2.1 Introduction

- Mechanical working of a metal is a simply plastic deformation performed to change the dimensions, properties and surface conditions with the help of mechanical pressure.
- Depending upon the temperature and strain rat, mechanical working may be either hot working or cold working, such that recovery process takes place simultaneously with the deformation.
- The plastic deformation of metal takes place due to two factors i.e. deformation by slip and deformation by twin formation.
- During deformation the metal is said to flow, which is called as plastic flow of the metal and grain shapes are changed.
- If the deformation is carried out at higher temperatures, then the new grains start growing at the locations of internal stresses.
- When the temperature is sufficiently high, the grain growth is accelerated and continues till the metal comprises fully of new grains only.
- This process of formation of new grains is called as **recrystallization** and the corresponding temperature is the recrystallization temperature of the metal.
- Recrystallization temperature is the point which differentiates hot working and cold working.
- Mechanical working of metals above the recrystallization temperature, but below the melting or burning point is known as **hot working** whereas; below the recrystallization temperature, is known as **cold working.**

2.2 Hot working

- Hot working is accomplished at a temperature above the recrystallization temperature but below the melting or the burning point of the metal, because above the melting or the burning point, the metal will burn and become unsuitable for use.
- Every metal has a characteristic hot working temperature range over which hot working may be performed.
- The upper limit of working temperature depends on composition of metal, prior deformation and impurities within the metal.
- The change in structure form hot working improves mechanical properties such as ductility, toughness, resistance to shock and vibration, % elongation, % reduction in the area, etc.

- The principal hot working process applied to various metals are as follows:
    1. Hot rolling
    2. Hot extrusion
    3. Hot spinning
    4. Roll piercing
    5. Hot drawing
    6. Hot forging

Advantages

- Due to hot working, no residual stresses are introduced in the metal.
- Hot working refines grain structure and improves physical properties of the metal.
- Any impurities in the metal are disintegrated and distributed throughout the metal.
- Porosity of the metal is minimized by the hot working.
- During hot working, as the metal is in plastic state, large deformation can be accomplished and more rapidly.
- Hot working produces raw material which is to be used for subsequent cold corking operations.

Disadvantages

- As hot working is carried out at high temperatures, a raid oxidation or scale formation takes place on the metal surface which leads to poor surface finish and loss of metal.
- Due to the loss of carbon from the surface of the steel piece being worked, the surface layer loses its strength.
- This weakening of the surface layer may give rise to fatigue crack which results in failure of the part.
- Close tolerances cannot be obtained.
- Hot working involves excessive expenditure on account of high tooling cost.

2.3 Cold working

- The working of metals at temperatures below their recrystallization temperature is called as cold working.
- Most of the cold working process are performed at room temperature.
- Unlike hot working, it distorts the grain structure and does not provide an appreciable reduction in size.
- Cold working requires much higher pressure than hot working.
- If the material is more ductile, it can be more cold worked.

- Residual stresses are setup during the process, hence to neutralize these stresses a suitable heat treatment is required.
- The principal methods of cold working are as follows:

1. Cold rolling	2. Cold drawing
2. Cold spinning	4. Stretch forming
5. Cold forging and swaging	6. Cold extrusion
7. Coining	8. Embossing
9. Cold bending	10. Roll forming
11. Shot peening	12. High Energy Rate Forming (HERF)

Advantages

- Better dimensional control is possible because there is not much reduction in size.
- Surface finish of the component is better because no oxidation takes place during the process
- Strength (tensile strength and yield strength) and hardness of metal are increased.
- It is an ideal method for increasing hardness of those metals which do not respond to the heat treatment.

Disadvantages

- Ductility of the metal is decreased during the process.
- Only ductile metals can be shaped through the cold working.
- Over-working of metal result in brittleness and it has to be annealed to remove this brittleness.
- To remove the residual stresses setup during the process, subsequent heat treatment is mostly required.

2.4 Comparison between Hot working and Cold working

Sl.No.	Hot Working	Cold Working
1.	Hot working is carried out above the recrystallization temperature but below the melting point, hence deformation of metal and recovery takes place simultaneously.	Cold working is carried out below the recrystallization temperature and as such there is not appreciable recovery of metal.
2.	During the process, residual stresses are not developed in the metal.	During the process, residual stresses are developed in the metal.
2.	Because of higher deformation temperature used, the stress required	The stress required to cause deformation is much higher.

	for deformation is less.	
4.	Hot working refines metal grains, resulting in improved mechanical properties.	Cold working leads to distortion of grains.
5.	No hardening of metal takes place.	Metal gets work hardened.
6.	If the process is properly perfumed, it does not affect ultimate tensile strength, hardness, corrosion and fatigue resistance of the metal.	It improves ultimate tensile strength, yield and fatigue strength but reduces corrosion resistance of the metal.
7.	It also improves some mechanical properties like impact strength and elongation.	During the process, impact strength and elongation are reduced.
8.	Due to oxidation and scaling, poor surface finish is obtained.	Cold worked parts carry better surface finish.
9.	Close dimensional tolerance cannot be maintained.	Superior dimensional accuracy can be obtained.
10.	Hot working is most preferred where heavy deformation is required.	Cold working is preferred where work hardening is required.

2.4.1 Warm working

Warm working refers to plastic deformation carried out at intermediate temperatures of hot and cold working. Thus, the temperature during warm working is above the room temperature and below the crystallization temperature. Also, the working temperature is usually about 0.3 to 0.5 times the melting temperature of metal. Warm working requires less force to perform an operation than cold working hence it is more preferable than the cold working.

2.5 METAL FORMING

- Metal forming includes a large number of manufacturing processes in which plastic deformation property is used to change the shape and size of metal workpieces.
- During the process, for deformation purpose, a tool is used which is called as **die.** It applies stresses to the material to exceed the yield strength of the metal.
- Due to this the metal deforms into the shape of the die. Generally, the stresses applied to deform the metal plastically are compressive.
- But, in some forming processes metal stretches, bends or shear stresses are also applied to the metal.

- For better forming of metal, the desirable properties of metal are low yield strength and high ductility.
- These properties are highly affected by the temperature. When the temperature of the metal is increased, its ductility increases and yield strength decreases.
- The other factors which affect the performance of metal forming process are, strain rate, friction, lubrication, etc.
- Metal forming processes can be classified as follows:

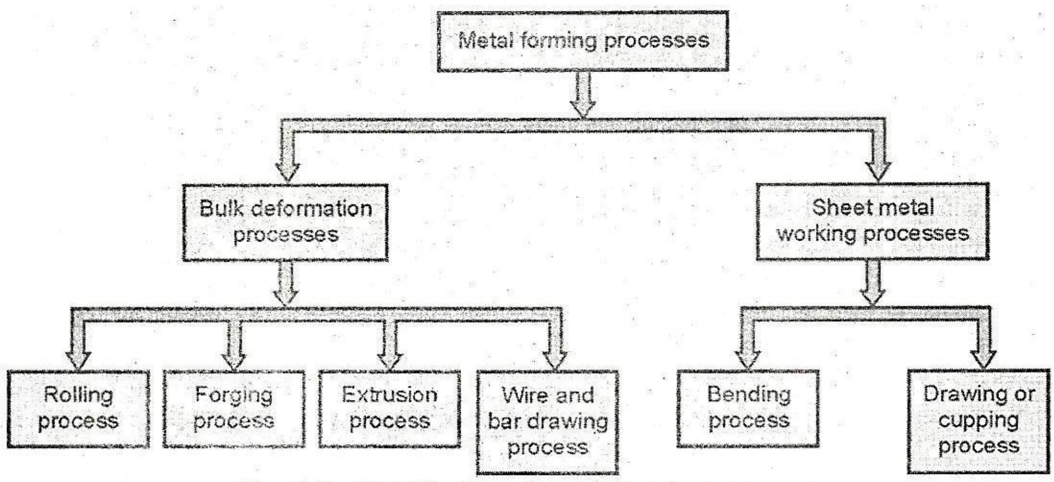


Fig. 3.1 : Classification of metal forming processes

2.5.1 Bulk Deformation Processes

These process are characterized by significant deformations and massive shape changes but the surface area to the volume of the work is relatively small. The workpieces which have this low area to volume ratio is called as bulk. Initial workpiece shape for bulk deformation processes include cylindrical billet (hot material) and rectangular bars. Figure 2.2 shows the basic operations in bulk deformation process.

1. Rolling

It is a compressive deformation process in which the thickness of a plate or slab (hot) is reduced by two opposing cylindrical rolls. The rolls rotate in order to draw the workpiece into the gap between them and squeeze the workpiece. Refer Figure 2.2 (a).

2. Forging

In this process, the workpiece is compressed between the two opposing dies in order to produce the die shapes on the workpiece. Refer Figure2.2 (b). It is generally a hot working process but sometimes it can be included in cold working also.

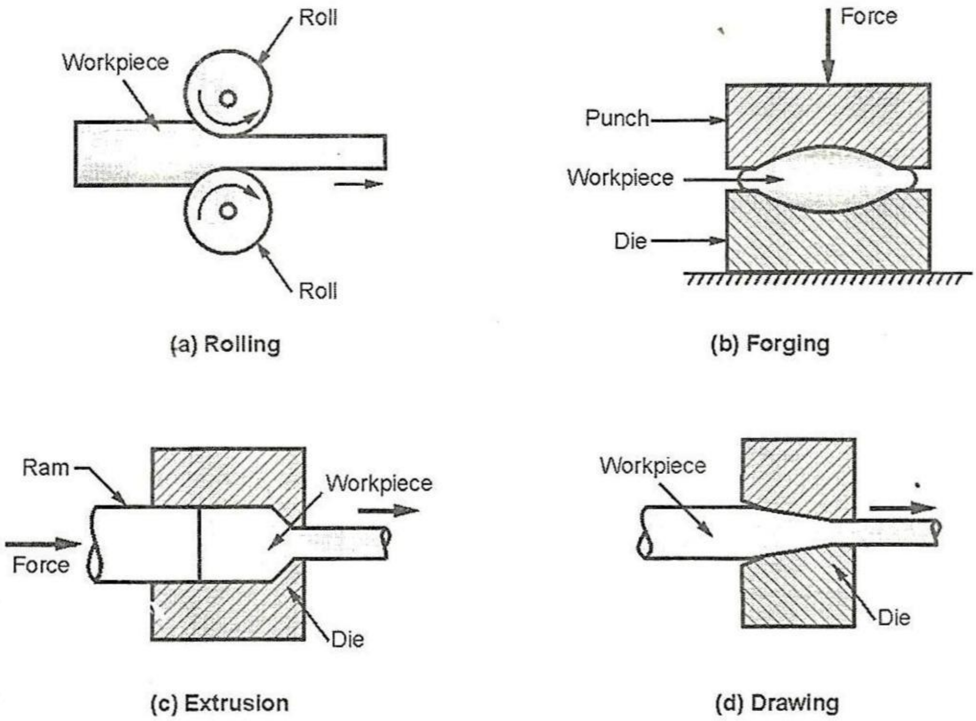


Fig. 3.2 : Basic bulk deformation processes

2. Extrusion

It is a compressive deformation process in which the work metal is forced to flow through a die opening as shown in figure2.2 (c). During the flow through a die, the work metal takes the shape of the opening as its cross-section.

4. Wire drawing

In this type of forming process, the diameter of a round bar (billet) is reduced by pulling it through a die opening. Figure 2.2 (d) shows the drawing process.

2.5.2 Sheet Metal Working Processes

In this type of metal forming processes, the operations are performed on metal sheets, strips and coils. In these processes, the surface area to volume ratio is high.

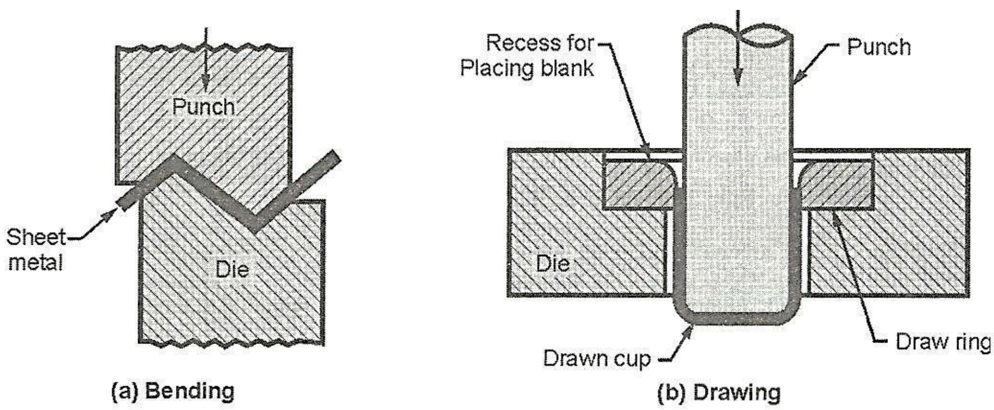


Fig. 3.3 : Basic sheet metal working operations

Generally, the sheet metal working processes are carried out on punching press machine, hence sheet metal working is also called as press working. A component produced by sheet metal working process is called as stamping. These operations are performed as cold working processes. The tools used for the operations is called as punch and die. The punch is a positive portion whereas the die is a negative portion of the tool set. Figure 2.3 shows the basic operations in sheet metal working process.

1. Bending

In this process, there is straining of metal sheet or plate to take an angle along a straight axis. Refer figure 2.3(a). The bending may be of V shape, U shape or any other shape.

2. Drawing or Cupping

It refers to the forming of a flat metal sheet into a hollow or concave shape like a cup by stretching the metal. During the process, a blank holder is used to hold the blank and the punch pushes into the sheet metal. Refer figure 2.3(b).

HOT WORKING PROCESSES

2.6 HOT ROLLING:

The process of rolling consists of passing the hot ingot through the two rolls, rotating in opposite directions, at a uniform peripheral speed. To confirm the desired thickness of the rolled section, the space between the rolls is adjusted and is always less than the thickness of the ingot being fed. Hence, to reduce the cross-section and increase the length of passing ingot, the rolls are squeezed. Refer Figure 2.4.

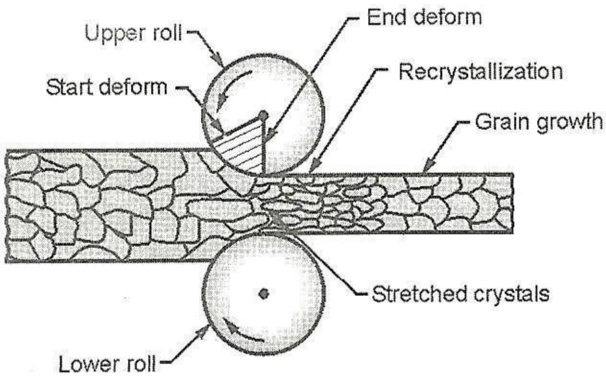


Fig. 3.4 : Hot rolling recrystallisation

When the metal passes through the rolls, there is change in its grain structure. Due to squeezing, the grains are elongated in the direction of rolling and the velocity of material at the exit is higher than that at the entry. After crossing the stress zone, the grains start refining.

2.6.1 Basic Definitions

The following are the basic terms used related to rolling process:

1. **Ingot:** Ingot is a large casting section of suitable shape made for further processing.
2. **Bloom:** A bloom is a square or rectangular piece formed after reducing ingots. The size of bloom ranges between 150 mm × 150mm to 250 mm × 250 mm. Rolling products from bloom: Structural shapes, Rails, etc.
3. **Billets:** Billets also formed after reducing ingot but have smaller cross sections. The size of billet ranges from 50 mm × 50 mm to 150 mm × 150mm. Rolling product from billets: Road, wires, etc.
4. **Slabs:** Slabs are metal pieces with rectangular cross section. It has thickness between 50-150 mm and width between 300-1500 mm. Rolling products from slabs: Sheets, plates, strips, etc.

2.6.2 Rolling of Various Sections

- The main purpose of rolling is to convert larger sections such as ingots into smaller sections, which can be used directly in as rolled state or stock for working through other processes.
- As a result of rolling, there is an improvement in physical properties of cast ingot such as strength, toughness, ductility, shock resistance, etc.

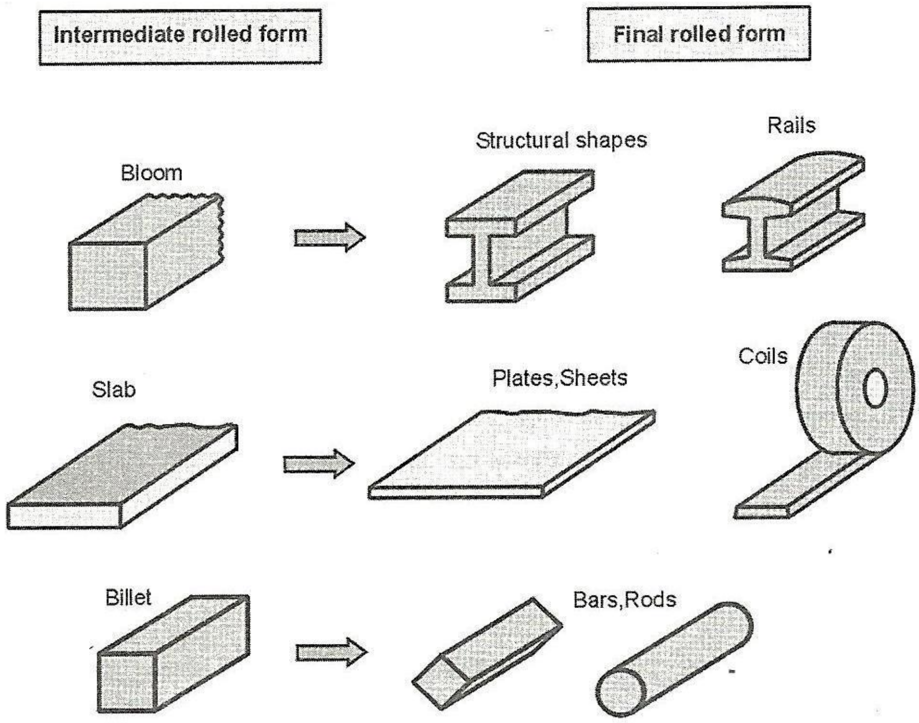


Fig. 3.5 : Steel components made from rolling

- Various useful articles like structural section, sheets, rails, plates and bars, etc. are produced through rolling.

- Figure 2.5 shows some commonly used rolled steel sections.
- The desired reduction in the cross-section of the billet and the required shape of the rolled section are not obtained in a single pass.

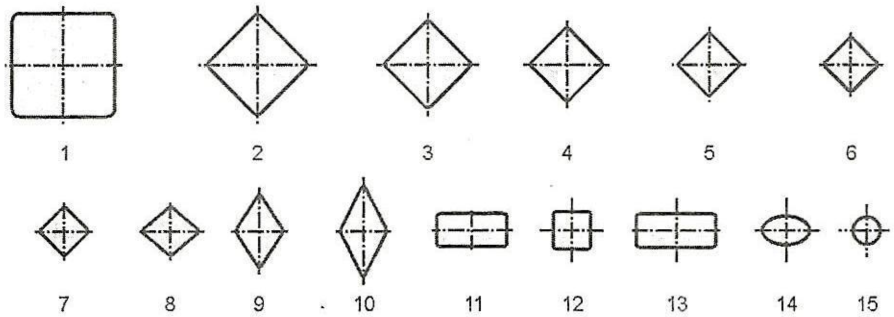


Fig. 3.6 : Various stages of rolling and number of passes for converting a steel billet into a round bar

- Figure 2.6 shows the sequence of rolling and the number of passes required to reduce the cross-section of a billet to a round steel bar.
- The process starts with the reduction of ingots which have been heated in a gas fired furnace up to a temperature of 1200 °C.
- The ingots are then taken to the rolling mill where they are rolled into immediate shapes as blooms, billets or slabs.
- A bloom has a square cross section with minimum size of 150 × 150 mm and a billet is smaller than bloom and it may have any square section from 38 mm up to the size of a bloom.
- Slabs have a rectangular cross section with a minimum width of 250 mm and minimum thickness of 38 mm.

2.6.3 Types of Rolling Mills

According to the number and arrangement of the rolls, rolling mills are classified as follows:

1. Two-high rolling mill	2. Three-high rolling mill
2. Four-high rolling mill	4. Tandem rolling mill
5. Cluster rolling mill	6. Planetary rolling mill
7. Universal rolling mill	

1. Two-high rolling mill:

- It consists of two heavy horizontal rolls placed exactly one over the other.
- The space between the two rolls can be adjusted by raising or lowering the upper roll, whereas the position of the lower roll is fixed.
- Both the rolls rotate in opposite direction to each other. Refer figure 2.7 (a).

- In this type, their direction of rotation is fixed and cannot be reversed.
- There is another type of two-high rolling mill which incorporates a drive mechanism that can reverse the rotation direction of the rolls.
- This type of rolling mill is called as **two-high reversing mill**.

2. Three-high rolling mill

- It consists of three horizontal rolls positioned directly one over the other.
- The direction of rotation of the upper and lower rolls are same but the intermediate roll rotates in the opposite direction to each other. Refer figure2.7 (b).
- All the three rolls revolve continuously in the same fixed direction and they 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.
- This results in high production rate than the two-high rolling mill.

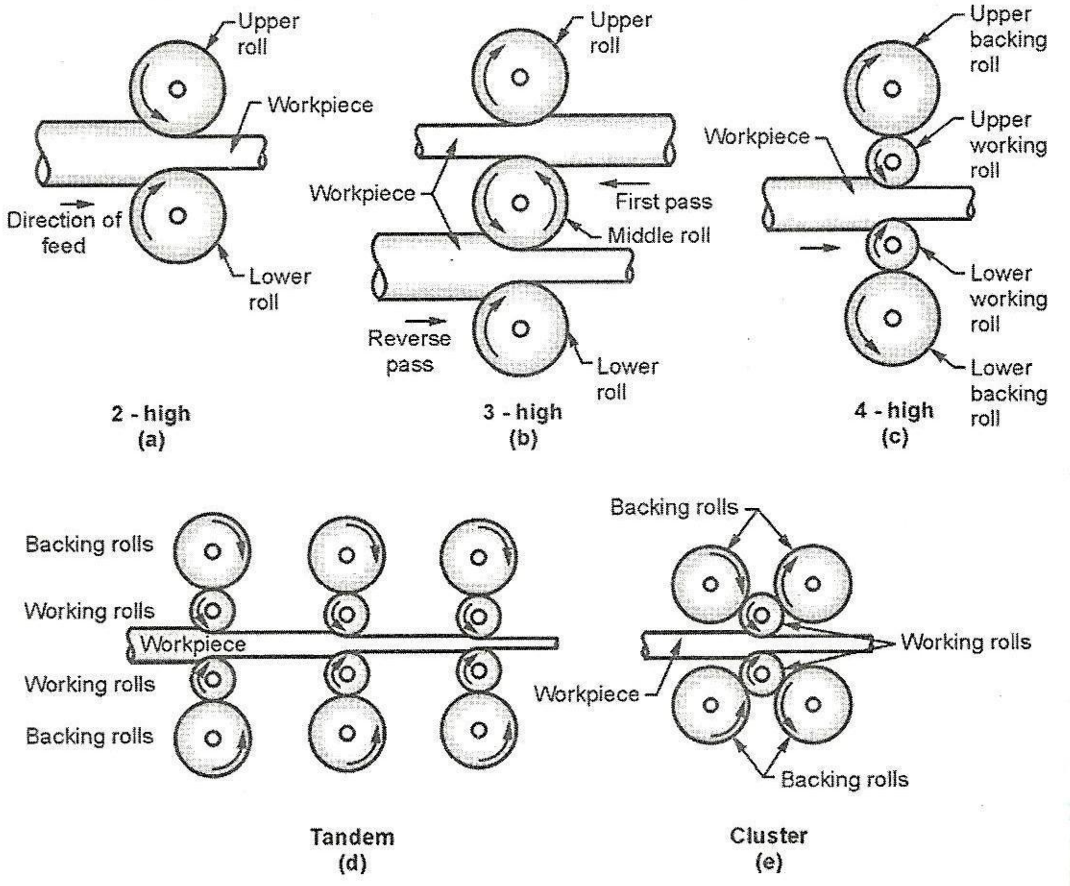


Fig. 3.7 : Types of rolling mills

3. Four-high rolling mill

- It consists of four horizontal rolls i.e. two of smaller diameter and two of larger diameter arranged directly one over the other. Refer figure 2.7 (c).
- The larger diameter rolls are called as back-up rolls and they are used to prevent the deflection of the smaller rolls, which otherwise would result in thickening of rolled plates or sheets at the centre.
- The smaller diameter rolls are called as working rolls, which concentrate the total rolling pressure over the metal.
- The common products of these mills are hot or cold rolled sheets and plates.

4. Tandem rolling mill

- It is a set of two or three stands of rolls set in parallel alignment.
- This facilitates a continuous pass through each one successively without change of direction of the metal or pause in the rolling process.
- Figure 2.7 (d) Shows the tandem rolling mill.

5. Cluster rolling mill

- It is a special type of four-high of rolling mill.
- In this, each of the two working rolls is backed up by two or more of the larger back up rolls. Refer Figure 2.7 (e).
- For rolling hard thin materials, it is necessary to employ work rolls of very small diameter but of considerable length.
- In such cases, adequate supports of the working rolls can be obtained by using a cluster mill.

6. Planetary rolling mill

- For the rolling arrangements requiring large reduction, a number of free rotating wheels are used instead of a single small roll.

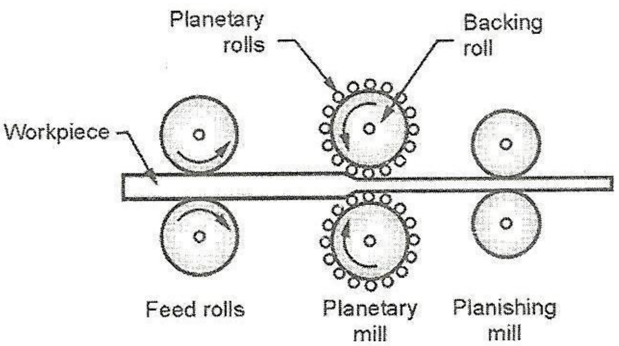


Fig. 3.7 (f) : Planetary rolling mill

- Planetary mill consists of a pair of heavy backing rolls surrounded by a large number of planetary rolls. Refer figure 2.7 (f).
- The main feature of this mill is that, it reduces a hot slab to a coiled strip in a single pass.
- Each pair of planetary rolls gives an almost constant reduction to the slab.
- The total reduction is the sum of a series of such small reductions follower each other in rapid succession.
- The feed rolls are used to push the slab through a guide into planetary rolls.
- On the exit side planning mill is installed to improve the surface finish.

7. Universal rolling mill

- In this type of rolling mill, the metal is reduced by both horizontal and vertical Rolls. Refer figure 2.7 (g).
- The vertical rolls are mounted either on one side or on both sides of horizontal roll stand which makes the edges of bar even and smooth.
- The horizontal rolls may be either two-high, three-high or four –high arrangement.

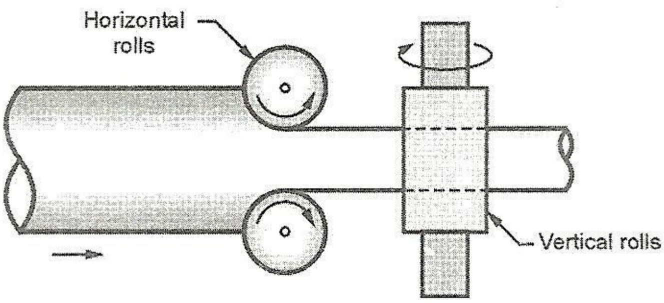


Fig. 3.7 (g) : Universal rolling mill

2.7 FORGING

- **Forging** is the process of shaping heated metal by the application of sudden blows (hammer forging) or steady pressure (press forging) and makes use of the characteristic of plasticity of the material.
- Forging may be done by hand or by machine.
- Forging by machine involves the use of dies and is mostly used in mass production.
- In hand forging, hammering is done by hand.
- Whatever may be the method of applying pressure for shaping the metal, the primary requirement is to heat the metal to a definite temperature to bring it into the plastic state.
- This may be done in an open hearth, known as Smith's forge, for small jobs or in closed furnaces for bigger jobs.

- Now-a-days forging is an important industrial process used to make variety of high strength components for automobile, aerospace and other so many application.
- For example: Engine crankshafts, connecting rods, gears, jet engine and turbine parts, aircraft structural components, etc.

Forging process is classified as follows:

1. According to the working temperature

a) Hot forging

Most of the forging operations are performed above the recrystallization temperature but below the melting point of the metals. During the process there is deformation of the metal which reduces the strength and increases the ductility of metal.

b) Cold forging

For certain products like bolts, rivets, screws, pins, nails, etc. cold forging is also very common. It increases the strength which results from the strain hardening of the component.

2. According to the method of applying the blows.

a) Impact forging

In this method of forging, a machine that applies impact load on the work piece is called as **forging hammer.**

b) Gradual pressure forging

In this method of forging, a machine that applies gradual pressure on the work piece is called as **forging press**.

3. According to the degree to which the flow of work piece is constrained by the dies

a) Open-die forging

In this method of forging, the work piece is compressed between two flat dies which allows the metal to flow without constraint in a lateral direction relative to the die surfaces. Refer figure 2.8 (a).

b) Closed-die or impression-die forging

In this method, the die surfaces contain an impression or shape which is applied to the work piece during the compression. Refer figure 2.8 (b). During the operation, some portion of the work piece flows beyond the die impression to form a flash. (Flash is excess metal which is trimmed off at the end).

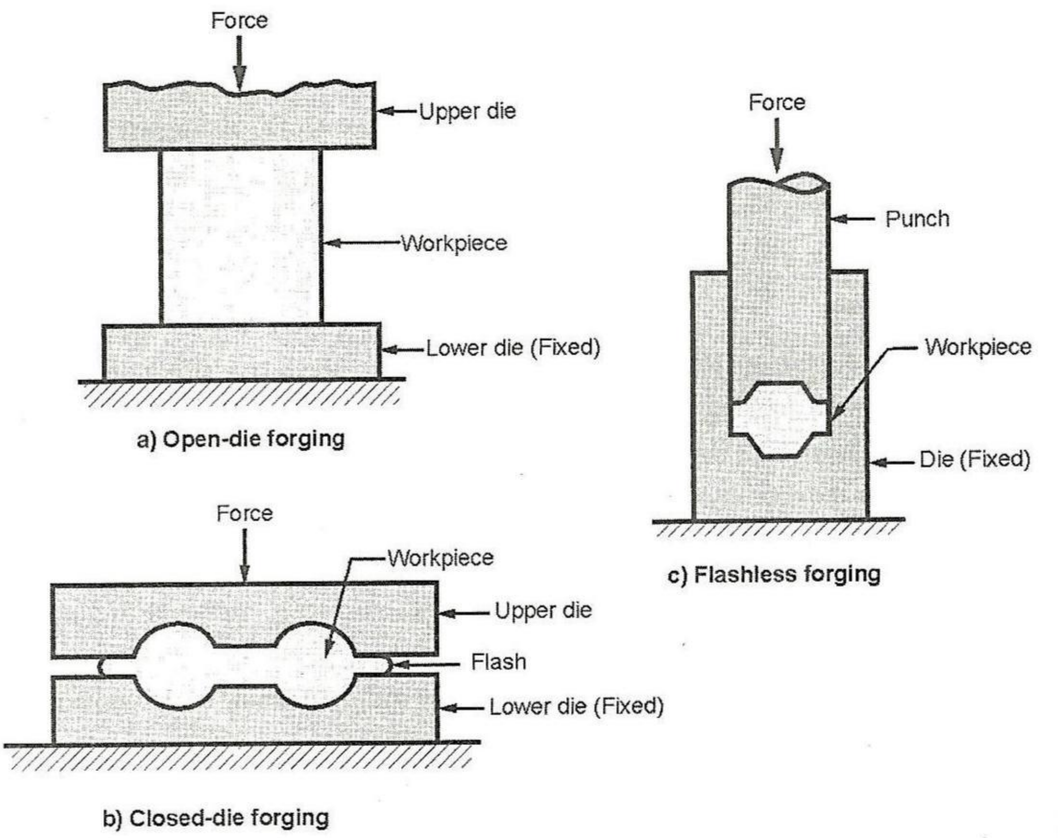


Fig. 3.8 : Types of forging operations

c) Flashless forging

In this method, the work piece is completely constrained within the die and no flash is produced. Refer figure 2.8 (c). The volume of the initial work piece much be controlled closely so that it matches with the volume of the die cavity.

2.8 OPEN-DIE FORGING

- It is the simplest and important forging process.
- The shapes generated by this process are simple like shafts, disks, rings, etc.

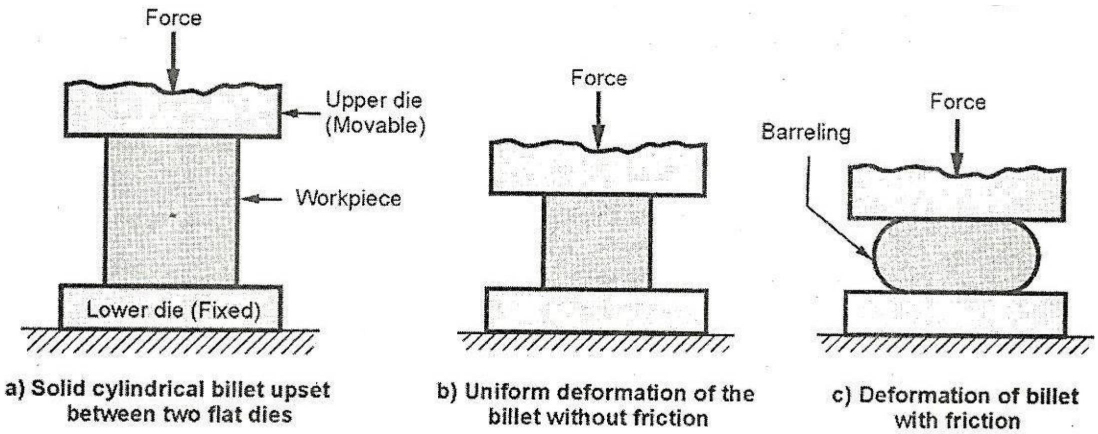


Fig. 3.9 : Open-die forging

- An example of open-die forging in the steel industry is the shaping of a large square cast ingot into a round cross-section.

- Open-die forging operation produce produces rough forms of work piece hence, subsequent operations are required to refine the parts to final shape.
- Open-die forging process can be depicted by a solid work piece placed between the two flat dies (lower die is fixed and upper die is moving) and reduced in height by compressing it. This process is called as upsetting or flat-die forging. Refer figure 2.9.
- The deformation of the work piece is shown in Figure. Due to constancy of volume, any reduction in height of the work piece increases its diameter.
- In figure 2.9 (b) the work piece is deformed uniformly but practically the work piece develops a barrel shape which is called as pancaking or barreling.
- It is caused by the frictional forces at the die-work piece interfaces and it can be minimized by using an effective lubricant.

Some of the important operations performed in open-die forging process are as follows

1. Fullering

It is performed to reduce the cross-section and redistribute the metal in a work piece in preparation for subsequent shape forging. It is performed with dies of convex surfaces. Refer figure 2.10 (a).

2. Edging

Its working principle is similar to fullering operation, only the difference is that the dies have concave surfaces. Refer figure 2.10 (b).

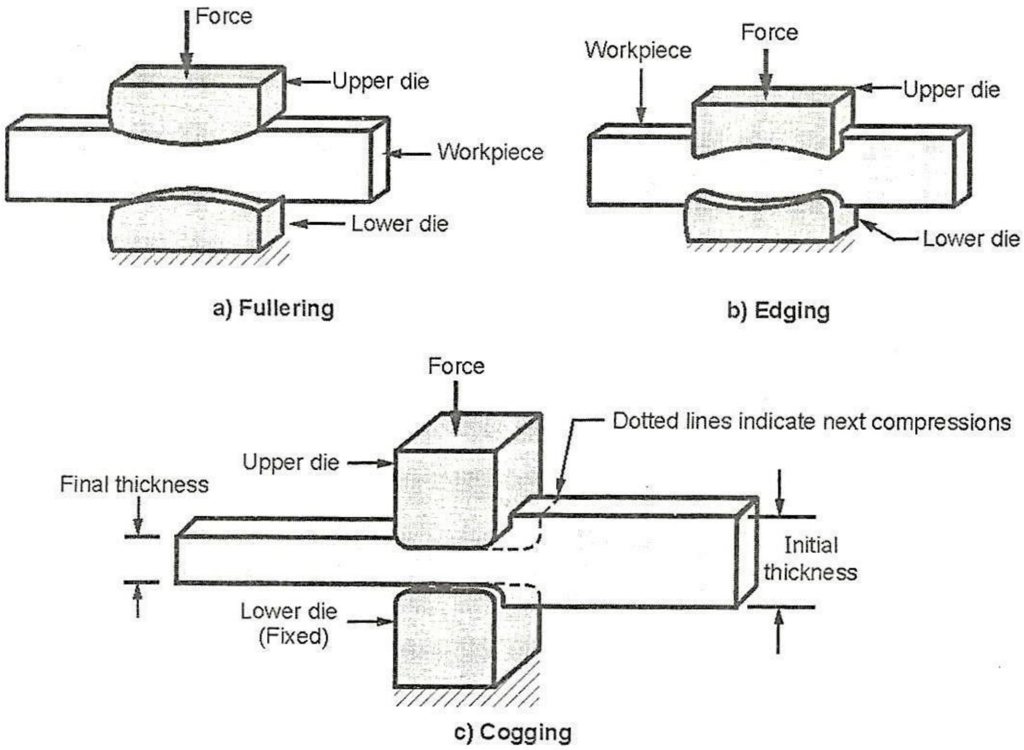


Fig. 3.10 : Open-die forging operations

2. Cogging

It consists of a sequence of forging compressions along the length of work piece to reduce the cross-section and to increase the length. Refer figure 2.10 (c). It is used to produce blooms, slabs, etc. from the cast ingots. The dies used in this operation are flat or have slightly contoured surfaces. This operation is also called as incremental forging.

2.9 IMPRESSION-DIE OR CLOSED-DIE FORGING

- Impression-die or closed-die forging is performed with dies which contain the invers of the required shape of the component. Refer figure 2.11.

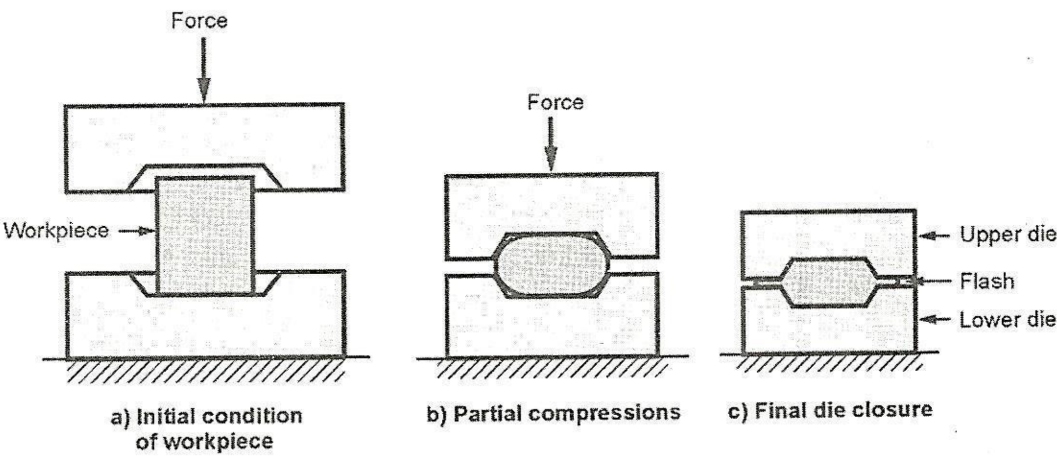


Fig. 3.11 : Closed or impression die forging

- Initially the cast ingot is placed between the two impressed dies. As the die closes to its final position, flash is formed by the metal.
- This flash flows beyond the die cavity and into the small gap between the die plates.
- The formed flash must be cut away from the final component in a subsequent trimming operation but it performs an important function that, it increases the resistance to the deformation of the metal.
- The initial steps in the process are used to redistribute the metal in the workpart to achieve a uniform deformation and required metallurgical structure in the subsequent steps.
- The final steps bring the component to its final geometry. Also, when drop forging is used, number of blows of the hammer may be used for each step.
- As the flash is formed during the process, this process is used to produce more complex components by using dies.

2.9.1 Comparison between open – die and Closed- die Forging

Sr. No	Open-die forging	Closed-die forging
1.	In this method, the workpiece is compressed between the two flat dies.	In this method, the workpiece is compressed between the two impressed dies.
2.	The cost of dies is low.	The cost of dies is high.
2.	The process is simple.	The process is complex.
4.	During the process there is poor utilization of the material.	During the process there is better utilization of the material.
5.	After the process, machining of components is required.	After the process, machining of components is not required.
6.	The dimensional accuracy of obtained products is not good.	The dimensional accuracy of obtained products is good.
7.	This process is used for low quantity production.	This process is used for high quantity production.
8.	It is suitable only for production of simple components.	It is suitable for production of simple and complex components.

2.10 Forging Operations

A number of operations are used to change the shape of the raw material to the finished form. A typical smith forging operations are as follows:

1. Upsetting
2. Drawing out or drawing down
2. Cutting
4. Bending
5. Punching and Drifting
6. Setting down
7. Welding

1. Upsetting

- Upsetting is also called as jumping or heading.
- It is a process through which the cross-section of metal piece is increased with a corresponding increase in its length.
- When a metal is sufficiently heated, it acquires the plastic stage, so that it becomes soft.

- If some pressure (blows) is applied to it, then the metal tends to swell or increase in its dimensions at right angles to the direction of application of force with corresponding reduction in its dimensions.
- This is what actually takes place during upsetting or jumping a metal part.

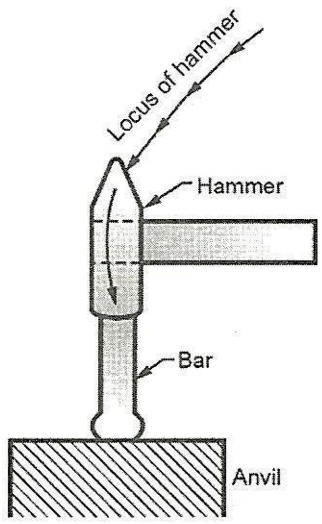


Fig. 3.33 : Upsetting a bar

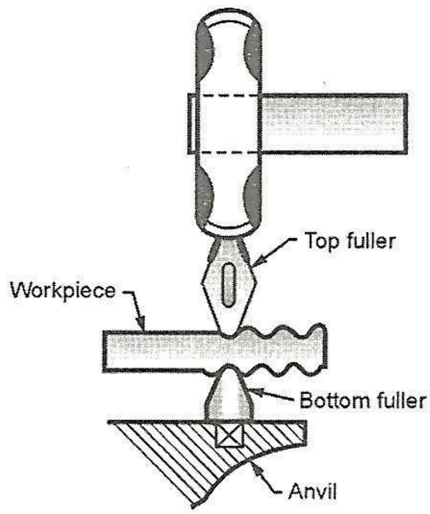


Fig. 3.34 : Drawing out

2. Drawing out or drawing down

- Drawing out is exactly a reverse process to that of upsetting.
- It is employed when a reduction in thickness, width of a bar is desired with a corresponding increase in its length.
- The desired effect is obtained by the use of either the peen of a cross peen hammer, a set of fullers or a pair of swages.
- Figure2.34 shows the drawing out operation by using top and bottom fullers.

3. Cutting

- Cutting – off is a form of a chiseling whereby a long piece of stock is cut into several specified lengths, or a forging is cut-off from its stock.
- A notch is first made about one-half the thickness or diameter of the stock. After that, the workpiece must be turned an angle of 180° and the chisel is placed exactly opposite the notch.
- The required length of metal can then be cut-off by giving the chisel a few blows with a sledge hammer.

4. Bending

- Bending is an important operation in smith forging and it is very frequently used.
- It may be classified as angular or curvilinear.

- Any required angle or curvature can be made through this operation.
- Bending operation is carried out on the edge of the anvil or on the perfectly square edge of a rectangular block.
- For making a right angle bend, particular portion of the stock is heated and jumped on the outer surface.
- When metal is bent, the layers of metal on the inside are compressed and those on the outside are stretched.
- Figure 2.35 shows a round bar being bent to form a helical spring.

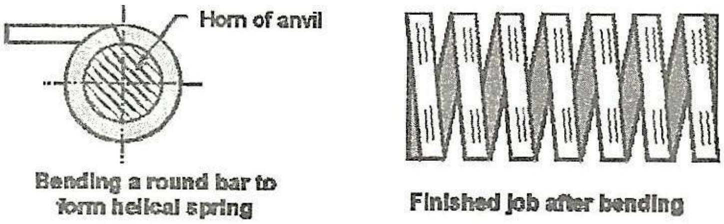


Fig. 3.35 : Bending a round bar to form a helical spring

5. Punching and Drifting

- The term punching refers to the operation in which a punch is forced though a workpiece to produce a hole.
- The workpiece is first heated and then placed on the anvil face.
- The punch is then forced into it upto about half its thickness.
- The workpiece is then turned upside down and placed over a tool called as bolster.
- The punch is again forced into the workpiece and made to pass through by hammering. Refer figure.
- Punching without using a die, is generally followed by drifting.
- In drifting, a tool known as drift, is made to pass through the punched hold to produce a finished hole of the require size.

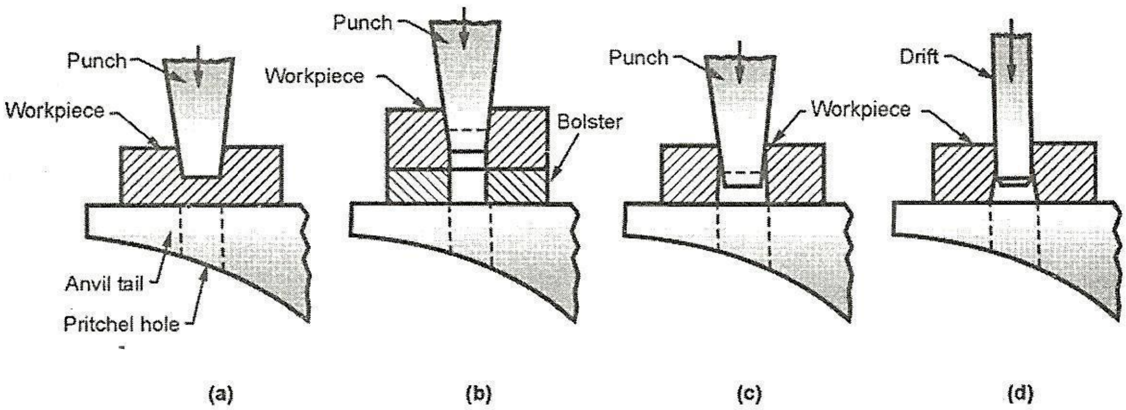


Fig. 3.36 : Punching and drifting operations

6. Setting down

- Setting down is the operation through which the rounding of a corner is removed, to make it square by using a set hammer.
- By putting the face of the hammer over the round portion, formed by bending or fullering of the corner and hammering it at the top a local reduction in thickness takes place resulting in sharp corner.
- Hence, finishing operation is performed through which the unevenness of a flat surface is removed by using a flatter or a set hammer.

7. Welding

- Welding or shutting is the principle operation performed by the smith.
- The metal which remains pasty over a wide range of temperature is most easily welded.
- For production of sound weld, the surfaces in contact must be perfectly clean, both mechanically and chemically, so that cohesion will take place when the metal is in a plastic state.
- A protection to the metal is a coating of flux which covers the surfaces of the metal and prevents oxidation.
- A forge weld is made by hammering together the ends of two bards which have been formed to the corrected shape and heated to a welding temperature in a forge fire.
- The method of preparing the metal pieces for welding is called scarfing.

Following are the forms of welded joint which are commonly used:

a) **Lap scarf weld:** In this, the ends are prepared so that they may be welded one upon the other with the joint in an inclined position.

b) **Butt weld:** In this, the ends of the pieces to be joined are butted together, the weld being between the ends at right angles to the length of the piece.

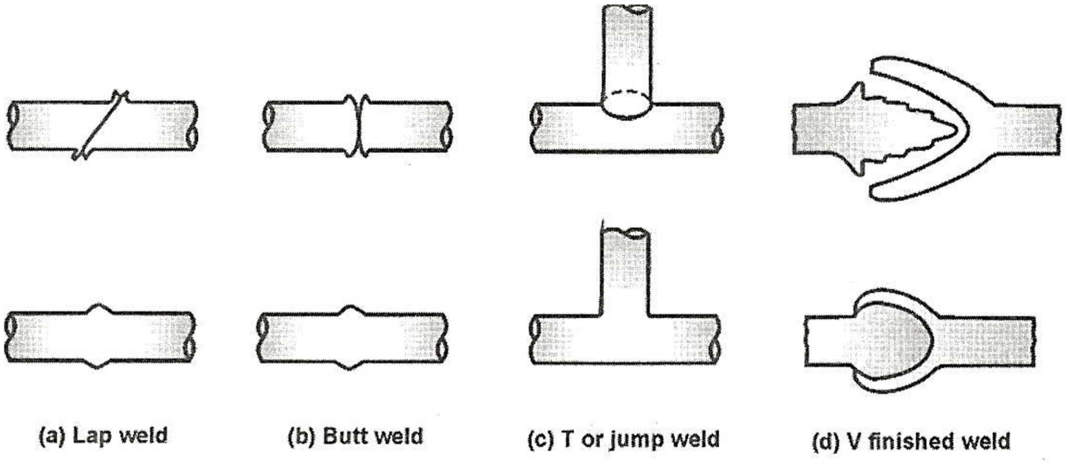


Fig. 3.36 : Forge welded joints

c) **T or Jump weld:** In this, one piece is place at the center of another at right angle to each other in the form of an inverted T.

d) **V-weld or Splice:** In this, the ends are first brought to the shape of fork and tongue respectively.

2.11 DEFECTS IN FORGING

The defects commonly observed in forged components are as follows:

1. Defective metal structure:

The main cause of this defect is defective original metal.

2. Presence of cold shuts or cracks at corners or surfaces

This defect is due to improper forging and faulty die design.

2. Incomplete components:

This is due to less metal used, inadequate heating of metal, improper forging design, faulty die design, metal not placed properly in the die and inadequate flow of metal.

4. Mismatched forging:

When the die halves are not properly aligned, forging will be mismatched.

5. Burnt and overheated metal:

This defect is because of improper heating.

6. Fibre flowlines discontinued:

The main cause of this defect is very rapid plastic flow of metal.

7. Scale pits:

Scale pits are formed by squeezing of scale into the metal surface while forging.

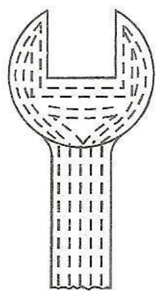
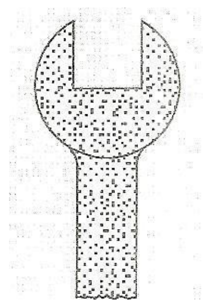
8. Oversized components

Worn out dies, incorrect dies, misalignment of die halves are the main causes of oversized components.

Forging defects can be removed as follows

- Shallow cracks and cavities can be removed by chipping out of the cold forging with pneumatic chisel.
- Surface cracks are removed from forgings by grinding on special machines. Care should be taken
- By taking into considerations, all relevant and important aspects die design should be made properly.
- To avoid mismatching of the dies, the parting line of a forgoing should lie in one plane.
- The mechanical properties of the metal can be improved by forging to correct fibre line and developed internal stresses are removed by annealing or normalising.

2.12 Comparison between Forging and Casting Processes

Sr. No	Forging	Casting
1.	In forging process, grain flow is continuous and uninterrupted Refer figure. 	In casting process, there is no grain flow. Refer figure. 
2.	Due to improved grain size and true grain flow, forging give greater strength and toughness.	Due to no grain flow and weak crystalline structure, casting is weak in withstanding working stresses.
2.	Requires minimum machine finish.	Requires more machine finish.
4.	Forged components have better mechanical properties like strength, toughness, resistance to shock and vibrations.	Cast components are brittle i.e. weak in tension. Also they have poor resistance to shock and vibrations.
5.	Welding of forged parts is easy.	Welding of cast parts is difficult.
6.	During the operation, cracks and blow holes are welded up.	Defects like cracks and blow holes make the casting weak and unsuitable for use.
7.	Accuracy is more.	Accuracy is less.
8.	Complicated shapes cannot be produced.	Complicated shapes can be produced.
9.	Generally used for large parts.	Generally used for small parts.
10.	Because of cost of dies, process is costly.	As there are not dies, hence casting is less expensive.

2.13 Roll Piercing of Seamless Tubing

- Roll piercing is a method of producing seamless tubes.
- Seamless tubing is a popular and economical raw stock for machining because it saves drilling and boring of parts.

- The piercing machine consists of two tapered rolls, called as piercing rolls.
- During the process, a round heated billet or steel is passed between these rolls over a mandrel.
- Both the rolls rotate in the same direction and the billet is provided with a small drilled hole at one end and uniformly heated to about 1100°C.
- It is then pushed into the two piercing rolls which impart axial and rolling movement to the billet and force it over the mandrel.

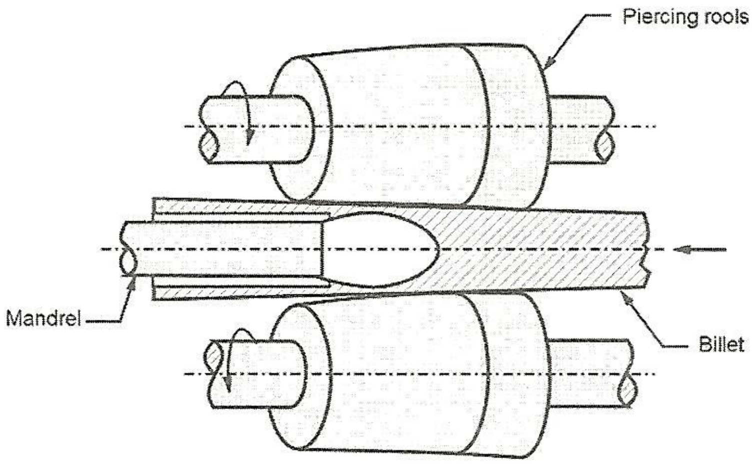


Fig. 3.38 : Tube piercing

- Hence, the combination of the revolving motion of billet and mandrel together with the axial advancement of the billet, provides a helical tubing effect on the material.
- For production of 12m length of upto 150 mm diameter rough tubing will take 10 to 30 seconds, whereas for tubing of larger diameter (upto 350 mm) second piercing operation is required.
- As above produced rough tubing is further subjected to rolling, reeling and sizing, to bring it to the correct shape and size for providing a find surface finish.
- Such tubes are produced in various metals and alloys such as steel alloys, aluminium brass, copper, etc.

2.14 Extrusion

- Extrusion is a compression process in which the work metal is forced to flow through a small opening which is called as die to produce a required cross-sectional shape.
- The Extrusion process is similar to squeezing toothpaste or cream from a tube.
- Almost any solid or hollow cross-section may be produced by extrusion process.
- As the geometry of the die remains same during the operation, extruded parts have the same cross-section.

- During the process, a heated cylindrical billet is placed in the container and it is forced out through a steel die with the help of a ram or plunger.
- The products made by extrusion process are tubes, rods, railing for sliding doors, structural and architectural shapes, door and window frames, etc.
- Extrusion process is suitable for the non-ferrous alloys, steel alloys, non-ferrous metals, stainless steel, etc.
- Extrusion process is carried out on horizontal hydraulic press machines which are rated from 250 to 5500 tones in capacity.

Extrusion process is classified as follows:

1. According to physical configuration

a) Direct (Forward) extrusion

b) Indirect (Backward) extrusion

2. According to working temperature

a) Hot extrusion

b) Cold extrusion

2.14.1 Direct Extrusion

- Direct or forward hot extrusion is most widely used and the maximum numbers of extruded parts are produced by this method.
- Figure 2.39 shows the direct extrusion process in which the raw material is a billet.

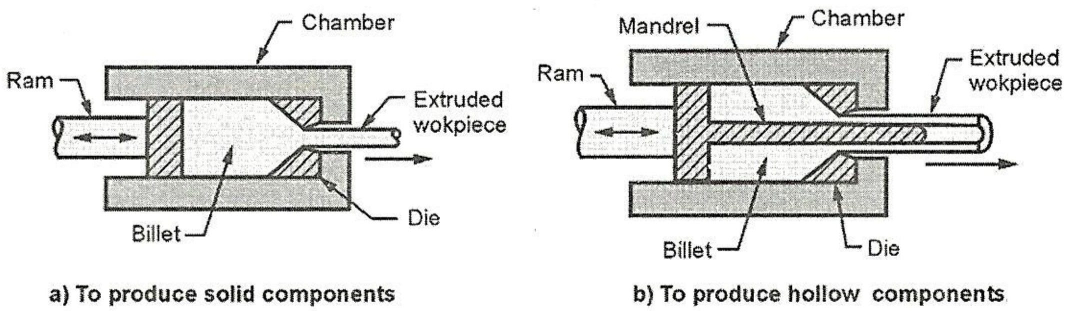


Fig. 3.39 : Direct extrusion

- A billet is heated to its forging temperature and fed into the machine chamber.
- Pressure is applied to the billet with the help of ram or plunger which forces the material through the die.
- The length of extruded part will depend on the billet size and cross-section of the die.
- The extruded part is then cut to the required length.
- As the ram approaches the die, a small portion of billet remains which cannot be forced through the die opening. This extra portion is known as butt which is separated from the product at the end.

- When the billet is forced to flow through the die opening, there is friction between the workpiece and chamber walls. This friction is overcome by providing additional ram force. This is the major problem with this process.
- To overcome this problem oxide layer is provided on the billet or dummy block is used between the ram and billet.
- Direct extrusion process is also used to produce hollow or semi-hollow sections.
- To produce hollow sections, by direct extrusion process, a mandrel is used. Refer figure 2.39 (b).
- When the billet is compressed, the material is forced to flow through the gap between the mandrel and die opening. This result in tubular cross-section.

2.14.2 Indirect Extrusion

- Indirect extrusion is also called as backward extrusion.
- In this type, the ram or plunger used is hollow and as it presses the billet against the backwall of the closed chamber, the metal is extruded back into the plunger, Refer figure 2.40.

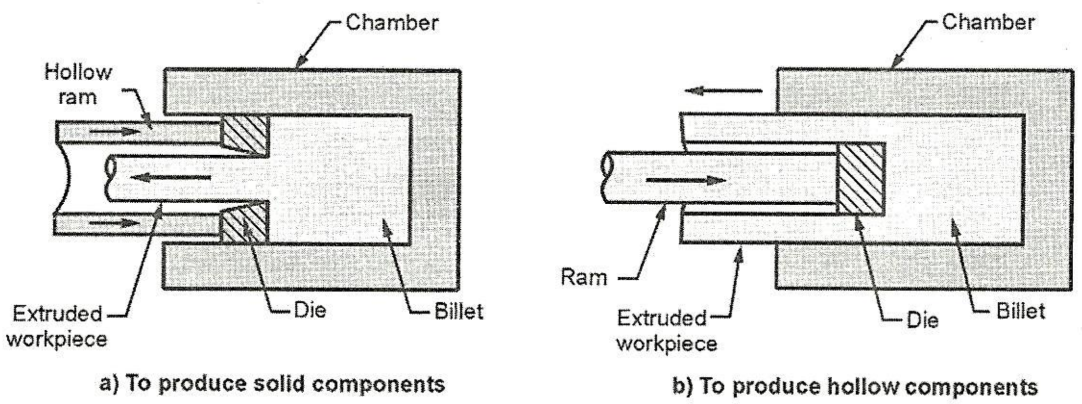


Fig. 3.40 : Indirect or backward or reverse extrusion

- It involves no friction between the metal billet and the chamber because the billet does not move inside the chamber.
- As compared to direct extrusion, less total force is required in this method.
- But the equipment used is mechanically complicated in order to support the passage of the extruded shape through the centre of the hollow ram.
- Indirect extrusion is also used to solid as well as hollow components. For producing solid parts, ram is hollow whereas for producing hollow parts ram is solid. Refer figure 2.40 (b).

2.14.3 Comparison between Direct and Indirect Extrusion

Sl. No	Direct / Forward Extrusion	Indirect / Backward Extrusion
1.	During the process a solid ram is used.	A hollow ram is used for the process.
2.	Flow of metal is in the same direction as the movement of the ram.	Flow of metal is in the opposite direction as the movement of the ram.
2.	A dummy block is used during the operation.	Dummy block may or may not be used. Die plays a part of the dummy block.
4.	Die is mounted on the cylinder or container.	Die is mounted over the bore of the ram.
5.	Because of relative motion between the heated metal billet and the cylinder walls, friction problem arises.	As the billet in the container remains stationary, there is no friction.
6.	Large amount of force is required to move the billet in the cylinder.	As the billet is stationary, process does not require large amount of force.
7.	Handling of extruded metal is very easy.	Handling of extruded metal is difficult.

COLD WORKING PROCESSES

2.15 COLD ROLLING:

Cold rolling is use for producing bars of all shapes, rods, sheets and strips. Cold rolling is generally employed for providing a smooth and bright surface finish to the previously hot rolled steel. It is used to finish the hot rolled components, to close tolerances and improve their hardness and toughness. Before cold rolling, the hot rolled articles are cleaned through pickling and other operations. The same types of rolling mills, as in hot rolling, are used for cold rolling. The part being rolled is generally annealed and pickled before the final pass is made, so as to bring it to accurate size and obtain a perfectly clean surface.

2.15.1 Comparison between Hot Rolling and Cold Rolling

Sl. No	Hot rolling	Cold rolling
1.	Metal is fed into the rolls after being heated above recrystallisation temperature.	Metal is fed into the rolls when its temperature is below recrystallisation temperature.

2.	Hot rolled metal does not show work hardening effect.	Cold rolled metal shows work hardening effect.
2.	Coefficient of friction between the rolls and stock is higher.	Coefficient of friction between the rolls and stock is relatively lower.
4.	Heavy reduction is cross-sectional area is possible.	Heavy reduction is cross-sectional area is not possible.
5.	Close dimensional tolerances cannot be obtained.	Section dimensions can be finished to close tolerances.
6.	Very thin sections cannot be obtained.	Aluminum foils upto 0.02 mm can be made.
7.	Poor surface finish with scale on it.	Smooth and oxide free surface can be obtained.
8.	Roll radius is larger.	Roll radius is smaller.

2.16 Shape Rolling Operations

In shape rolling process various shapes like structural sectins (beams of I, T or C sections), sheets, rails, plates and bars are produced. Shape rolling process can be divided in two parts:

1. Ring rolling 2. Thread rolling

1. Ring Rolling

- Ring rolling is generally used for producing steel tyres of railway car wheels, rotating rights of jet engines, races, of ball bearings, etc.
- The initial material for ring rolling is a pierced billet for producing a thick walled ring.
- The ring is placed between driving roll and pressure as shown in figure 2.41.

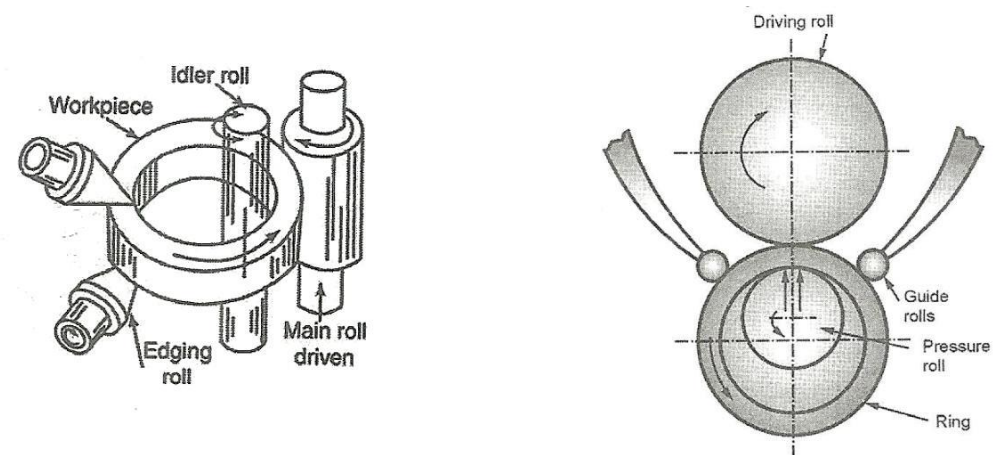


Figure 2.41 Ring Rolling

- The driving roll is fixe but it can rotate freely about its axis.
- The pressure roll applies pressure on the ring towards the driving roll.
- When the ring is gripped, it is caused to rotate and at the same time reduced in thickness continuously.

In order to ensure that a cirucular ring is rolled, a pair of guide rolls must be used.

Thread Rolling

- Thread rolling is the most economical and fastest method of making threads.
- It is actually a cold working process in which a plastic deformation takes place.
- No metal is removed and no chips are produced.
- Cold rolling strengthens the thread in tension, shear and fatigue.

Thread Rolling Machines

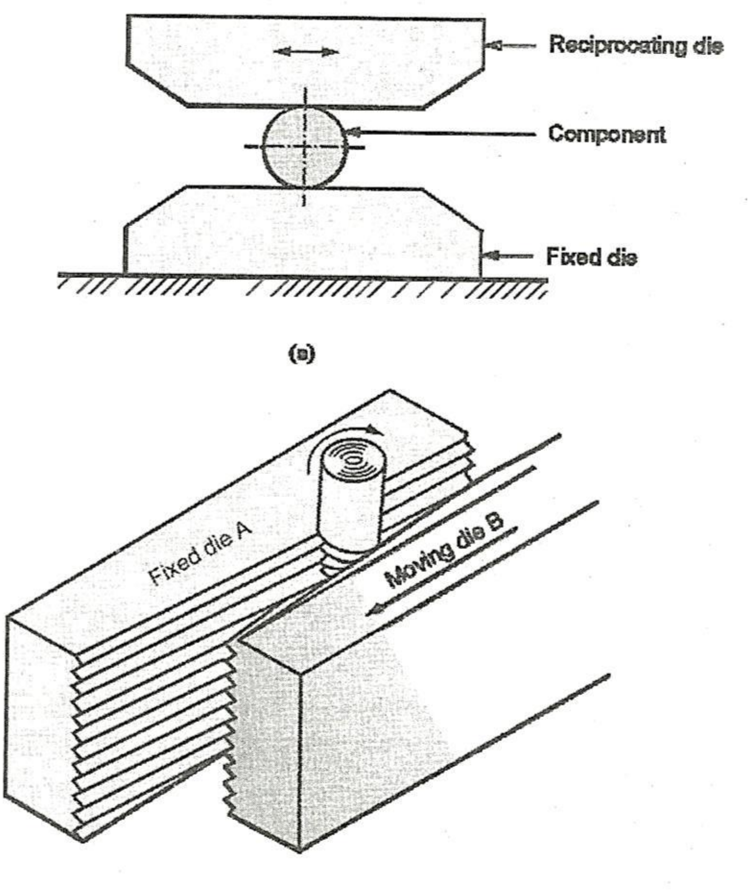
There are three types of thread rolling machines:

i. Reciprocating flat die machines.
ii. Cylindrical die machines.
iii. Rotary planetary machines having rotary die and one or more stationary concave-die segments.

The choice of machine depends upon the size and design of the workpiece, The work material and the number pieces to be produced.

i) Reciprocating flat die machines

- In this process two dies are used. One of them is stationary and another is reciprocating.
- The component to be threaded is rolled between these dies. The moving die reciprocates in reference to the fixed die as shown in figure 2.42 (a) and (b).
- The reciprocating die stroke depends on thread diameter to be produced, as in one stroke the blank makes one complete revolution.
- In one complete revolution thread is completely formed.
- It is very popular machine, as both right and left hand threads can be rolled.
- This is mainly used for production of threads on nuts and bolts.



(b) Reciprocating flat die machine
Fig. 3.42 : Thread rolling

Advantages of Thread Rolling

- It is the fastest method of producing a thread, with production rate more than 2000 pieces per minute.
- Being a chipless forming process, there is lot of material saving (about 16 to 27%).
- During thread rolling, the material is strained plastically and work hardened, therefore it becomes stronger against tension and fatigue.
- A rolled thread is superior to one that has been cut since the process work hardens the thread surface and promotes a grain direction which adds to the strength of the thread.
- Surface finish is better than thread milling and it is in the order of 0.08 to 0.2

Limitations of Thread Rolling

- Best suitable only for diameters upto 20 mm.
- Necessary to hold close blank tolerance.
- Uneconomical for low quantities.
- Cannot roll material having a hardness exceeding RC37.
- Only external threads can be rolled.
-

Thread Rolling Applications

- To produce external thread, thread rolling is the best method.
- Electric light bulb, wood screws, machine screws, sheet metal screws, hooks and eyes of bolts are produced by this method.
- Thread rolling g is also used for producing threads on stamped parts.

2.17 Cold Drawing

The most commonly used components which are cold drawn are tubes, bard, rods, wires and some typical shapes and items of novelties.

2.17.1 Wire Drawing

- Drawing is an operation in which the cross-section of a bar, rod or wire is reduced by pulling it through a die opening.

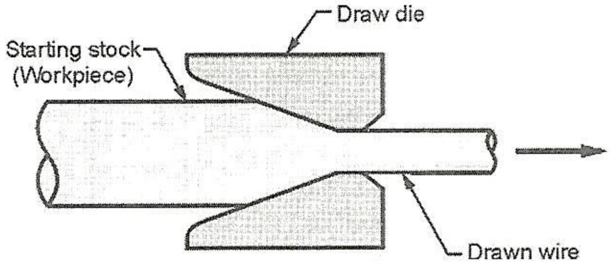
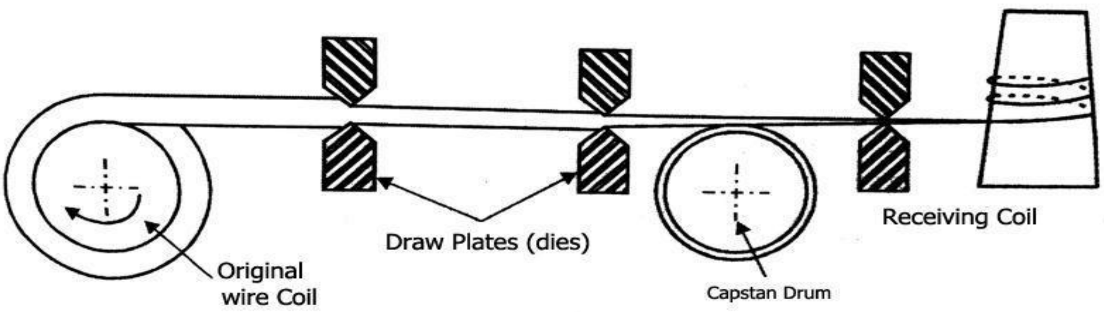


Fig. 3.45 : Wire drawing

- The general features of the drawing process are similar to extrusion. But the difference is that, in drawing the workpiece is pulled through the die whereas in extrusion workpiece is pushed through the die.
- During the process, tensile as well as compressive stress is produced in the material. The main difference between the bar drawing and wire drawing is the stock size (workpiece size). Bar drawing is used for large diameter (bar and rod) stock whereas wire drawing is used for small diameter stock.



- Wire size upto 0.03 mm can drawn by wire drawing process.
- The process consists of pulling the hot drawn bar or rod through a die of which the bore size is similar to the finished product size.
- Depending upon the material to be drawn and the amount of reduction required, total drawing can 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 using 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 reduces.
- The die is made of highly wear resistant material.
- Generally, tungsten carbide is used for die making.
- The die made of tungsten carbide is suitably supported in a die holder which is made of mild steel or brass.

2.17.2 Tube Piercing

Tube piercing is the tube drawing with mandrel. In tube drawing, cylinders and tubes which are made by extrusion process is finished by drawing process.

Tube drawing is classified into:

1. Tube sinking
2. Tube drawing with plug, and
3. Tube drawing with mandrel

In tube sinking process, only the outer diameter of the tube is reduced. For reducing the inner diameter of the tube, the other two processes. i.e., tube drawing with plug or Tube drawing with mandrels is used.

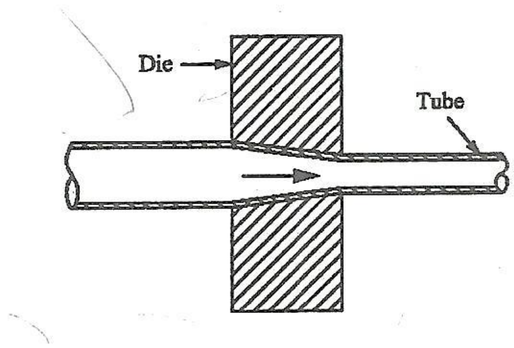


Figure 2.46 (a) Tube Sinking

In tube mandrel, the mandrel is place in the tube and the pull is given to the tube. It will reduce the inside diameter of the tube.

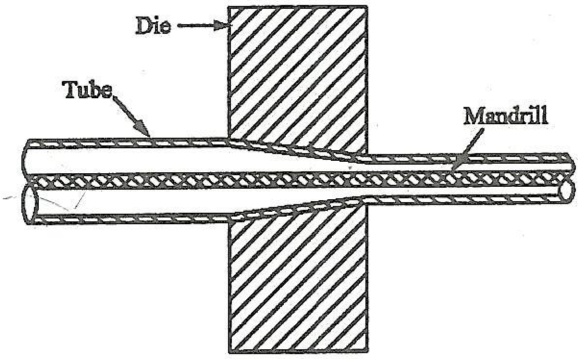


Figure 2.46 (b) Tube Mandrel

In plug drawing, both internal and external surfaces of the tube are controlled and the dimensional accuracy is good compared to other two methods. In this process, the plug is fixed or floating. The friction obtained in fixed plug is more than floating plug and drawing load is high is fixed plug and less in floating plug.

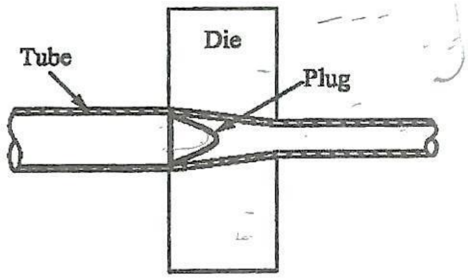


Figure 2.46 (c) Tube Plug

2.18 Cold Extrusion (Impact Extrusion)

- The most common cold extrusion process is impact extrusion.
- Various daily use products such as tubes for shaving creams, tooth paste and paints, condenser cans and such other thin walled products are impact extruded.
- The raw material is in slug form which have been turned from a bar or punched from a strip.
- By using punch and dies, the operation is performed.
- The slug is placed in the die and struck from top by the punch operating at high pressure and speed. Refer figure 2.49.

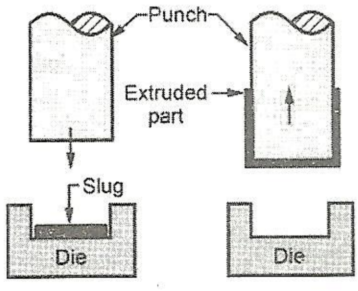


Fig. 3.49 : Principle of impact extrusion

- The metal flows up along the surface of the punch, forming a cup shaped component.
- When the punch moves up, to separate the component from the punch compressed air is used.
- At the same time, a fresh slug is fed into the die.
- The rate of production is fairly high i.e.60 components per minute.
- This process is used only for 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 no wastage.