving shaft. Thus, in case of too heavy loading, if there is any damage, it will occur only in the wabbler, which is a much weaker section, and the main body will remain absolutely free from it. The rolls are generally made from cast or forged steel or cast iron. Two types of rolls, in general use, are shown in Fig. 19.10.

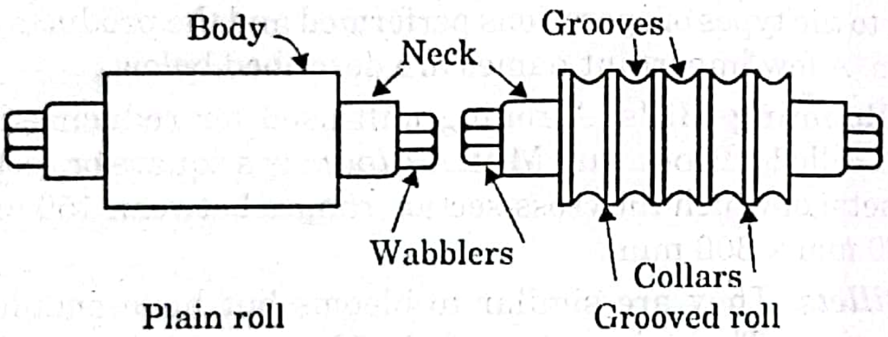

Fig. 19.10. Types of rolls.

19.9 HOT FORGING

This process basically consists of *heating* the metal to *plastic state* and then applying pressure to form it into different shapes and sizes. Unlike rolling, the pressure in this case is not continuous but intermittent. The hot metal piece may be compressed along its length to increase its cross-section, along its cross-section to increase its length, within a closed cavity to acquire the shape of that cavity or in different directions to bend it into different shapes. The pressure may be applied by **Hand Hammer** called **Hand or Smith Forging,** by **Power Hammers,** called **Hammer Forging,** by *presses* **(Press Forging)** or **Upset Forging Machines.** Details of these processes are omitted here since they are covered in detail in chapter 20.

19.10 HOT SPINNING

The process consists of heating the metal to *Forging Temperature* and then forming it into the desired shape on a **Spinning Lathe** which is similar to an engine lathe. Usually, shapes of circular cross-section, which are symmetrical about the axis of rotation, are formed by this process. The workpiece is shaped over a formed revolving metal holding device, called **Chuck**, with the help of *Spinning Tools*. It very well compares with *drawing* or *stamping* in so far as the production in small quantities is concerned, since the cost of *dies* for such small quantities will lead to uneconomical production through the latter methods. **Hot Spinning** is generally used for thicker plates and sheets which cannot be shaped through **Cold Spinning.** In operation, it is similar to *Cold Spinning* and, therefore, the details of equipment, tools and procedure, etc., will be given later under **'Cold Spinning'.**

19.11 HOT EXTRUSION

The process of **Extrusion** consists of compressing a metal inside a chamber to force it out through a small opening called **Die.** Any plastic material can be extruded successfully. Most of the presses used for extruding metals are hydraulically operated horizontal presses. A large number of extruded shapes are in common use, such as tubes, rods, structural shapes and lead covered cables. The principles of operation are the same for both **Hot** and **Cold Extrusion,** and the choice of one of these is governed by factors like the metal to be extruded, thickness of the extruded section, size of the raw material being used, capacity of the press and the type of product, etc. *Billets* of 125 mm to 175 mm in diameter and 300 to 675 mm in length are in general use as raw material for extrusion. *Extrusion of steel* needs adequate lubrication around the billet. This is done by providing a coating of finely powdered glass over the surface of hot billet. The process of *Extrusion* suits best to the *non-ferrous* metals and alloys, although some steel alloys, like stainless steel, are also extruded.

The extrusion processes can be classified as :

1. **Direct** or **Forward** Extrusion
2. **Indirect** or **Backward** Extrusion.

Direct or Forward Extrusion

Direct or **Forward** *Hot Extrusion* method is the most widely used method, and the maximum number of extruded parts are produced by this method. The process is illustrated in Fig. 19.11. The raw material used is a *billet*. It is heated to its forging temperature and fed into the *machine chamber*. *Pressure* is applied to the billet, forcing the material through the **die.** The length of extruded part will depend upon the size of the billet and cross-section of the die. The extruded part is then cut to the required length. The overhanging extruded length is fed onto a long support called the **Run Out Table.** It is a usual practice to leave the last nearly 10% length of billet as unextruded. This portion is known as **Discard** and contains the surface impurities of the billet.

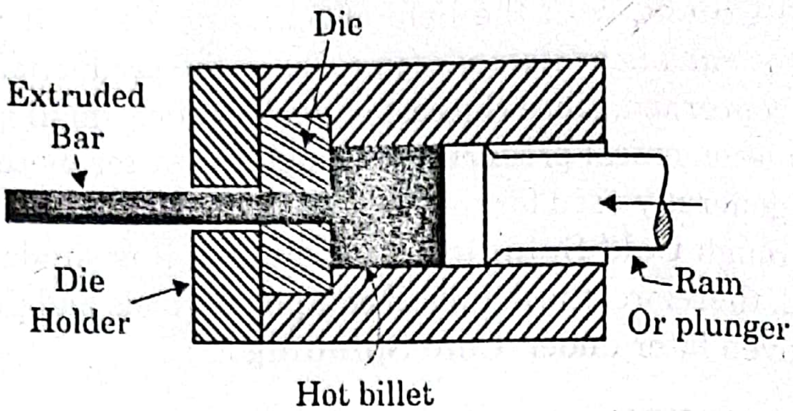

Fig. 19.11. Direct or forward extrusion.

Backward or Indirect Extrusion. For this type of extrusion the **Ram** or **Plunger** used is *hollow*, and as it presses the billet against the backwall of the closed chamber and the metal is *extruded back* into the *plunger*. As the billet does not move inside the chamber, there is no friction between them. As such, less force is needed in this method in comparison to the direct extrusion. A more *complicated* type of *equipment* is required because the **Plunger** becomes weak due to the reduction in its *effective area* of cross-section and difficulty is experienced in supporting the overhanging extruded part. The process is illustrated in Fig. 19.12.

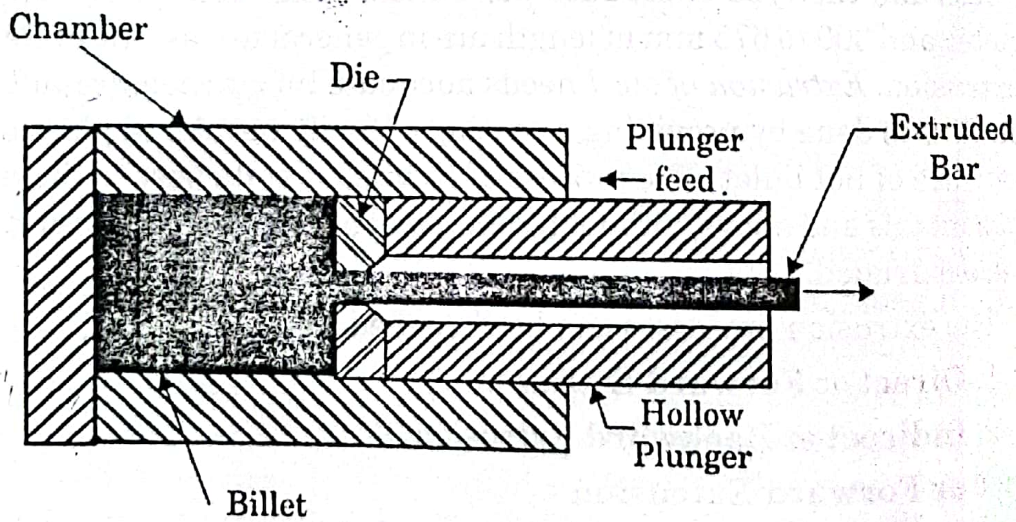

Fig. 19.12. Backward or indirect extrusion.

Advantages and Limitations of Hot Extrusion

1. A very dense structure of metal is obtained because of high pressures used and compressive nature of the process.
2. Surface finish of the product is quite smooth with relatively close tolerances.
3. It is a very rapid process and involves low tool costs.
4. It is an ideal process for producing parts of uniform cross-section in large quantities.
5. In many cases it proves cheaper than pressure die casting with comparable finish and tolerances.

Tube Extrusion

A common method of *Hot extrusion* of **Tubes** is shown in Fig. 19.13. It is actually a *forward extrusion* method using a **mandrel** to form the *bore* of the tube. First the mandrel is pushed through the centre of the billet and the die, followed by applying pressure on the billet by advancing the plunger. The metal is forced to *flow* through the opening between the *die* and the *mandrel*. The operation is performed quite rapidly. Most of the metals and alloys are hot extruded, although some of these are cold extruded also, for production of *seamless tubes*.

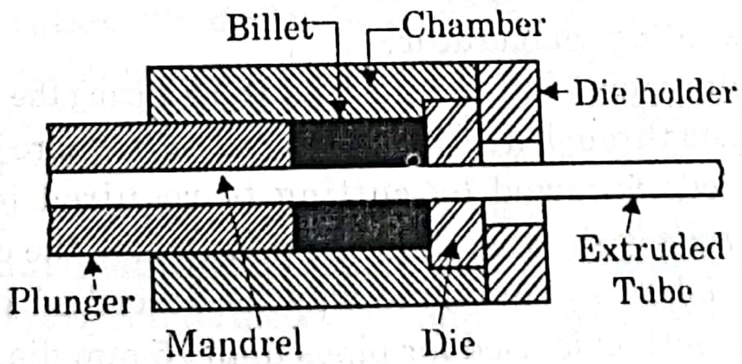

Fig. 19.13. Extrusion of a seamless tube.

19.12 WELDED PIPE AND TUBE MANUFACTURING

Welded Pipe is made from a flat strip of which one end is *crimped*. It is known as the **Skelp.** Its edges are *bevelled* to butt properly when the skelp is formed into a round shape for welding the seam. The *skelp* is charged into a furnace and heated to its welding temperature. It is then drawn out of the furnace by gripping its *crimped end* with tongs which are attached to a *draw chain*. The gripped skelp is pulled through a *Welding Bell* which forms it into the round shape and simultaneously enables pressing and welding together of the bevelled edges. Thus, on one side of the bell enters the **hot skelp** and on the other side emerges the **welded pipe**, as shown in Fig. 19.14. This welded pipe is then passed through the *sizing rolls*, shown in Fig. 19.15, to bring it to the correct outside diameter. Finally it is passed through the *finishing* and *straightening rolls* where it is correctly finished, its surface appearance improved by removing scale and it is straightened. It is then cut into desired lengths, its ends finished and threaded. The above method is an intermittent method of forming welded pipes.

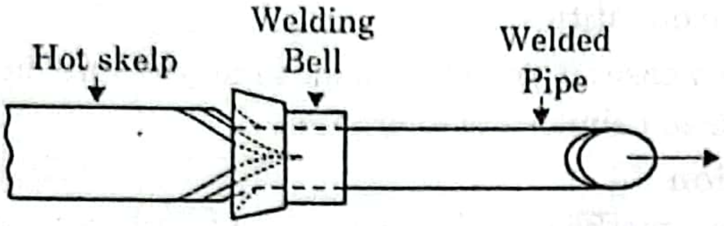

Fig. 19.14. Production of a welded pipe.

A **Continuous Butt-Welded Pipe** is produced by using the *skelp* in the form of a *coil*. The ends of the coiled strips are welded to form a continuous strip. It is then passed through the furnace where the flames are directed towards the edges to bring them to welding temperature. As the hot skelp comes out of the furnace it is passed through a series of *grooved rolls* where it is rounded, welded and sized, followed by cutting to required lengths. The arrangement of *rolls* is shown in Fig. 19.16. As usual, the cut lengths of the pipe are finished in the same way as described in the above paragraph. This method is used for pipes upto 75 mm dia.

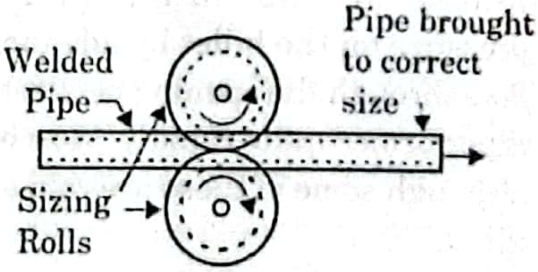

Fig. 18.15. Sizing the welding pipe..

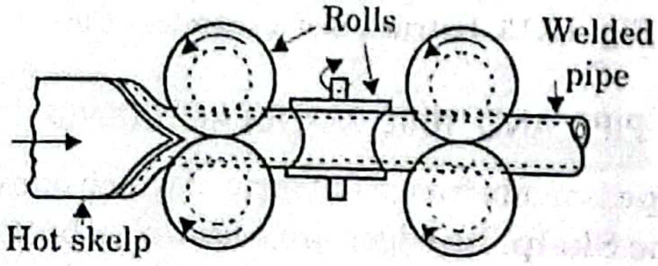

Fig. 19.16. Production of a continuous butt-welded pipe.

Another method of making **Continuous Butt-Welded Pipes** is to weld them by **Electric Resistance Welding.** For this, the first thing is to roll form the *steel strip* into a *circular* shape by passing it through

Advantages and Limitations of Hot Extrusion

1. A very dense structure of metal is obtained because of high pressures used and compressive nature of the process.
2. Surface finish of the product is quite smooth with relatively close tolerances.
3. It is a very rapid process and involves low tool costs.
4. It is an ideal process for producing parts of uniform cross-section in large quantities.
5. In many cases it proves cheaper than pressure die casting with comparable finish and tolerances.

Tube Extrusion

A common method of *Hot extrusion* of **Tubes** is shown in Fig. 19.13. It is actually a *forward extrusion* method using a **mandrel** to form the *bore* of the tube. First the mandrel is pushed through the centre of the billet and the die, followed by applying pressure on the billet by advancing the plunger. The metal is forced to *flow* through the opening between the *die* and the *mandrel*. The operation is performed quite rapidly. Most of the metals and alloys are hot extruded, although some of these are cold extruded also, for production of *seamless tubes*.

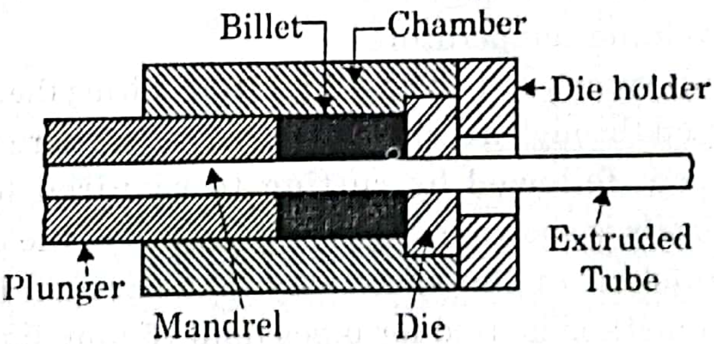

Fig. 19.13. Extrusion of a seamless tube.

19.12 WELDED PIPE AND TUBE MANUFACTURING

Welded Pipe is made from a flat strip of which one end is *crimped*. It is known as the **Skelp.** Its edges are *bevelled* to butt properly when the skelp is formed into a round shape for welding the seam. The *skelp* is charged into a furnace and heated to its welding temperature. It is then drawn out of the furnace by gripping its *crimped end* with tongs which are attached to a *draw chain*. The gripped skelp is pulled through a *Welding Bell* which forms it into the round shape and simultaneously enables pressing and welding together of the bevelled edges. Thus, on one side of the bell enters the **hot skelp** and on the other side emerges the **welded pipe,** as shown in Fig. 19.14. This welded pipe is then passed through the *sizing rolls*, shown in Fig. 19.15, to bring it to the correct outside diameter. Finally it is passed through the *finishing* and *straightening rolls* where it is correctly finished, its surface appearance improved by removing scale and it is straightened. It is then cut into desired lengths, its ends finished and threaded. The above method is an intermittent method of forming welded pipes.

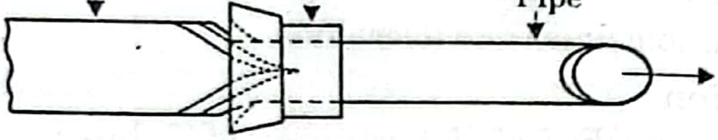

Fig. 19.14. Production of a welded pipe.

A Continuous Butt-Welded Pipe is produced by using the *skelp* in the form of a *coil*. The ends of the coiled strips are welded to form a continuous strip. It is then passed through the furnace where the flames are directed towards the edges to bring them to welding temperature.

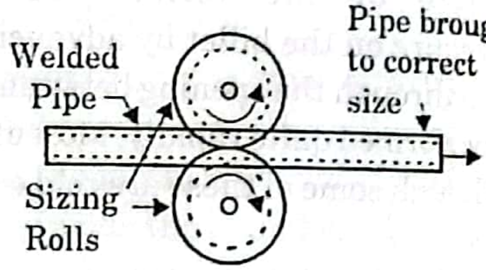

Fig. 18.15. Sizing the welding pipe.

As the hot skelp comes out of the furnace it is passed through a series of *grooved rolls* where it is rounded, welded and sized, followed by cutting to required lengths. The arrangement of *rolls* is shown in Fig. 19.16. As usual, the cut lengths of the pipe are finished in the same way as described in the above paragraph. This method is used for pipes upto 75 mm dia.

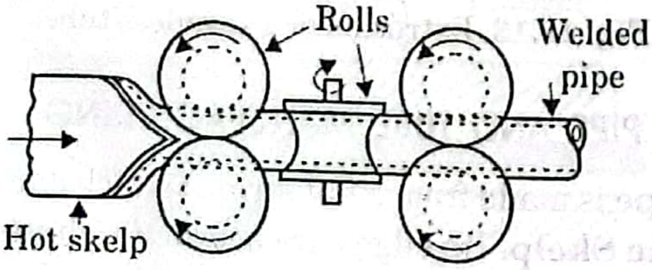

Fig. 19.16. Production of a continuous butt-welded pipe.

Another method of making **Continuous Butt-Welded Pipes** is to weld them by **Electric Resistance Welding.** For this, the first thing is to roll form the *steel strip* into a *circular* shape by passing it through a series of rolls where its shape is gradually changed into circular. The operation is known as **Roll Forming.** After emerging from the roll forming machine the pipe is passed through a set of **Centering** and **Pressure Rolls** and two **Electrode Rolls,** as shown in Fig. 19.17. After this, the pipe is passed through sizing and finishing operations as usual. This method is used for pipes upto 400 mm diameter and wall thickness between 3 mm to 6 mm. Larger pipes than this are welded by **Submerged Arc Welding** after being formed to shape in heavy presses.

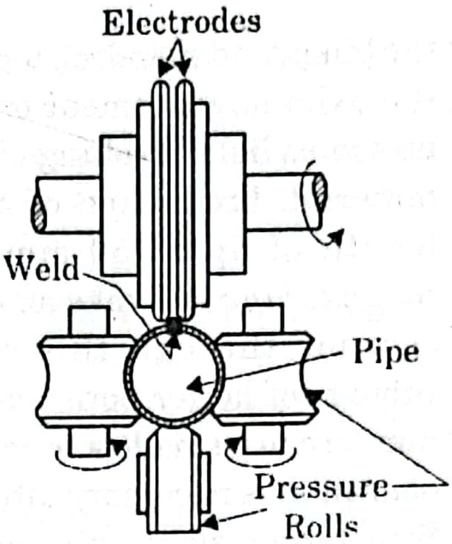

Fig. 19.17. Use of electric resistance welding for production of continuous welded pipe.

Lap welding. This method of welding is used for pipes from 50 mm to 400 mm dia. For this the **skelp** is heated as usual in the furnace, and as it comes out its edges are *bevelled*. It is then *rounded* through a suitable method with its edges overlapping. It is then reheated to welding heat and passed through a pair of *grooved rolls* over a *mandrel* positioned between them. The lapped ends are pressed together and welded as the pipe passes through the rolls. The mandrel forms the inside bore of the pipe.

Welded tubes. Welded tubes can also be manufactured through *Butt* and *Lap* welding methods. Both *Electric Resistance Welding* and *Fusion Welding* methods are used. **Butt welding** is suitable for diameters between 3 mm to 75 mm, **Lap welding** from 50 mm to 500 mm, **Hammer welding** (a *forge welding process*) from 500 mm to 2400 mm and **Fusion welding** for diameters above 150 mm. Before welding, the steel strips are roll formed to circular shape in cold state.

19.13 ROLL PIERCING

It is a method of producing seamless tubes. The piercing machine used in the process consists of two *tapered rolls*, called **Piercing Rolls.** Round heated *billet* of steel is passed between these rolls over a *mandrel*, as shown in Fig. 19.18. Both the rolls rotate in the same direction. The billet is centre punched or provided with a small drilled hole at one end and heated to proper temperature. It is then pushed forward into the rolls. The rolls grip the billet and pull it further into them. The *axes* of the rolls are crossed and, therefore, they revolve the billet as well as draw it forward to force it on to the mandrel. The mandrel can also revolve in its own position. This combination of the *revolving motions* of the billet, and mandrel, together with the axial advancement of the billet, provide a helical rolling effect on the material. Production of a 12 metre length of upto 150 mm diameter *rough tubing* will take about 10 to 30 seconds through this method. If tubings of larger bore (say upto 350 mm) are to be made a *second* piercing operation is necessary after the first. Still larger sizes will need a *third* piercing operation.

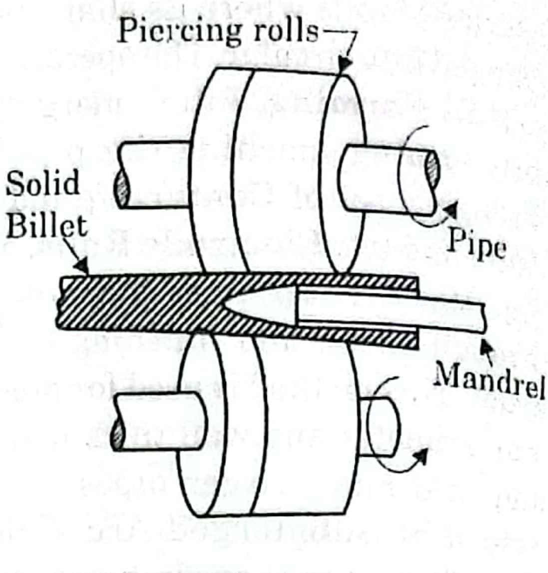

Fig. 19.18. Roll piercing.

The rough tubing produced, as above, is further subjected to rolling, reeling and sizing etc., to bring it to the correct shape and size and to provide a fine surface finish. Such tubes are produced in various metals and alloys like steel alloys, aluminium, brass and copper etc.

19.14 HOT DRAWING

This process is widely used for the production of *thicker walled* **Seamless Tubes** and **Cylinders.** It is usually performed in two stages. The first stage consists of drawing a *cup shape* out of a hot circular plate with the help of a die and a punch. The second stage consists of reheating the drawn cup and drawing it further to the desired length having the required wall thickness. The *second* drawing operation is performed through a number of dies, which are arranged in a *descending order* of their diameters, so that the reduction in wall thickness is gradual in various stages. The farther end of the drawn object is always blind, which may be cut off to produce a through hole, if required.

19.15 COLD WORKING

Inspite of a number of operations being common to both **Hot** and **Cold** working of metals the latter has an altogether different effect on the structure and physical properties of the worked metal. Unlike *Hot working* it distorts the grain structure and does not provide an appreciable reduction in size. It requires much *higher pressures* than hot working. Since *recrystallisation* does not take place in cold working, the grains are permanently distorted. As a result of the greater resistance offered by the metal to deformation, its strength and hardness are increased. This type of hardening of metal is called **Strain Hardening.** The extent to which a metal can be cold worked depends upon its *ductility*. The higher the ductility of the metal, the more it can be cold worked. **Residual Stresses** are setup during cold working. As their presence is undesirable a suitable **Heat Treatment** is generally necessary to neutralise these stresses and restore the metal to its original structure.

Advantages and Limitations

1. Better dimensional control than hot working is possible because the reduction in size is not much.
2. Surface finish of the component is better because no oxidation takes place during the process.
3. Strength and hardness of the metal are increased, but ductility is decreased.
4. It is an ideal method for increasing hardness of those metals which do not respond to the heat treatment.
5. Only ductile metals can be shaped through cold working.
6. Over-working of metal results in brittleness and it has to be annealed to remove the same.
7. Subsequent heat treatment is mostly needed to remove the residual stresses setup during cold working.

The common cold working processes are described in the following articles.

19.16 COLD ROLLING

Cold Rolling is generally employed for providing a smooth and bright surface finish to the previously *Hot Rolled* steel. It is also used to finish the hot rolled components to close tolerances and improve their toughness and hardness. The items generally subjected to cold rolling for this purpose are bars, rods, sheets, plates, strips and wires, etc. Before being put to cold rolling the *hot rolled* articles are cleaned through *Pickling* and other operations. The same types of *Rolling Mills*, described earlier in connection with hot rolling, are used in cold rolling. In order to obtain a smooth surface finish the roll surfaces are polished and scratches, if any, removed. The part being rolled is usually *annealed* and *pickled* before the final pass is made, so as to bring it to accurate size and obtain a perfectly clean surface.

19.17 COLD DRAWING

The common items which are cold drawn are tubes, bars, rods, wires and a few typical shapes and items of novelties.

Tube Drawing. *Seamless* and *Welded tubes*, produced through hot working, are further cold drawn for providing a good surface finish, better dimensional accuracy and improve physical properties. *Cold Drawing* also enables production of tubes with much finer bore than that possible through hot drawing. The *Hot Drawn* tubes are pickled and washed before being put to cold drawing in order to clean their surfaces from *scale*, etc.

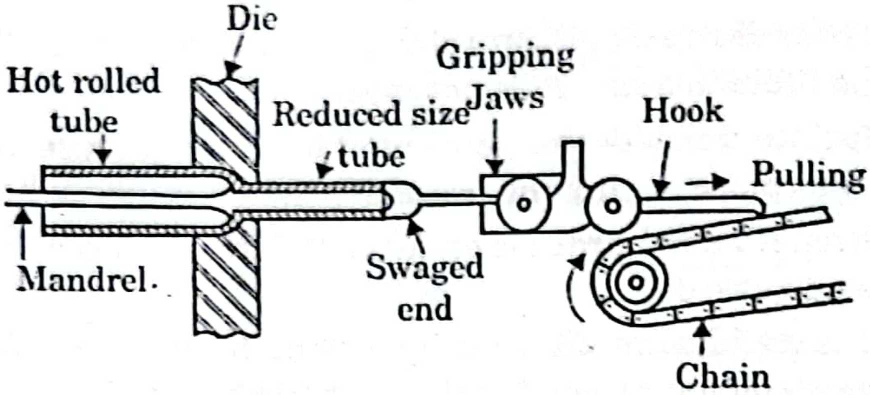

Fig. 19.19. Cold drawing of tubes.

The *Drawing Equipment* consists of a *draw bench* and a *die*. One end of a tube is reduced in diameter by *swaging* and passed through the die. On the other side of the die this end is gripped in *tongs* which are connected to the draw bench. The tube is pulled through the die over a fixed mandrel. The outside diameter of the tube is controlled by the opening of the die and the inside bore by mandrel. The operation is shown in Fig. 19.19. Tubes with very small bores, or those in which the inside diameter is not of very specific importance, may be drawn without using the mandrel. Reduction in one pass is not more than 40 percent. If a heavier reduction is desired, several passes may be required. The metal is annealed after every pass in order to remove the effect of strain hardening.

Wire, Rod and Bar Drawing. Hot drawn bars and rods are pickled and washed, before putting them to cold drawing. A high surface finish ana dimensional accuracy is obtained by cold drawing and, therefore, these products can be used directly without requiring any further machining. The process consists of pulling the hot drawn *bar* or *rod* through a die of which the bore size conforms to the finished size of the product.

For Wire Drawing, the rolled bars obtained from the mills are first pickled, washed and coated to prevent oxidation. They are then passed through a die to provide the desired reduction in size. Depending upon the material to be drawn and the amount of the reduction required, total drawing may be accomplished in a single die or in a series of *Successive Dies.*

One end of the rod to be drawn into wire is made pointed, entered through the die and gripped at the other end by means of *tongs*. After pulling a certain length, this end is wound to a reel or *Draw Pulley*. When the pulley or reel is rotated the rod is pulled through the die and its diameter reduced. A die and reduction of bar diameter are depicted in Fig. 19.20.

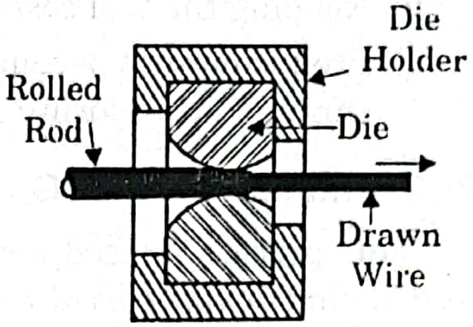

Fig. 19.20. Wire drawing.

The *die* should be of a highly wear resistant material. The most widely used material for this purpose is *tungsten carbide*. The die made out of it is suitably supported in a *die holder* made of mild steel or brass.

19.18 COLD SPINNING

The process is similar to *Hot Spinning*, described earlier. The metal is pressed on to the surface of a wooden or metallic **Form, called Chuck,** attached to the lathe spindle. An *adapter* fitted in the barrel of the *tailstock* holds the work against the form. The tools used, called *Spinning Tools*, are provided with blunt edges and are supported on the *toolrest* fitted on the *cross slide*, as shown in Fig. 19.21.

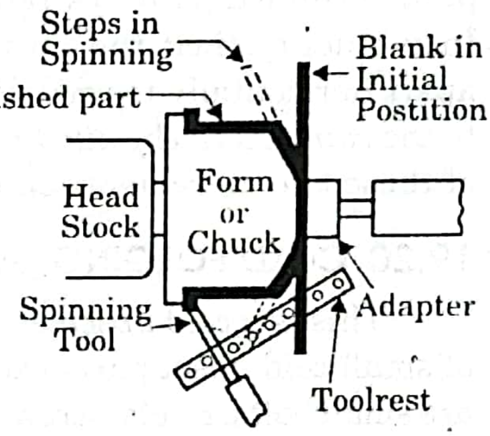

Fig. 19.21. Cold spinning.

Aluminimum and other soft metals are best suited for cold spinning. A few commonly used spun articles out of aluminium and its alloys are processing kettles, cooking utensils, liquid containers and light reflectors etc. Various other *ductile metals*, particularly non-ferrous ones, are quite successfully spun into various typical shapes. The thickness of the metal is reduced during spinning, and proper allowance should be made for this in the *blank* to be cut. At the end of the operation the unwanted material is trimmed off to bring the product to required size. The *form* or *chuck* may be in single piece or composed of many sections attached together, depending upon the possibility of removal of the spun part from it. Where the shape of the part does not permit its removal from chuck, **Off-centre Chucks** are used. This process of spinning is generally used for :

1. Limited production.

2. Keeping the tool costs low.
3. Producing such peculiar shapes which are difficult to be produced through other forming methods.

19.19 STRETCH FORMING

This process is used for forming of *smoothly contoured* parts, or those having *double curvatures* on the same curved surface, out of large and thin metal sheets. The operation can be performed in two ways. One method is to grip the two edges of the metal sheet firmly and stretch the same over a fixed **Form Block**. This sheet is gripped on both sides by two *jaws*. These jaws are attached to the rods of pistons which work inside respective *hydraulic cylinders*. By providing pressure on these pistons the jaws can be pulled away and tensile forces provided on the sheet. At the same time the cylinders can be moved in guides along a predetermined path to stretch the sheet along the contour of the form. In another method, the jaws are mounted on two sides which are moved apart horizontally to provide tension on the seat. The form is attached to the *ram* of a *Hydraulic Press* which moves upwards. The combination of these two movements enables the desired *Forming* of the sheet.

19.20 COLD FORGING, SWAGING OR COLD HEADING

This is a cold *upsetting* process adopted for large scale production of small cold upset parts from *wire stock*. A few examples of such parts are small bolts, rivets, screws, pins, nails and small machine parts. Small balls for ball bearings are also made by this method.

The machine used is similar in *Hot Forging*. **Dies** are used for forming the desired shapes. In cold heading of bolts and rivets etc., the rod is fed upto stops through *straightening rolls*, cut to size and pushed into the *Header die*. The rod is gripped in the die and a punch operates on the projected part to apply pressure and form the head. The *Heading* operation may be completed in a single or two strokes. **Automatic Machines** for producing bolts and screws are also available in which all the operations like cutting stock to size, shank extrusion, heading, trimming and threading etc. are performed simultaneously to produce finished components. The process is also successfully adopted for producing *rivets* and *nails*.

Rotary Swaging

It is an interesting cold forging operation used for producing round components through *impact*. An example is the copper nozzle of a welding torch. The operation of dies in this process is shown in Fig. 19.22. A typical application of *Rotary Swaging* is to reduce and taper the surfaces of tubes, bars, rods and wires. The dies are engaged in a slot provided on the face of a spindle which revolves at a fairly high speed. A *housing* surrounds the *spindle* and a number of hardened *steel balls* are provided between the housing and the spindle. As the spindle revolves the dies pass between pairs of opposite rolls, which close the dies. Thus, the dies are opened and closed alternately as they pass between the *gaps* and *rolls*, and the metal is gradually squeezed to the required shape and size. As the *Swaging pressure* is quite high, the metal gets hardened and annealing has to be done to reduce the same.

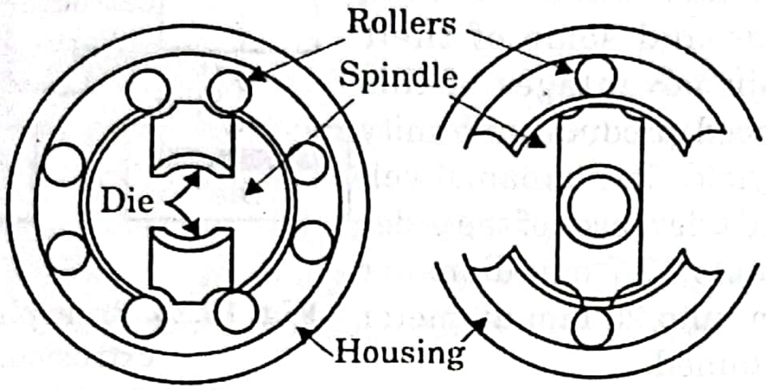

Fig. 19.22. Rotary swaging.

19.21 COLD HOBBING

It is a process used for producing cavities of various shapes in a blank of soft metal by pressing a hardened *steel form* into it. This form is known as a **Hob.** The operation may require several pressings and annealings in between. *Hydraulic presses* are used for providing the required pressure. The main advantage of this process is the economical production of identical cavities in large number. *Moulds* for *Plastic Moulding* can be produced through this method.

19.22 COLD EXTRUSION

The most common *cold extrusion* process is **Impact Extrusion,** shown in Fig. 19.23. Various items of daily use such as tubes for shaving creams, tooth pastes and paints, condenser cans and such other thin walled products are *impact extruded*. The raw material used is in *slug form* having been either turned from a bar or punched out of a strip. The operation is performed with the help of a **punch** and a **die.** The prepared **slug** is placed in the die and struck from top by the punch operating at high pressure and speed. The metal *flows* up along the surface of the punch, forming a cup shaped component. When the punch moves up compressed air is used to separate the component from the punch. In the meanwhile a fresh slag is fed into the die. The production rate is fairly high, giving about 60 components per minute.

The minimum base thickness and wall thickness available respectively are 0.7 mm and 0.1 mm. The application of the process is, however, limited to soft and ductile materials such as lead, tin, aluminium, zinc and some of their alloys. The main advantages of this process are its speed, product uniformity and low scrap yield. It compares well with drawing and tolerances of the order of ± 0.762 mm upto 12.7 mm diameter and ± 0.127 mm upto 25 mm diameter can be easily obtained.

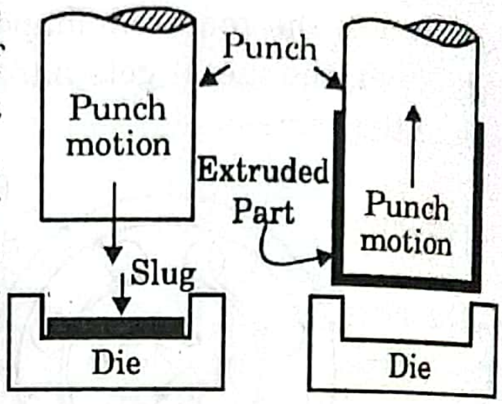

Fig. 19.23. Principle of impact extrusion.

19.23 EMBOSSING

It is a process through which **Blanks** of sheet metal are *stretched* to shape under pressure by means of a *Punch* and a *Die*. The punch operates at a low speed to allow time for proper stretching. A simple example is depicted in Fig. 19.24. The operation gives a *stiffening* effect to the metal being embossed. Stress in the material may be reduced by producing deep parallel *ridges*. A large number of ornamental wares, such as **plates**, in sheet metal, are produced by embossing. A simple form of this process, called *Open Embossing*, consists of producing simple shallow shapes by the punch only.

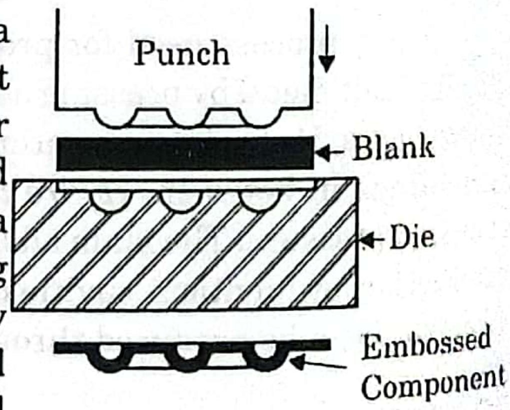

Fig. 19.24. Embossing.

19.24 COINING

This operation is carried out in **dies** in which the metal is confined and its *lateral flow* is restricted. It is vastly used for the production of medals and coins etc. which carry shallow configurations on their surfaces. The process consists of placing a metal *slug* (blank) in the *die* and applying heavy pressure by the *punch*. The metal flows plastically and is squeezed to the shape between punch and die. The process, on account of the very high pressures required, can be employed only for soft metals with high plasticity. An example is shown in Fig. 19.25.

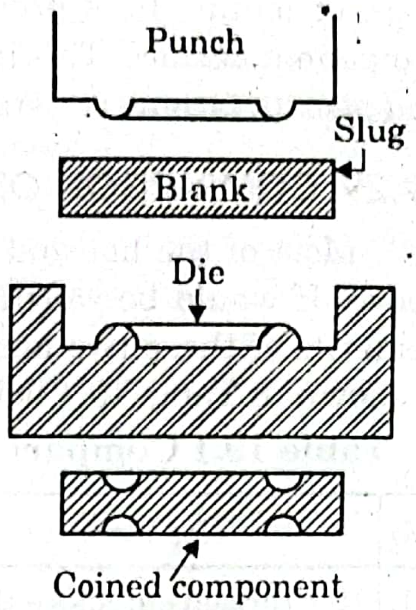

Fig. 19.25. Coining.

19.25 COLD BENDING

It is employed for *bending* into desired shapes various stock materials like rods, wires, bars, pipes, tubes and various structural shapes. *Formed dies* are used for bending these articles and the operation is usually performed in many stages. Well designed *fixtures* are also used where mass bending of such components is required.

19.26 ROLL FORMING

This process consists of feeding a continuous metal strip through a series of *rolls*, whereby it is gradually formed into desired shapes. The roll formed may be used in *'as formed'* condition with their both edges separate from each other. Alternatively, they may be welded to form a closed section such as tubing and pipes. The number of rolls employed in the series depends upon the shape to be formed. The forming machines also carry *Guide Rolls* and *Straightening Rolls*.

19.27 ROLL BENDING

It is also a kind of *Roll forming* operation through which metal sheets and plates are bent into cylindrical shapes. The roll bending machine carries three rolls ; two being fixed and the third adjustable. Diameters of all the rolls are same. By adjusting the position of the adjustable roll the plates or sheets can be bent in different curvatures.

19.28 SHOT PEENING

This process consists of throwing a blast of *metal shots* on to the surface of a component. The *blast* may be thrown either by air pressure or with the help of a wheel revolving at high speed. This high velocity blast of metal shots provides a sort of compressive action over the component surface. This increases strength and hardness of the surface and also its fatigue resistance.

19.29 COMPARISON OF HOT WORKING WITH COLD WORKING

Most of the hot and cold working processes have been discussed above. If would be worthwhile to summarise the relative merits and demerits of these two metal working processes here. This comparison is shown in Table 19.1 below :

Table 19.1 Comparison of hot working and cold working.

No.	*Hot Working*	*Cold Working*
1.	It is carried out above the recrystallisation temperature but below the melting or burning point. Hence, deformation of metal and recovery take place simultaneously.	It is carried out below the recrystallisation temperature. As such, there is no appreciable recovery.
2.	No internal or residual stresses are set up in the metal in hot working.	In this process internal or residual stresses are set-up in the metal.
3.	Due to recrystallisation and recovery no or very negligible hardening of metal takes place.	Since this is done below recrystallisation temperature the metal gets work hardened.
4.	Due to higher deformation temperatures used the stress required for effecting deformation is less.	The stress required to cause deformation is much higher.
5.	Hot working refines metal grains, resulting in improved mechanical properties.	Most of the cold working processes lead to distortion of grains.
6.	If cracks and blow holes are present in the metal, they are finished through hot working.	In cold working the existing cracks propagate and new cracks may develop.
7.	If properly performed, it does not effect UTS, hardness, corrosion resistance, yield strength and fatigue strength of the metal.	It improves UTS, hardness, yield strength and fatigue strength but reduces the corrosion resistance of the metal.
8.	It helps in removing the irregularities in metal composition, breaking up the non-metallic impurities into tiny fragments and dispersing them throughout the metal and, thus, promotes uniformity of composition in the metal.	It results in the loss of uniformity of metal composition and, thus, effects the metal properties.

No.	Hot Working	Cold Working
9.	It results in improvement of some mechanical properties like impact strength and elongation.	Impact strength and elongation are reduced in this process.
10.	Surface finish of hot worked parts is relatively poorer due to oxidation and scaling.	Cold worked parts carry better surface finish.
11.	Close dimensional tolerances can not be maintained.	Superior dimensional accuracy can be obtained.
12.	It is mainly preferred where heavy deformation is required and work hardening is not the primary requirement.	It is preferred where work hardening is required and it is desired to obtain a better surface finish with close dimensional tolerances.

19.30 SUGGESTED BIS CODES FOR FURTHER REFERENCE

IS 11505 : 1986	IS 11524 : 1986	IS 11684 : 1986
IS 11742 : 1986	IS 13344 : 1985	IS 1292 : 1958
IS 1852 : 1985	IS 1863 : 1979	IS 1864 : 1979
IS 513 : 1986	IS 1079 : 1988	IS 1148 : 1982
IS 1956(3) : 1975	IS 1993 : 1982	IS 2385 : 1977
IS 2507 : 1975	IS 2591 : 1982	

TEST QUESTIONS

1. Explain the terms 'Mechanical working' and 'Plastic flow' of metals.
2. What do you understand by 'recrystallisation' and 'recrystallisation temperature' ?
3. What is 'hot working' ? What are its advantages and disadvantages' ?
4. What are the common hot working processes ?
5. What principle is involved in hot rolling ? Explain.
6. How is the grain structure of the metal effected during rolling ?
7. Is the pressure of the roll over the metal surface in contact uniform throughout ? If not, how does it vary ?
8. How many types of rolling mills are in commercial use ? Describe their arrangements of rolls, specific uses and other details.
9. What is a continuous rolling mill ? What are its advantages.
10. Sketch and describe the different types of rolls used in rolling mills.

11. Write short notes on :
    (a) Hot spinning. (b) Hot forging.
    (c) Hot drawing.
12. What is hot extrusion ? In how many ways it can be performed ?
13. How does direct extrusion differ from indirect extrusion ? Discuss their relative merits and demerits.
14. Describe the process of hot extrusion of tubes.
15. How are welded pipes and tubes manufactured ?
16. Explsain the different methods of welding used for the manufacture of welded pipes and tubes.
17. What is roll piercing, and for what purpose is it used ?
18. How does cold working differ from hot working ?
19. What are the specific advantages and limitations of cold working ?
20. Explain the following cold working processes :
    (a) Cold rolling. (b) Stretch forming.
    (c) Cold hobbing. (d) Cold bending.
21. Explain the various cold drawing process. For what purpose is a draw bench used in these operations ?
22. Describe the process of cold spinning stating its advantages and specific uses.
23. What are cold forging and swaging ? What for is cold heading used ? Explain the process of rotary swaging with the help of a neat sketch.
24. What is impact extrusion ? Explain this process and state its specific applications.
25. Describe the following cold working process :
    (a) Embossing (b) Coining.
    (c) Roll forming. (d) Roll bending.
    (e) Shot peening.