MODULE 4

Forging

- A metal forming process through the application of compressive stress for deformation.
- carried out either in hot or cold condition, but generally is a hot working process.
- Hot working process: In this process, the work material is heated and a force is applied either by impact or by gradual pressure to deform the material to the required size and shape

Grain flow

- When a metal is subjected to plastic deformation through forging, the existing grains in the material undergo deformation and rearrangement. This is refers as Grain flow.
- The grain flow pattern that develops during forging plays a crucial role in determining the mechanical properties and performance of the final forged product.

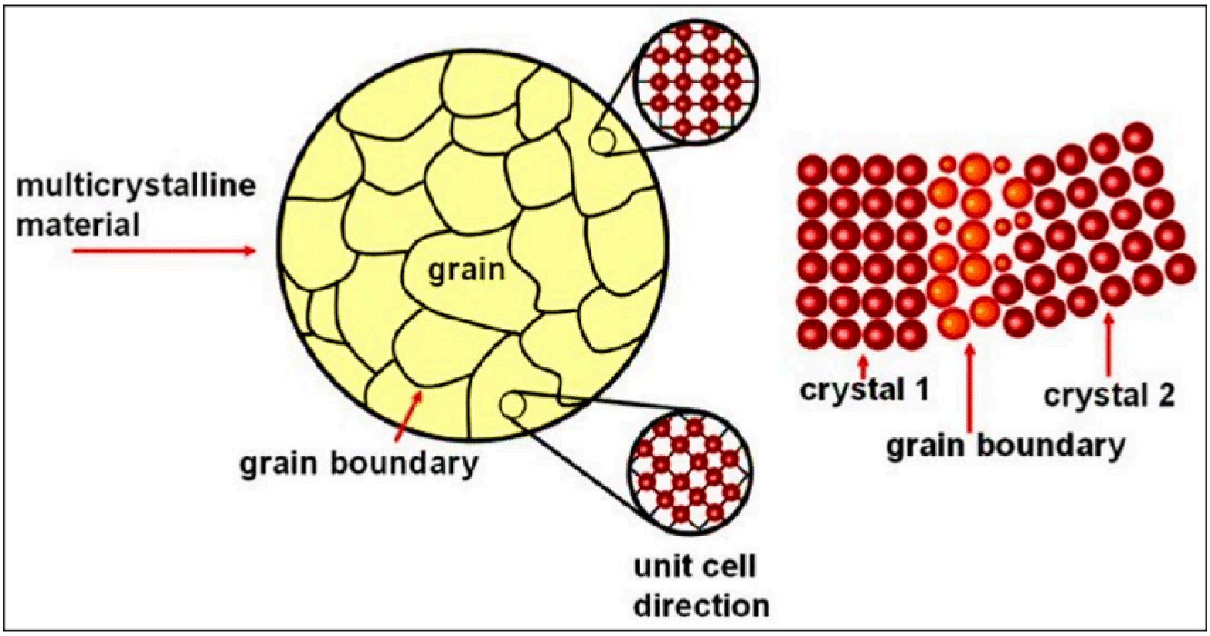
Properties like fatigue strength, impact toughness and ductility can be improved while strength and hardness of the material are not influenced by grain flow

Key points about grain flow in forging

1) Grain Structure:

- Metals are composed of individual crystalline grains.
- Each grain has a distinct crystal structure with atoms arranged in a specific pattern.

These grains are randomly oriented in the raw material before forging



2)Deformation:

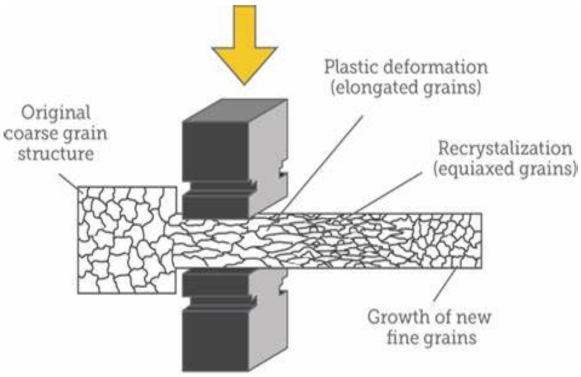
- During forging, the raw material is subjected to compressive forces, typically through the application of pressure or impact.
- This causes the metal to deform plastically, resulting in the rearrangement of grains.

3)Elongation and Orientation:

- As the metal is compressed and shaped, the grains tend to elongate in the direction of the applied force.
- This elongation causes the grains to align along the forging direction, creating a preferred orientation.

4) Grain Flow Lines:

- The aligned grains form a pattern of flow lines, also known as "grain flow lines" or "grain flow direction." These flow lines are observable on the surface of a forged part and provide visual evidence of the metal's deformation during the forging process.



How the open die forging process affects the crystal structure.

FORGING OPERATIONS

- There are several basic steps of forging by which hand
- forging is carried out. In power forging, these steps are carried out together by the actions of different areas of the dies.

a) Upsetting.

b) Drawing Down:

c) Fullering:

d) Flattening:

e) Edging:

f) Swaging:

g) Bending:

h) Punching:

I)Piercing:

- **Upsetting:**

 This process applied to increase the cross sectional area at the expense of its length.

 Force is applied along the axial direction to reduce the length and thereby increasing the cross sectional area.

This is also known as jumping or heading

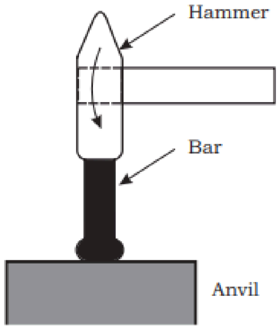


Figure 4.3

- **Drawing Down:**

 This is an operation just opposite to upsetting.

 Here the length is increased at the expense of its width, or thickness or both.

 Here, force is applied perpendicular to the length direction of the component.

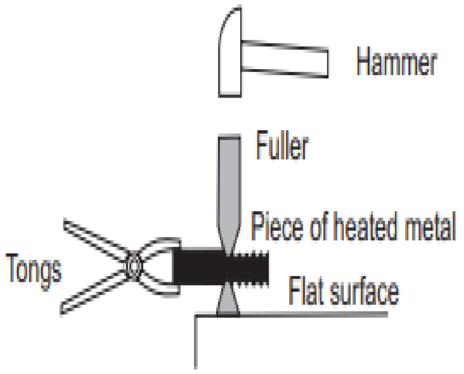
This is also called as Drawing out

Fullering

 This is the process of reducing the cross sectional area of a portion of the workpiece.

 Here also the length of workpiece is increased through an outward metal flow away from the centre of the fuller.

- Fuller is a hard tool used for this purpose.



Flattening:

- The surface of workpiece after drawing down or
- fullering will have marks left on it.
- These are leveled off by the flattening operation with suitable tools.

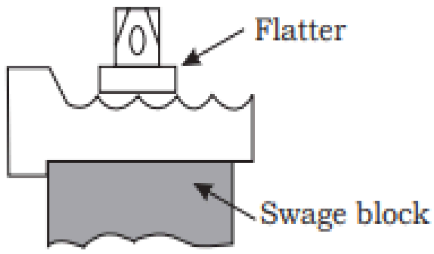


Figure 4.5

- **Swaging:**

- Swaging is a finishing process to convert the bar stock to final dimension and cross sectional shape like round, square or hexagonal.
- It is achieved by means of successive rapid hammer blows. Concave shaped dies of the required shape are used here.

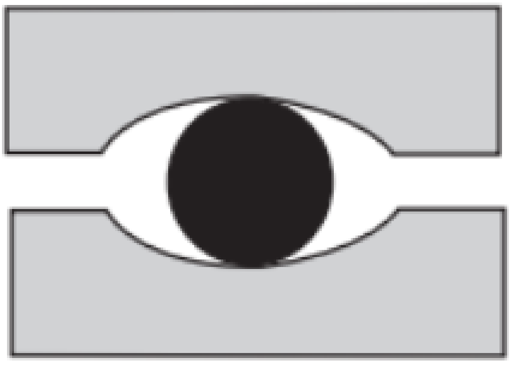
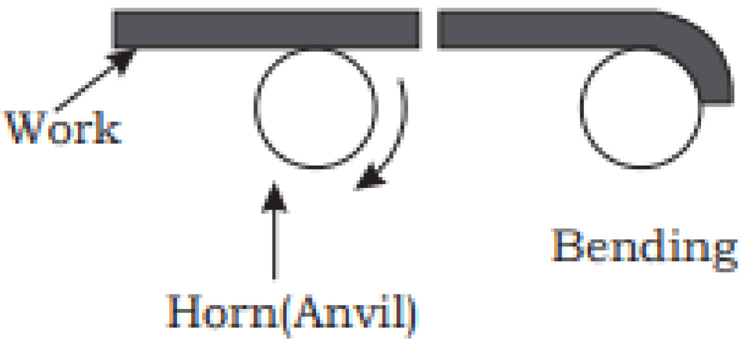


Figure 4.8

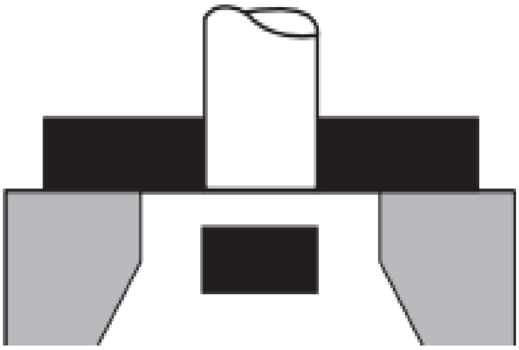
- **Bending:**

- Angular and curvilinear bending can be carried out by forging.
- Usually in smith forging, the edge of anvil is used to develop a curvilinear bend on a bar stock.
- Various edges of rectangular block are used for making angular bends



- **Punching:**

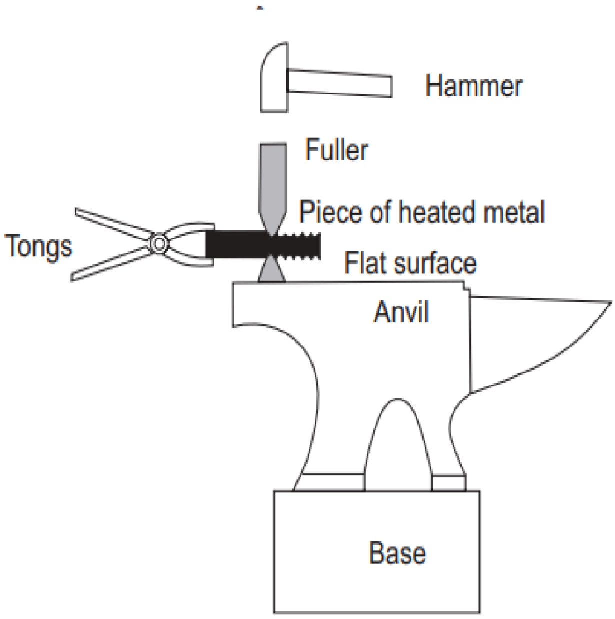
- It refers to the operation in which a punch is forced through a work piece to create a hole.
- The hot work piece is usually placed over the anvil face. Punching creates a hole by removing some material from it



FORGING METHODS

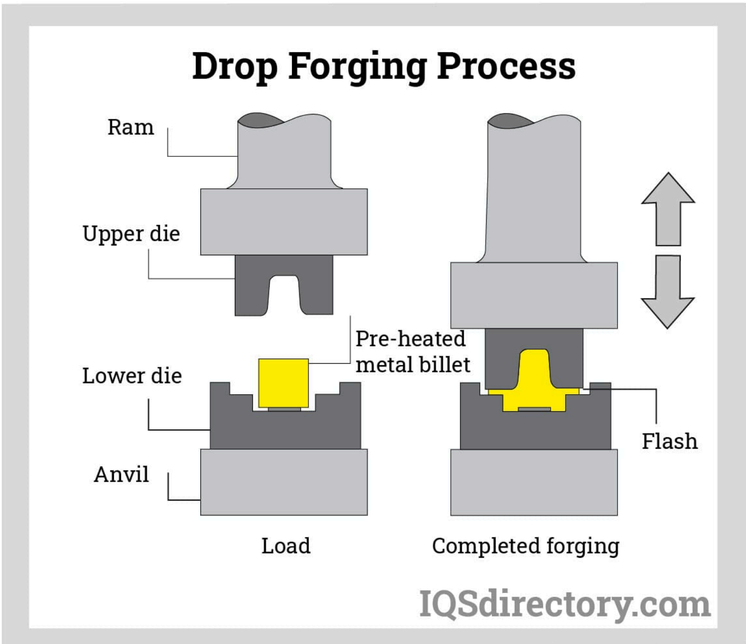
- Smith Forging:

- Smith forging involves heating the work piece in a black smith's furnace and hammering it over the surface of anvil.
- This needs skilled operators who select suitable tools and operations to manipulate the workpiece to attain the final shape.
- The forging operations like upsetting, drawing out, fullering, flattening, bending etc. are used by the operator for carrying out the work.
- This is a time consuming process, but still economical for small scale production.
- Different tools used by the smith forging process include anvils, swages, hammers of various types, tongs, punches, swage block etc.



Drop Forging:

- In drop forging, repeated hammering is used to shape the work piece as per the shape of die cavity.
- The machine used for drop forging is called drop stamp or drop hammer.
- The drop forging machines are powered by different means.



- The hot work piece is placed above the lower die while the ram along with the upper die delivers a few blows on the work piece, so that the metal spreads and fills the die cavity completely.
- It is not easy to remove forgings of complex shapes from the die cavity. Hence drop forging is not used for complex shapes with deep pockets, internal cavities
- A few products made by drop forging are crane hook, wrench, crank and crank shaft.

- **Press Forging:**

- Instead of a series of blows as in drop forging, here the metal is shaped by means of a single continuous squeezing action by the dies.
- Press forging dies are similar to drop forging dies, but here the squeezing is obtained by the pressing action by mechanical or hydraulic means.

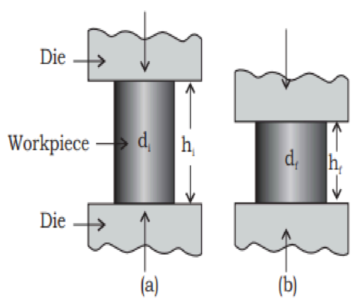
- Hydraulic presses are used for heavy work and mechanical presses for lighter work.
- The presses provide high squeezing force and the continuous action gets the material deformed throughout the entire depth
- The press forging process is suitable even for complex shapes with internal cavities, deep pockets etc. Compared to drop forging, this is a faster and quite process.
- Quality of the forged product is superior to that obtained from drop forging.

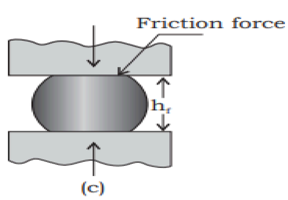
Open Die Forging

- The work piece is placed between two flat dies allowing the metal to flow freely without any constraints along the lateral directions.
- Eg: A solid cylindrical work piece is placed between two flat dies (platens) and compressed to reduce the height and deform it laterally. This process is known as upsetting.
- **Ideal case**: The workpiece gets deformed with length reduced and diameter increased uniformly.

Actual case: Due to friction between the die and workpiece surface, the work piece deforms into a barrel .This Phenomena is called **Barreling**. [Reason: The lateral deformation is less at the contact surface of die and workpiece because of the friction between them]

- The basic forging operations of upsetting, fullering, edging and drawing down can be carried out by the open die forging method.
- Only simple shapes can be generated by open die forging. Some examples are shafts, discs and rings.





Ideal case (no friction between the dies and work piece)

Impression Die Forging

- Here the work piece gets deformed into the shape of die cavities when it is forged between the closed dies.
- The die cavities have the replicated shape of the forged component.
- When the two dies are brought together, the work piece undergoes plastic deformation until its deformed sides touch the side walls of die.
- As the die closes to its final position, some metal flows out through the small gap between the dies to form a flash. The flash cools rapidly and provides increased resistance to further deformation.

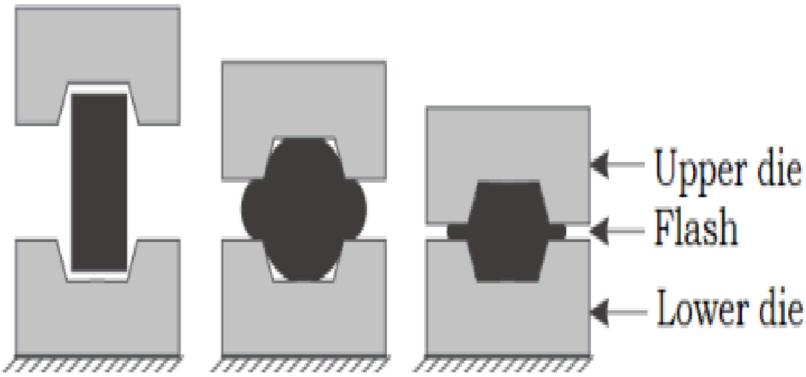
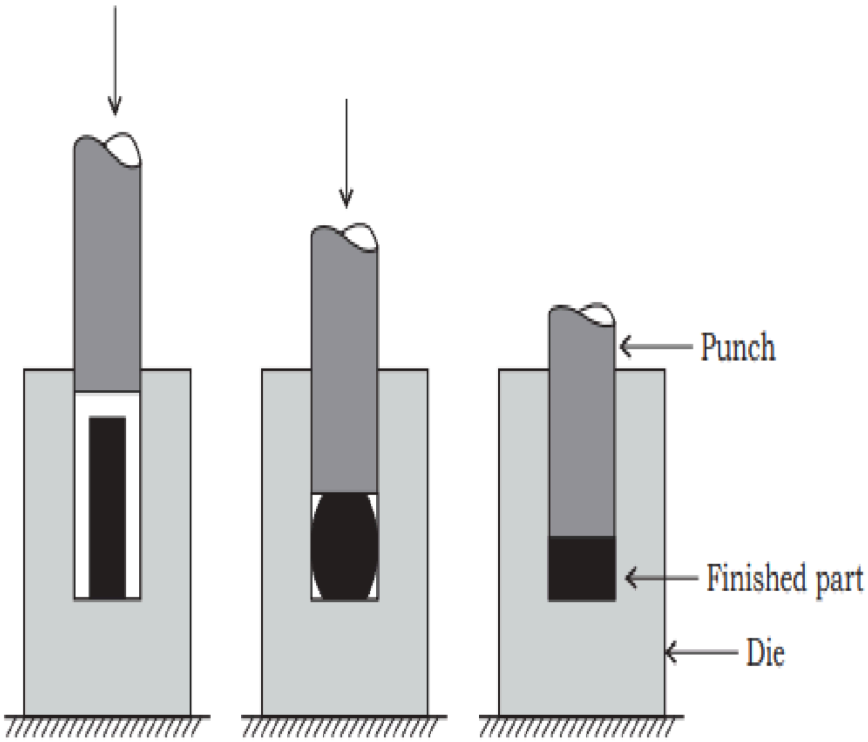


Figure 4.16

- Further forging pressure acting on the dies lead to increased pressure on the work piece and helps the material flow into unfilled areas of the die cavity.
- **Note:[Several steps may be required in impression die forging to transform the starting blank into the desired final shape of product. Separate sets of dies with different cavities are needed for this]**

Flashless Forging

- In the true closed die forging, no flash is formed.
- Here the hot workpiece is deformed to completely fill the cavity.
- Proper control of the volume of work material is essential to obtain a good quality forging as there is no provision for flash formation.
- If the starting blank is larger in volume than the volume of cavity, it may damage the dies upon application of pressure. If the blank is smaller in volume than needed, the cavity will not be filled completely.



FORGING DEFECTS

- **Cold shut:**

When the corner and fillet radii are small, metal does not flow properly into the corners and cold shut results. These appear as small cracks at the corners of the forgings.

- **Unfilled section:**

Due to insufficient metal or insufficient heating of the metals die cavity may not be filled completely and this defect occurs.

- **Flakes:**

Flakes are formed due to improper cooling of large forgings. Specifically, it is internal cracks in the forged parts that are caused by the quick cooling of the forged parts, which reduces the strength of the forged parts.

- **Scale pits:**

These irregular depressions on the surface of the forging are caused due to improper cleaning of the workpiece used for forging. Because of this, it create small cracks or holes in the metal.

- **Internal cranks:**

These are resulted from too drastic change in the shape of the work material at a faster rate

- **Die shift:**

Misalignment of the two halves of dies causes die shift. Due to this defect two halves of the forging to be of improper shape.

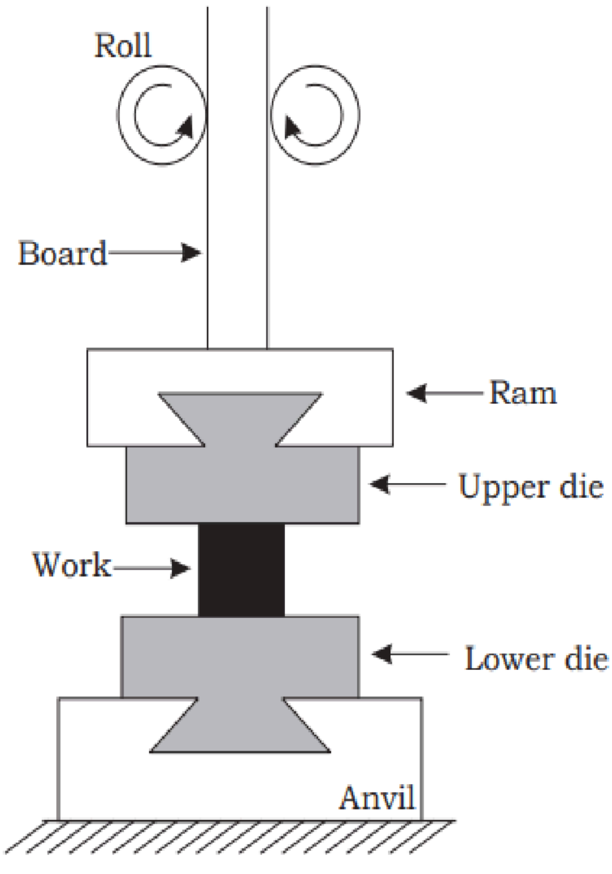
- **Surface cracks:**

Due to die wall chilling, an increase in resistance to metal flow near surface may result. This leads to surface cracks.

FORGING MACHINES

Board drop hammer

- A heavy mass called ram is mounted on a wooden board which passes between two pinch rolls.
- As the rolls rotate, the board along with ram is raised to a predetermined height and is allowed to fall down under gravity.
- The die attached to the ram hits the work piece placed above the lower die attached to the anvil.

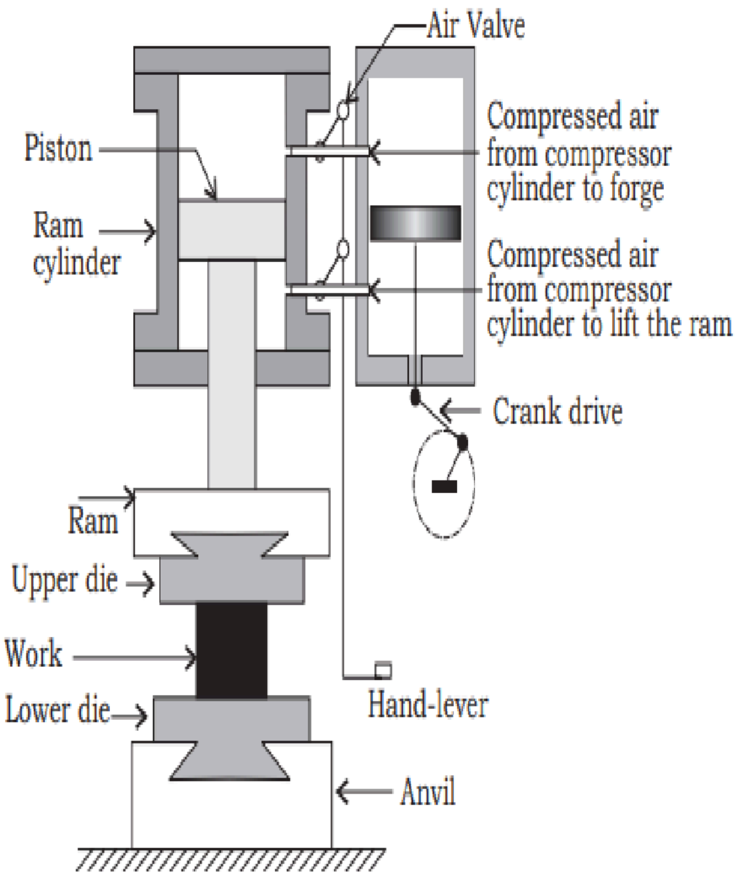


Pneumatic hammer

- Here, there are two cylinders called compression

cylinder and ram cylinder.

- Air is compressed in the compressor during upward and downward strokes of the piston in the compressor cylinder.
- When the compressed air is delivered to the lower side of ram cylinder, the piston moves upwards along with ram.
- By operating a hand lever, compressed air can be diverted to the upper side of piston in the ram cylinder, thereby moving the ram downwards delivering the hammer blow to the work piece

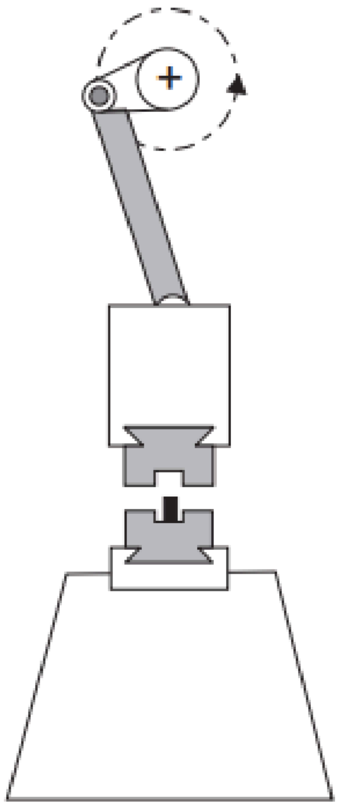


Mechanical Presses

- Corresponding to the rotation of crank, the ram moves up and down.
- The compressive force exerted by the ram on

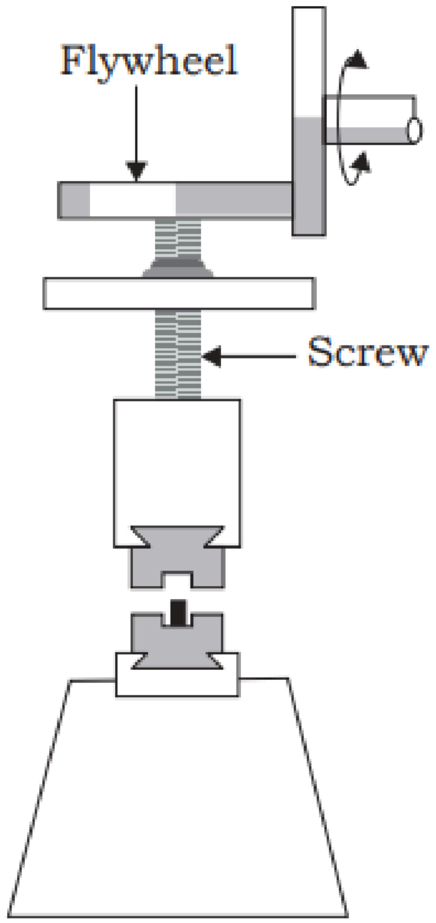
the die and work piece depends on the stroke position with the maximum at the bottom dead centre position.

- An electric motor is used to drive the crank though a flywheel and belt drive



Screw Press

- A flywheel is used to provide power to a screw press.
- As the flywheel is rotated, it rotates a screw which passes through a nut.
- The ram is moved up and down by the screw as the
- flywheel is driven by the driving discs.
- Here the ram speed can be controlled precisely and is suitable for small quantity production of precision components

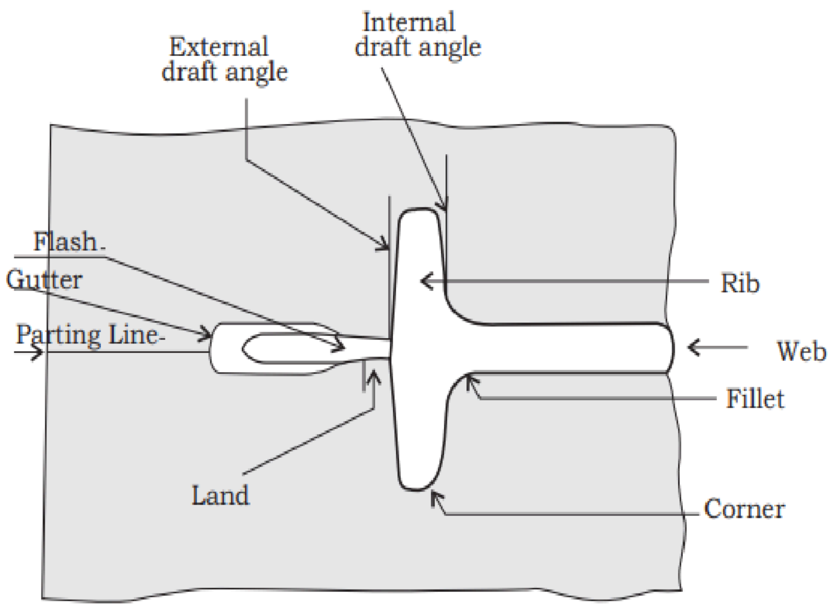


DIE DESIGN

Die Design Features

Parting line:

- It is the plane that divides the upper part of die from the lower part.
- This line is also called as flash line in impression die forging.
- Selection of location of parting line affects grain flow in the part, required load and flash formation.
- Parting line should be at the largest cross section of the part.
- Wherever possible, it should be a straight line along the centre of the forging.
- Parting line is to be so chosen such that the flow of material is uniformly divided between the two dies

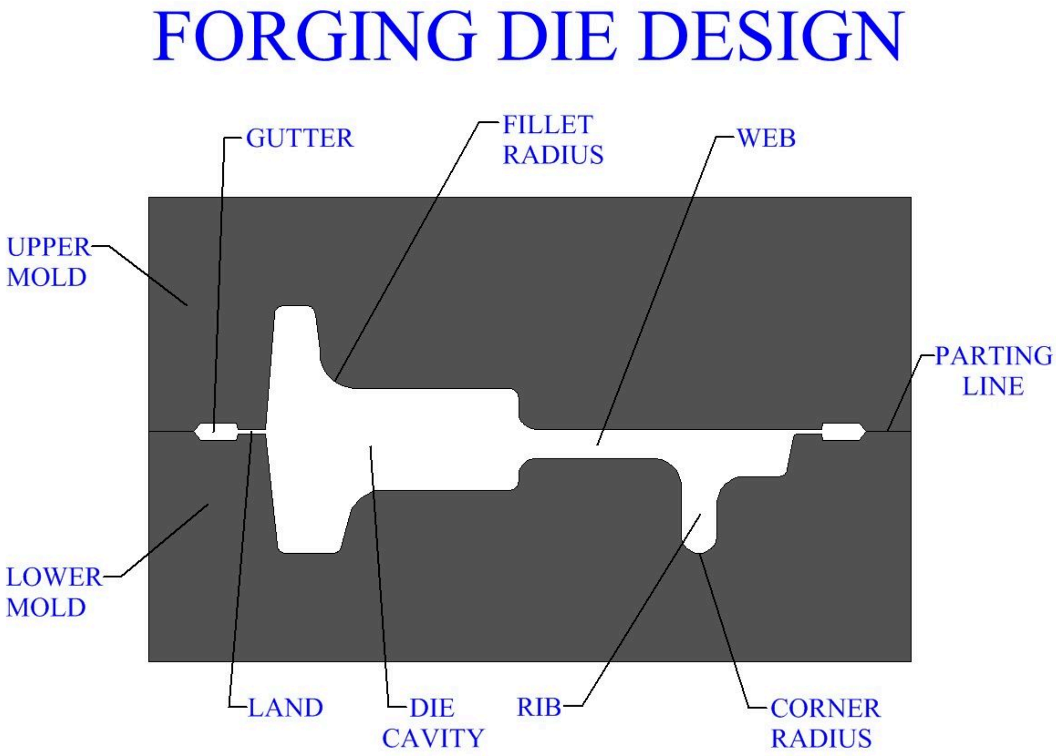


Draft Angles:

- Draft is the amount of taper on the sides of the product to facilitate easy removal from the die.
- Taper on the sides of die cavity also referred to as draft. Typical draft angles are 5^{o} to 7^{o} on steel forgings and 3^{o} on aluminium and magnesium forgings.

Webs and Ribs:

- A web is a thin portion that is parallel to parting line, while rib is a thin portion perpendicular to parting line.
- The webs and ribs cause difficulty in metal flow as they become thinner.



Fillet and corner radii:

- Small radii tend to limit metal flow and increase stresses on die surface during forging. Hence small radii are undesirable.
- Small fillet radii can cause fatigue cracking of the dies. In general, these radii need to be as large as permitted by the forging design

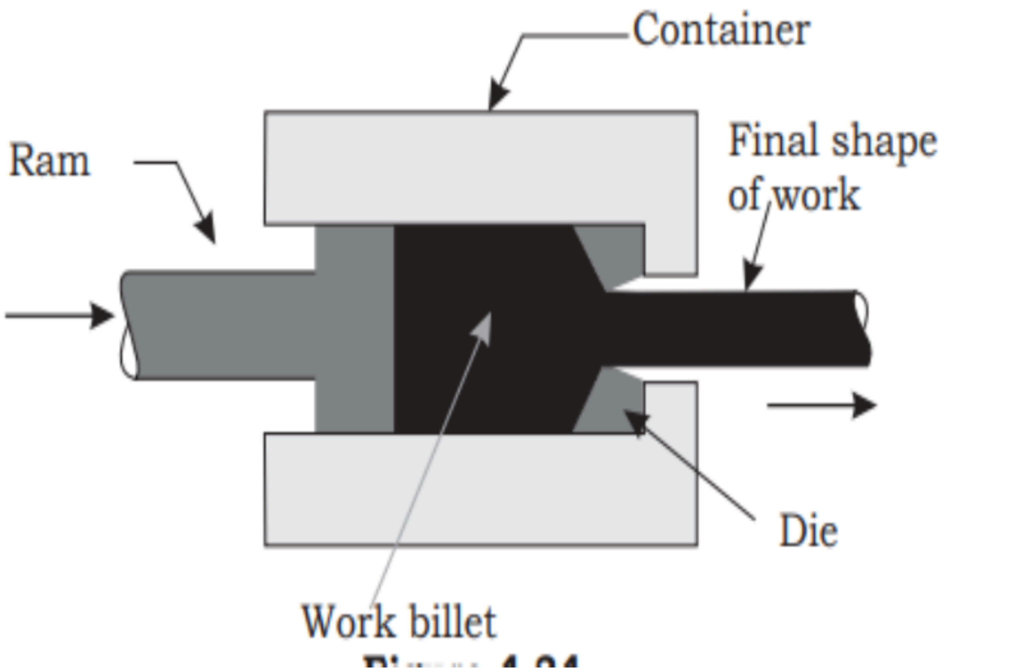
Land:

- Land determines the surface area along which the lateral flow of metal occurs.
- Hence it controls the pressure increase inside the die.
- The length of land is usually 2 to 5 times the flash thickness

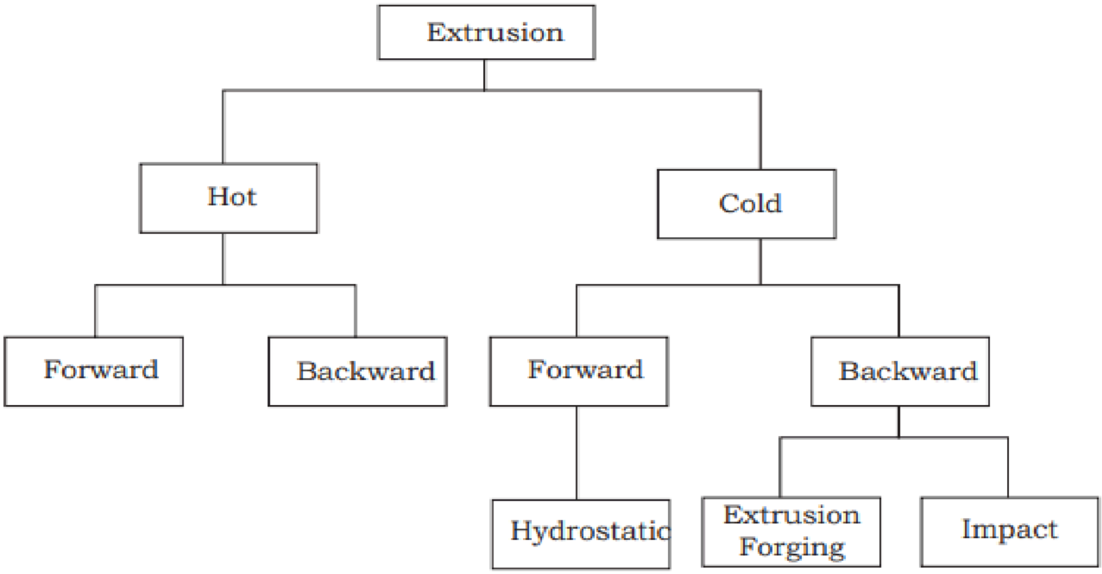
Extrusion

- **Extrusion is the process by which a block of metal is reduced in cross section by forcing it to flow through a die orifice under high pressure.**
- **Depending on the shape of orifice, the shape of extruded cross section can be different.**

- **Typical products made by extrusion are tubes having various cross sections; structural and architectural shapes; door and window frames.**
- **Commonly extruded materials are aluminium, copper, magnesium and their alloys; steel and lead.**
- ***Characteristic of extrusion: Large deformation with out fracture because of high triaxial compressive stress acting on the material***
- ***Each billet is extruded individually thus extrusion is a batch or semicontinuos operation***



CLASSIFICATION OF EXTRUSION

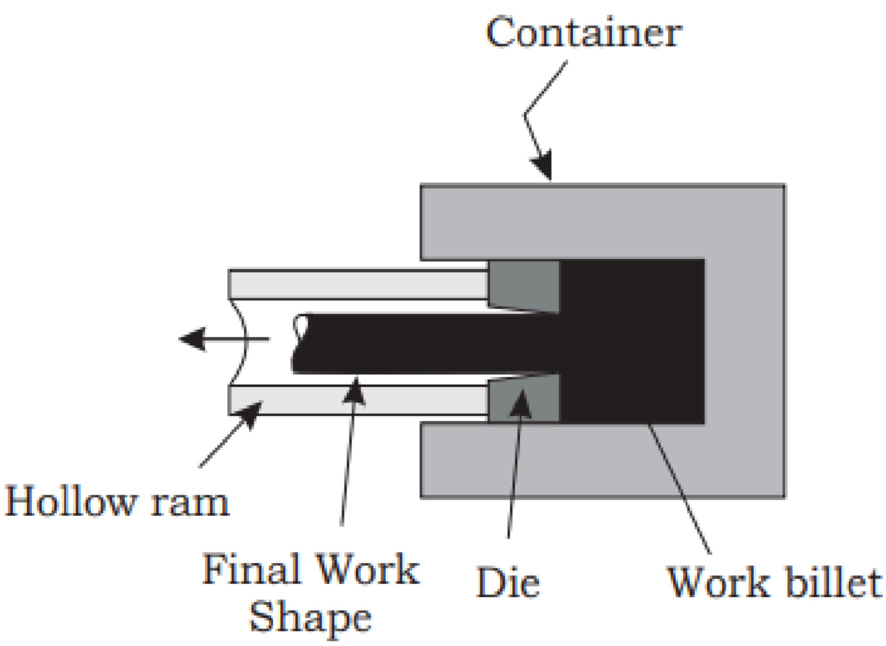


Hot Extrusion

- In hot extrusion, the work material is heated to a temperature above its recrystallisation temperature.
- The high temperature reduces the strength and increases ductility of the material.
- This facilitates extreme size reductions and complex shapes to be extruded.
- *While extruding steel, special lubricants like glass are used. In addition to reducing friction, it also provides thermal insulation between the billet and extrusion chamber*.
- Hot extrusion can be carried out as forward or backward process

Backward Extrusion

- Here the extruded metal moves out in the opposite direction of the movement of the ram. The process is also known as indirect or reverse extrusion.
- Here the billet in the container remains stationary and hence no friction is involved.
- The ram or plunger houses the die within it, and the extruded metal comes out through the hollow plunger. Handling the extruded metal is not much easy and the use of backward extrusion is limited.



Cold Extrusion

- Extrusion at room temperature or at temperatures lower than recrystallization temperature of work material is known as cold extrusion.
- It is primarily used to produce parts in finished or nearly finished forms.
- Main advantages of cold extrusion are:

a) increased strength due to strain hardening,

b) better surface finish, closer tolerances and higher production rates.

c)As the metal is not heated, it eliminates formation of oxide layers on the surface of the extruded parts.

- Usually cold extrusion is not a continuous process.
- Cold extrusion done in forward form is known as hydrostatic extrusion and in the backward form it is called impact extrusion

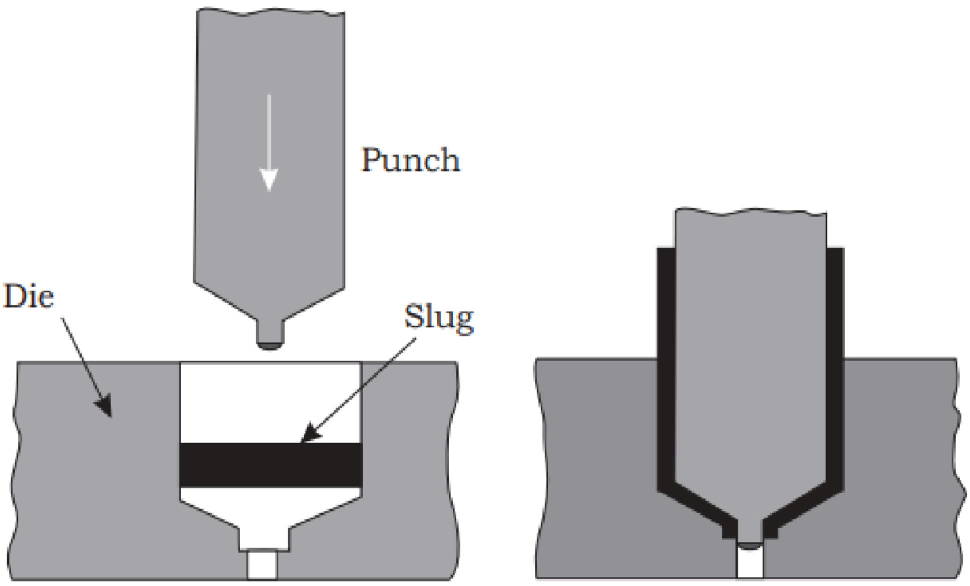
Hydrostatic Extrusion

- This is an extrusion method in which the required pressure is applied through a fluid medium surrounding the cold billet.
- The presence of fluid inside the extrusion chamber eliminates the friction between billet and chamber walls.

- It needs specialized equipment, tooling and higher set up time. This process is having only limited industrial applications.
- Even brittle materials can be extruded by this process. Commonly used fluids are glycerine, mineral lubricating oil, castor oil and isopentane.
- A few applications of the process are in making wires of less ductile materials and extrusion of nuclear reactor fuel rods.

Impact Extrusion

- Backward cold extrusion is usually called as impact extrusion.
- It works with softer materials like aluminium and its alloys.
- The setup consist of a punch and die arranged vertically.
- The billet is kept on the die as shown in figure.
- The punch is then allowed to strike the billet against the die.
- Due to the impact, the metal is extruded through the gap between the punch and die.
- The extruded metal moves out in the direction opposite to the movement of punch and hence it is called backward extrusion



EXTRUSION DEFECTS

Centre cracking:

- The central portion of extruded products may develop cracks called internal cracking, centre burst, arrow head fracture, or chevron cracking .
- The state of hydrostatic tensile stress at the centre line in the deformation zone is the reason for this kind of defects.
- The chances for centre cracking increases with increase in die angle, presence of impurities, extrusion ratio and friction

Pipe defect:

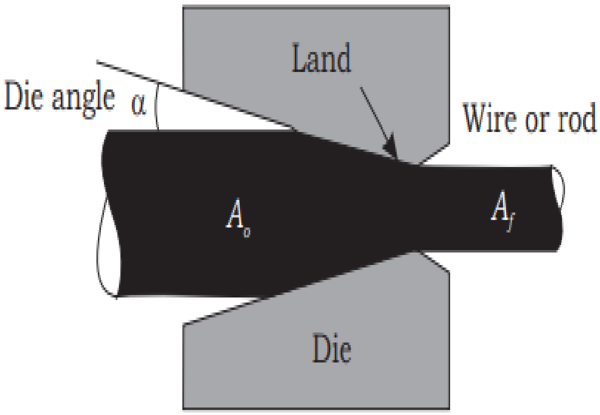
- The metal flow pattern during extrusion may draw the surface defects and impurities towards the centre of the billet like a funnel.
- This defect occurs when the friction is high and metal flow is not uniform.
- This is also known as tailpipe or fishtailing or simply as extrusion defect

Surface Cracking:

- Development of surface cracks are due to the rise in temperature of billet due to the heat generated by extrusion process.
- When the speed of extrusion is reduced, the temperature and hence chances of surface cracks can be reduced.

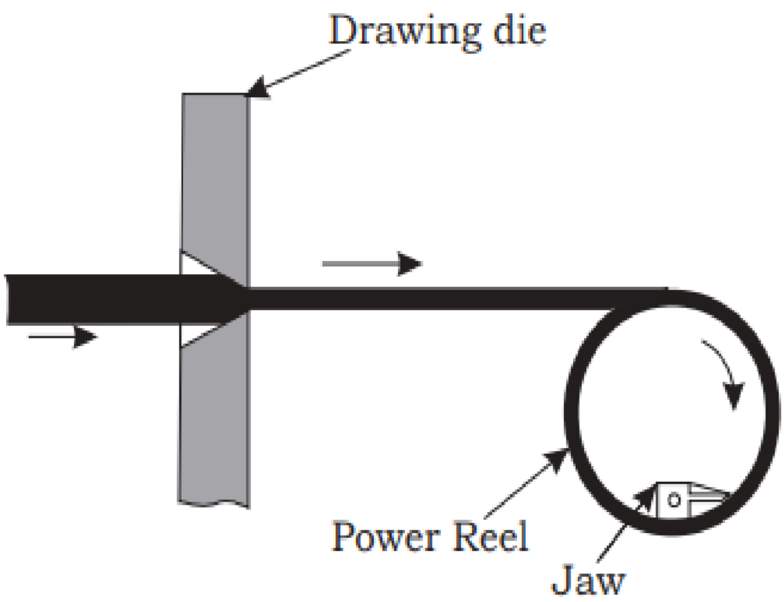
Drawing

- **This is the process of pulling metal though a die to achieve a reduction in diameter.**
- **Bars, rods and tubes are subjected to tensile force at the exit side of die to deform by this cold working process.**
- **The process can be used to reduce the size, increase strength and better surface finish.**
- **The major parameters in the process are reduction in cross sectional area, die angle, friction between die and work piece and drawing speed. The die angle influences the drawing force and the quality of drawn product**



Wire Drawing

- The process of wire drawing is to obtain wires from bars of larger diameter.
- Diameters as small as 0.03mm can be made with the wire drawing process.
- This is always used as a cold working process.
- Initially the end of bar or rod to be drawn is made into a pointed shape and inserted through the die opening.
- This end is gripped on the other side with a gripper to pull it through the die.
- During pulling, compressive stresses act on the material, at the dies along with the tensile stress exerted by the gripper.



- This will help reduce the cross sectional area and increase length of the wire.
- The wire coming out the die is coiled in a round power reel
- In order to impart sufficient ductility, the bar stock is initially annealed property before the drawing process. To clean the surface of bars of any scales and rust, it is also subjected to acid pickling before drawing.
- The required reduction in cross section may not be obtained in a single pass of the wire drawing process. In such cases, the wire is successively passed through a number of dies having holes of decreasing sizes. This kind of an arrangement is called as continuous wire drawing or tandem process
- Wire drawing improves the mechanical properties of the wire due to strain hardening. But intermediate annealing may be needed to improve ductility when it is continuously drawn.
- The dies are usually made of die steels, tungsten carbide or diamond. Large amount of heat is generated during the drawing process and proper cooling arrangement is made by circulating water for continuous cooling of dies and wires
- Wire drawing employs speeds upto 50 m/sec in drawing wires of smaller diameter

Rod or Bar Drawing

- Rod or bar drawing is very much similar in principle to the wire drawing process.
- The basic difference is in the larger size of bar stock used for bar drawing.
- Straight bars of round or other shapes are used in this cold forming process.
- In general, rods may have sections smaller than bars.
- Draw benches and heavy equipment are used for rod or bar drawing.
- Close dimensional tolerances and good surface finishes are obtained in rod or bar drawing.
- Maximum reduction in cross sectional area per pass is limited to 45%.
- Drawn rods are used for shafts, spindles and as raw materials for bolts, nails, screws, rivets etc.

Drawing dies are usually made of carbide or diamond, to increase die life.

Tube Drawing

- The starting material is a tube.
- Cylinders or tubes made by extrusion process are finished to the required inner and outer dimensions by the tube drawing.
- The tube drawing process is used to reduce the wall thickness, improve surface finish and improve dimensional accuracy, in addition to the reduction in the diameter of tube.
- In general, tube drawing can be classified into the following types:

❑ Tube sinking

❑ Tube drawing with fixed plug or mandrel

❑ Tube drawing with floating mandrel

❑ Tube drawing with moving mandrel

Tube sinking

- A mandrel or plug of suitable shape and dimensions is placed inside the tube and the tube is pulled out through the die.
- The tube is drawn through a die and a mandrel
- Outer dimension is governed by the die and inner dimension by the mandrel.
- Good dimensional accuracy and surface finish are obtained.

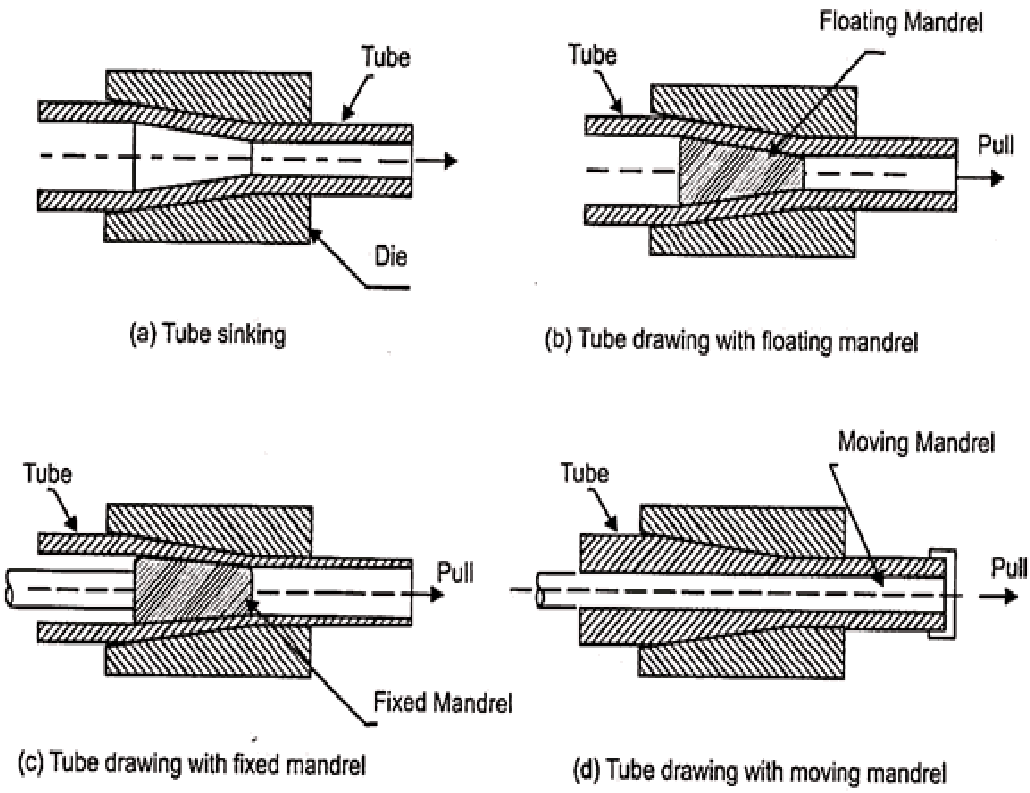
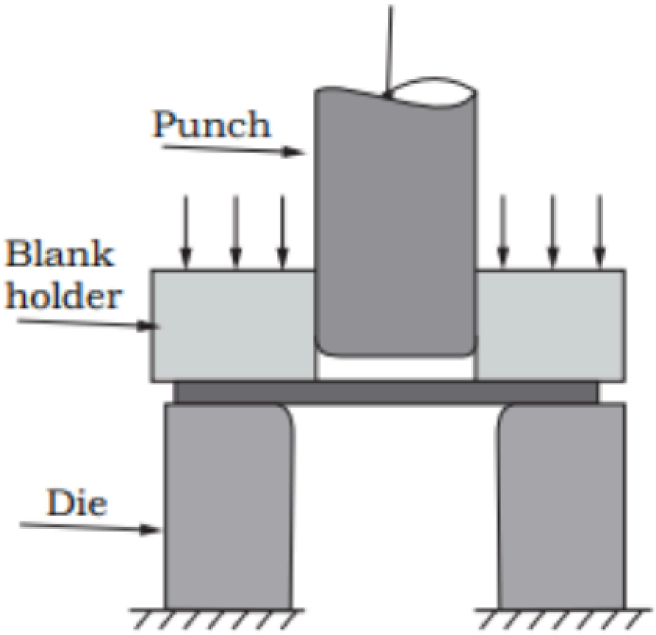


Fig. 9.17. Tube drawing processes

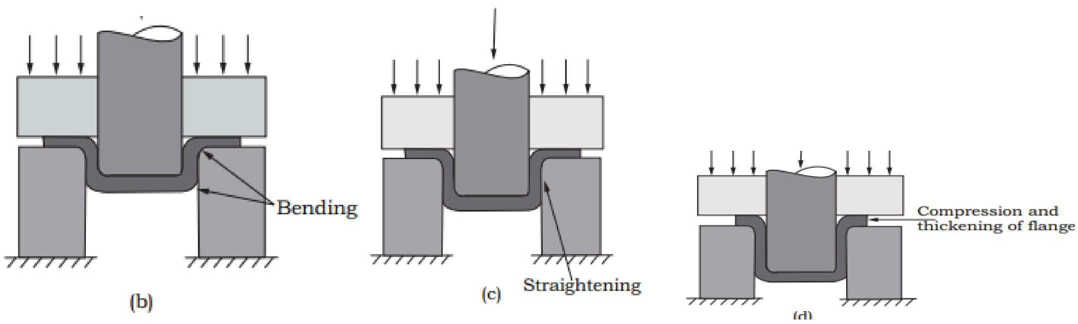
- The position of mandrel may be adjusted by the bar attached to its rear end in order to change the thickness of tube and the internal diameter
- While using a fixed plug, friction will be more, drawing load will be more and maximum reduction is limited to 40%.

DEEP DRAWING

- Deep drawing is a sheet metal forming process where a sheet metal blank is radially drawn into a forming die by penetrating with a punch by mechanical action.
- In deep drawing, usually, the depth of cup is one or more times the diameter.
- The process is also called stamping or cup drawing, using which circular, rectangular or complex outlined cups can be drawn
- Initially a round sheet metal blank is placed over a circular die opening and is held in position by a blank holder.
- Then the punch is allowed to move down to force the blank into the die cavity to form a cup shaped product. This is the basic process of deep drawing



- At the beginning, as the punch begins to push the work, it is bent over the corner of punch. The outer edges of the blank moves slightly towards the centre at this stage.
- As the punch moves down, the material also moves down, and a straightening action takes place in the bent metal. During this process, the flange is likely to wrinkle, but the force applied by the blankholder reduces or eliminates it.
- When the bent metal gets straightened and moves down, more material comes from the outside edges of the blank. Here the metal is drawn towards the die opening by the action of punch.



Here some thinning of the side walls of the cup occurs.

- This process can be used to make cup shaped, box shaped or any complex shaped hollow parts. Some of the products made by the drawing process, are kitchen sinks, cooking utensils, containers for food and beverages, automobile fuel tanks, body parts.

limiting drawing ratio

The ratio between the initial blank diameter and the diameter of the deep drawn cup is called the limiting drawing ratio

- Force needed for deep drawing a circular cup from a circular blank

$$\text{Drawing force,} \quad F = \pi d t \left[\frac{D}{d} - 0.6 \right] \sigma_Y$$

Blank size calculation

For a cylindrical cup of diameter d and height h,

Total surface area = bottom area + cylindical surface area

$$= \frac{\pi}{4} d^2 + \pi d h = \frac{\pi}{4}\left(d^2 + 4dh\right)$$

If D is diameter of the blank, area $= \frac{\pi}{4} D^2$

Equating these two areas, $\frac{\pi}{4} D^2 = \frac{\pi}{4}\left(d^2 + 4dh\right)$

$$\text{Blank diameter, } D = \sqrt{d^2 + 4dh} \qquad (4.14)$$

The percentage reduction can be calculated using the relationship,

$$\%\text{Reduction} = \frac{D - d}{D} \times 100 \qquad (4.15)$$

The inside diameter of cup wall is usually used for the above calculations. This diameter is same as the punch diameter.

Determine the force required for drawing a cup of 40 mm diameter from a mild steel blank of 70mm diameter and 2mm thickness. Also determine the maximum height of the cup drawn, if the yield strength of mild steel is 300MPa

Solution

Given, Diameter of blank, D = 70mm

Thickness of blank, t = 2mm

Diameter of cup, d = 40mm

Yield strength of mild steel, σ_Y =300MPa

Drawing force, $F = \pi dt\left[\frac{D}{d} - 0.6\right]\sigma_Y$

$$= \pi \times 40 \times 2\left[\frac{70}{40} - 0.6\right] \times 300$$

$$= 86664\text{N} = 86.664\text{kN}$$

Dimensions of blank and cup are related by

$$\frac{\pi}{4}D^2 = \frac{\pi}{4}\left(d^2 + 4dh\right)$$

From this, height, $h = \frac{D^2 - d^2}{4d} = \frac{70^2 - 40^2}{4 \times 40} = 20.625\text{mm}$

Height of the cup will be 20.625mm