# Manufacturing Science
# (BME-29)

## Unit 2

**Sunil Kumar Yadav**

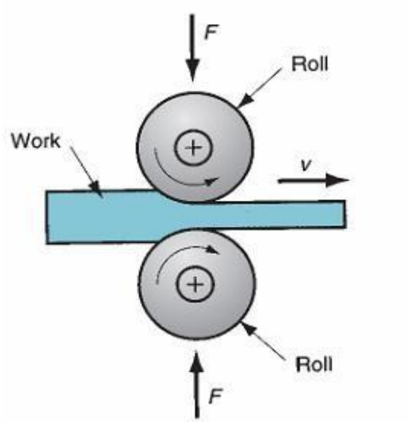
**Assistant Professor**

**Mechanical Engineering Department**

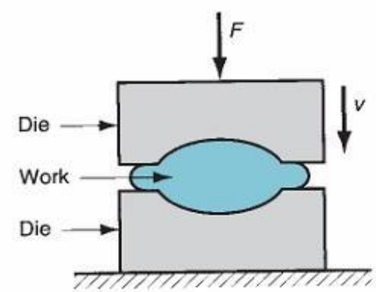
***Madan Mohan Malviya University of Technology Gorakhpur*** ***(UP State Govt. University)***

**Email: skyme@mmmut.ac.in**

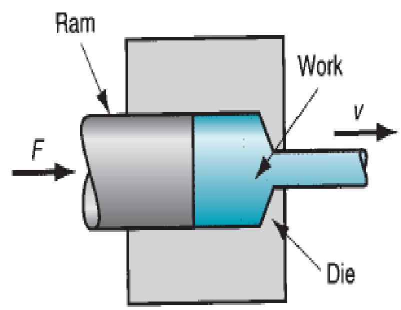
# Classification of Forming Processes



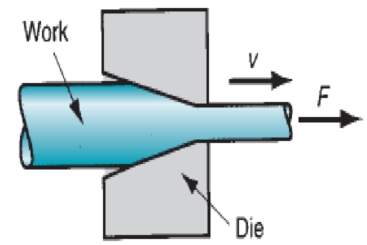

**Rolling**



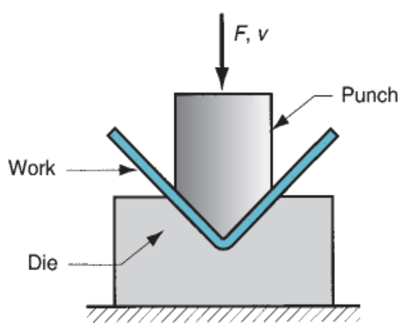

**Forging**



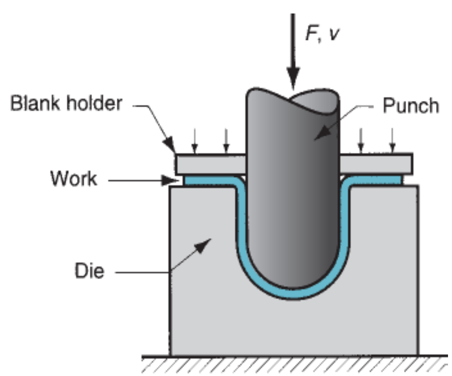

**Extrusion**



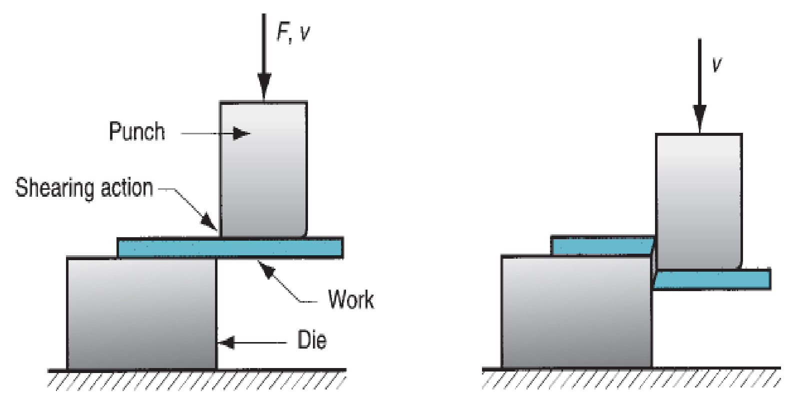

**Wire drawing**




**Bending**




**Deep drawing**

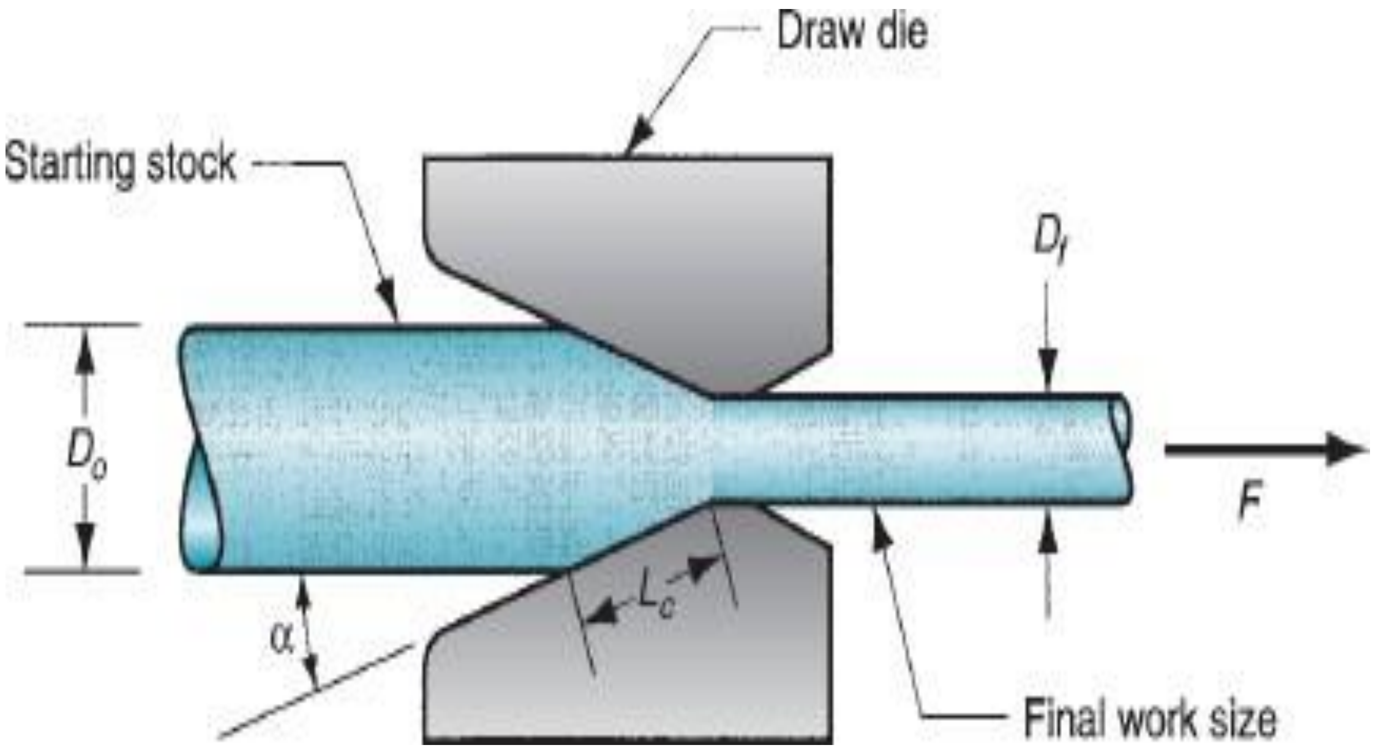



**shearing**

# Wire Drawing

# Wire Drawing

- Wire drawing involves reducing the diameter of a rod or wire by passing through a series of drawing dies.
- The subsequent drawing die must have smaller bore diameter than the previous drawing die.
- Drawing operations involve pulling metal through a die by means of a tensile force applied to the exit side of the die.
- Material should have high ductility and good tensile strength.
- Bar, wire and tube drawing are usually carried out at room temperature, except for large deformation, which leads to considerable rise in temperature during drawing.


Draw die
Starting stock
$D_f$
$D_o$
F
α
$L_c$
Final work size

# Difference between wire drawing and rod drawing

- **Initial stock size:**

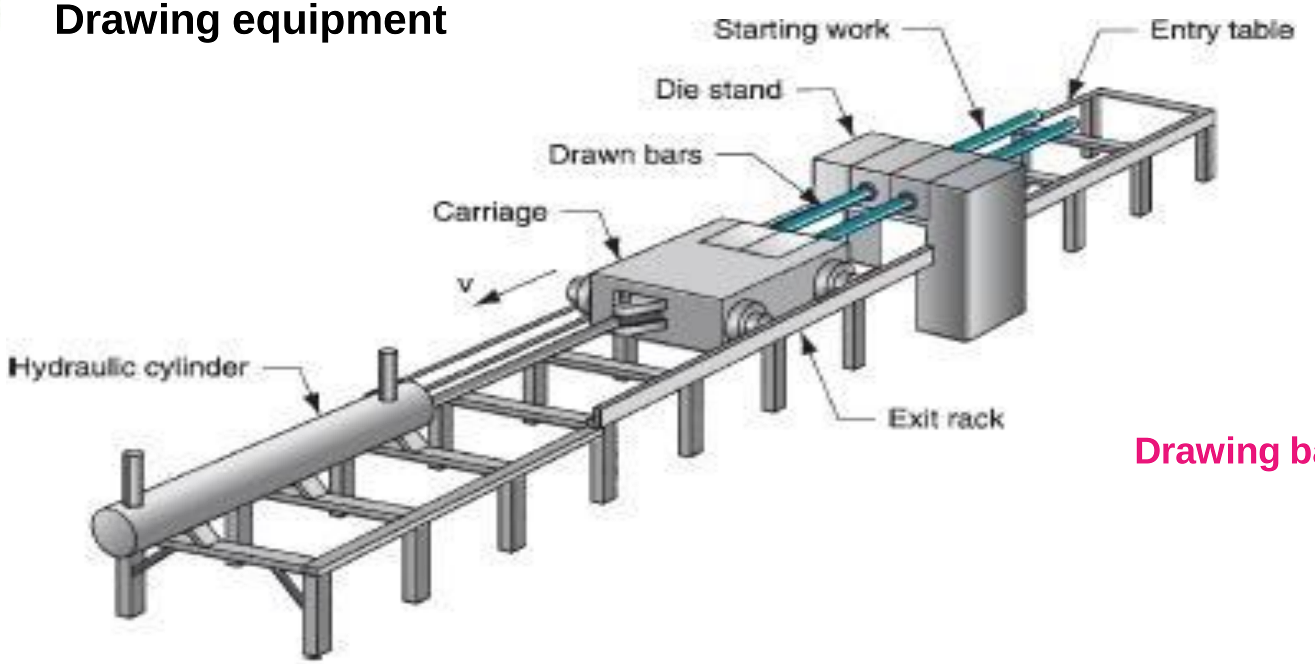
- The basic difference between bar drawing and wire drawing is the stock size that is used for forming. Bar drawing is meant for large diameter bar and rod, while wire drawing is meant for small diameter stock. Wire sizes of the order of 0.03 mm are produced in wire drawing.

- **Operating stages:**

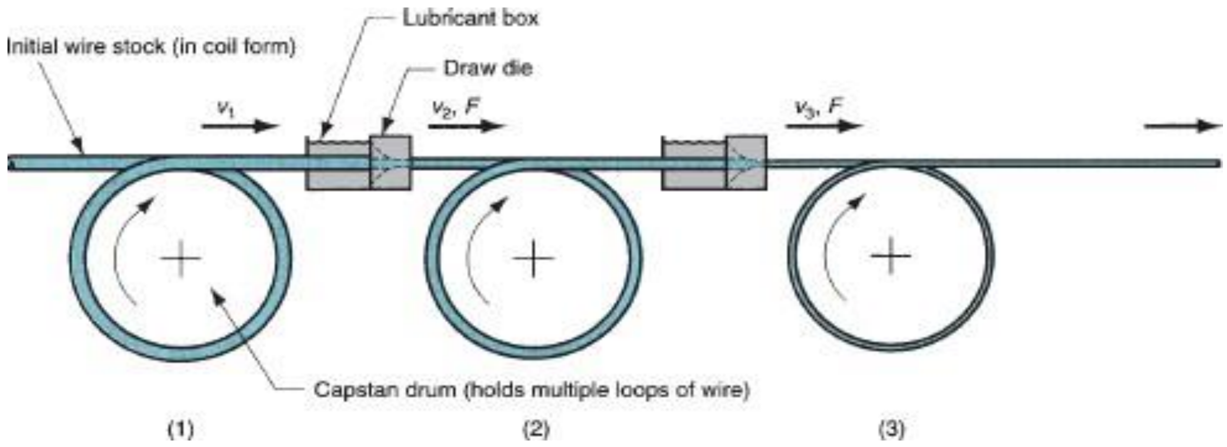
Bar drawing is generally done as a single stage operation, in which stock is pulled through one die opening. The inlet bars are straight and not in the form of coil, which limits the length of the work that can be drawn. This necessitates a batch type operation.

- In contrast, wire is drawn from coils consisting of several hundred meters of wire and is drawn through a series of dies. The number of dies varies between 4 and 12. This is termed as ‘continuous drawing’ because of the long production runs that are achieved with the wire coils. The segments can be butt-welded to the next to make the operation truly continuous.

## Drawing equipment



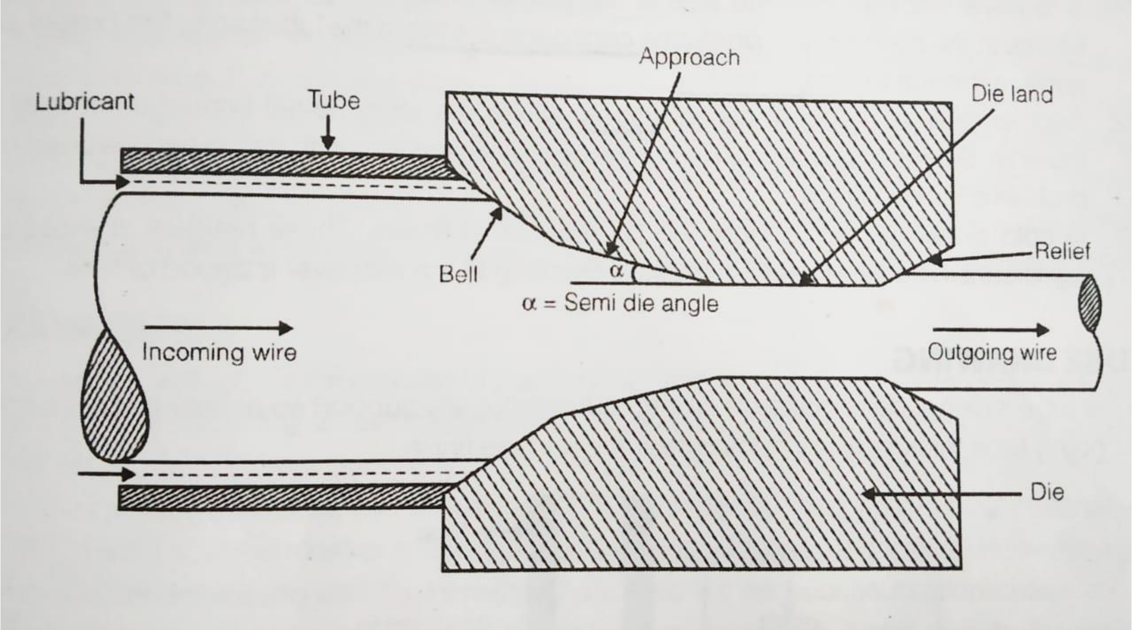

**Drawing bar by draw bench**




**Continuous drawing of wire**

# Drawing dies

- The entry region is generally a bell-shaped mouth that does not contact the work- piece. Its function is to contain and push the lubricant into the die and prevent wearing of work and die surfaces




- The approach region is where the drawing operation occurs. It is cone-shaped with an angle (half-angle) normally ranging from 6° to 20°.
- The bearing surface or land, determines the size of the final drawn work-piece.
- Finally, the back relief is the exit zone. It is provided with a back relief angle (half-angle) of about 25-30°.

# Die Materials

- Cemented carbides are the most used for drawing dies due to their superior strength, toughness, and wear resistance.

- Cemented carbide is composed of carbides of Ti, W, Ni, Mo,
- Polycrystalline Diamond (PCD) used for wire drawing dies – for fine wires. Longer die life, high resistance to wear, cracking or bearing.

Figure : Die

# Wire drawing process

Hot rolled rod

↓

Pickling, descaling — Remove scale- causing surface defects.

↓

Lubricating →

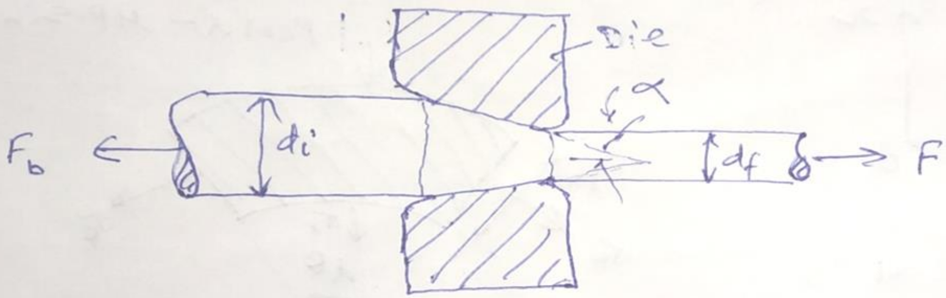
- Cu and Sn are used as lubricants for high strength materials.
- Oils and greases for wire drawing
- Soap for dry drawing.

↓

Drawing

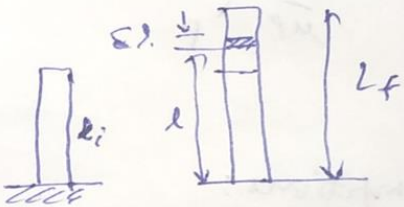
# Analysis of wire drawing

## Analysis of Drawing




True Strain

$$\varepsilon = \ln\left(\frac{A_i}{A_f}\right)$$




$$\varepsilon = \int_{l_i}^{l_f} \frac{dl}{l}$$

$$= \ln l \Big|_{l_i}^{l_f}$$

$$= \ln\left(\frac{l_f}{l_i}\right)$$

for constant volume

$$l_i A_i = l_f A_f$$

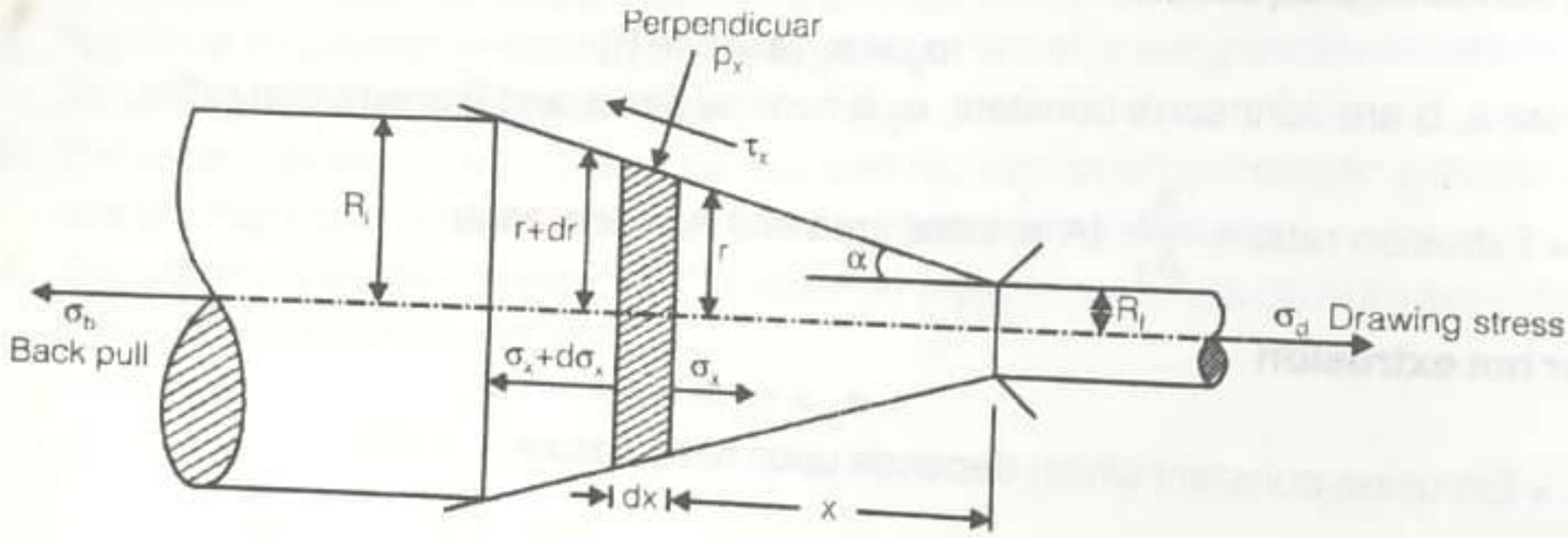
$$\frac{l_f}{l_i} = \frac{A_i}{A_f}$$

Degree of a drawing operation (D)

$$D = \frac{A_i - A_f}{A_i}$$

$$D = 1 - \left(\frac{d_f}{d_i}\right)^2$$

# Analysis of wire drawing ( cont..)



# Assumptions

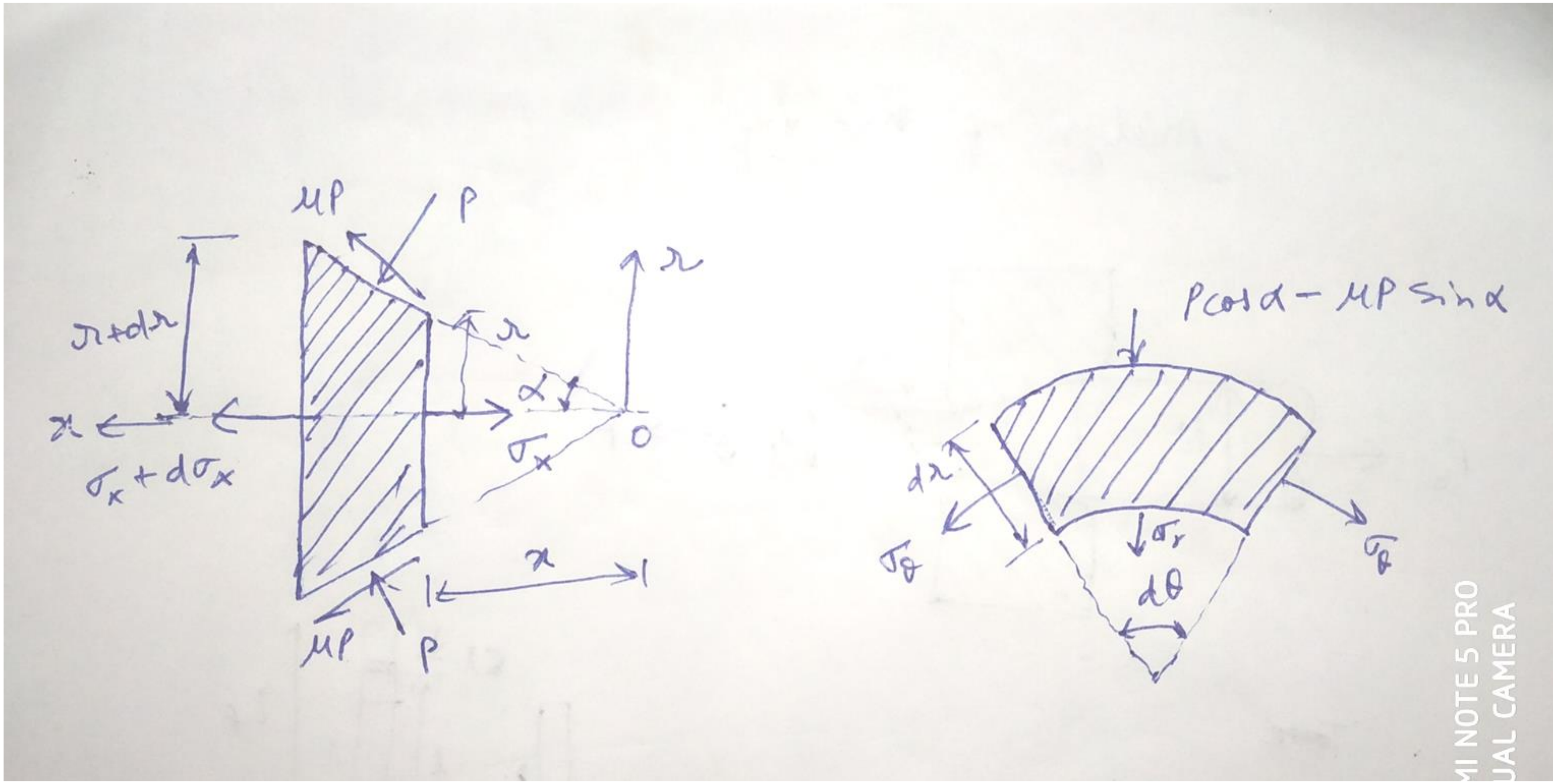
Assumptions:

(i)- The coefficient of friction $\mu$ and the half cone angle $\alpha$ are small.

(ii). The yield stress $\sigma_Y$ is constant and given by the average of the initial and the final values.

(iii). $-p$ and $\sigma_x$ are the principal stresses.

(iv)- $\sigma_x$ does not vary in the radial direction.



μP
P
r+dr
r
α
x
σx + dσx
σx
O
x
μP
P
Pcos α − μP sin α
dr
σθ
σr
dθ
σθ

Considering the equilibrium of the element in x- dir^n

$$(\sigma_x + d\sigma_x)\pi(r+dr)^2 - \sigma_x \pi r^2 + \mu p\, 2\pi r \frac{dx}{\cos\alpha}\cdot\cos\alpha$$

$$+ p\, 2\pi r \cdot \frac{dx}{\cos\alpha}\cdot \sin\alpha = 0 \qquad \text{— (1)}$$

Neglecting the higher order terms

$$r\,d\sigma_x + 2\left[\sigma_x + p\left(1 + \frac{\mu}{\tan\alpha}\right)\right] dx = 0$$

$$r\,d\sigma_x + 2\left[\sigma_x + p + p\mu\cdot\cot\alpha\right] dx = 0 \qquad \text{— (2)}$$

Using von Mises yield criterion

$$\boxed{\sigma_x + p = 2K'}$$

$$r\, d\sigma_x = -2\left[2K' + (2K' - \sigma_x)\,\mu \cot\alpha\right] dr$$

let $\mu \cot\alpha = B$

$$\frac{d\sigma_x}{dr} = \frac{-2}{r}\left[2K' + B(2K' - \sigma_x)\right]$$

$$\frac{d\sigma_x}{\left[2K' + B(2K' - \sigma_x)\right]} = \frac{-2}{r} \cdot dr$$

$$\frac{d\sigma_x}{[2K' + B(2K' - \sigma_x)]} = -\frac{2}{r}\cdot dr$$

$$\int \frac{d\sigma_x}{[2K' + B(2K' - \sigma_x)]} = -\int \frac{2}{r}\, dr$$

$$-\frac{1}{B}\ln\left[2K' + B(2K' - \sigma_x)\right] = -2\ln r + C_1 \quad -(3)$$

apply Boundary conditions

at $r = R_i$ ; $\sigma_x = \sigma_b$ , where $\sigma_b$ = back pull

$$-\frac{1}{B}\ln\left[2K' + B(2K' - \sigma_b)\right] = -2\ln R_i + C_1 \quad \text{— (4)}$$

By equating eqn (3) & (4)

$$\frac{\left[2K' + B(2K' - \sigma_x)\right]}{\left[2K' + B(2K' - \sigma_b)\right]} = \left(\frac{r}{R_i}\right)^{2B}$$

$$\sigma_x = 2K'\left(\frac{1+B}{B}\right)\left(1-\left(\frac{r}{R_i}\right)^{2B}\right) + \sigma_b\left(\frac{r}{R_i}\right)^{2B}$$

$$(\sigma_d)_{r=R_f}$$

$$\boxed{\sigma_d = 2K'\left(\frac{1+B}{B}\right)\left(1-\left(\frac{R_f}{R_i}\right)^{2B}\right) + \sigma_b\left(\frac{R_f}{R_i}\right)^{2B}}$$

$$\sigma_d = \frac{\sigma_o(1+B)}{B}\left[1-\left(\frac{r_f}{r_o}\right)^{2B}\right]+\left(\frac{r_f}{r_o}\right)^{2B}.\sigma_b$$

$\sigma_0$ = yield strength of metarial

B = $\mu \cot \alpha$

$\mu$ = co-efficient of friction

$\alpha$ = half die-angle

$r_f$ = radius of work piece at exist

$r_0$ = raidus of work piece at entry.

# For frictionless wire drawing

Drawing force P:

$$P = A_f \sigma_o \ln\left(\frac{A_o}{A_f}\right) = 2 \times \frac{\pi d_f^2}{4} \times \sigma_o \times \ln\left(\frac{d_o}{d_f}\right)$$

Drawing Stress

$$\sigma_d = \frac{P}{A_f} = \sigma_o \ln\left(\frac{A_o}{A_f}\right) = 2 \times \sigma_o \times \ln\left(\frac{d_o}{d_f}\right)$$

# Problem

- An aluminium rod of 6.25 mm diameter is drawn into wire of 5.6 mm diameter. Semi die angle is 10.1. find the drawing stress, considering the friction to be 0.04 and nominal stress 35 MPa. Also calculate the maximum reduction that can be given to material.

Sol^n

$d_i = 6.25$ mm

$d_o = 5.6$ mm

$\alpha = 10.1^\circ$

$\mu = 0.04$

$\sigma_o = 35$ MPa

$\sigma_d = ?$

Since $\sigma_b$ is not given so it is zero

$$\sigma_d = \sigma_o \left(\frac{B+1}{B}\right)\left(1 - \left(\frac{r_f}{r_i}\right)^{2B}\right)$$

$B = \mu \cot \alpha$

$= 0.224$

$\sigma_d = 9.17$ MPa

For maximum reduction

$$\sigma_d = \sigma_0$$

$$1 = \left(\frac{B+1}{B}\right)\left[1 - \left(\frac{A_f}{A_i}\right)^B\right]$$

$$\frac{A_f}{A_i} = 0.403$$

$$\% \text{ reduction} = \left(\frac{A_i - A_f}{A_i}\right) \times 100$$

$$= (1 - 0.403) \times 100$$

$$= 59.6\,\%$$

# Tube Drawing

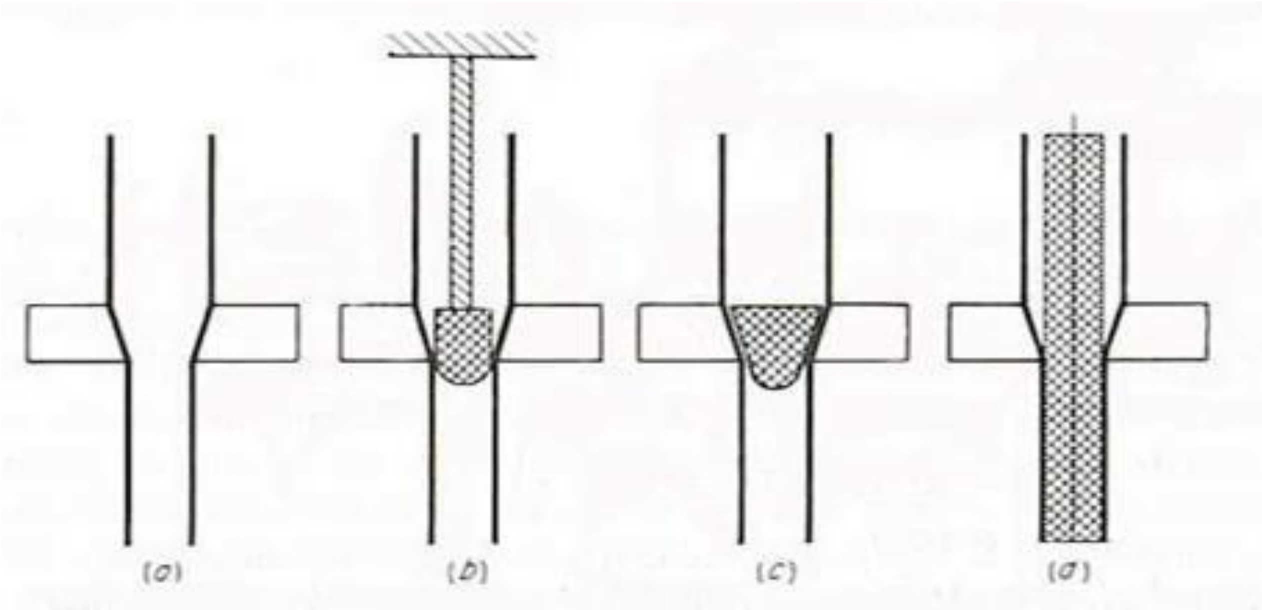
# Tube Drawing

- Tube drawing involves reducing the diameter of a tube by passing through a drawing dies.
- The subsequent drawing die must have smaller bore diameter than the previous drawing die.
- Drawing operations involve pulling metal through a die by means of a tensile force applied to the exit side of the die.
- Material should have high ductility and good tensile strength.
- Tube drawing are usually carried out at room temperature, except for large deformation, which leads to considerable rise in temperature during drawing.

# Classification of tube drawing processes

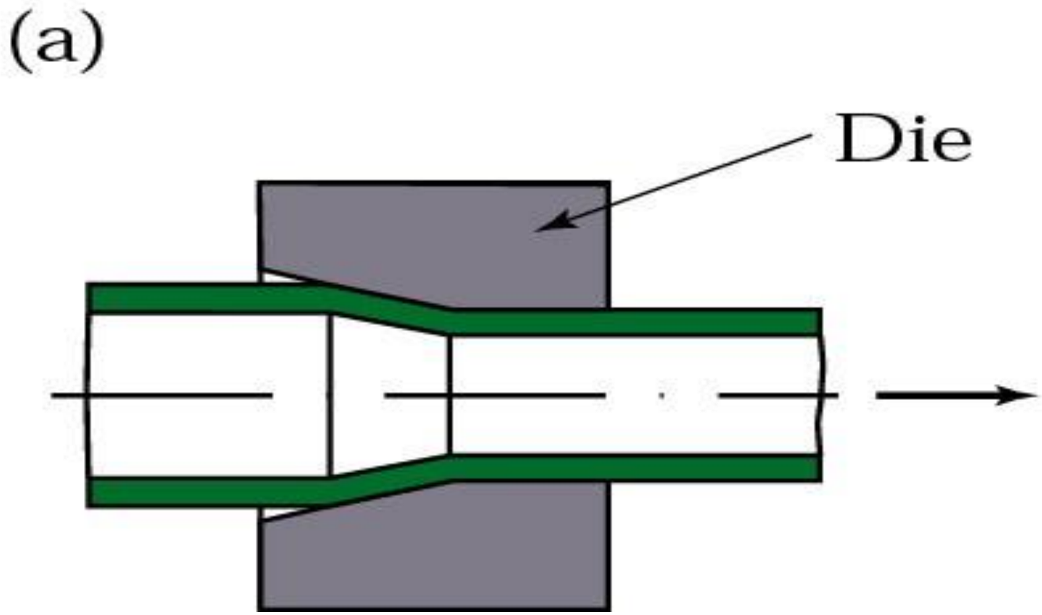
- There are three basic types of tube-drawing processes

- Sinking
- Plug drawing
  - Fixed plug
  - Floating plug
- Mandrel drawing.



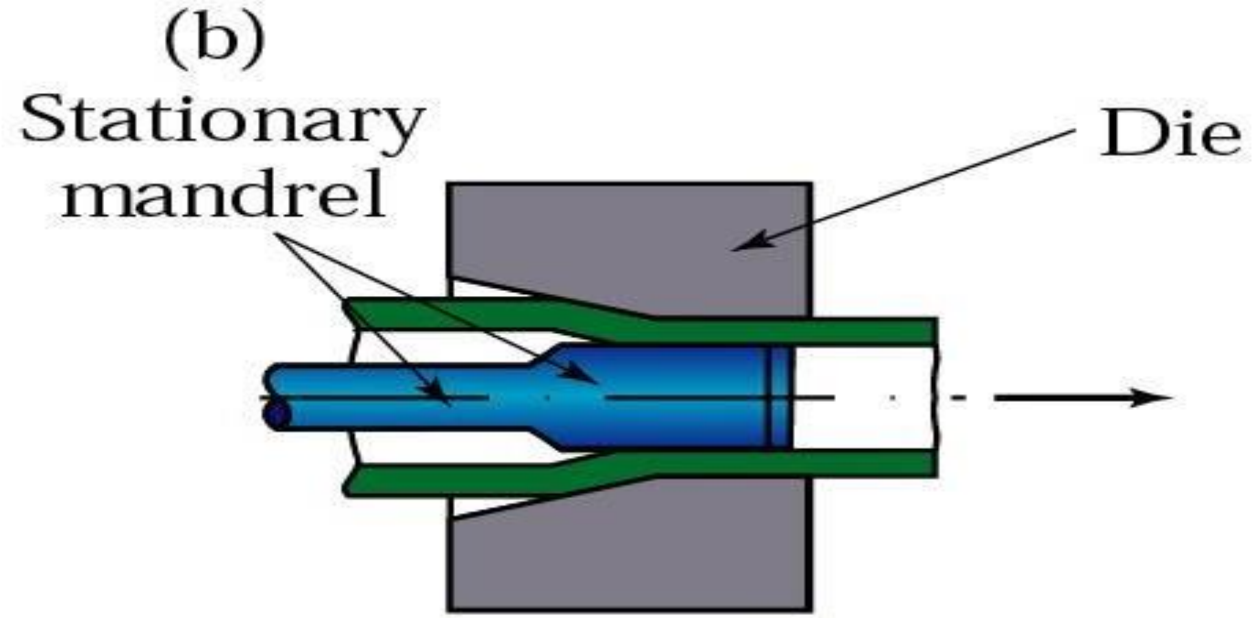

Tube sinking    Fixed plug    Floating plug    Moving mandrel

# Sinking



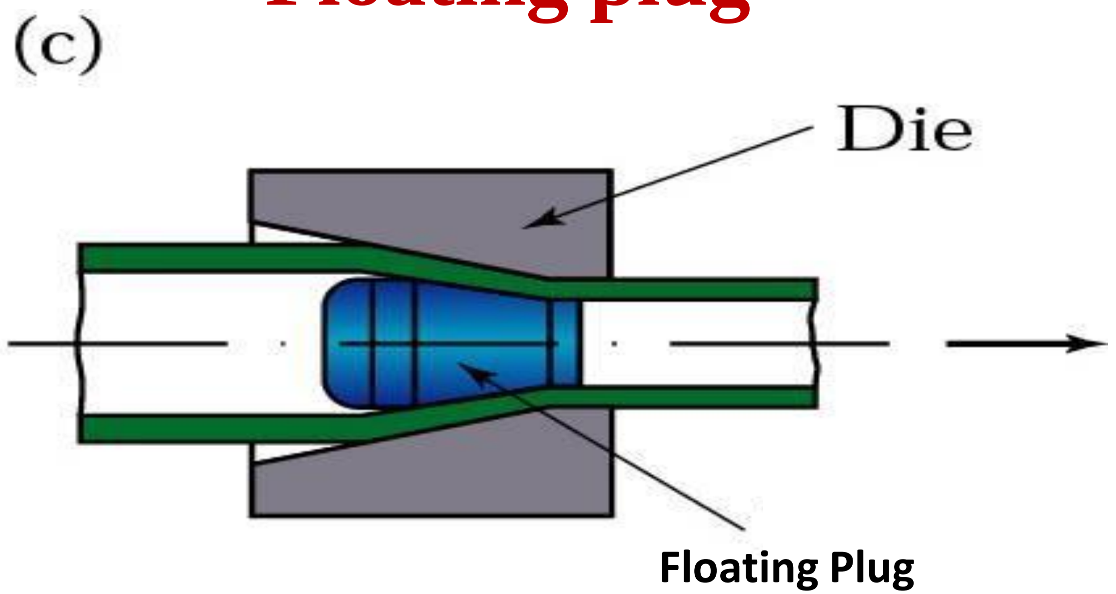

•The tube, while passing through the die, shrinks in outer radius from the original radius
•No internal tooling (internal wall is not supported), the wall then thicken slightly.
•The final thickness of the tube depends on original diameter of the tube, the die diameter and friction between tube and die.
•Lower limiting deformation.

# Fixed plug



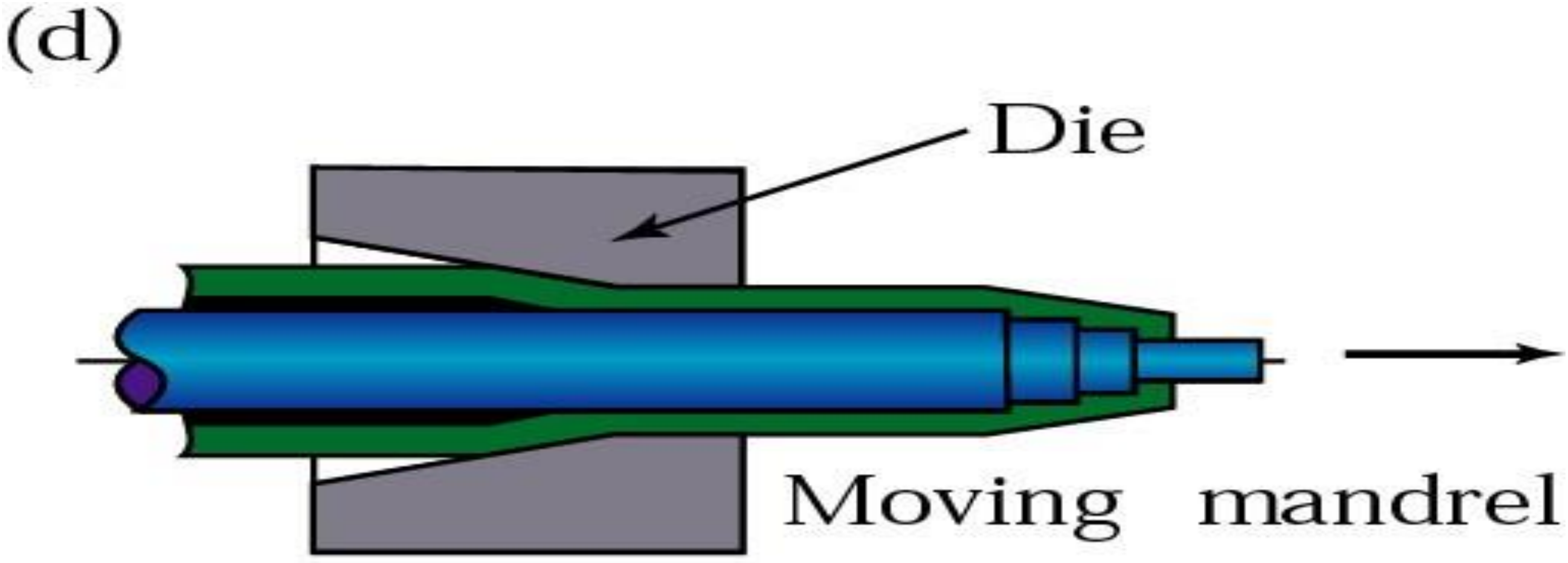

- Use conical plug to control size/shape of inside diameter.
- Use higher drawing loads than floating plug drawing.
- Greater dimensional accuracy than tube sinking.
- Increased friction from the plug limit the reduction in area (seldom > 30%).
- can draw and coil long lengths of tubing.

# Floating plug




- A tapered plug is placed inside the tube.
- As the tube is drawn the plug and the die act together to reduce both the outside/inside diameters of the tube.
- Improved reduction in area than tube sinking (~ 45%).
- Lower drawing load than fixed plug drawing.
- Long lengths of tubing is possible.
- Tool design and lubrication can be very critical.

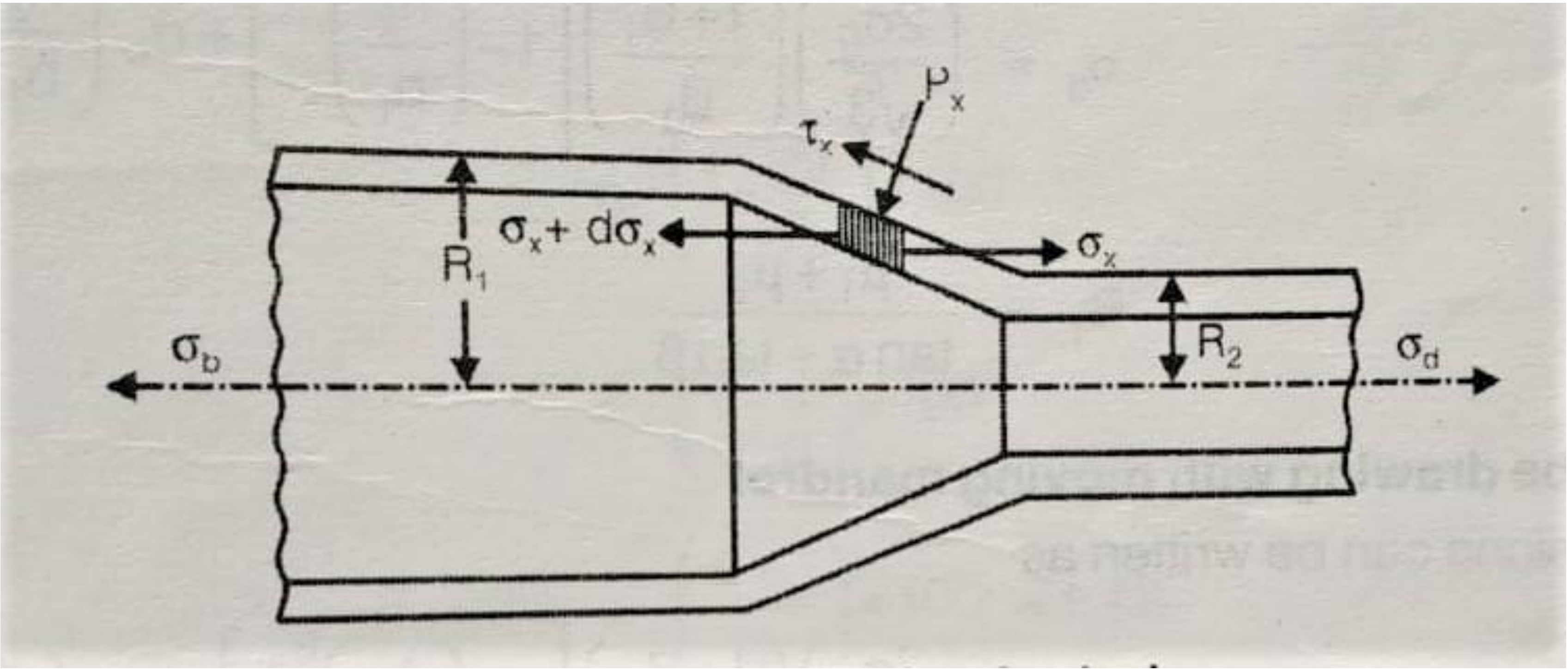
# Moving mandrel




- Draw force is transmitted to the metal by the pull on the exit section and by the friction forces acting along the tube -mandrel interface.
- minimized friction.
- V mandrel = V tube
- The mandrel also imparts a smooth inside finish surface of the tube.
- mandrel removal disturbs dimensional tolerance.

# Analysis of Tube Drawing

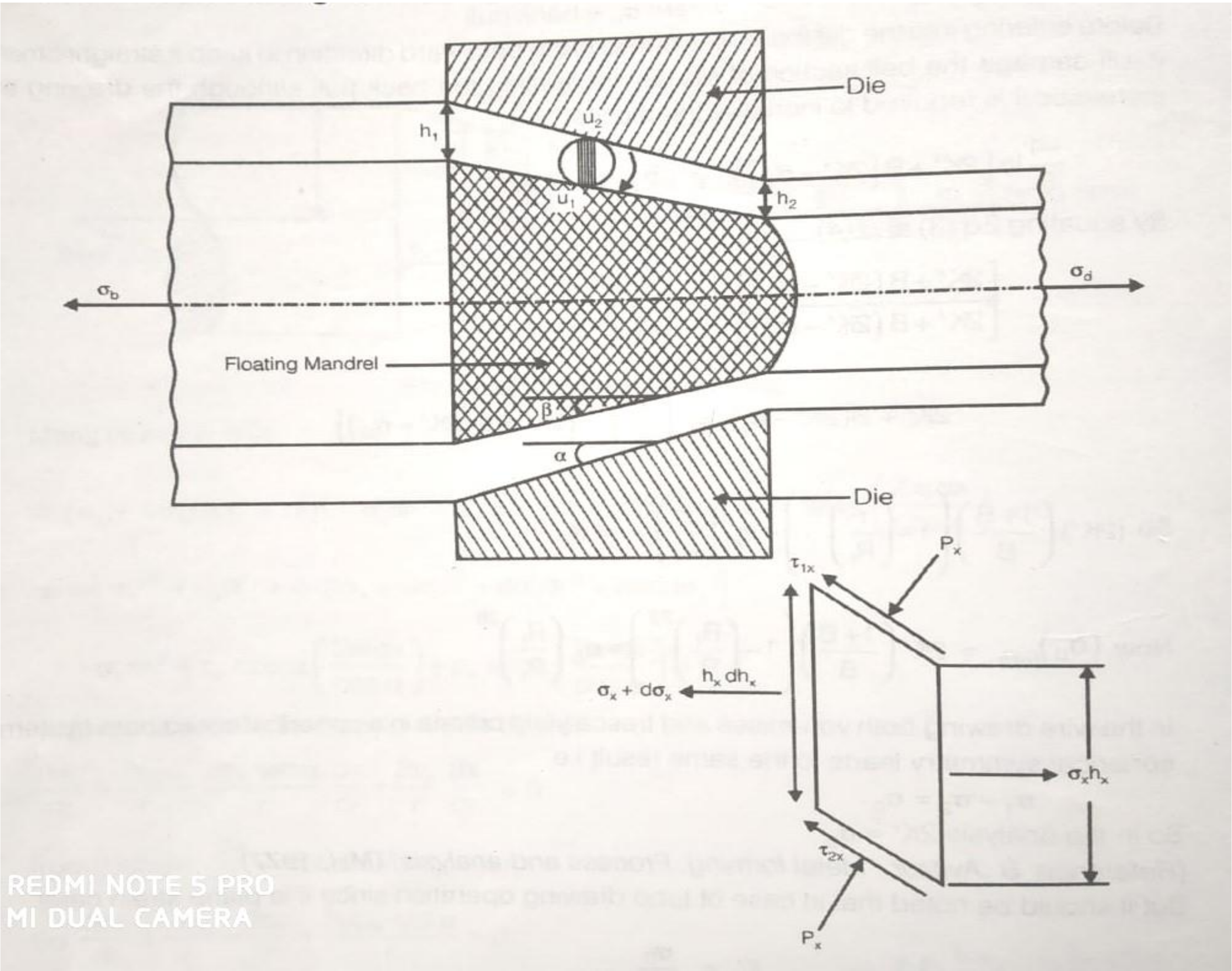
- Case 1. Tube Sinking



$$\sigma_d = \left(\frac{2\sigma_0}{\sqrt{3}}\right)\left(\frac{1+B}{B}\right)\left[1-\left(\frac{R_2}{R_1}\right)^{2B}\right]+\sigma_b\left(\frac{R_2}{R_1}\right)^{2B}$$

where $B = \mu \cot \alpha$

# Case 2. Tube Drawing with Floating mandrel



$$\sigma_d = \left(\frac{2\sigma_0}{\sqrt{3}}\right)\left(\frac{1+B_1}{B_1}\right)\left[1-\left(\frac{h_2}{h_1}\right)^{B_1}\right]+\sigma_b\left(\frac{h_2}{h_1}\right)^{B_1}$$

$$B_1 = \frac{\mu_1+\mu_2}{\tan\alpha-\tan\beta}$$

## Case 3. Tube Drawing with moving mandrel

$$\sigma_d = \left(\frac{2\sigma_0}{\sqrt{3}}\right)\left(\frac{1+B_2}{B_2}\right)\left[1-\left(\frac{A_2}{A_1}\right)^{B_2}\right]+\sigma_b\left(\frac{A_2}{A_1}\right)^{B_2}$$

Where $$B_2 = \frac{\mu_1-\mu_2}{\tan\alpha-\tan\beta}$$

$A_1$ is incoming area at tube and $A_2$ is exit area at tube

# Extrusion

# Extrusion

Extrusion is a bulk forming process in which the work metal is forced or compressed to flow through a die hole to produce a desired cross-sectional shape.

Example: squeezing toothpaste from a toothpaste tube, Sliding doors, window and door frame etc

# Advantage of extrusion:

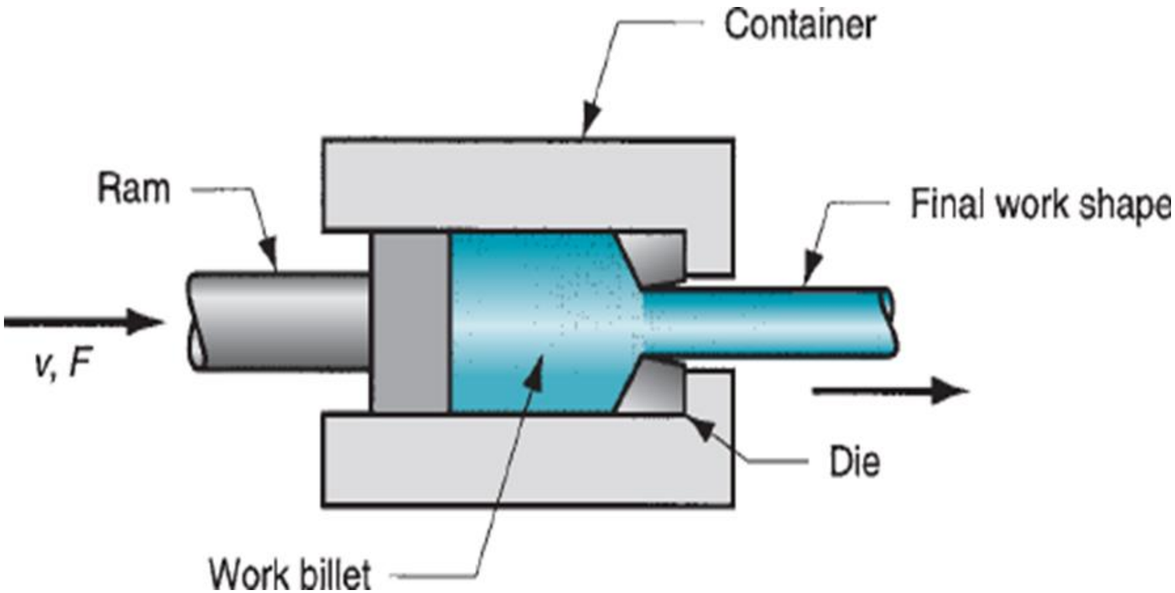
- Extruded object having very dense grain structure and good mechanical properties.
- Thin cross sectional part can be manufactured.
- Good surface finish product.
- Complicated cross sectional part easily extruded.
- Good dimensional accuracy
- Mass production of seamless tube can be machined
- Fast rate of production.

# Types of extrusion

- Direct or forward extrusion,
- Indirect or backward extrusion
- Impact extrusion
- Hydrostatic extrusion

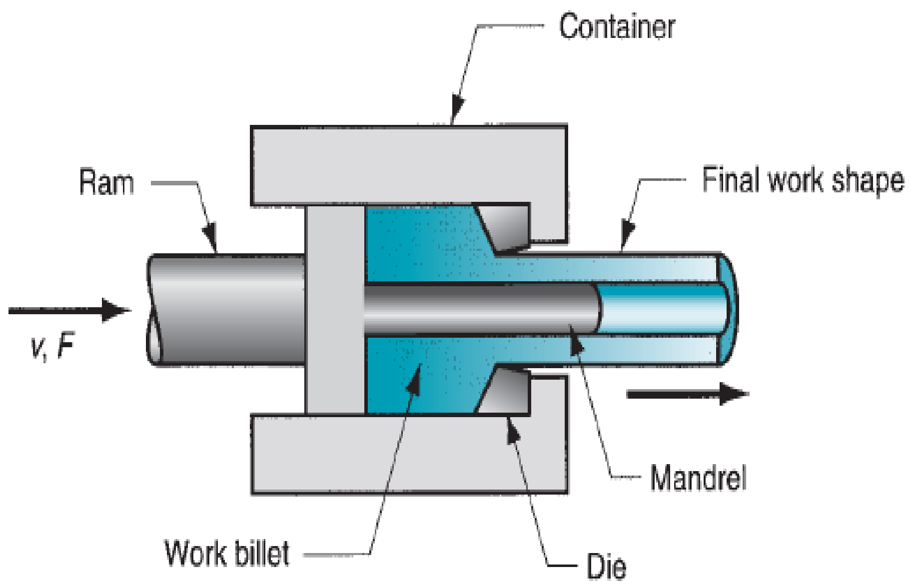
# Direct extrusion

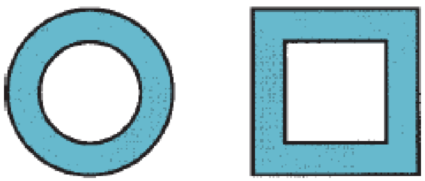
- A metal billet is first loaded into a container having die holes. A ram compresses the material, forcing it to flow through the die holes.
- Some extra portion of the billet will be present at the end of the process that cannot be extruded and is called butt. It is separated from the product by cutting it just beyond the exit of the die.



-In direct extrusion, a significant amount of friction exists between the billet surface and the container walls, as the billet is forced to slide toward the die opening. Because of the presence of friction, a substantial increase in the ram force is required.

-In hot direct extrusion, the friction problem is increased by the presence of oxide layer on the surface of the billet. This oxide layer can cause defects in the extruded product.



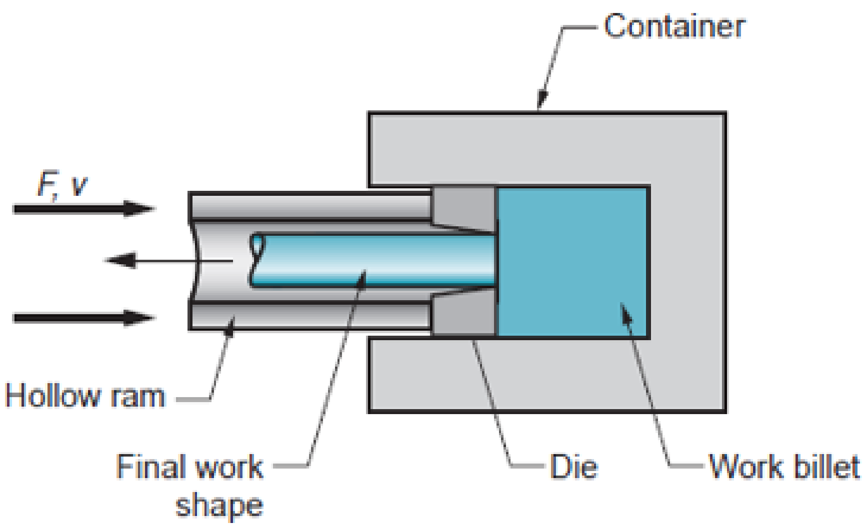



Making hollow shapes using direct extrusion

-Hollow sections like tubes can be made using direct extrusion setup shown in above figure. The starting billet is prepared with a hole parallel to its axis. As the billet is compressed, the material will flow through the gap between the mandrel and the die opening.

# Indirect extrusion

- In this type, the die is mounted to the ram and not on the container. As the ram compresses the metal, it flows through the die hole on the ram side which is in opposite direction to the movement of ram.
- Since there is no relative motion between the billet and the container, there is no friction at the interface, and hence the ram force is lower than in direct extrusion.
- Limitations: lower rigidity of the hollow ram, difficulty in supporting the

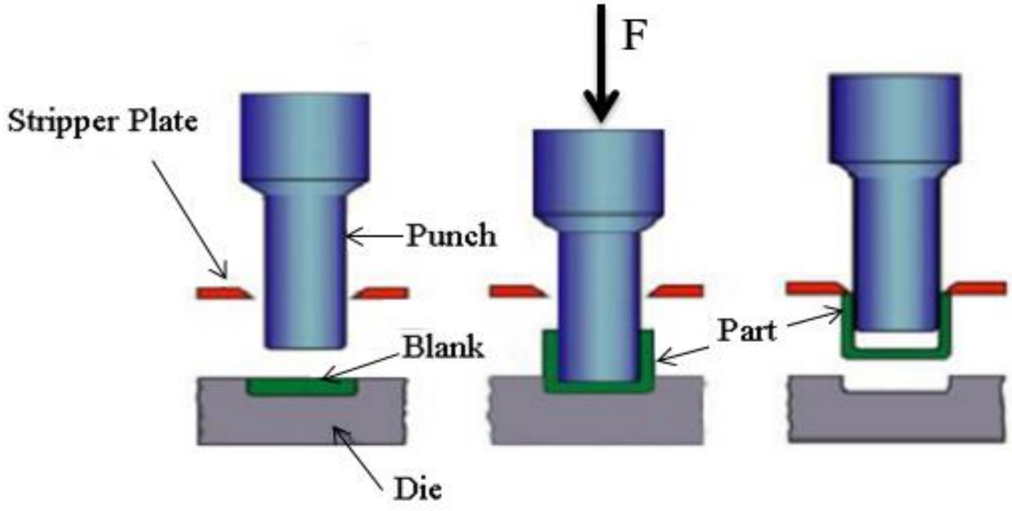


# Difference Between Direct and Indirect Extrusion

| Direct extrusion | Indirect extrusion |
|---|---|
| •More fore required in extrusion process | •Less fore required |
| •Not complicated equipment used | •Complicated equipment used, because of hollow ram |
| •More friction | •Less friction |
| •Tools life is less | •More tool life |
| •Finished part contain oxides of metal | •Not contain oxides of metal |

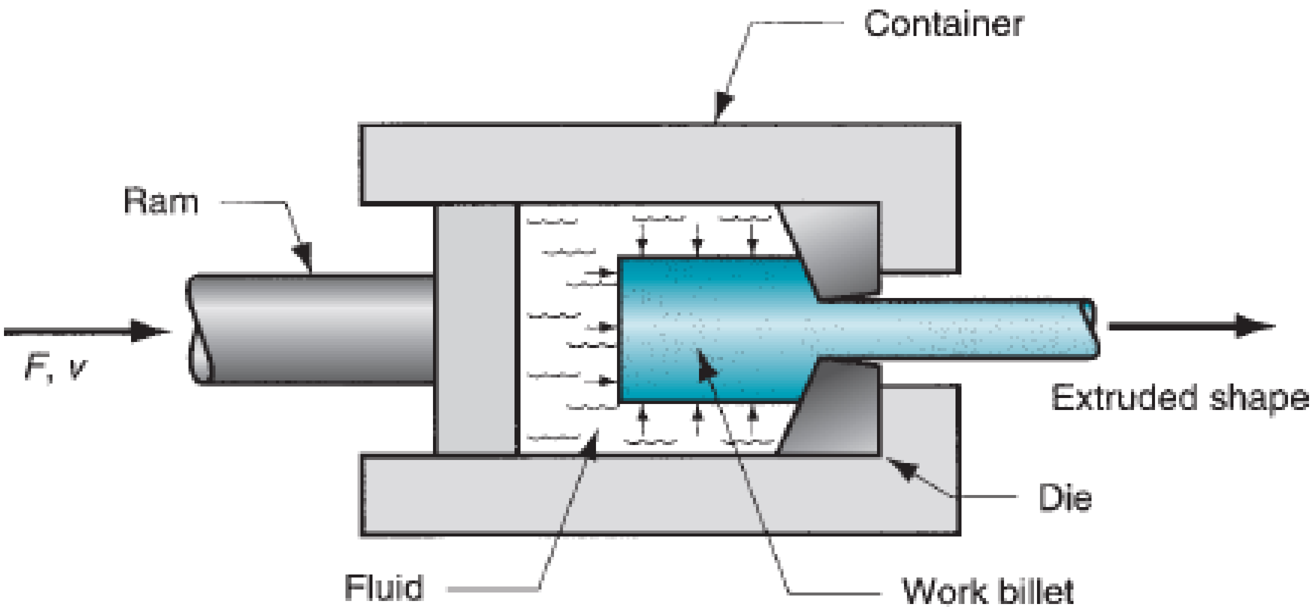
# Impact Extrusion

- It is performed at higher speeds and shorter strokes. The billet is extruded through the die by impact pressure and not just by applying pressure.
- This is used to make collapsible tubes of soft alloys.
- This process is limited to soft and ductile materials.



# Hydrostatic extrusion

- In hydrostatic extrusion, the billet is surrounded with fluid inside the container and the fluid is pressurized by the forward motion of the ram.
- There is no friction inside the container because of the fluid, and friction is minimized at the die opening. If used at high temperatures, special fluids and procedures must be followed.

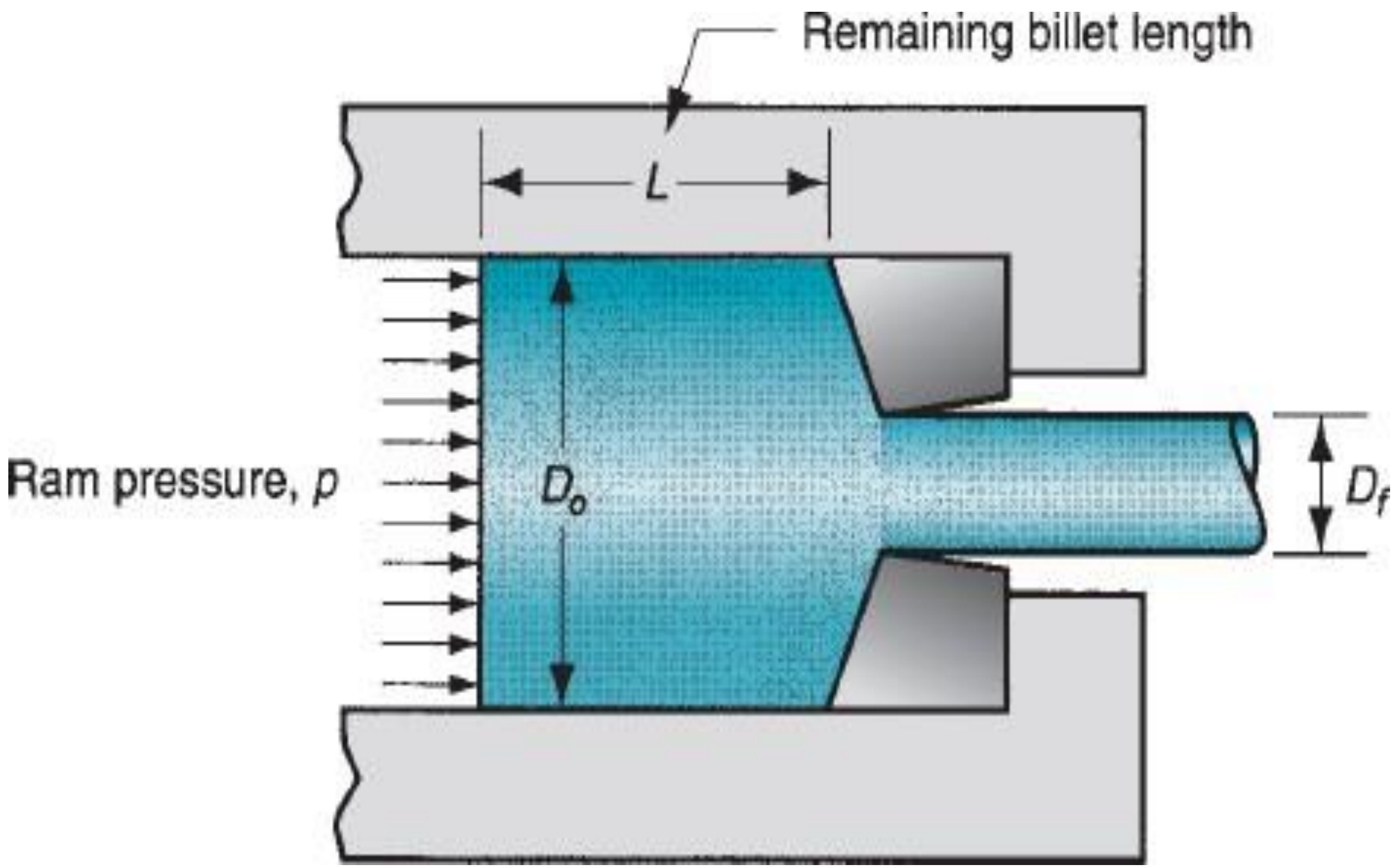


- Hydrostatic pressure on the work and no friction situation increases the material's ductility. Hence this process can be used on metals that would be too brittle for conventional extrusion methods.

- This process is also applicable for ductile metals, and here high reduction ratios are possible.

- The preparation of starting work billet is important. The billet must be formed with a taper at one end to fit tightly into the die entry angle, so that it acts as a seal to prevent fluid leakage through die hole under pressure.

# Simple analysis of extrusion



Assuming the initial billet and extrudate are in round cross-section. An important parameter, extrusion ratio (re), is defined as below:

$$r_e = \frac{A_0}{A_f}$$

A0 - CSA of the initial billet
Af - CSA of the extruded section

True strain in extrusion under ideal deformation (no friction and redundant work) is given by,

$$\varepsilon = \ln(r_e) = \ln(\frac{A_0}{A_f})$$

**Under ideal deformation, the ram pressure required to extrude the billet through die hole is given by,**

$$p = \bar{Y}_f \ln(r_e) = \bar{Y}_f \ln\left(\frac{A_0}{A_f}\right) \quad \text{where} \quad \bar{Y}_f = \frac{K\varepsilon^n}{1+n}$$

**Where $Y_f$ is average flow stress, and $\varepsilon$ is maximum strain value during the extrusion process.**

**The actual pressure for extrusion will be greater than in ideal case, because of the friction between billet and die and billet and container wall.**

**There are various equations used to evaluate the actual true strain and associated ram pressure during extrusion. The following relation proposed by Johnson is of great interest.**

$$\varepsilon_x = a + b \ln r_e = a + b\varepsilon$$

$$p = Y_f \, \varepsilon_x$$

**Where $\varepsilon_x$ is extrusion strain; *a* and *b* are empirical constants for a given die angle.**

**Typical values are: *a* = 0.8, *b* = 1.2 - 1.5**

**In direct extrusion, assuming that friction exists at the interface, we can find the actual extrusion pressure as follows:**

**billet-container friction force = additional ram force to overcome that friction**

$$\mu p_e \pi D_0 L = \frac{p_f \pi D_0^{\,2}}{4}$$

**Where $p_f$ is additional pressure required to overcome friction, $p$ is pressure against the container wall**

**The above eqn. assume sliding friction condition. Assuming sticking friction at the interface, we can write:**

$$K \pi D_0 L = \frac{p_f \pi D_0^{\,2}}{4}$$

**Where $K$ is shear yield strength & $m = 1$**

**The previous eqn. gives,**

$$p_f = \frac{4KL}{D_0}$$

**Assuming,** $K = \frac{\bar{Y}_f}{2}$ **we get,**

$$p_f = \bar{Y}_f \frac{2L}{D_0}$$

**This is the additional pressure required to overcome friction during extrusion.**

**Now the actual ram pressure required for direct extrusion is given by,**

$$p = \bar{Y}_f\left(\varepsilon_x + \frac{2L}{D_0}\right)$$

***L*** **is the billet length remaining to be extruded, and** $D_0$ **is the initial diameter of the billet. Here** ***p*** **is reduced as the remaining billet length decreases during the extrusion process.**

# Defects during extrusion

## Centerburst:

-This is an internal crack that develops as a result of tensile stresses along the center axis of the workpiece during extrusion.

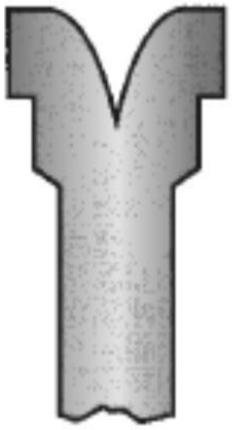
-A large material motion at the outer regions pulls the material along the center of the work. Beyond a critical limit, bursting occurs.

-Conditions that promote this defect are higher die angles, low extrusion ratios, and impurities in the work metal. This is also called as Chevron cracking.

Centerburst

## Piping:

•It is the formation of a sink hole in the end of the billet. This is minimized by the usage of a dummy block whose diameter is slightly less than that of the billet.



Piping

## Surface cracking:

•This defect results from high workpiece temperatures that cause cracks to develop at the surface.

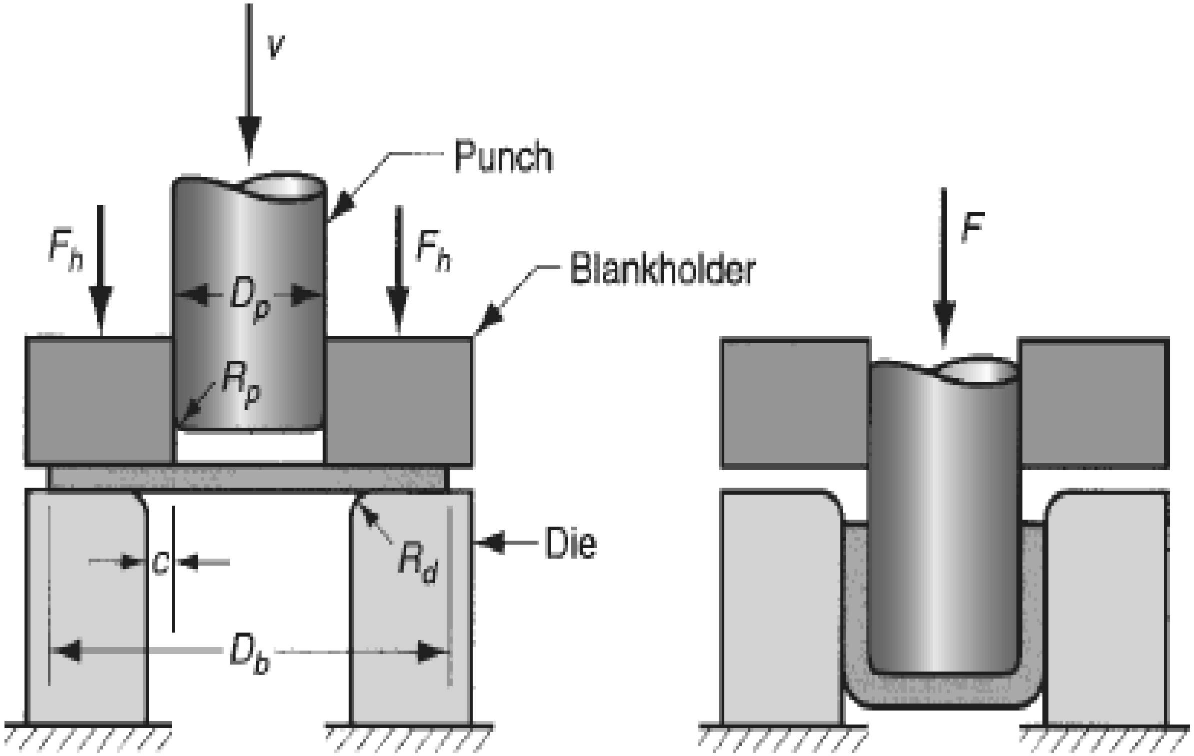
•They also occur at higher extrusion speeds, leading to high strain rates and heat generation.

•Higher friction at the surface and surface chilling of high temperature billets in hot extrusion also cause this defect.

# Deep Drawing

# Deep Drawing

- It is a sheet forming operation, in which the sheet is placed over the die opening and is pushed by punch into the opening. The sheet is held flat on the die surface by using a blank holder.




c – clearance
$D_b$ – blank diameter
$D_p$ – punch diameter
$R_d$ – die corner radius
$R_p$ – punch corner radius
F – drawing force
$F_h$ – holding force

- The clearance ‘*c*’ is defined to equal to 10% more than the sheet thickness ‘*t*’.

$$c = 1.1t$$

- Common parts made by drawing
- beverage cans,
- ammunition shells,
- sinks, cooking pots,
- automobile body panels.

# Stages in deep drawing:

i. As the punch pushes the sheet, it is subjected to a bending operation. Bending of sheet occurs over the punch corner and die corner. The outside perimeter of the blank moves slightly inwards toward the cup center

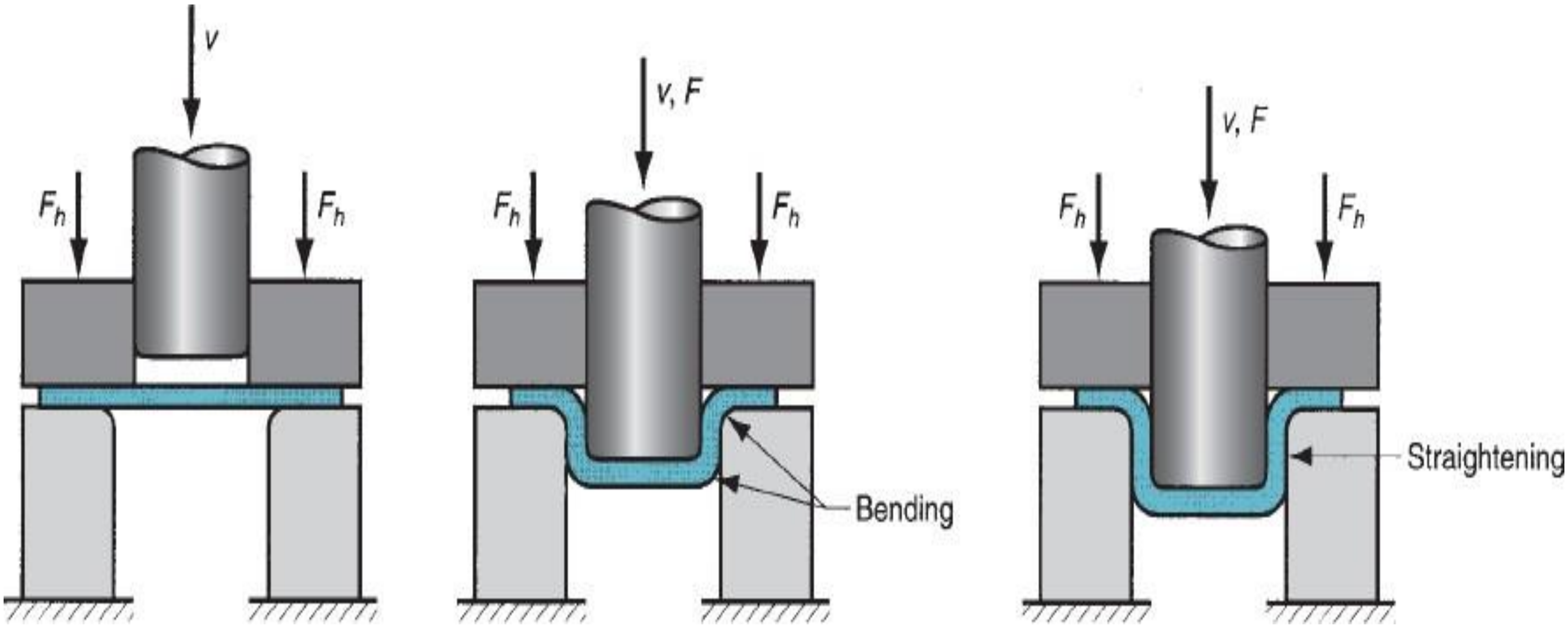
ii. In this stage, the sheet region that was bent over the die corner will be straightened in the clearance region at this stage, so that it will become cup wall region. In order to compensate the presence of sheet in cup wall, more metal will be pulled from the sheet edge, i.e., more metal moves into the die opening.

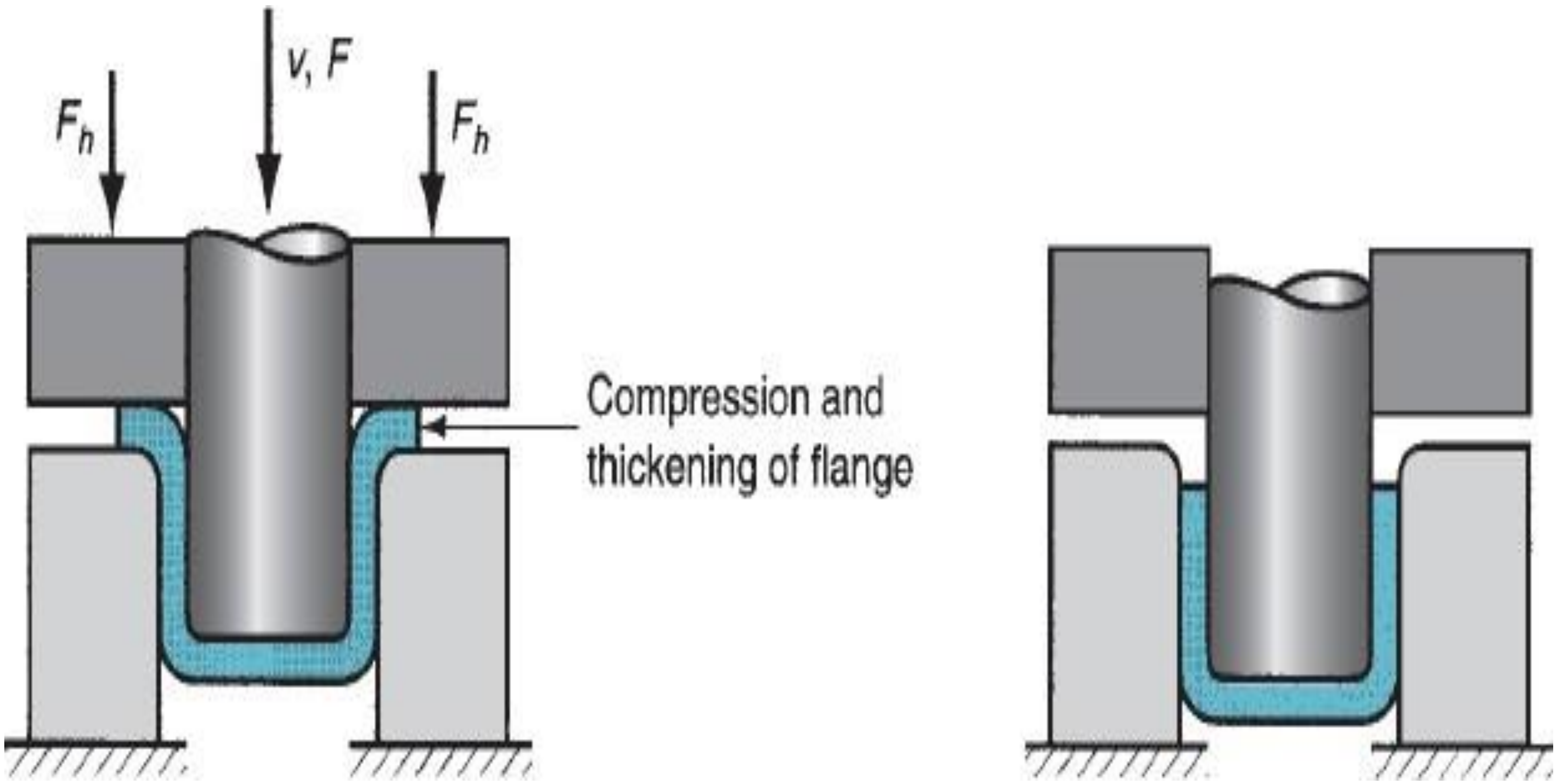
iii. Friction between the sheet and the die, blank holder surfaces restricts the movement of sheet into the die opening. The blank holding force also influences the movement. Lubricants or drawing compounds are generally used to reduce friction forces.

iv. Other than friction, compression occurs at the edge of the sheet. Since the perimeter is reduced, the sheet is squeezed into the die opening. Because volume remains constant, with reduction in perimeter, thickening occurs at the edge.

In thin sheets, this is reflected in the form of wrinkling. This also occurs in case of low blank holding force. If BHF very small, wrinkling occurs. If it is high, it prevents the sheet from flowing properly toward the die hole, resulting in stretching and tearing of sheet.

(v) The final cup part will have some thinning in side wall.




v, F
$F_h$
$F_h$
Compression and thickening of flange

Drawing ratio: ratio of blank diameter, Db, to punch diameter, Dp. The greater the ratio, the more severe the drawing operation.

$$DR = \frac{D_b}{D_P}$$

The limiting value for a given operation depends on punch and die corner radii, friction conditions, draw depth, and quality of the sheet metal like ductility, degree of directionality of strength properties in the metal.

**Reduction, R, is defined as,**

$$R = \frac{D_b - D_P}{D_b}$$

**Limiting values: $DR \leq 2$; $R \leq 0.5$**

**Thickness to diameter ratio, $t/D_b > 1\%$;**

**As the ratio decreases, tendency for wrinkling increases.**

**The maximum drawing force, F , can be estimated approximately by the following equation .**

$$F = \pi D_p t \sigma_{UTS} \left( \frac{D_b}{D_p} - 0.7 \right)$$

Correction factor for friction

**The holding force, Fh, is given by,**

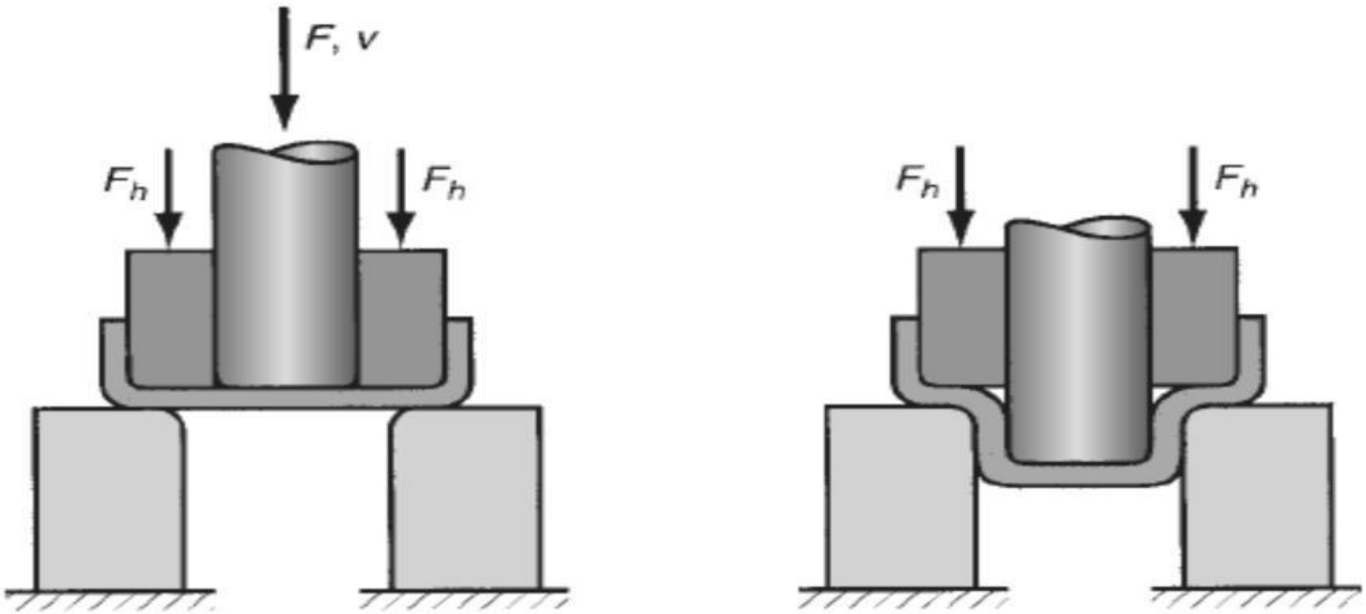
$$F_h = 0.015\, \sigma_{ys} \pi \{ \mathrm{D}_\mathrm{b}^2 - (\mathrm{D}_\mathrm{p} + 2.2\mathrm{t} + 2\mathrm{R}_\mathrm{d})^2$$

$$F_h = \frac{F}{3}$$

(approx. holding force is one-third of drawing force)

# Redrawing

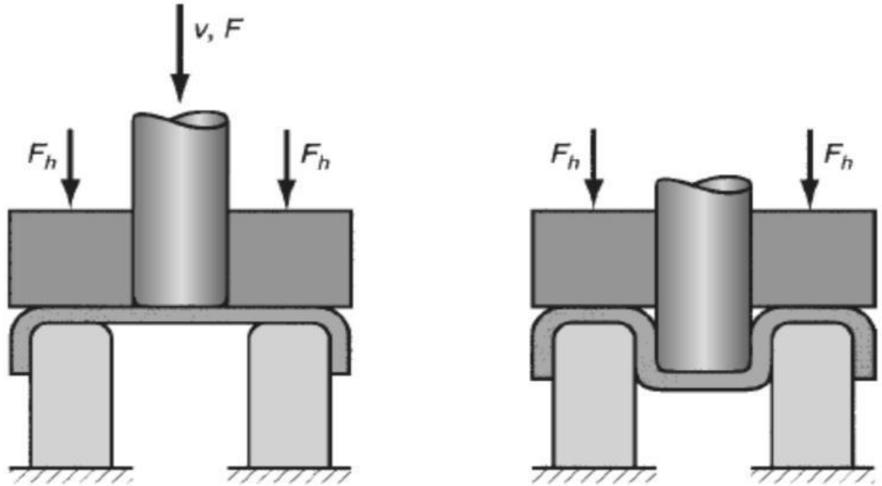
In many cases, the shape change involved in making that part will be severe (drawing ratio is very high). In such cases, complete forming of the part requires more than one deep drawing step.
Redrawing refers to any further drawing steps that is required to complete the drawing operation.




**Redrawing**

**Guidelines for successful redrawing:**

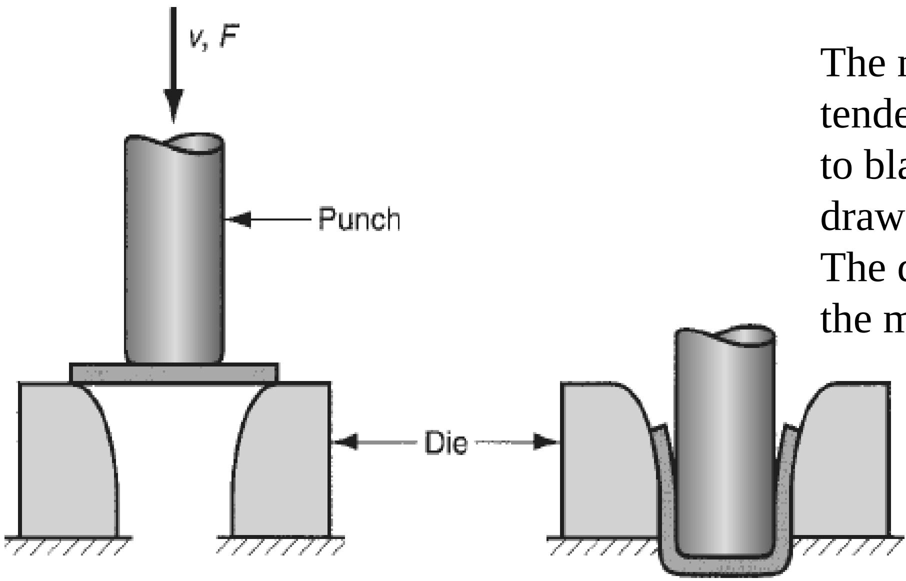
**First draw:** **Maximum reduction of the starting blank - 40% to 45%**
**Second draw:** **30%**
**Third draw :** **16%**




## Reverse redrawing

In reverse redrawing, the sheet part will face down and drawing is completed in the direction of initial bend.

## Drawing without blank holder

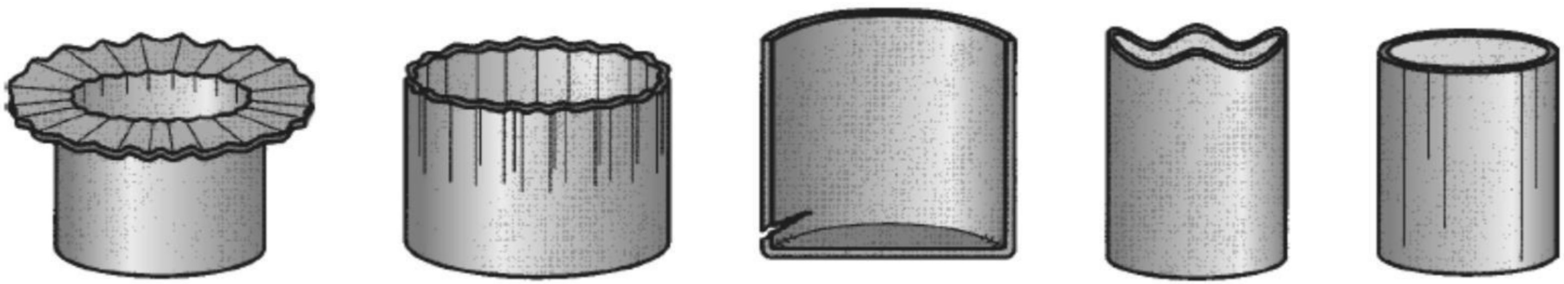



The main function of BH is to reduce wrinkling. The tendency of wrinkling decreases with increase in thickness to blank diameter ratio (t/Db). For a large t/Db ratio, drawing without blank holder is possible.
The die used must have the funnel or cone shape to permit the material to be drawn properly into the die cavity.

**Limiting value for drawing without BH:**

$$D_b - D_p = 5t$$

# Defects in deep drawing



**wrinkling in flange and cup wall** **tearing** **earing** **surface scratches**

**Wrinkling** in flange and cup wall: This is like ups and downs or waviness that is developed on the flange. If the flange is drawn into the die hole, it will be retained in cup wall region.

**Tearing:** It is a crack in the cup, near the base, happening due to high tensile stresses causing thinning and failure of the metal at this place. This can also occur due to sharp die corner.

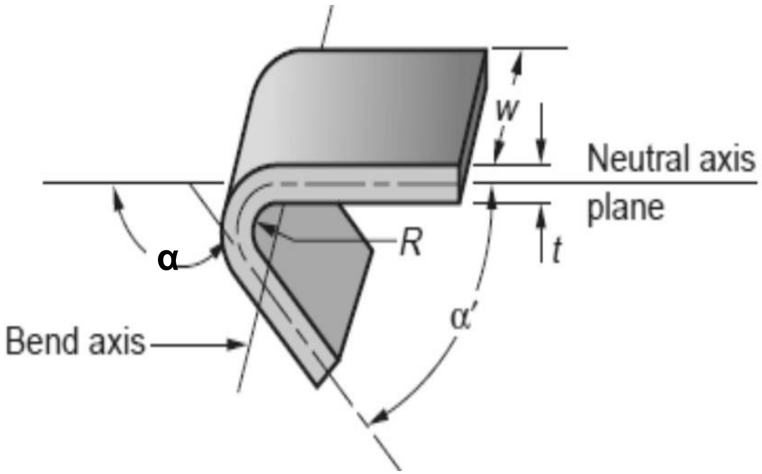
**Earing:** The height of the walls of drawn cups have peaks and valleys called as earing. There may be more than four ears. Earing results from planar anisotropy ($\Delta R$), and ear height and angular position correlate well with the angular variation of R.

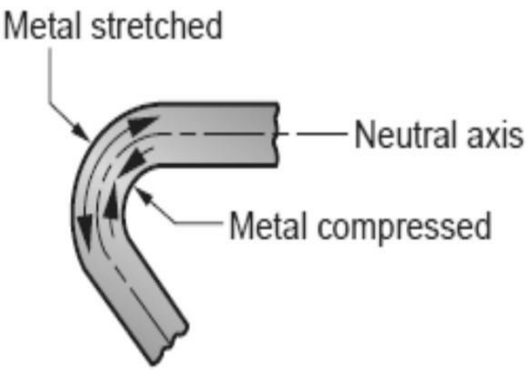
**Surface scratches**: Usage of rough punch, dies and poor lubrication cause scratches in a drawn cup.

# Bending

# Bending

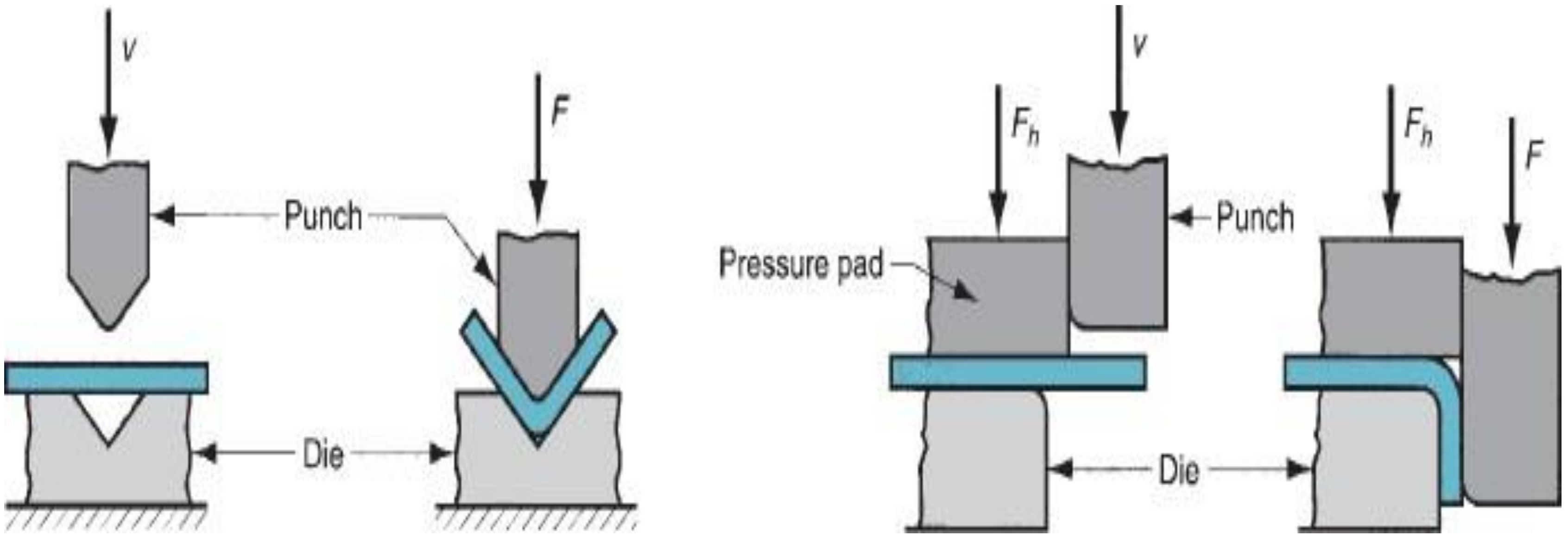
Sheet bending is defined as the straining of the metal around a straight axis as shown in figure. During bending operation, the metal on the inner side of the neutral plane is compressed, and the metal on the outer side of the neutral plane is stretched. Bending causes no change in the thickness of the sheet metal.



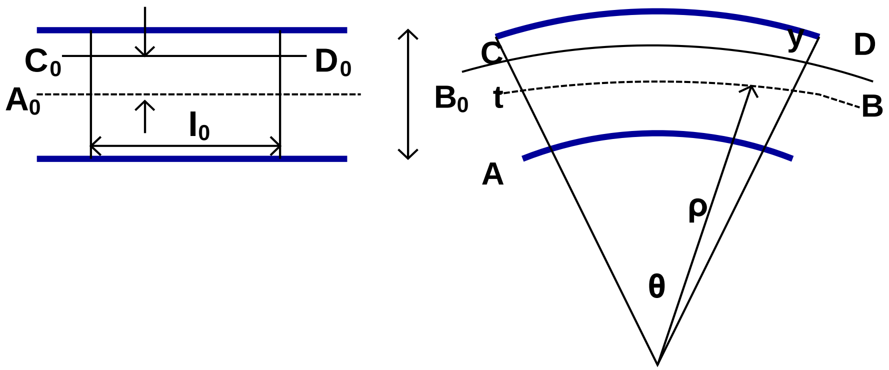



In V-bending, the sheet metal is bent between a V-shaped punch and die set up. The included angles range from very obtuse to very acute values.

In edge bending, cantilever loading of the sheet is seen. A pressure pad is used to apply a force to hold the sheet against the die, while the punch forces the sheet to yield and bend over the edge of the die.



## Deformation during bending




For our analysis, it may be assumed that a plane normal section in the sheet will remain plane and normal and converge on the center of curvature as shown in Figure. The line $A_0B_0$ at the middle surface may change its length to AB, if the sheet is under stretching during bending. The original length $l_o$ becomes, $l_s = \rho\theta$. A line $C_0D_0$ at a distance $y$ from the middle surface will deform to a length,

$$l = \theta(\rho + y) = \rho\theta(1+\frac{y}{\rho}) = l_s(1+\frac{y}{\rho})$$

where $\rho$ is the radius of curvature.

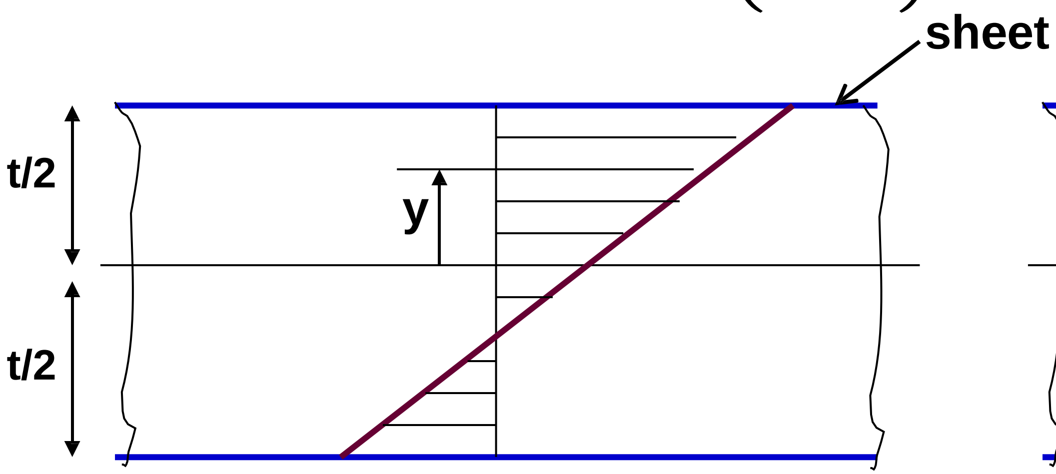
The axial strain of the fiber CD is,

$$\varepsilon_1 = \ln\frac{l}{l_0} = \ln\frac{l_s}{l_0} + \ln\left(1+\frac{y}{\rho}\right) = \varepsilon_a + \varepsilon_b$$

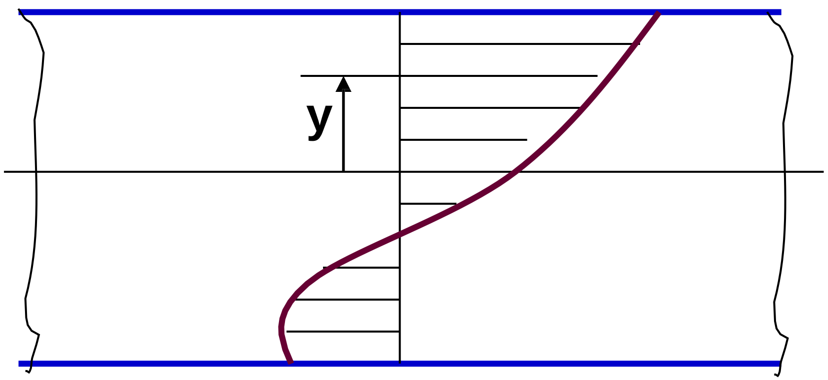
where '$\varepsilon_a$' and '$\varepsilon_b$' are the strains at the middle surface and bending strain respectively.

In the case of bending with radius of curvature larger compared to the thickness, the bending strain is approximated as,

$$\varepsilon_b = \ln\left(1 + \frac{y}{\rho}\right) \approx \frac{y}{\rho}$$




Strain distribution in bending



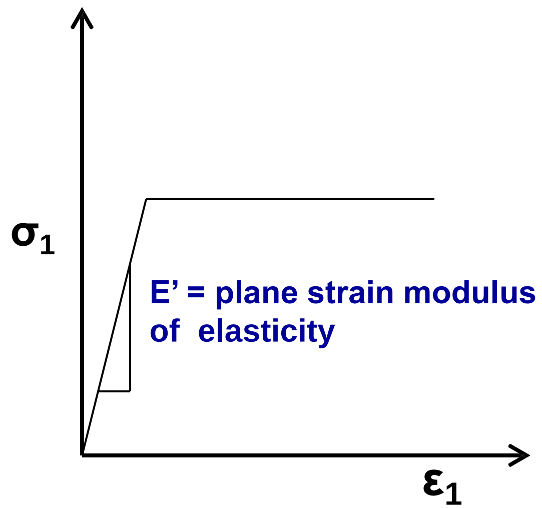

Typical stress distribution in bending

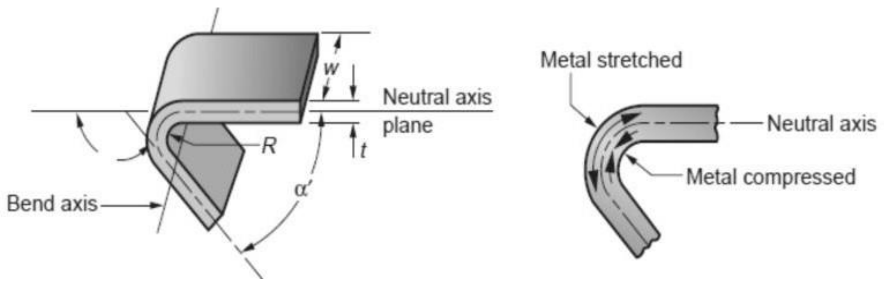
## Choice of material model

**For the strain distribution given by equation (1) for bending, the stress distribution on a section can be found out by knowing a stress-strain law.**

**Generally elastic-plastic strain hardening behavior is seen in sheet bending. But there are other assumptions also.**

**Elastic, perfectly plastic model: Strain hardening may not be important for a bend ratio (ρ/t) (radius of curvature/thickness) of about 50. For this case the stress-strain behavior is shown in Figure below.**




**Bending can be seen as plane strain deformation as strain along bend can be zero**

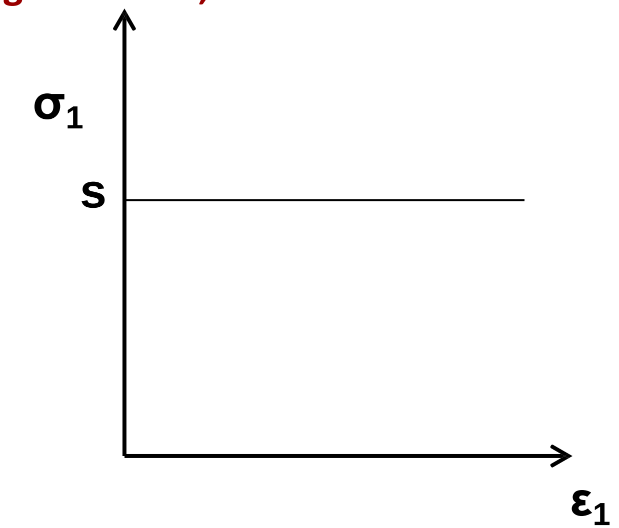
**For elastic perfectly plastic model, for stress less than plane strain yield stress, S,**

$$\sigma_1 = E' \varepsilon_1 \quad \text{where } E' = E/1-\gamma^2$$

**For strains greater than yield strains,** $\sigma_1 = S$ *where* $S = \sigma_f (2/\sqrt{3})$

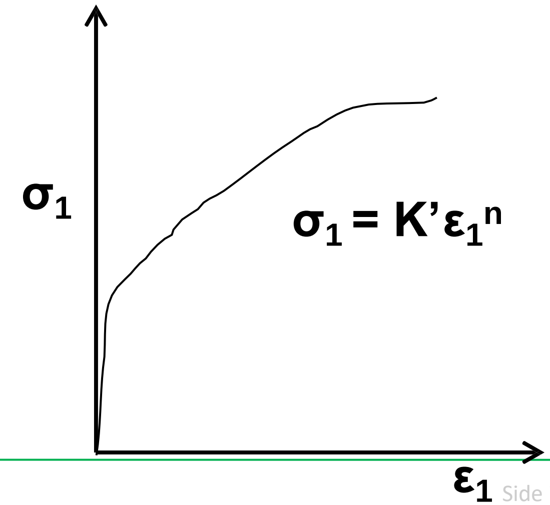
**Rigid, perfectly plastic model:** For smaller radius bends, where elastic springback is not considered the elastic strains and strain hardening are neglected. So,

$$\sigma_1 = S$$




**Strain hardening model:** When the strains are large, elastic strains can be neglected, and the power hardening law can be followed.

$$\sigma_1 = K'\varepsilon_1^n$$



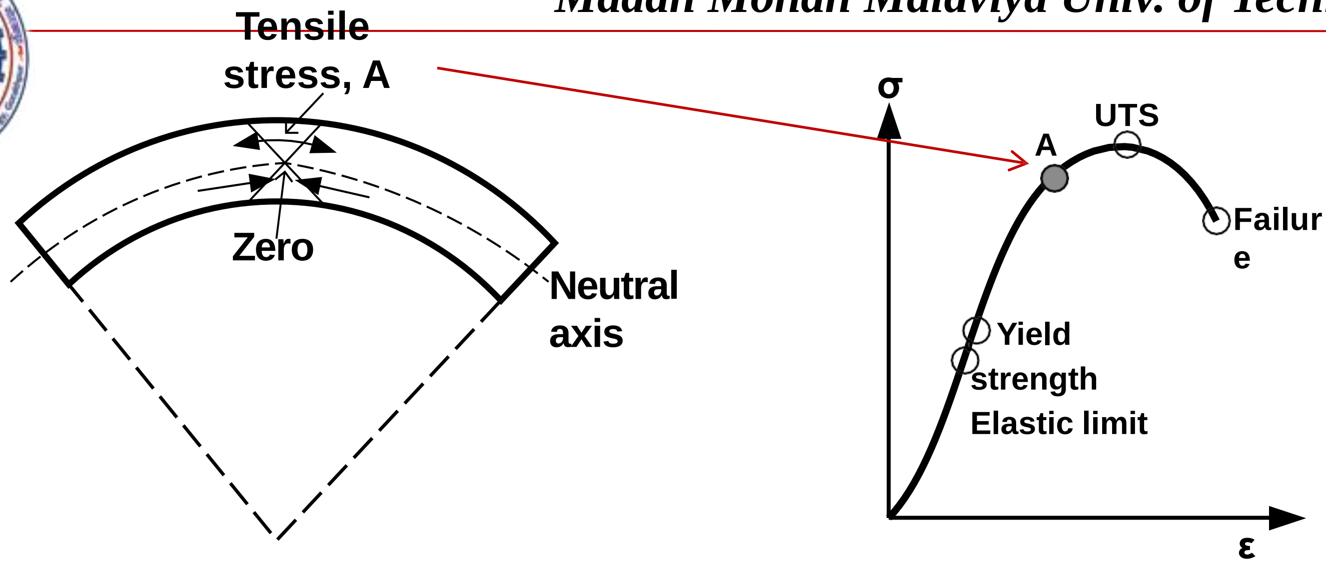
# Spring back

•*Spring back* occurs because of the variation in bending stresses across the thickness, i.e., from inner surface to neutral axis to outer surface. The tensile stresses decrease and become zero at the neutral axis.

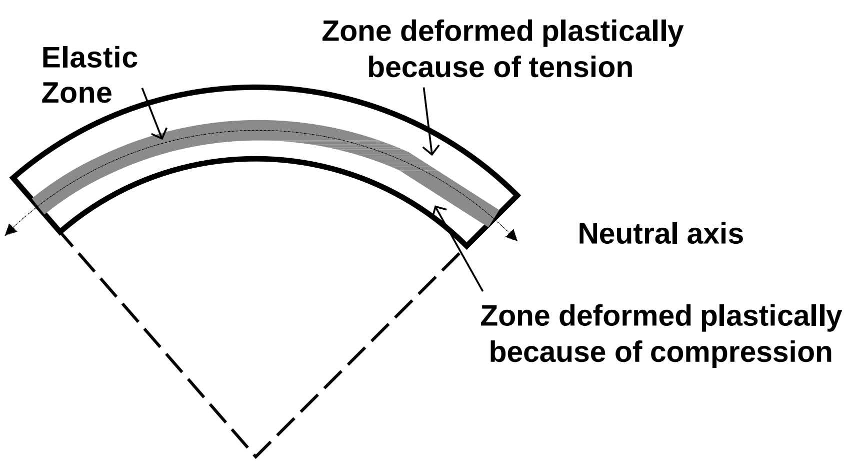
•Since the tensile stresses above neutral axis cause plastic deformation, the stress at any point (say '*A*') in the tensile stress zone should be less than the ultimate tensile strength in a typical tensile stress-strain behavior. The outer surface will crack, if the tensile stress is greater than ultimate stress during bending.

•The metal region closer to the neutral axis has been stressed to values below the elastic limit. This elastic deformation zone is a narrow band on both sides of the neutral axis, as shown in Fig. The metal region farther away from the axis has undergone plastic deformation, and obviously is beyond the yield strength.

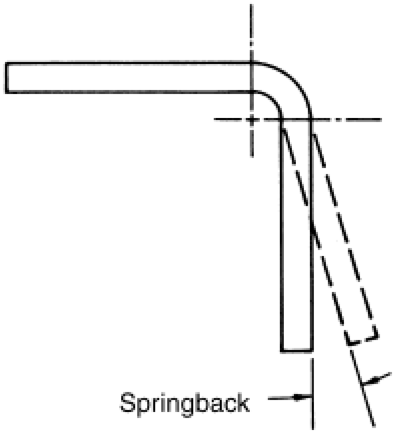
•Upon load removal after first bending, the elastic band tries to return to the original flat condition but cannot, due to the restriction given by the plastic deformed regions. Some return occurs as the elastic and plastic zones reach an equilibrium condition and this return is named as *spring back*.




Changing stress patterns in a bend




Elastic and plastic deformation zones during bending




Springback

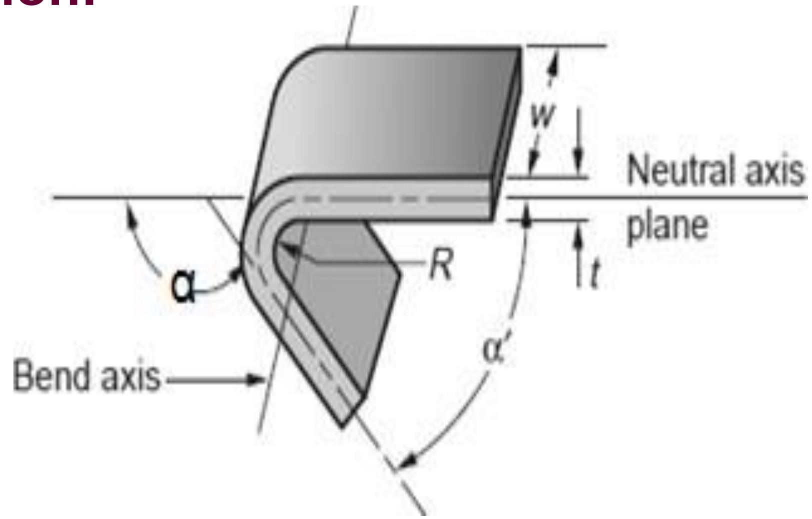
- **Sprinback can be minimized by overbending, bottoming and stretch forming.**

- In overbending, the punch angle and radius are made smaller than the specified angle on the final part so that the sheet metal springs back to the desired value.

- Bottoming involves squeezing the part at the end of the stroke, thus plastically deforming it in the bend region.

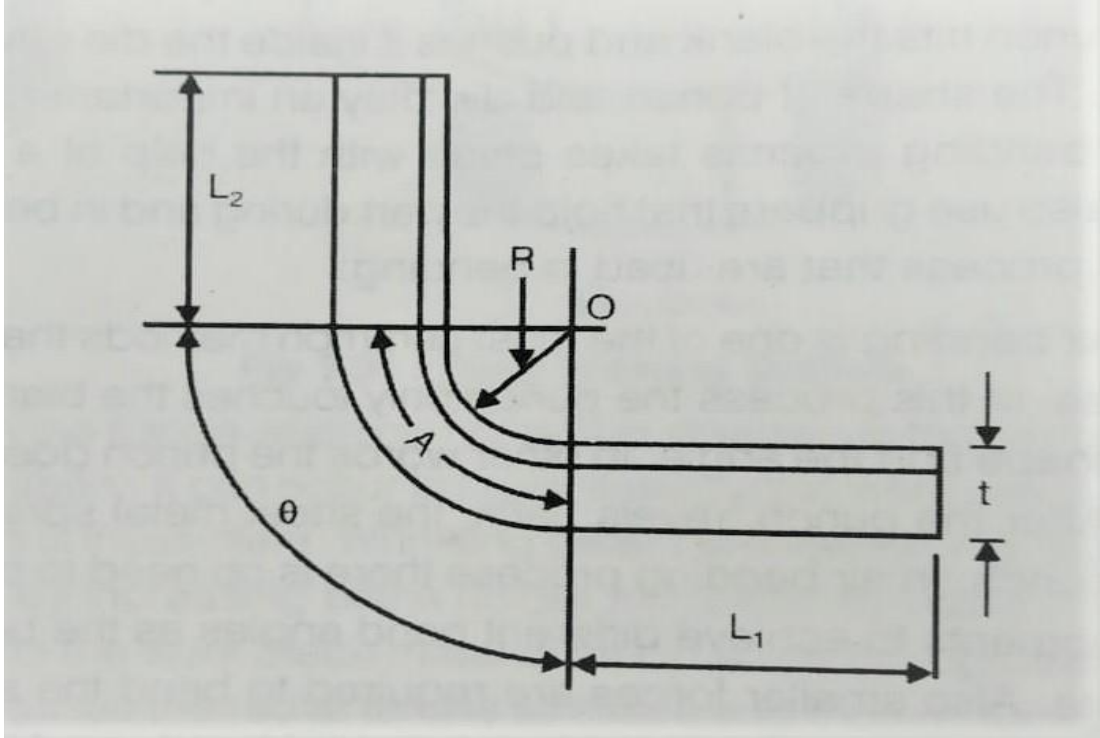
**Spring back is defined by the equation:**

$$SB = \frac{\alpha' - \alpha_{tool}}{\alpha_{tool}}$$



# Bend Allowance

- The length of neutral axis in the curvature region of bend is called bend allowance.
- In order to estimate the required flat work piece length to make a bend, calculation of bend allowance is essential.



$$Bend\ Allowance = \theta(R + Kt)$$

Where t = sheet thickness

θ = angle in radians

R = bend radius

K = stretch factor

= 0.33 when R $<$ 2t

= 0.5 when R $>=$ 2t

# Numerical

- A cylindrical cup without flange is to be drawn from a 2 mm thick sheet. The cup shall have 15 mm diameter and 40 mm height. Reduction ratio in the first and subsequent draws may not exceed 40% and 15% respectively. Determine the blank size and the number of draws necessary.

By equating Surface area

$$\frac{\pi}{4} D^2 = \frac{\pi}{4} d^2 + \pi d h$$

Where D is diameter of blank, d is diameter of cup
h is cup height

$$D = 51.23 \text{ mm}$$

So overall ratio $= \frac{D}{d} = 3.41$

let us say $d_1$ is the diameter of cup after first draw and it will be the blank diameter for 2nd draw and so on.

So overall draw ratio can be written as

$$\underbrace{\frac{D}{d_1}}_{1st} \times \underbrace{\frac{d_1}{d_2}}_{2nd} \times \cdots = 3.41$$

Since 40% reduction can be given in first draw

$$d_1 = 0.6\,D$$

and 15% reduction can be given subsequent

$$d_2 = 0.85\,d_1 \quad \ldots$$

$$\frac{1}{0.6}\left(\frac{1}{0.85}\right)^{n-1} = 3.41$$

$$(n-1)\ln\left(\frac{1}{0.85}\right) = \ln(2.049)$$

$$= 0.717$$

$$n-1 = 4.41$$

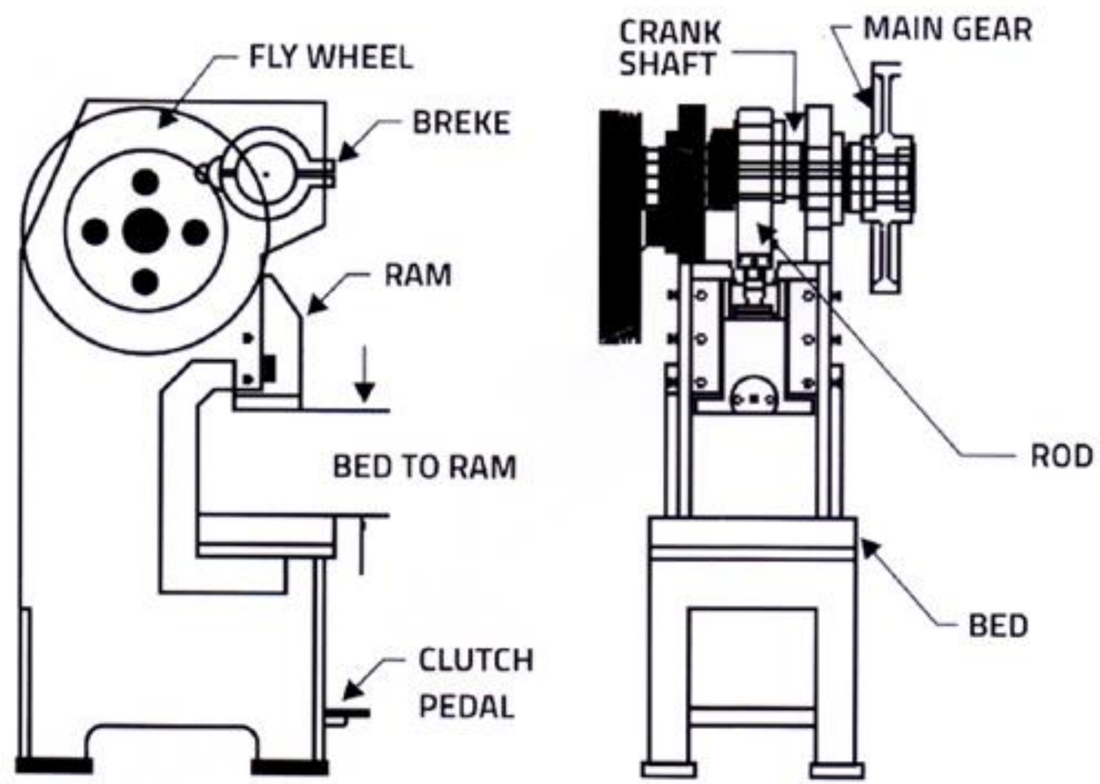
$$n = 5.41$$

So total 6 draws are necessary

# Press and It's Classification

# Press

A press is a sheet metal working tool with a stationary bed and a powered ram can be driven towards the bed or away from the bed to apply force or required pressure for various metal forming operations.



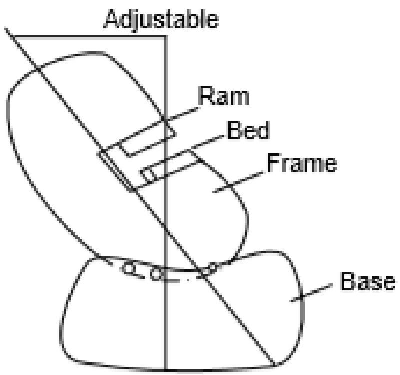
# TYPES OF PRESSES

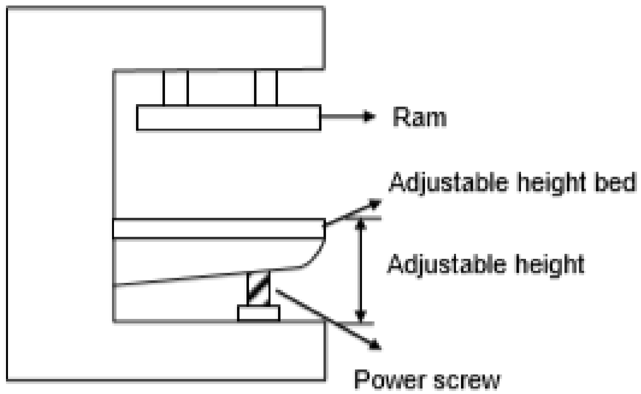
## ➢ According to the Power Source

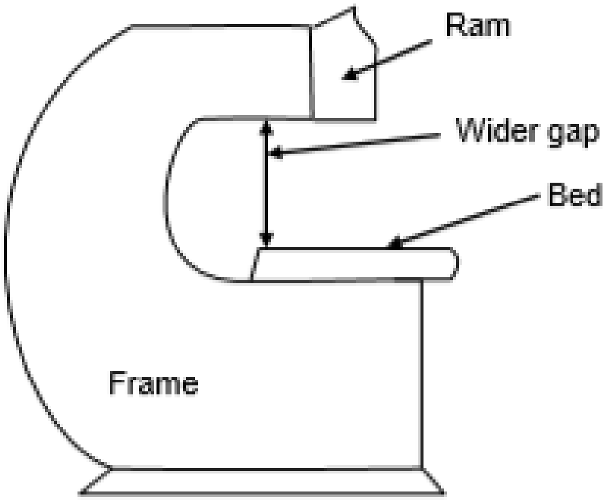
- Manually Operated
- Power Presses

## ➢ According to the Type and Design of Frame

- Inclinable Frame Press
- Gap Frame Press
- Straight Side Press
- Adjustable Bed Type Press



## ➢ According to the Position of Frame

- Vertical Frame
- Horizontal Frame
- Inclined Frame

## ➢ According to the Actions

- Single action,
- Double action
- Triple action

## ➢ According to Mechanism Used to Transmit Power to Ram

- Crank Press
- Cam Driven Press
- Eccentric Press
- Knuckle Press
- Screw Press
- Hydraulic Press
- Rack and Pinion Press

# SPECIFICATIONS OF A PRESS

- **Maximum Force** :

  Maximum force that its ram can exert on the workpiece, this is expressed in tones and called tonnage. It varies from 5 to 4000 tonnes for mechanical press. It may be up to 50,000 tonnes by hydraulic press.

- **Maximum Stroke Length** :

  Maximum distance traveled by the ram from its top most position to extreme down position. It is expressed in mm. the stroke length is adjustable so different values that can be obtained between minimum and maximum of stroke length.

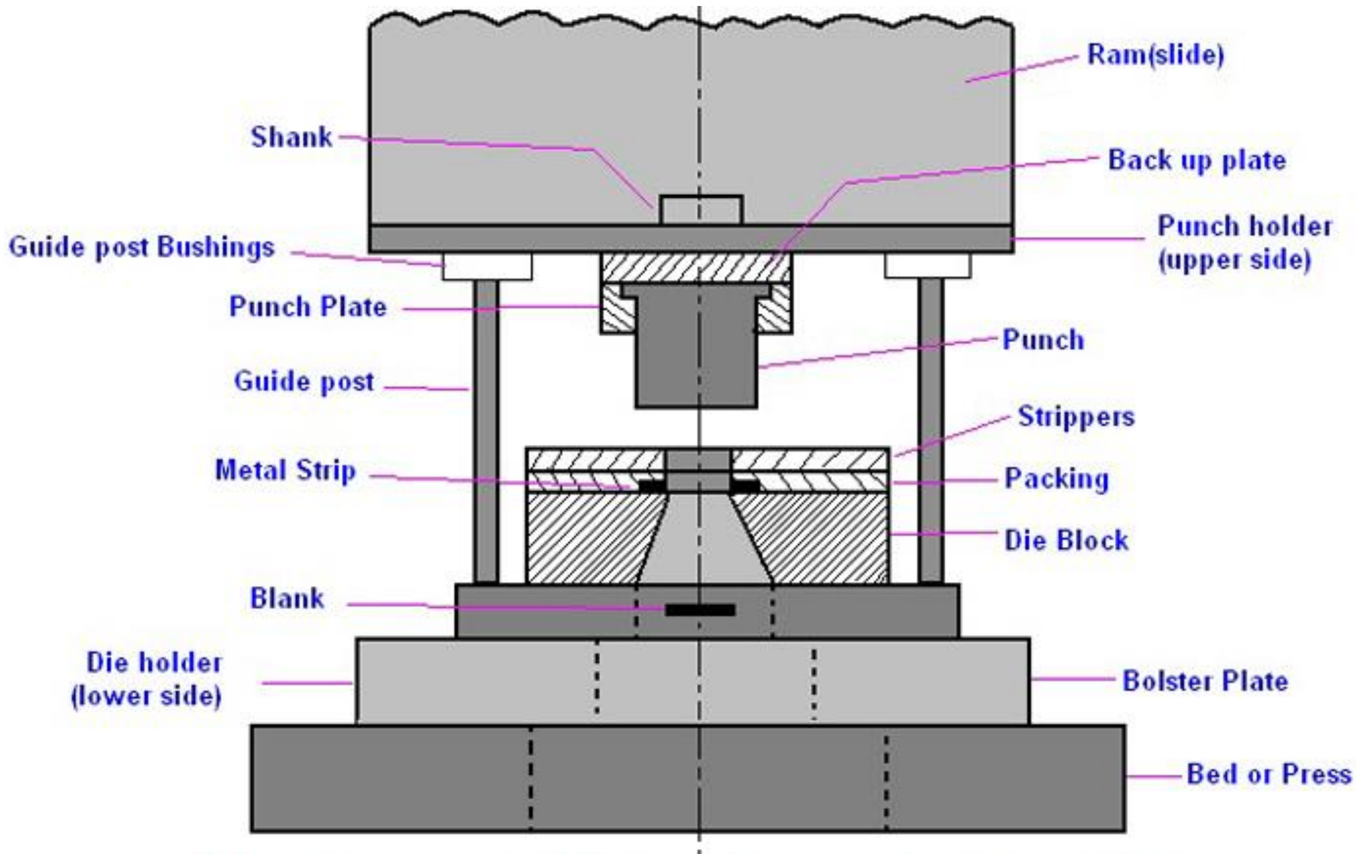
- **Die Space :**

  Total (maximum) surface area (b x d) of bed, along with base, ram base. This is the area in which die can be maintained..

- **Ram Speed :** It is expressed as number of strokes per minute. Generally it can be 5 to 5000 strokes per minute.

# Die

- A die is a specialized tool used in manufacturing industries to cut or shape material mostly using a press.




Component of die and punch Assembly

- Punch Holder

  It is also known by its other name upper shoe of die set. Punch holder is clamped to the ram of press. It holds the punch below it.

- Punch

  It is the main tool of die assembly which directly comes in contact of workpiece during its processing.

- Die Holder

  It is also called die shoe. Its work as a support for the die block and it is rigidly fastened to the balster plate of the press.

- Stops

  Stops are used for maintaining correct spacing of the sheet metal when it is fed below the punch to maintain the quality of output. These restrict the feed of stock (workpiece) to a pre-determined length each time without doing any precise measurements.

- Pilots

Pilot is used for correct location of blank when it is fed by mechanical means.

- Strippers

Stripper is used to discard the workpiece out side the press after the completion of cutting or forming operation. After the cutting when punch follows upward stroke the blank is stripped off from the punch cutting edge and prevents it from being lifted along with the punch.

- Backing Plate

Backing plate is used to distribute pressure uniformly over the whole area (maintains uniform stress), it prevents the stress concentration on any portion of punch holder. This is generally made of hardened steel inserted between the punch and punch holder.

# CLASSIFICATION OF DIES

- Single operation dies are designed to perform only a single operation in each stroke of ram.
- Multi operation dies are designed to perform more than one operation in each stroke of ram.

- Single operation dies are further classified as:
  - Cutting Dies
  - Forming Dies

- multi-operation dies are further classified as:
  - Compound Dies
  - Combination Dies
  - Progressive Dies

# Compound Dies

- .A compound die performs two operations at a single station, such as blanking and punching, or blanking and drawing
- A good example is a compound die that blanks and punches a washer.

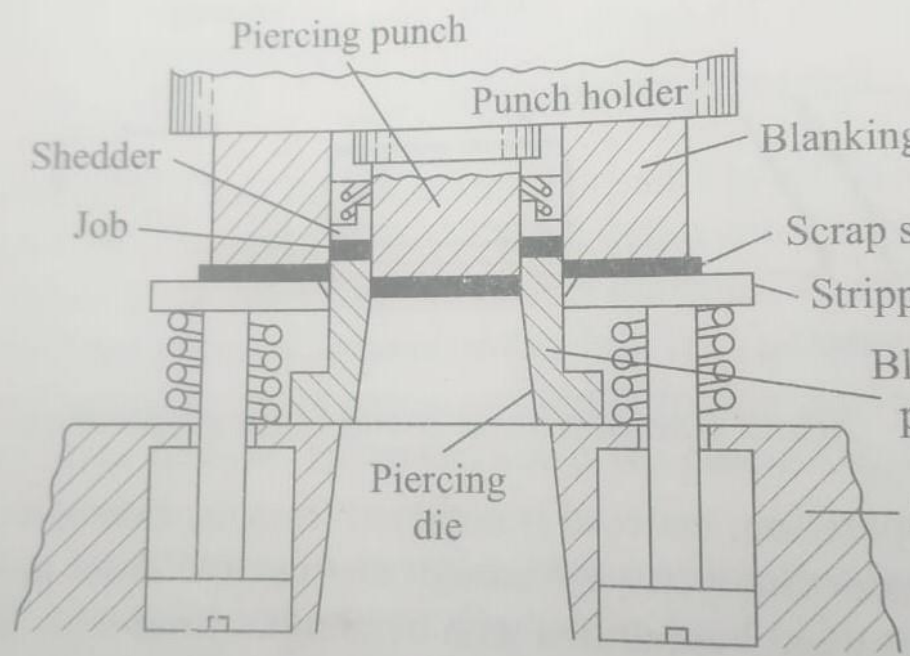
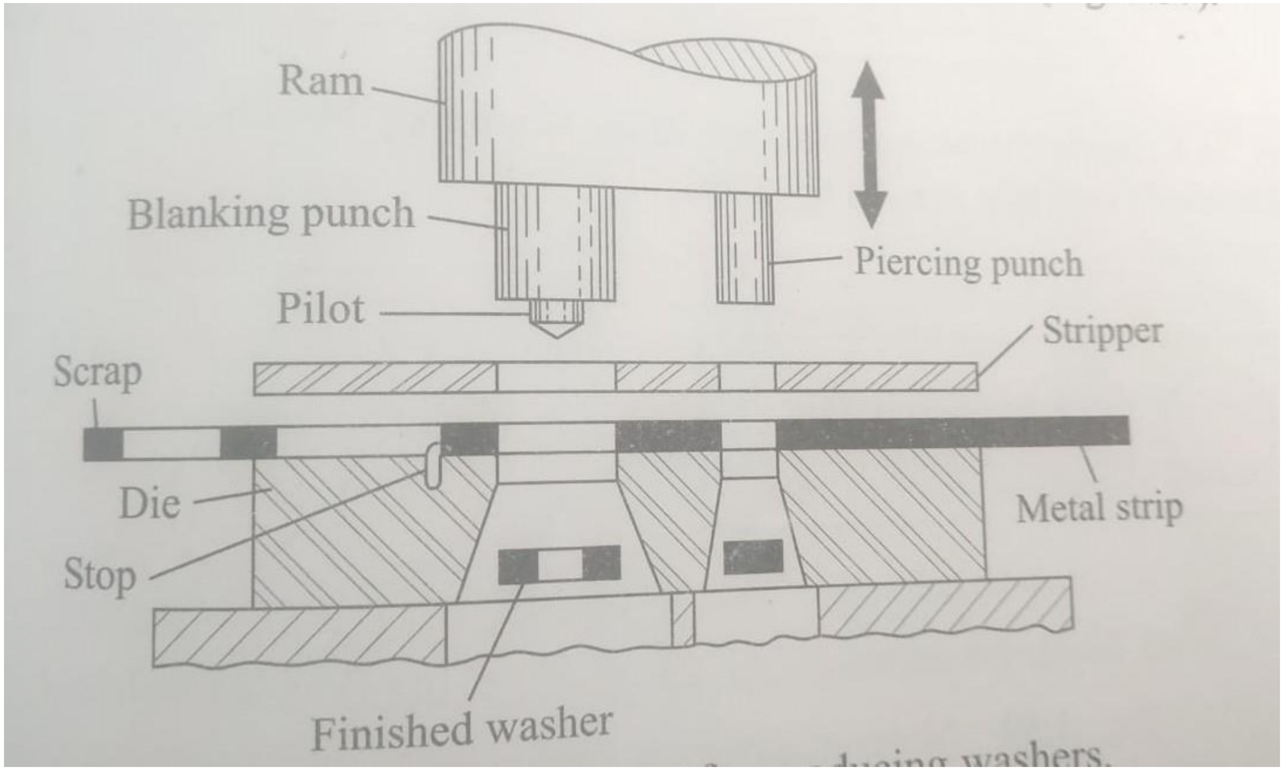



Fig. 3.56 Compound die assembly.

# Progressive Dies

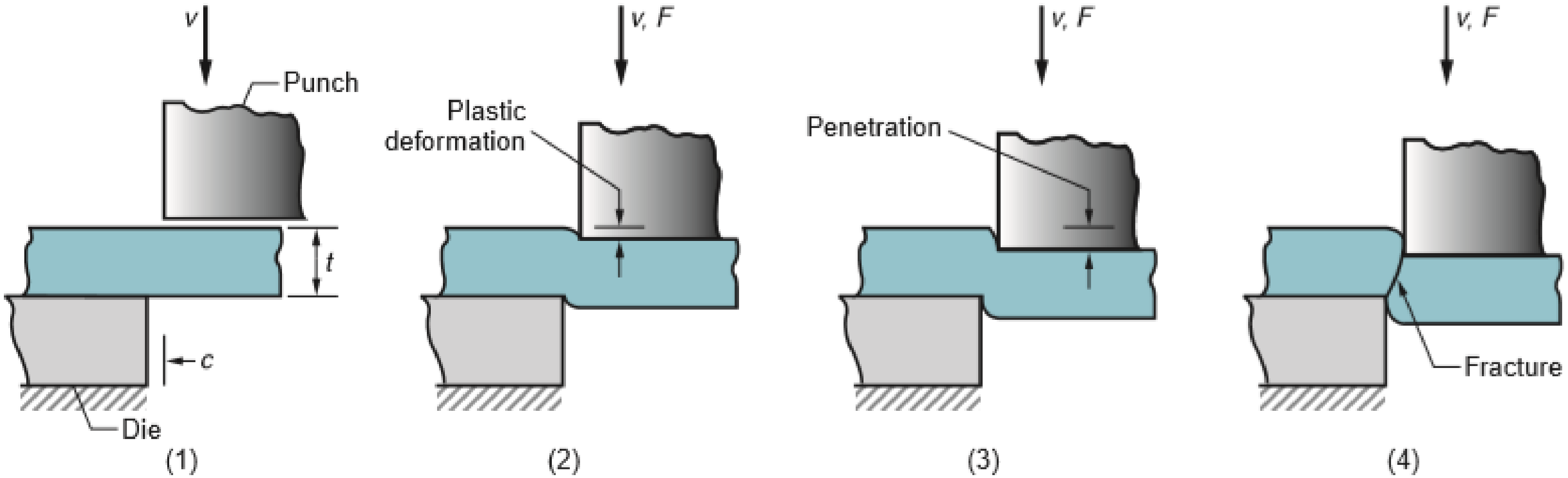
- A progressive die performs two or more operations on a sheet-metal coil at two or more stations with each press stroke. The part is fabricated progressively.



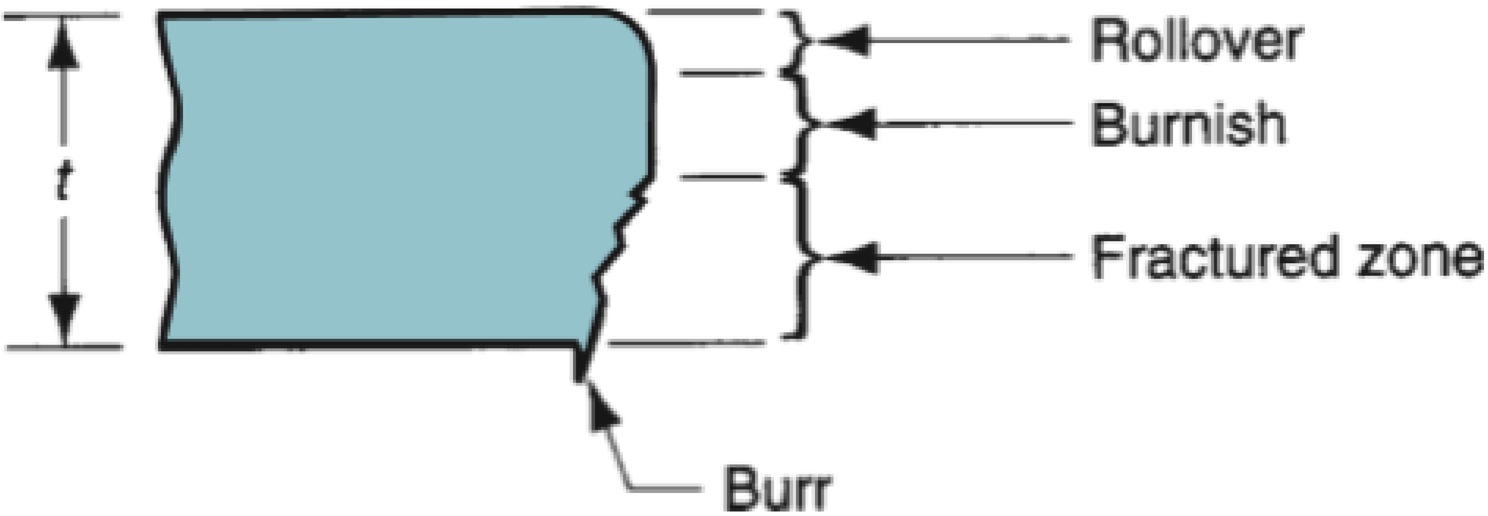
# Sheet Metal Operation

# CUTTING OPERATIONS

- Cutting of sheet metal is accomplished by a shearing action between two sharp cutting edges.
- In shearing action the upper cutting edge (the punch) sweeps down past a stationary lower cutting edge (the die). As the punch begins to push into the work, plastic deformation occurs in the surfaces of the sheet. As the punch moves downward, penetration occurs in which the punch compresses the sheet and cuts into the metal. This penetration zone is generally about one-third the thickness of the sheet.
- As the punch continues to travel into the work, fracture is initiated in the work at the two cutting edges.
- If the clearance between the punch and die is correct, the two fracture lines meet, resulting in a clean separation of the work into two pieces.



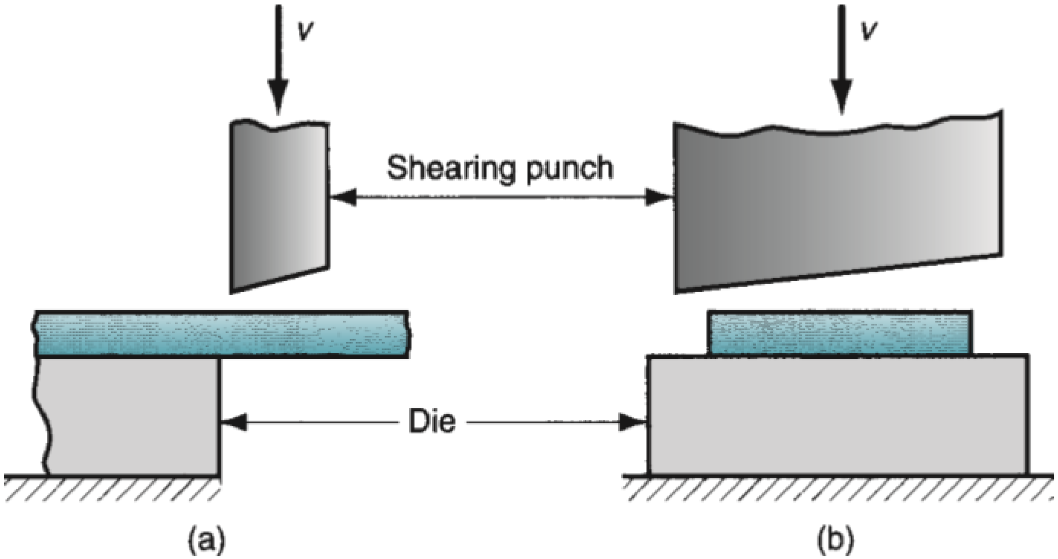

- FIGURE 1. Shearing of sheet metal between two cutting edges: (1) just before the punch contacts work; (2) punch begins to push into work, causing plastic deformation; (3) punch compresses and penetrates into work causing a smooth cut surface; and (4) fracture is initiated at the opposing cutting edges that separate the sheet.




**Characteristic sheared edges of the work.**

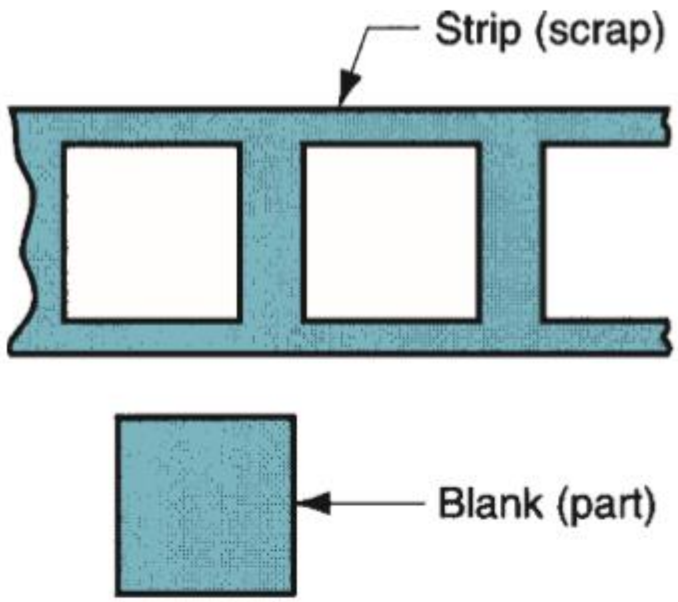
# Shearing

- Shearing is a sheet-metal cutting operation along a straight line between two cutting edges, as shown in Figure (a).
- Shearing is typically used to cut large sheets into smaller sections for subsequent press working operations. It is performed on a machine called a power shears or squaring shears.
- The upper blade of the power shears is often inclined, as shown in Figure (b), to reduce the required cutting force.



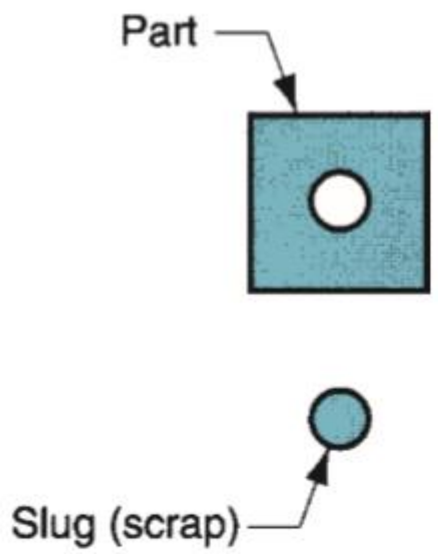
# Blanking

- Blanking involves cutting of the sheet metal along a closed outline in a single step to separate the piece from the surrounding stock, as in Figure. The part that is cut out is the desired product in the operation and is called the blank.



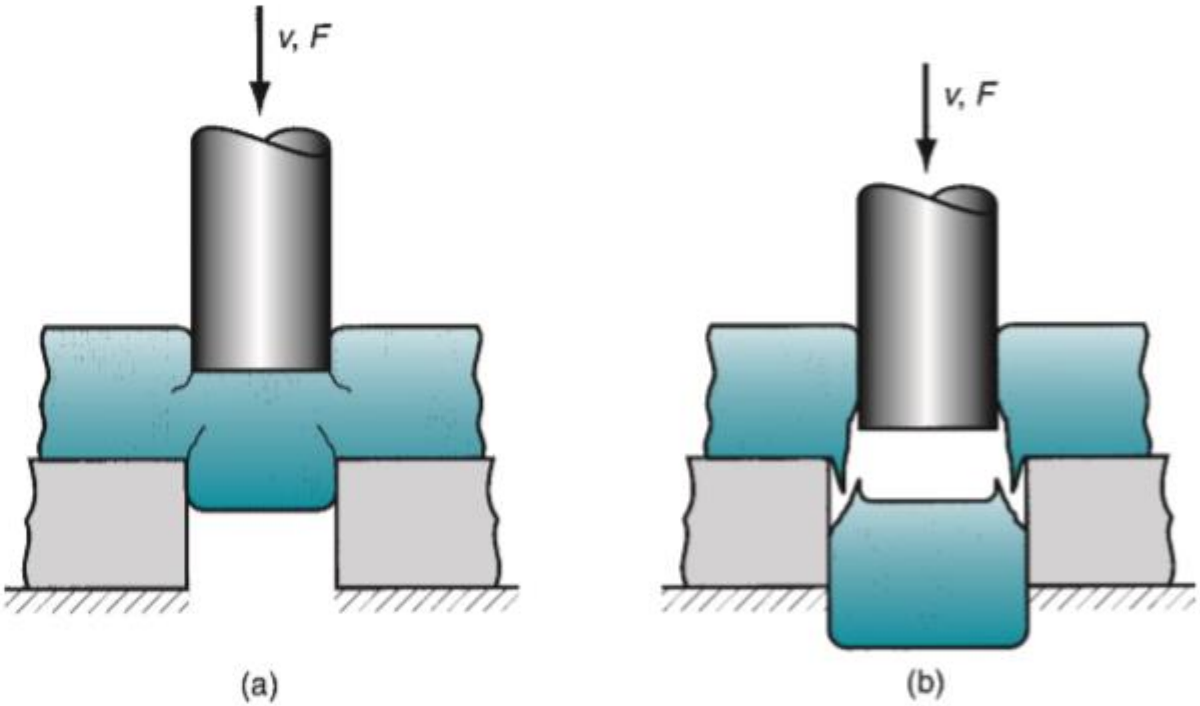
# Punching

- Punching is similar to blanking except that it produces a hole, and the separated piece is scrap, called the slug. The remaining stock is the desired part.

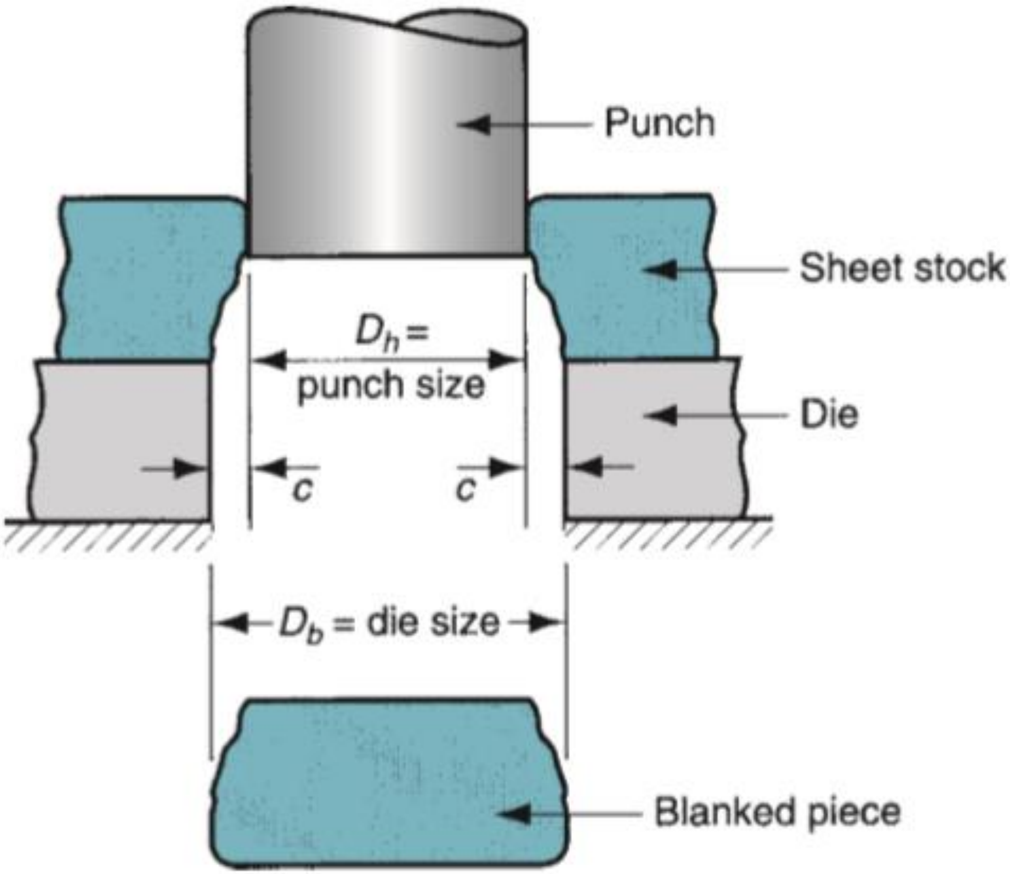


# Clearance

- The clearance c in a shearing operation is the distance between the punch and die.
- Typical clearances in conventional press working range between 4% and 8% of the sheet-metal thickness t.
- If the clearance is too small, then the fracture lines tend to pass each other, causing a double burnishing and larger cutting forces.
- If the clearance is too large, the metal becomes pinched between the cutting edges and an excessive burr results.
- In special operations requiring very straight edges, such as shaving and fine blanking, clearance is only about 1% of stock thickness.




- Effect of clearance: (a) clearance too small causes less-than optimal fracture and excessive forces; and (b) clearance too large causes oversized burr.




- Die size determines blank size Db; punch size determines hole size Dh.;

c = clearance.

# Clearance

- Die opening must be larger than punch and known as ‘clearance’ clearance.
- Punching
- Punch=size of hole
- Die=punch size+ 2clearance
- Remember: In punching punch is correct size.
- Blanking
- Die=size of product
- Punch=Die size-2clearance
- Remember: In blanking die size will be correct.
- Note: In punching clearance is provided on Die

  In Blanking clearance is provided on punch

# Clearance (Contd)…

- The clearance is determined with following equation:

$$C = 0.0032t\sqrt{\tau}$$

- Where τ is the shear strength of the material in (MPa)
- Total clearance between punch and die size will be twice these ‘C’ i.e. 2C

- If the allowance for the material is a=0.075 given, then

  C =0.075 x thickness of the sheet

- If clearance is 1% given, then

  C=0.01 x thickness of the sheet

# Numerical

- Determine the die and punch sizes for blanking a circular disc of 20-mm diameter from a sheet whose thickness is1.5 mm.

  Shear strength of sheet material=294MPa

- Also determine the die and punch sizes for punching a circular hole of 20-mm diameter from a sheet whose thickness is1.5 mm

- The clearance to be provided is given by,

$$C = 0.0032 \times t \times \sqrt{\tau}$$

Shear strength of Sheet material= 294 MPa

$$\text{Hence, } C = 0.0032 \times 1.5 \times 294$$

$$= 0.0823 \text{ mm}$$

Since it is a blanking operation,

Die size = blank size = 20 mm

Punch size = blank size – 2 C

$$= 20 - 2 \times 0.0823$$

$$= 19.83 \text{ mm}$$

Now when it is punching operation,

Punch size= size of hole = 20 mm

Die size = Punch size +2 C

$$= 20 + 2 \times 0.0823$$

$$= 20.1646 \text{ mm}$$

- A metal disc of 20 mm diameter is to be punched from a sheet of 2 mm thickness. The punch and the die clearance is 3% The required punch diameter is

- It is blanking operation
- Therefore Diameter of die = metal disc diameter

= 2 mm 3% clearance (c)

= 0.06 mm

Diameter of punch = 20 – 2c

= 20 – 2 x 0.06

= 19.88 mm

# Punching Force and Blanking Force

$$F_{max} = Lt\tau$$

- where L = the perimeter length of the blank or hole being cut

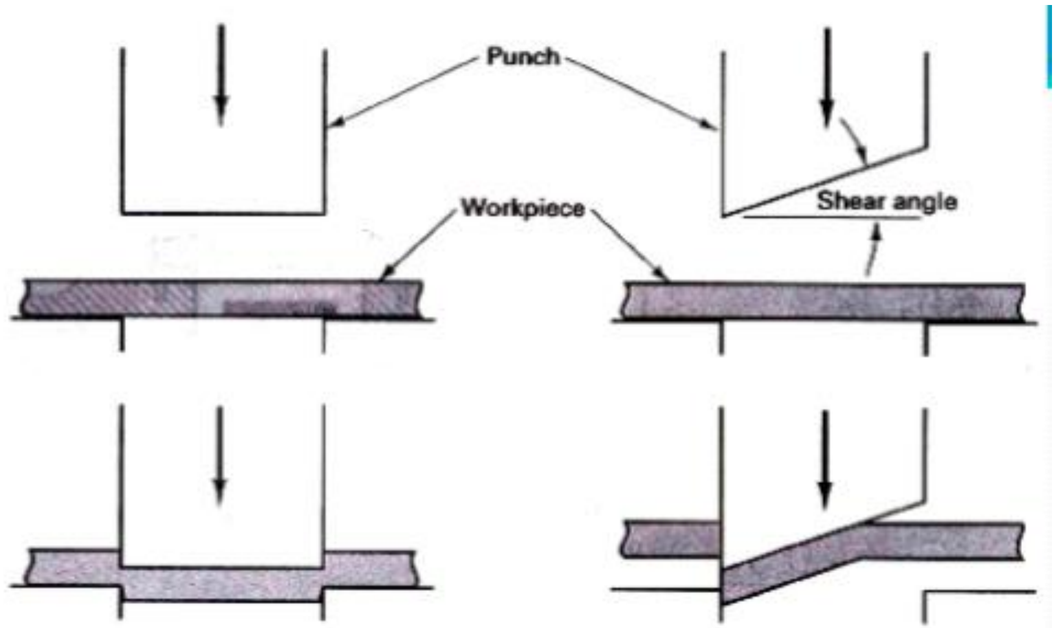
  $\tau$ = shear strength of the sheet metal, MPa

  t = stock thickness, mm

- A rectangular hole of size100 mm × 50 mm is to be made on a 5 mm thick sheet of steel having ultimate tensile strength and shear strength of 500 MPa and 300 MPa, respectively.
- The hole is made by punching process. Neglecting the effect of clearance, the punching force (in kN) is

# Shear angle on Punch

- To reduce shearing force, shear is ground on the face of the die or punch.
- It distribute the cutting action over a period of time.
- Shear only reduces the maximum force to be applied but total work done remains same.



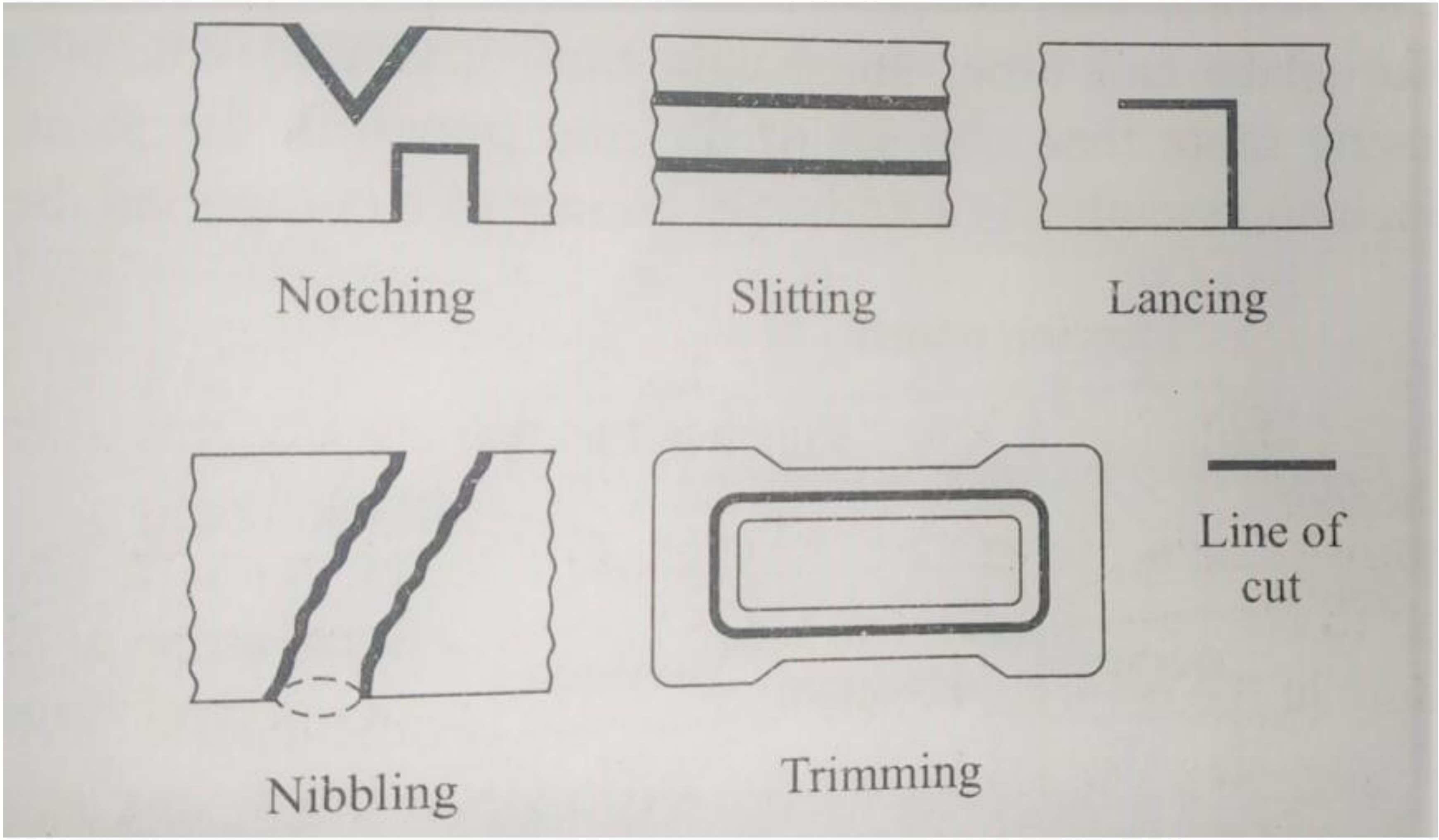
# Other Sheet Metal Operations

- Slitting-moving rollers trace out complex paths during cutting (like a can opener).
- Perforating : Multiple holes which are very small land close together are cut in flat work material.
- Notching : Metal pieces are cut from the edge of a sheet, strip or blank.
- Trimming- Cutting unwanted excess material from the periphery of a previously formed component.
- Shaving- Accurate dimensions of the part are obtained by removing a thin strip of metal along the edges

- Lancing– A hole is partially cut and then one side is bent down to form a sort of tab or louver. No metal removal, no scrap.

- Nibbling-a single punch is moved up and down rapidly, each time cutting off a small amount of material. This allows a simple die to cut complex slots.

- Fine blanking is a shearing operation used to blank sheet-metal parts with close tolerances and smooth, straight edges in one step


Notching
Slitting
Lancing
Nibbling
Trimming
Line of cut

# Unconventional Forming Process

- In these forming processes large amount of energy is applied for a very short interval of time.

- Many metals tend to deform more readily under extra – fast application of load which make these processes useful to form large size parts out of most metals including those which are otherwise difficult – to – form.

- ✓ Parts are formed at a rapid rate, and thus these processes are also called high – velocity forming processes.

- ✓ There are several advantages of using these forming processes,
- ✓ like die costs are low,
- ✓ easy maintenance of tolerances,
- ✓ possibility of forming most metals,
- ✓ and material does not show spring-back effect.

- ✓ Production cost of components by such processes is low.

- ✓ Limitation of these processes is the need for skilled personnel.

# Types of high energy rate forming processes:

1. **Explosive forming**
2. **Electro Magnetic forming**
3. **Electro hydraulic forming**

# Explosive Forming

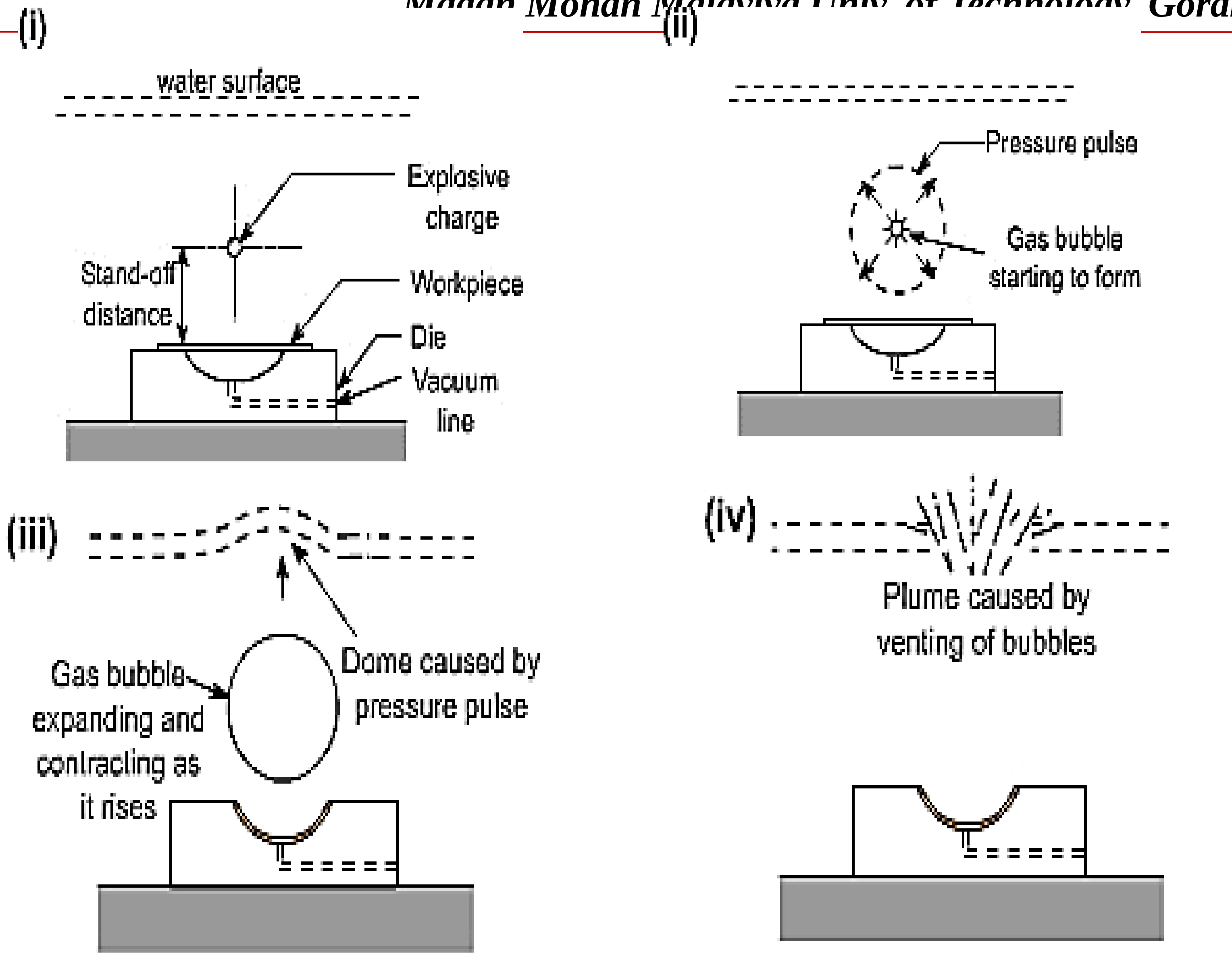
- Explosive forming, is distinguished from conventional forming in that the punch or diaphragm is replaced by an explosive charge.

- Explosives used are generally high – explosive chemicals, gaseous mixtures, or propellants.

- There are two techniques of high – explosive forming:
- Stand – off technique
- Contact technique

# Standoff Technique (Unconfined)

- Sheet metal work piece blank is clamped over a die and the assembly is lowered into a tank filled with water.
- Air in the die is pumped out.
- Explosive charge is placed at some predetermined distance from the work piece.
- On detonation of the explosive, a pressure pulse of very high intensity is produced.
- Gas bubble is also produced which expands spherically and then collapses.
- When the pressure pulse impinges against the work piece, the metal is deformed into the die with as high velocity as 120 m/s.




Sequeuce of underwater explosive forming operations.(i) explosive charge is set in position (ii) pressure pulse and gas bubble are formed as the detonation of charge occurs, (iii) workpiece is deformed, and (iv) gas bubbles vent at the surface of water.

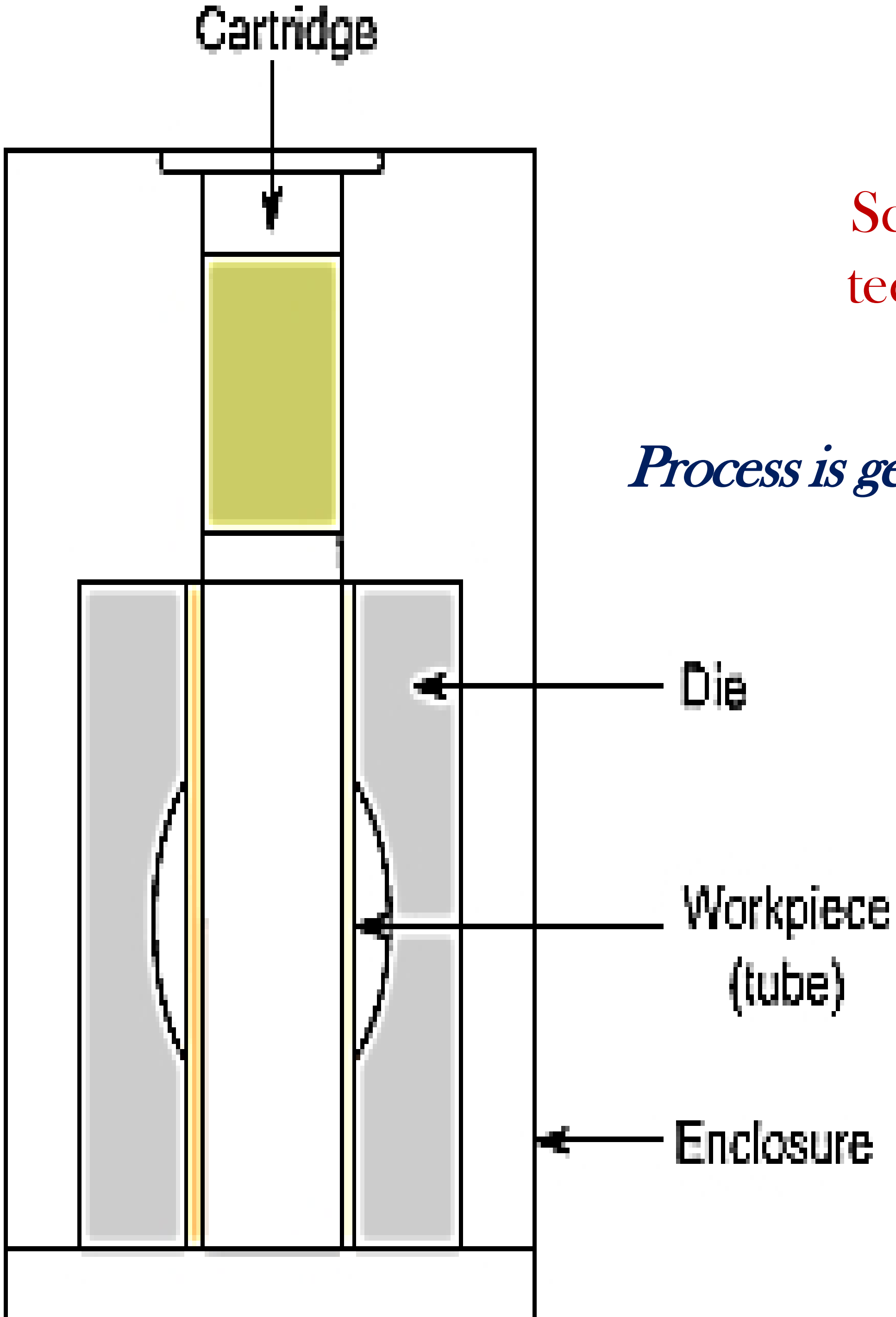
Use of water as the energy transfer medium ensures a uniform transmission of energy and muffles the sound of the explosive blast.

Process is versatile – a large variety of shapes can be formed, there is virtually no limit to the size of the work piece, and it is suitable for low – quantity production as well.

Process has been successfully used to form steel plates 25 mm thick x 4 m diameter and to bulge steel tubes as thick as 25 mm.

# Contact Technique (Confined)

- ✓ Explosive charge in the form of cartridge is held in direct contact with the work piece while the detonation is initiated.
- ✓ Detonation builds up extremely high pressures (upto 30,000MPa) on the surface of the work piece resulting in metal deformation, and possible fracture.
- ✓ Process is used often for bulging tube.




Schematic illustration of contact technique of explosive forming.

*Process is generally used for bulging of tubes*

# Applications

- Explosive forming is mainly used in :
- aerospace industries
- automotive industries

- Process has the greatest potential in limited – production prototype forming and for forming large size components for which conventional tooling costs are prohibitively high.

# Explosives used

- High energy chemicals like TNT, RDX, and Dynamite.
- Gun Powder for lower energy

# Factors to be considered while selecting an HERF process:

- Size of work piece
- Geometry of deformation
- Behavior of work material under high strain rates
- Energy requirements/ source
- Cost of tooling / die
- Cycle time
- Overall capital investment
- Safety considerations.

# Role of water

- Acts as energy transfer medium
- Ensures uniform transmission of energy
- Muffles the sound of explosion
- Cushioning/ smooth application of energy on the work without direct contact.

# Process Variables

- Type and amount of explosive: wide range of explosive is available.
- Stand off distance – SOD- (Distance between work piece and explosive): Optimum SOD must be maintained.
- The medium used to transmit energy: water is most widely used.
- Work size
- Work material properties
- Vacuum in the die

- Peak Pressure p obtained is given by:

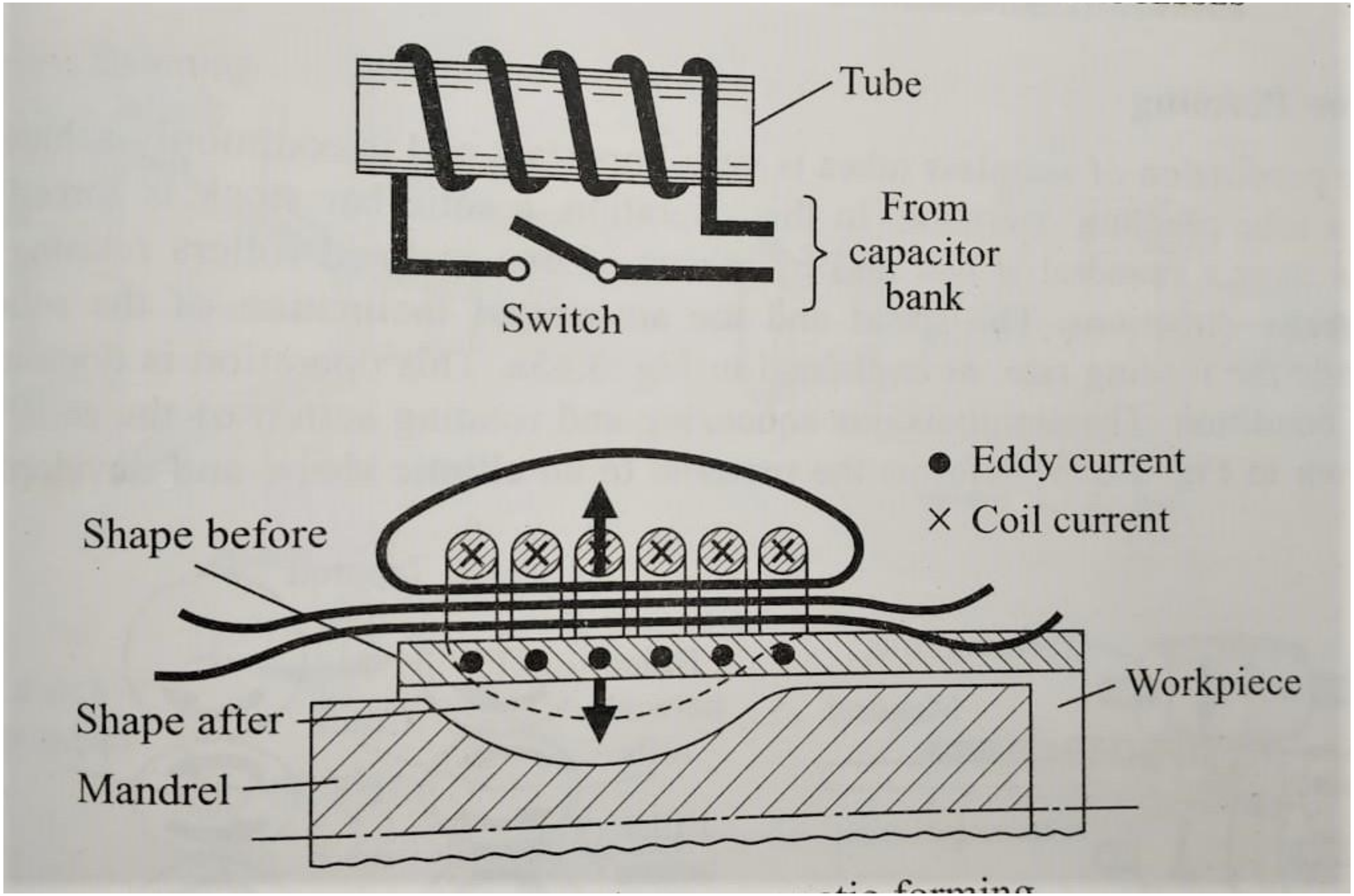
$$p = CW^{n/3} D^{-n}$$

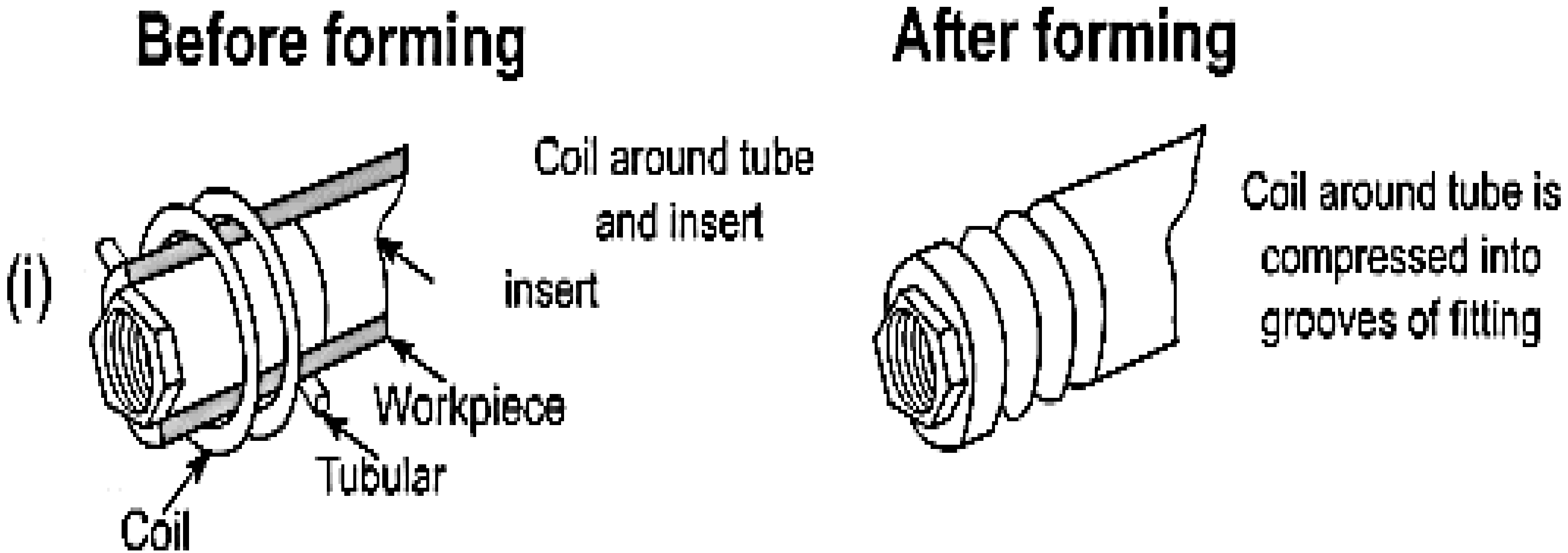
- Where W is the weight of the explosive in Newtons,
- D is the distance of the workpiece from the explosive (Stand off distance)
- c is constant of proportionality.

# Electro Magnetic Forming

- ✓ Process is also called magnetic pulse forming and is mainly used for swaging type operations, such as fastening fittings on the ends of tubes and crimping terminal ends of cables.

- ✓ Other applications are blanking, forming, embossing, and drawing.


Tube
From capacitor bank
Switch
Eddy current
Coil current
Shape before
Shape after
Mandrel
Workpiece

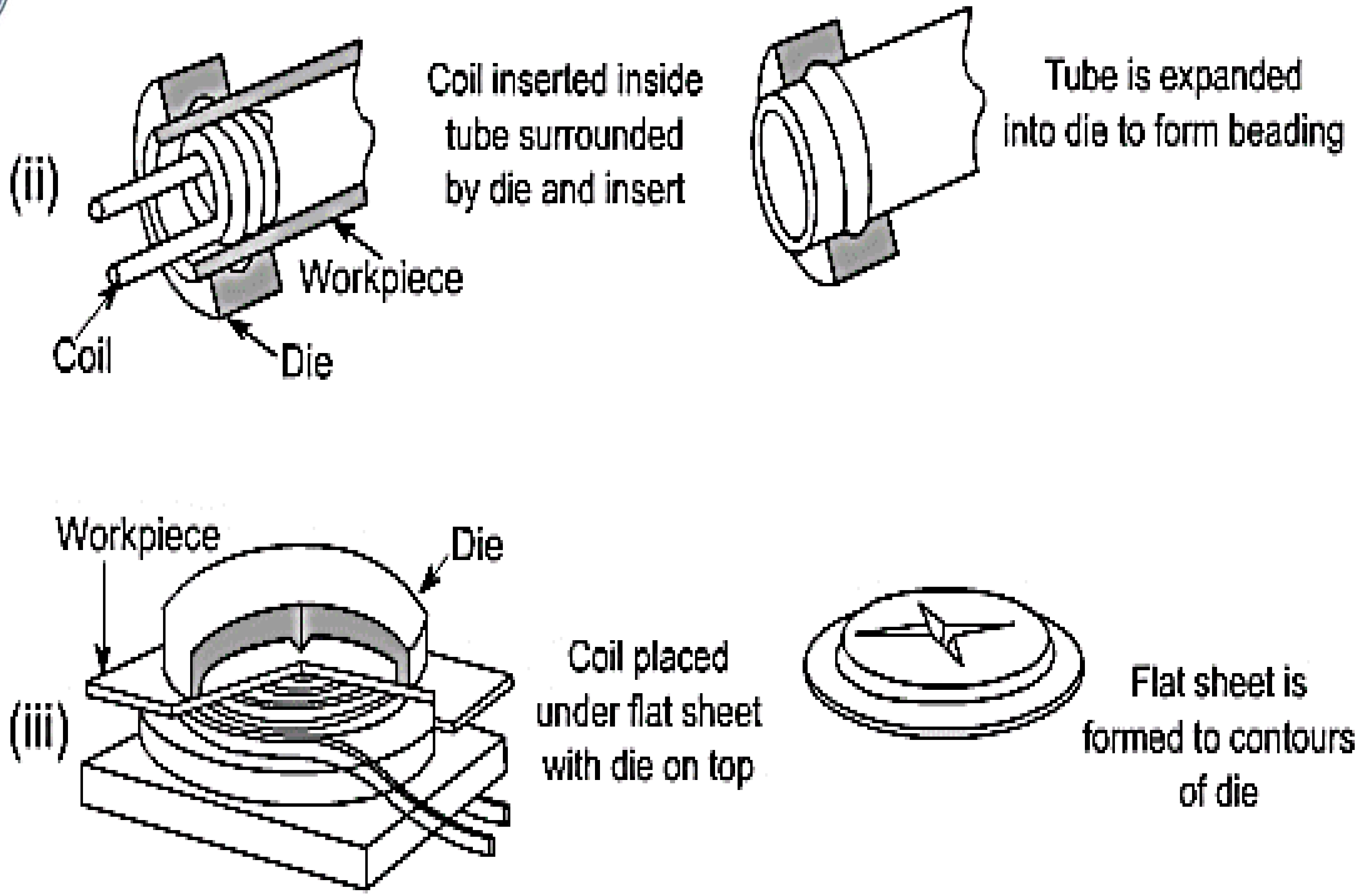



Various applications of magnetic forming process. (i) Swaging

# Process details:

- The electrical energy is stored in the capacitor bank
- The tubular work piece is mounted on a mandrel having the die cavity to produce shape on the tube.
- A primary coil is placed around the tube and mandrel assembly.
- When the switch is closed, the energy is discharged through the coil
- The coil produces a varying magnetic field around it.
- In the tube a secondary current is induced, which creates its own magnetic field in the opposite direction.
- The directions of these two magnetic fields oppose one another and hence the rigidly held coil repels the work into the die cavity.
- The work tube collapses into the die, assuming its shape.

- ✓ A high charging voltage is supplied for a short time to a bank of capacitors connected in parallel. (The amount of electrical energy stored in the bank can be increased either by adding capacitors to the bank or by increasing the voltage).
- ✓ When the charging is complete, which takes very little time, a high voltage switch triggers the stored electrical energy through the coil.
- ✓ A high – intensity magnetic field is established which induces eddy currents into the conductive work piece, resulting in the establishment of another magnetic field.
- ✓ The forces produced by the two magnetic fields oppose each other with the consequence that there is a repelling force between the coil and the tubular work piece that causes permanent deformation of the work piece.




Various applications of magnetic forming process. (ii) Expanding, and (iii) Embossing or blanking.

## Magnetic forming can be accomplished in any of the following three ways, depending upon the requirements.

- Coil surrounding work piece:- When a tube – like part x is to fit over another part y, coil is designed to surround x so that when energized, would force the material of x tightly around y to obtain necessary fit.
- Coil inside work piece:- Consider fixing of a collar on a tube – like part. The magnetic coil is placed inside the tube – like part, so that when energized would expand the material of the part into the collar.
- Coil on flat surface:- Flat coil having spiral shaped winding can also be designed to be placed either above or below a flat work piece. These coils are used in conjunction with a die to form, emboss, blank, or dimple the work piece.

- Either permanent or expandable coils may be used. Since the repelling force acts on the coil as well the work, the coil itself and the insulation on it must be capable of withstanding the force, or else they will be destroyed.

- Expandable coils are less costly and are also preferred when high energy level is needed.

- In electromagnetic forming, the initial gap between the work piece and the die surface, called the fly distance , must be sufficient to permit the material to deform plastically.

- From energy considerations, the ideal pressure pulse should be of just enough magnitude that accelerates the part material to some maximum velocity and then let the part come to zero velocity by the time it covers the full fly distance.

# Process parameters:

- Work piece size
- Electrical conductivity of the work material.
- Size of the capacitor bank
- The strength of the current, which decides the strength of the magnetic field and the force applied.
- Insulation on the coil.
- Rigidity of the coil.

# Advantages

- Suitable for small tubes
- Operations like collapsing, bending and crimping can be easily done.
- Electrical energy applied can be precisely controlled and hence the process is accurately controlled.
- The process is safer compared to explosive forming.
- Wide range of applications.

# Limitations

- Applicable only for electrically conducting materials.
- Not suitable for large work pieces.
- Rigid clamping of primary coil is critical.
- Shorter life of the coil due to large forces acting on it.

# Applications

- Fabrication of hollow, non – circular, or asymmetrical shapes from tubular stock.
- Compression applications involve swaging to produce compression, tensile, and torque joints or sealed pressure joints, and swaging to apply compression bands or shrink rings for fastening components together.
- Flat coils have been used on flat sheets to produce stretch (internal) and shrink (external) flanges on ring and disc – shaped work pieces.
- Electromagnetic forming has also been used to perform shearing, piercing, and rivettting.

# Electro Hydraulic Forming

- Electro hydraulic forming (EHF), also known as electro spark forming, is a process in which electrical energy is converted into mechanical energy for the forming of metallic parts.

- A bank of capacitors is first charged to a high voltage and then discharged across a gap between two electrodes, causing explosions inside the hollow work piece, which is filled with some suitable medium, generally water.

- These explosions produce shock waves that travel radially in all directions at high velocity until they meet some obstruction.

- If the discharge energy is sufficiently high, the hollow work piece is deformed.

- The deformation can be controlled by applying external restraints in the form of die or by varying the amount of energy released.

# ELECTRO HYDRAULIC FORMING

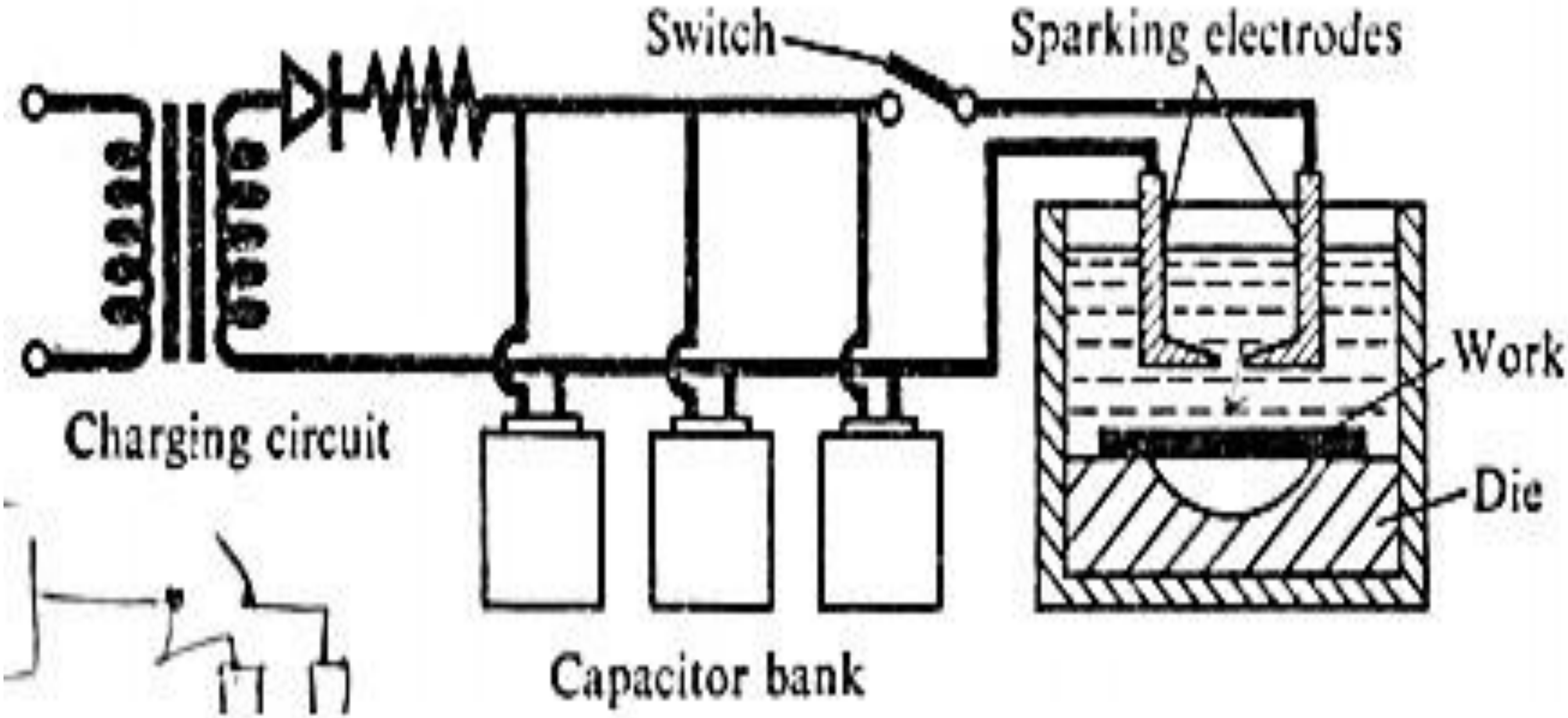
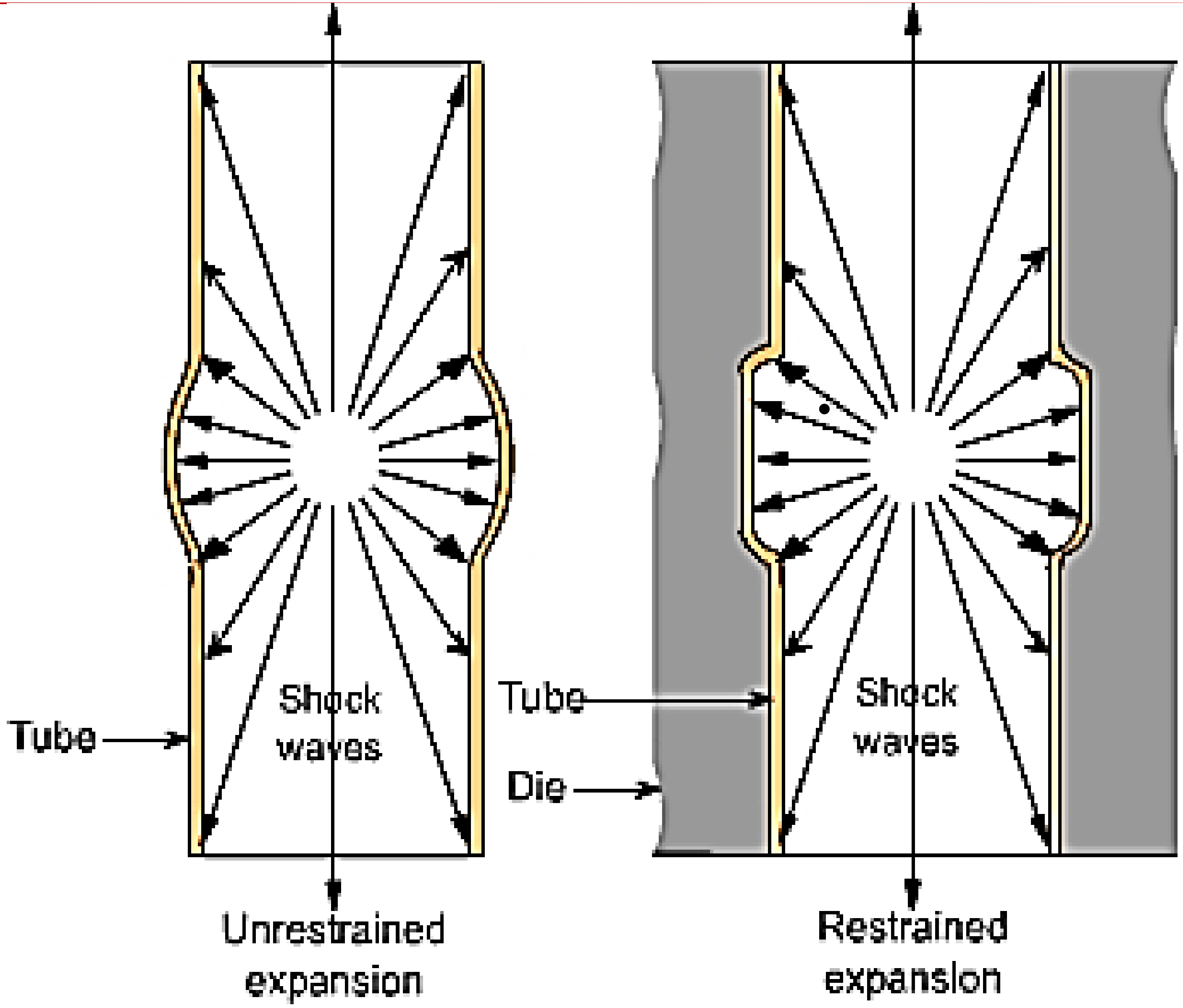



Fig. Electro Hydraulic Forming


Tube
Shock waves
Unrestrained expansion
Tube
Die
Shock waves
Restrained expansion

# Principle

- A sudden electrical discharge in the form of sparks is produced between electrodes and this discharge produces a shock wave in the water medium.
- This shock wave deforms the work plate and collapses it into the die.
- Characteristics of this process are similar to those of explosive forming.
- Major difference, however, is that a chemical explosive is replaced by a capacitor bank, which stores the electrical energy.
- Capacitor is charged through a charging circuit.
- When the switch is closed, a spark is produced between electrodes and a shock wave or pressure pulse is created.
- Energy released is much lesser than that released in explosive forming.

# Process Characteristics

- Stand off distance: It must be optimum.
- Capacitor used: The energy of the pressure pulse depends on the size of capacitor.
- Transfer medium: Usually water is used.
- Vacuum: the die cavity must be evacuated to prevent adiabatic heating of the work due to a sudden compression of air.
- Material properties with regard to the application of high rates of strain.

# Advantages

- ✓ EHF can form hollow shapes with much ease and at less cost compared to other forming techniques.
- ✓ EHF is more adaptable to automatic production compared to other high energy rate forming techniques.
- ✓ EHF can produce small –to intermediate sized parts that don't have excessive energy requirements.
- ✓ Better control of the pressure pulse as source of energy is electrical- which can be easily controlled.
- ✓ Safer in handling than the explosive materials.
- ✓ More suitable if the work size is small to medium.
- ✓ Thin plates can be formed with smaller amounts of energy.
- ✓ The process does not depend on the electrical properties of the work material.

# Limitations

- Suitable only for smaller works
- Need for vacuum makes the equipment more complicated.
- Proper SOD is necessary for effective process.

# Applications

- They include smaller radar dish, cone and other shapes in thinner and small works.

# Materials formed

- Materials having low ductility or having critical impact velocity less than 30 m/s are generally not considered to be good for EHF.
- All materials that can be formed by conventional forming processes can be formed by EHF also.
- These materials are aluminum alloys, nickel alloys, stainless steels, titanium and Inconel 718.

# ADVANTAGES OF HERF

- Production rates are higher, as parts are made at a rapid rate.
- Die costs are relatively lower.
- Tolerances can be easily maintained.
- Versatility of the process – it is possible to form most metals including difficult to form metals.
- No or minimum spring back effect on the material after the process.
- Production cost is low as power hammer (or press) is eliminated in the process. Hence it is economically justifiable.
- Complex shapes / profiles can be made much easily, as compared to conventional forming.
- The required final shape/ dimensions are obtained in one stroke (or step), thus eliminating intermediate forming steps and pre forming dies.
- Suitable for a range of production volume such as small numbers, batches or mass production

# Principle / important features of HERF processes

- The energy of deformation is delivered at a much higher rate than in conventional practice.
- Larger energy is applied for a very short interval of time.
- High particle velocities are produced in contrast with conventional forming process.
- The velocity of deformation is also very large and hence these are also called High Velocity Forming (HVF) processes.
- Many metals tend to deform more readily under extra fast application of force.
- Large parts can be easily formed by this technique.

- For many metals, the elongation to fracture increases with strain rate beyond the usual metal working range, until a critical strain rate is achieved, where the ductility drops sharply.

- The strain rate dependence of strength increases with increasing temperature.

- The yield stress and flow stress at lower plastic strains are more dependent on strain rate than the tensile strength.

- High rates of strain cause the yield point to appear in tests on low carbon steel that do not show a yield point under ordinary rates of strain.

# LIMITATIONS OF HERF

- Highly skilled personnel are required from design to execution.
- Transient stresses of high magnitude are applied on the work.
- Not suitable to highly brittle materials
- Source of energy (chemical explosive or electrical) must be handled carefully.
- Governmental regulations/ procedures / safety norms must be followed.
- Dies need to be much bigger to withstand high energy rates and shocks and to prevent cracking.
- Controlling the application of energy is critical as it may crack the die or work.
- It is very essential to know the behaviour or established performance of the work metal initially

# Applications

- In ship building – to form large plates / parts (up to 25 mm thick).
- Bending thick tubes/ pipes (up to 25 mm thick).
- Crimping of metal strips.
- Radar dishes
- Elliptical domes used in space applications.
- Cladding of two large plates of dissimilar metals.

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# THANK YOU