METAL FORMING PROCESS

Unit 1:Introduction and concepts

Manufacturing Processes can be classified as

i) Casting

ii) Welding

iii) Machining

iv)Mechanical working

v) Powder Metallurgy

vi)Plastic Technology etc.,

In Mechanical working Process the raw material is converted to a given shape by the application of external force. The metal is subjected to stress.It is a process of changing the shape and size of the material under the influence of external force or stress.Plastic Deformation occurs.

Classification of Metal Working Processes

1. General classification

i. Rolling
ii. Forging
iii. Extrusion
iv. Wire Drawing
v. Sheet Metal Forming

2. Based on Temperature of Working

i. Hot Working ii.

Cold Working

iii. Warm Working

3. Based on the applied stress

i. Direct Compressive Stress
ii. Indirect Compressive Stress
iii. Tensile Stress
iv. Bending Stress
v. Shear Stress

Classification of Metal Working based on temperature.

Hot working: It is defined as the mechanical working of metal at an elevated (higher) temperature above a particular temperature. This temperature is referred to RCT(Re Crystallization Temperature).

Cold Working: It is defined as the mechanical working of metal below RCT.

Warm Working: It is defined as the mechanical working of metal at a temperature between that of Hot working and Cold Working. Ingot is the starting raw metal for all metal working process.

Molten metal from the furnace is taken and poured into metallic moulds and allowed to cool or solidify. The cooled solid metal mass is then taken out of the mould. This solid metal is referred to as Ingot.This Ingot is later on converted to other forms by mechanical working.

What is a Cast Product?

It is a product obtained by just pouring molten metal into the mould and allowing it to solidify to room temperature.

It will have the final size and shape. Engine block ,Piston etc.,

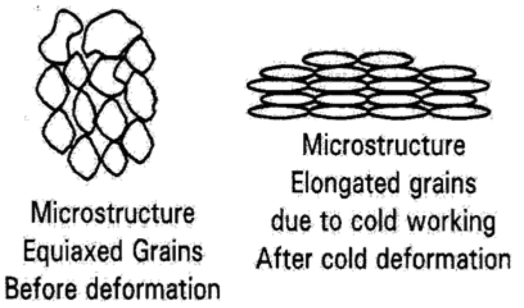
What is a wrought Product?

It is a product obtained by subjecting the hot ingot to mechanical working process to get a variety of products.Ex., spanner, screw driver, connecting rod, crank shaft etc.,

Characteristics of a Wrought Product

*Grains are oriented in a particular direction.

*The metal will show flow lines which are due to the presence of inclusions present between the metal layers.. The Metal will shows higher properties in the direction of metal flow. The defects get welded due to mechanical working.



Effect of cold working on grain structure

Difference between Cast and Wrought product.

Cast Product	**Wrought Product**
1.It is obtained by conversion of liquid metal to solid state, to get the required shape of the component in one step. The cast product may undergo machining operation.	1. It is obtained by subjecting the metal to external load or mechanical working to get the shape. It may be subjected to further operation.
2. The cast product will have uniform properties. The product is Isotropic in nature. Properties are same in all directions.	2. The wrought product will have directional properties . Properties are enhanced . The Product is anisotropic in nature. ie., properties are different in different directions.

3. The product will have uniform grain structure.	3. The product will have directional properties and the grain structure will be oriented. Grains get altered.
4. The product will have small amount of porosity which cannot be eliminated completely.	4. Due to mechanical working the porosity level is almost zero.
5. Cast product will have any shape size and complexity. Small to very huge components can be produced easily.	5. Wrought products are smaller in size but large size and moderately complex shapes can also be produced with some difficulty.

Based on the type of applied stress

Direct compression stress: Rolling and Forging

Indirect Compression: Extrusion and Wire drawing.

Tensile stress: Stretch forming

Bending stress: Sheet bending/ roll bending

Shear stress: Cutting of sheet

Advantages of metal working process

* Product with consistent high quality can be manufactured.
* Defects such as porosity and discontinuities are minimized.
* Inclusions get distributed evenly throughout the product.
* Grains are oriented in a particular direction and directional properties are obtained.
* In hot working the grains will be uniform and the properties are also uniform.

* In cold working the properties are enhanced due to strain hardening effect.

* Large tonnage can be easily produced.

*The process can be easily mechanized.

Limitations of Mechanical working process

*The product becomes highly anisotropic in nature.

*Final product has to be obtained after machining of the wrought product except in the case of structural components.

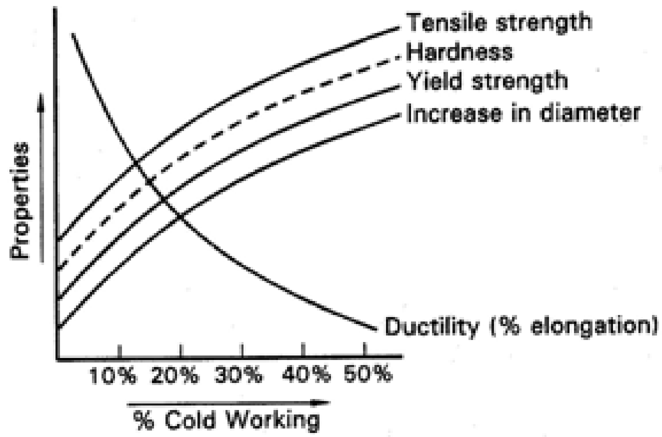
*Needs additional equipment and machinery for metal working process. Hence, initial investment is high.

*Maintenance cost is high.

*More safety precautions are to be exercised as hot metal and additional equipments are used.

Concept of cold working

Consider a cylindrical metal piece with a known height, H and diameter, D. Let us subject the piece to compressive load at room temperature. We shall take that the height is reduced by 10%,20%,30% ….. etc., Each of these reduction in height represents %cold working. For each of these the diameter the Tensile strength, hardness, yield strength, %elongation were measured. It is seen that the %elongation decreases with increase in %cold working whereas other properties UTS, YS, Hardness increases and the diameter of the specimen also increases. Similarly the specimen can be subjected to tensile load also. The changes that take place in the material due to cold working is an important aspect which needs to be born in mind while designing various steps in MW process

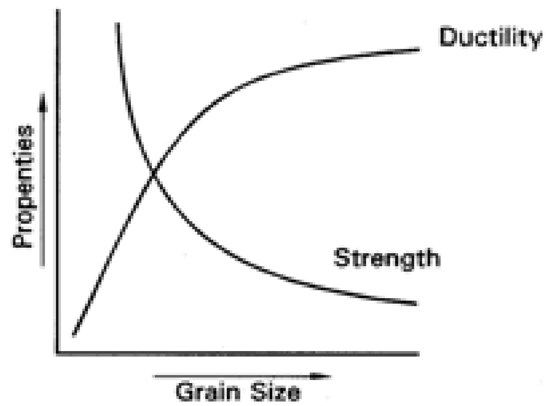


Effect of cold working on properties

Effect of Mechanical Working on the properties of the Metal

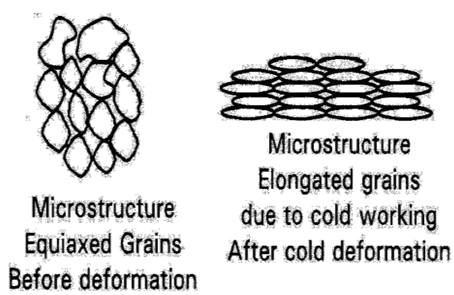
Due to working of the metal there will be changes in the grain structure. The grains may be elongated in one direction from its equiaxed shape. The pores are reduced and the inclusions are fragmented and distributed evenly in the metal. In hot working the coarse equiaxed grains will become fine equiaxed. The changes obtained in cold working is appreciable.

The behaviour of the metal with changes in grain size is shown in the figure. As grain size becomes coarse the strength property comes down and ductility increases.



Variation of properties with respect to grain size

As the percentage of cold working increases the material becomes strain hardened, the hardness and strength properties are increased but the ductility property decreases as shown in the figure It can be summarized as follows. Equiaxed grains will give uniform properties in all directions. Deformed grains show higher strength properties in the elongated direction.



Effect of cold working on grain structure

Concept of strain hardening

Straining of the metal/alloy occurs when subjected to cold working process. The metal will show more and more resistance for the external load as the cold working is Continued. At some it may become very difficult to deform the metal. This phenomenon is referred to as strain hardening effect. This can be explained in simple terms as given below.

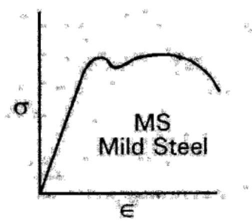
All metals have atoms arranged in a repetitive manner in three dimensions referred to as crystalline structure. The structure is associated with imperfections in the form of dislocations. These dislocations starts moving towards the grain boundary region under the influence of external load. The dislocations get piled up near the grain boundaries. The density of dislocations increases due to Frank Reed source and may reach a value as high as 10^8-10^{12}/cm^2. Since, dislocations pile up near the grain boundary the density increases and the mean free path for the movement of dislocations decreases. The metal offers more resistance to external force. The metal will realize higher strength and this goes on building up till all the dislocations are brought near the grain boundary. Then annihilation of like and unlike dislocations takes place. The net existing dislocations will then become effective. During this period the load required for deformation increases. This phenomenon is referred to as"Strain Hardening". If the cold working stress exceeds this range the metal will fracture.

To take care of this the metal is subjected to annealing before further working. In Mechanical working of metals, the metal is subjected to external load and is deformed plastically. The given shape is obtained and is retained even after the removal of the load. The metal is subjected to stress and is strained. Hence, to understand the different mechanical working process, it is necessary to understand the stress strain relationship of metals, types of stress and strains, deformation process, theories used for the prediction of plastic deformation etc.,

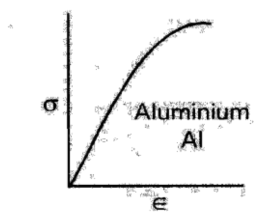
For easy mechanical working of metals the nature of stress strain curve needs to be **reviewed.** The factors associated with stress strain needs to be studied.

Different stress- strain curves

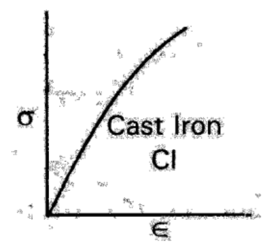
Some typical stress strain curves are shown below. Different stress strain curves. There exists relationship between stress and strain for all materials and it is very useful information for a design engineer and metallurgist alike. It clearly exhibits the behavior of the material. In order to understand the same we shall now look into stress strain curves of various materials. A study of these will help us in understanding the mechanical working process in a better way. The following figures represents pictorially the features of stress **and strain** behavior.



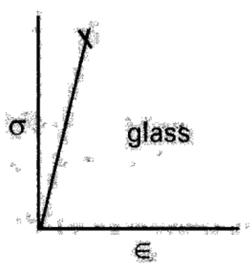
a) Highly ductile material



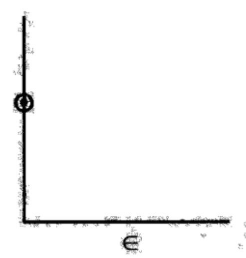
b) Mildly ductile material



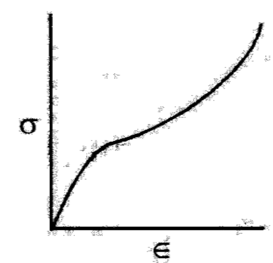
c) Brittle material



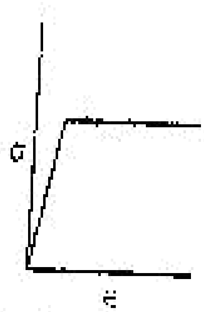
d) Highly brittle material



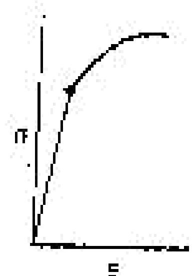
e) Highly Rigid material



f) Polymer material



g) Linear elastic - perfectly plastic material


g) Linearly elastic - Non linearly plastic material

Typical stress strain curves for easy deformation

In Mechanical working of metals it is important to know that efforts are to be made to make the metal undergo deformation easily with less effort. The following figures illustrate what are the typical characteristics involved in the material.

For easy deformation of metal the stress strain curve should have:

1. Lower yield point.

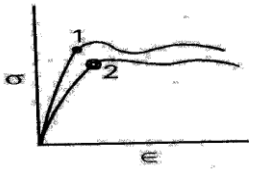
2. Gentle slope.

3. Larger elongation behavior.

Stress strain curve should have Lower yield point.

The load required for deformation is directly proportional to the yield point. Hence, if the yield point is high, higherload is required and lower the yield point of the material, lower is the loads required for deformation.The material with lower yield point can be easily shaped.

In the figure material 2 has the lower yield point as compared to 1. Hence, it is easier to deform material 2. Whenever a material is heated to higher temperature the yield point is reduced and it becomes easier to deform.

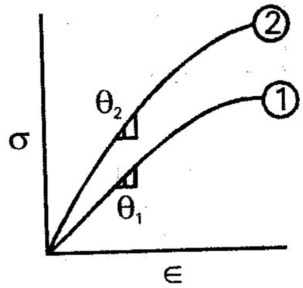


σ-∈ Curve for easy deformation

2. **Stress strain should have Gentle slope.**

The stress strain curve should have lower gradient ie., gentle slope. It means the stiffness of the material must be low. Stress strain curve with lower gradient will have gentle slope. Gentle slope needs lesser strain rate and hence lower rate of loading.

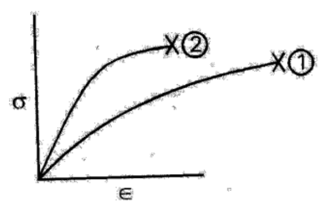
In figure material 1 has lower slope as compared to 2. Hence, material 1 is easier to deform.



Slope of σ-∈ Curve

Stress Strain curve should have Larger elongation behavior.

A material with larger elongation will undergo more deformation without undergoing fracture, and it is extremely to shape the material. In the figure material 1has larger elongation as compared to2. Hence, material1 can be easily deformed.

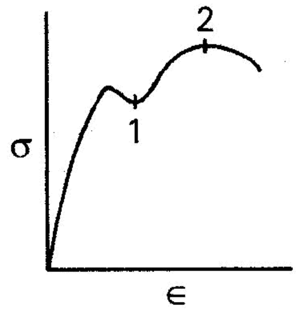


σ-∈ Curve with larger elongation

Strain hardening Type:

Some materials undergo strain hardening which means higher loads are required for deformation and more resistance is offered by the material. In the stress strain curve the strain hardening portion is represented by 12. If the slope12 is high, strain hardening of the material is more and it becomes difficult to deform.

By heating the material it can be softened and strain hardening is eliminated.



σ-∈ showing strain hardening

Unit 2: Effect of Parameters

Effect of Parameters on Mechanical Working Process.

Uniaxial, biaxial, and triaxial stresses their representation, stress tensor. Principal stresses and Principal planes.

Parameters affecting Mechanical Working Processes

The following parameters influence the Mechanical Working Process:

* Temperature of Metal
* Strain Rate
* Friction
* Nature of Forces
* Metal Structure

i)Temperature of Metal

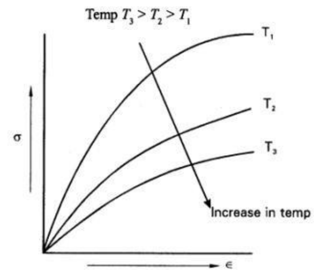
All metals posses hardness and strength. As a result of this one has to apply sufficient load to deform the metal. If the metal is heated to a higher temperature, the strength and hardness are reduced and the ductility is enhanced.

The metal can be deformed easily.

As the temperature of the metal is increased the metal can be deformed more easily. The metal becomes softer.

The same is exhibited graphically as shown.

As the temperature is increased the stress strain curve shows reduced slope or it will have gentle slope.



Variation of Stress-Strain w.r.t temperature. It can be seen that T3 is higher than other two temperatures. Thus it has decreased the yield strength of the material and the slope of the curve is gentle. Hence, one can work the material at T3 temperature easily.

ii) Strain Rate

Strain rate is the rate at which strain is induced in the metal. It is also a measure of rate of deformation, as the metal is being worked at a known speed. Viz., the rate at which deformation is taking place.

If V= Deformation Velocity

t= Instantaneous thickness of the metal

then strain rate, $\dot{\varepsilon} = V/t$

As strain rate increases, the metal becomes hardened and flow stress increases. An increase in the strain rate increases the strain hardening in the metal. The metal temperature required for deformation increases with increase in strain hardening.

iii) Friction

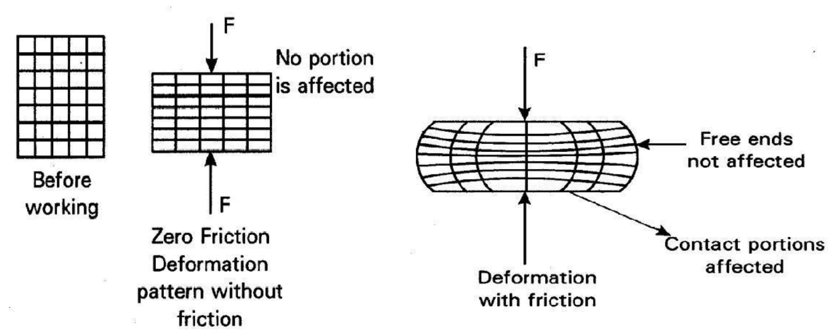
Friction is the resistance offered by one surface against the other whenever there is a relative motion between the two surfaces. More work is to be done in overcoming it. In metal working process also, friction place a very important role. Friction alters the

metal deformation pattern.Deformation tends to be non uniform. Heat is generated at the contact surface.Metal may stick to the tool face.Plastic flow occurs rather than sliding. Load required for deformation increases Loss of energy occurs. Die and tool wears out faster. The surface layers become irregular and develops microcracks.

Consider a specimen marked with vertical and horizontal grids as shown. Let it be subjected to compressive load and deformed with and without friction.

The deformation pattern is observed after the test.
It can be clearly seen from the figure the effect of friction on metal deformation pattern.
When there is no friction the deformation will be uniform.

The vertical and horizontal grids will remain uniform and straight.



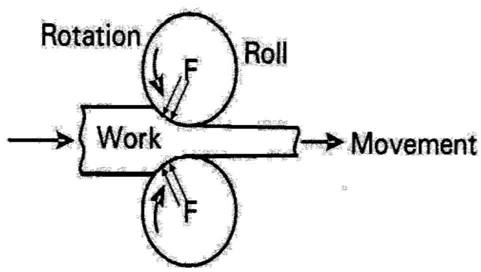
When there is friction, metal flow is affected to a large extent. The vertical grids and horizontal grids are bent as shown.

Free ends are not affected whereas the contact surfaces are held back causing bent pattern in the metal flow.
Metal flow is affected to a large extent at the contact surface as compared to the free end. It has been well established that for cold rolling the coefficient friction is around 0.1 and for hot rolling it is around 0.6.
Friction is a natural phenomenon and has to be controlled in mechanical working process for smooth and uniform deformation of the metal.This can be achieved to a great extent by use of lubricants.A lubricant prevents or reduces unnecessary rubbing of the surfaces and controls surface finish of the components.In general solid lubricants such as glass, MoS_2,graphite, lead,Teflon,polyethylene, BoN_2 are used for the purpose.

Basically they have low shear strength property.

* **Nature of Forces**

The type of forces influences the deformation process.Based on the type of Mechanical working process the nature of forces is automatically fixed. The nature of forces influences the metal flow and the process as such. The same is shown in the following figures:

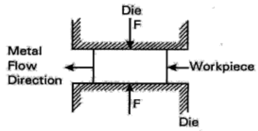


Rolling

In Rolling the flow of metal is at right angles to the applied load. This is Compressive Load.

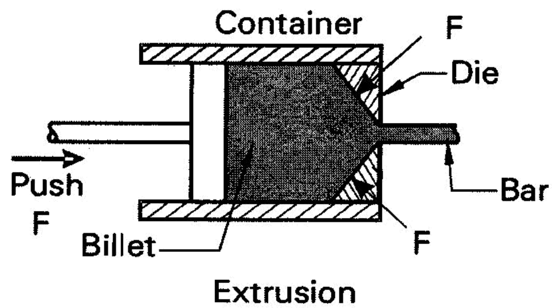
In rolling process there is a direct compressive load or stress acting on the metal (work). The direction of load will be acting at right angles to the flow of work. In open die forging process direct compressive load or stress will be acting on the metal and the direction of the metal flow will be at right angles to the applied load.

In Forging the flow of metal is at right angles to the applied load. This is Compressive Load

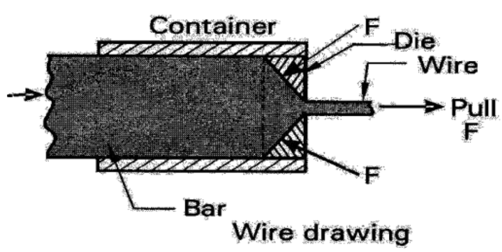


Open die Forging

In extrusion and wire drawing processes Indirect compressive load or stress will be acting. The primary applied force (push or pull force) is to cause metal to move. Indirect compressive force will be developed as a result of reaction of the work piece and the die surface.



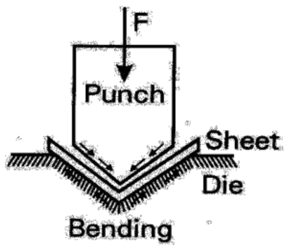
In Extrusion the flow of metal is at an angle to the applied load. The metal experiences the normal load at the inclined die surface. This is Indirect Compressive Load



In Wire Drawing as in Extrusion the flow of metal is at an angles to the applied load. The metal experiences the normal load at the inclined die surface.

This is Indirect Compressive Load. In bending operation a sheet is subjected to bending action where in the sheet is bent into an arc of a circle or through an angle. The sheet is subjected to deformation by using a punch and a die. The sheet experiences both tensile and compressive stresses on either side of the sheet and it is similar to a three point bending.

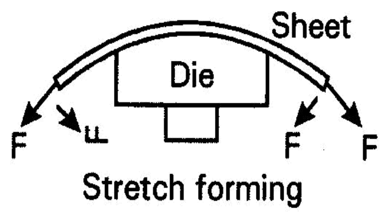
The required shape is obtained



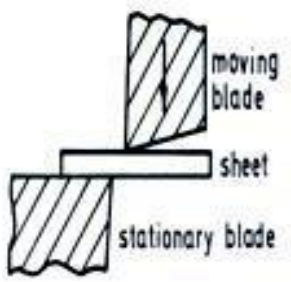
In Bending, The metal experiences Compressive force at the inside portion near the punch and tensile force at the outside portion near the die. Both tensile and compressive force is acting at the same time. This is Bending Stress. In Stretch Forming operation metal sheet is placed on a contoured die of required shape and pulled outward along the die surface. This will result in pulling force being induced in the sheet.

The sheet is also pulled inward towards the center of the arc of the die.By repeated pulling of the sheet the required load beyond the elastic limit is imposed on the sheet and the sheet will finally takes the shape of the die.

This type of deformation is used for producing large components having large radius of contour as in aircraft body or space craft structure or large dish type of object as in solar panels or reflectors etc.,



In Stretch Forming the flow of metal is along the direction of the pulling force applied . The metal experiences pulling force towards the center of the arc also.This is Pulling or Tensile force. In shearing a metal sheet is subjected to cutting action under the influence of two sharp blades. It is similar to a cutting of a sheet of paper using a scissors or punching of paper sheet using a punch. The force applied exceeds the yield load and reaches the ultimate load required for failure of the sheet.Using shear operation,various contours in the sheet can be created. The cut sheet is used for other operations like bending or stretching or coining etc.,



Shearing

In Shearing the forces will be acting parallel to the cross section of the metal The metal experiences tangential force at the surface. This is Shear force or Tangential force.

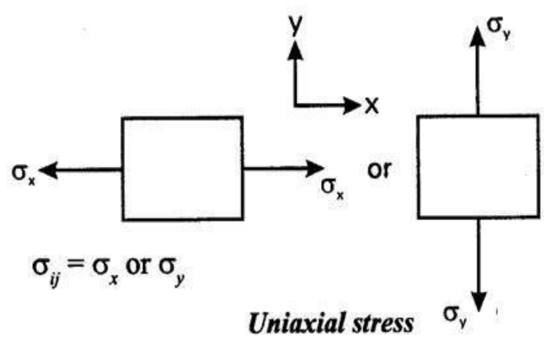
Hydrostatic Force:

It is a system of forces acting on the body whose magnitude is the same in all the three direction. Its effect on the mechanical working is to assist uniform deformation.

v) Metal structure

The arrangements of atoms in the crystal structure of the metal influences the mechanical working process. The metal could have Cubic or FCC or BCC or HCP structure. FCC structure undergoes more strain hardening and hence very difficult to mechanically work. HCP structure undergo less strain hardening and hence easy to mechanically work. BCC structure shows strain hardening in between that of FCC and HCP and hence it can be mechanically worked with some difficulty.Grain structure also influences metal working process.Coarse grains can be easily worked or deformed as compared to fine grain structure.This may be due to the fact that coarse grains can accommodate more dislocation movement as compared to fine grains.Fine grains strain harden faster than coarse grains.

Stress System:



For biaxial Stress System

$$\sigma_{ij} = \begin{bmatrix} \sigma_x & o \\ o & \sigma_y \end{bmatrix} \text{ is } \begin{bmatrix} \sigma_1 & o \\ o & \sigma_2 \end{bmatrix}$$

Principal Stresses

$$\sigma_1 = \sigma_x$$

$$\sigma_2 = \sigma_y$$

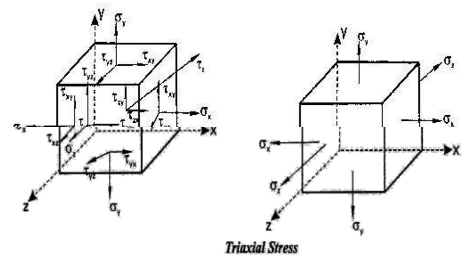
In uniaxial stress system the two stresses σx and σy are principal stresses since there are no shear stresses. Hence the planes on which they are acting are the principal planes. We can define Principal planes are the planes on which there are no shear stresses. Principal stresses are the stresses acting on the principal planes.

ii) In Biaxial stress system when only σx and σy are acting without shear stress then they are the Principal Stresses.

In matrix form it is written as

$$\sigma_{ij} \text{ or } \tau_{ij} = \begin{bmatrix} \sigma_x & \tau_{xy} & \tau_{xz} \\ \tau_{yx} & \sigma_y & \tau_{yz} \\ \tau_{zx} & \tau_{zy} & \sigma_z \end{bmatrix}$$

Triaxial Stress System



With shear stresses   Without shear stresses

With Shear Stress

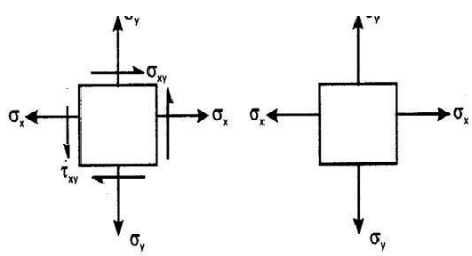
$$\sigma_{ij} = \begin{bmatrix} \sigma_x & \tau_{xy} & \tau_{xz} \\ \tau_{yx} & \sigma_y & \tau_{yz} \\ \tau_{zx} & \tau_{zy} & \sigma_z \end{bmatrix} \qquad \begin{matrix} \tau_{xy} = \tau_{yx} \\ \tau_{yz} = \tau_{zy} \\ \tau_{zx} = \tau_{xz} \end{matrix}$$

Without Shear Stress

$$\sigma_{ij} = \begin{bmatrix} \sigma_x & 0 & 0 \\ 0 & \sigma_y & 0 \\ 0 & 0 & \sigma_z \end{bmatrix}$$

σ_{ij} represents the state of the stress in a matrix form.

$$\begin{matrix} \tau_{xy} = \tau_{yx} \\ \tau_{yz} = \tau_{zy} \\ \tau_{zx} = \tau_{xz} \end{matrix}$$ are complimentary Shear Stresses



with shear stress   without shear stress

$$\sigma_{ij} = \begin{bmatrix} \sigma_x & \tau_{xy} & 0 \\ \tau_{xy} & \sigma_y & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

With Shear Stress

$$\sigma_{ij} = \begin{bmatrix} \sigma_x & 0 & 0 \\ 0 & \sigma_y & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

Without Shear Stress

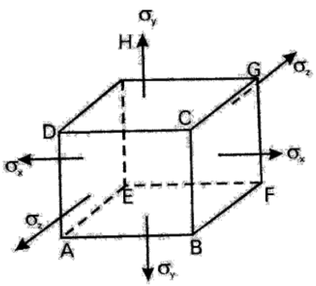
Biaxial Stress System

iii) In triaxial stress system when only σx, σy and σz are acting on the planes without any shear stresses then they are the principal stresses.

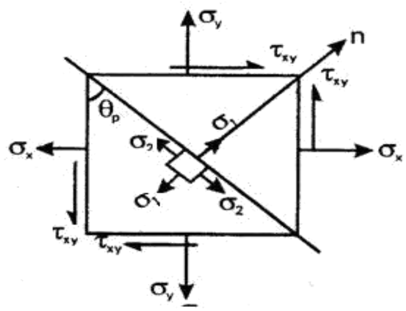
Principal stresses and their planes, Representation of 3D stress, Equations, Maximum Shear stress and its plane.Yield criteria for ductile material statement for all 5 Criteria, Von Mises and Tresca criteria statement and explanation, simple problems.

Principal stress is normal stress acting on a plane where there are no shear stresses.It is the normal stress acting on a principal plane.

Principal plane is a plane on which there are no shear stresses present.



Triaxial Principal Stress



Biaxial Principal Stress With Shear Stress

In figure ABCD,BCFG,EFGH ….. are planes where only normal stresses are acting and there are no shear stresses.They are the principal planes. σx, σy and σz are the principal stresses.For a 2D stress system with shear stress acting on the element one can find the principal planes and principal stresses.

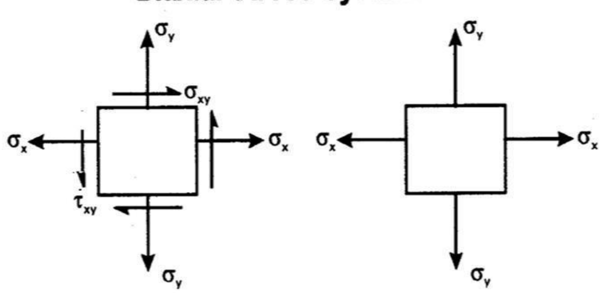
Max. and Min. Principal Stresses are

$$\sigma_{1,2} = \frac{\sigma_x + \sigma_y}{2} \pm \frac{1}{2}\sqrt{(\sigma_x - \sigma_y)^2 + 4}$$

Principal plane

$$\tan\theta_p = \frac{\sigma_x - \sigma_y}{2\tau_{xy}}$$

Biaxial Stress System

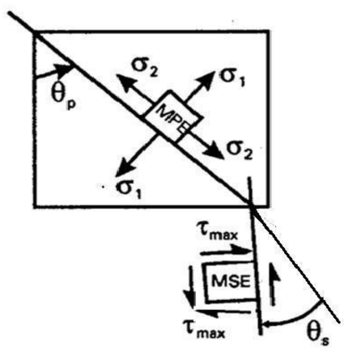


with shear stress   without shear stress

Consider a 2D stress system with shear stress, there exists a plane on which the value of shear stress is maximum.This plane will be inclined at 450 to the principal plane.The magnitude of the maximum shear stress is given by the equation:

Maximum shear stress is given by

$$\tau_{max} = \frac{1}{2}\sqrt{(\sigma_x - \sigma_y)^2 + 4\tau^2_{xy}} \qquad \cot 2\theta_s = \frac{-2\tau_{xy}}{\sigma_x - \sigma_y} \quad \text{and } \theta_p \sim \theta_s = \pi/4$$



Max Shear Stress and its plane

MPE = Maximum Principal Stress Element
MSE = Maximum Shear Stress Element

Theories of Elastic Failure

Materials will fail when they reach a maximum value of stress.

It is the ultimate stress of the material.But in a complex stress system it becomes very difficult to predict the failure of the material.Hence, theories have been formulated to predict the failure of the material when subjected to complex stress system.

It is mainly based on material characteristic obtained from direct uniaxial tension or compression. In mechanical working of metals failure mean the stress exceeding the yield stress value or permanent deformation. We can say yielding of material.

If a ductile material is subjected to gradually increasing load.
The material begins to undergo permanent deformation when the load reaches a certain value ie., yield load.There are five theories formulated for the purpose. But only two of them are very popularly used. The same is explained in the following paragraph.

At the moment when the material starts yielding in a complex stress system then

1.Maximum Principal Stress Theory

Permanent yielding will occur when the Max. Principal Stress σ1 reaches the elastic strength (yield strength= σ_0) of the material in simple tension. Max. Principal stress σ_1 = Elastic Yield strength σ_0

2.Maximum Shear Stress Theory

Permanent yielding will occur when the Max. Shear Stress reaches the corresponding value of shear stress in elastic limit = σ0/2 of the material in simple tension. σ_1 and σ_2 are the max.and min.principal stresses respectively.

3. Strain Energy Theory

Permanent yielding will occur when the Total Strain Energy U absorbed by the material per unit volume ie., Distortion Energy reaches a particular value in simple tension. $U=\sum(\sigma_1-\sigma_2)^2$ is the equation for strain Energy in a complex stress system and $2\sigma_0^2$ in simple tension.

4. Maximum Tensile Strain Theory

Permanent yielding will occur when the Maximum Tensile Strain σ1/E reaches a particular value in simple tension σ_0/E .

when $\sigma_1/E= \sigma_0/E$ yielding will occur σ_1 and σ_0 are the Principal Stress and Tensile Yield Stress respectively .

5. Octahedral Shear Stress Theory

Permanent yielding will occur when the Octahedral Shear Stress reaches the value equal to $0.47\sigma_0$. The following equation gives octahedral shear stress.

$$\tau_{Oct} = \frac{1}{3} \sum \sqrt{(\sigma_1 - \sigma_2)^2}$$

When this value reaches $0.47\sigma_0$ then yielding will occur.

Yielding criteria for ductile metals

In metal working process the work piece is subjected to plastic deformation due to external load. It becomes necessary to deduce a relationship for predicting the condition at which plastic yielding will occur. It is an emperical relationship.

Here only two theories are extensively used and they are i) Max.Shear Stress Criteria proposed by Tresca and ii) Strain Energy Criteria proposed by Von Mises .

The theories are named after them.

They basically consider the yielding taking place in uniaxial tensile loading for comparison viz, yield strength σo . Under uniaxial loading condition plastic flow begins at the yield stress.In a complex 3D stress system one can expect yielding to take place corresponding to the principal stresses. The above theories are based on the following: *They neglect the effect of mean stress σmean=(σ1 +σ2 +σ3)/3 where σ1,σ2 and σ3 are the three principal stresses in 3D.*Knowledge of material constant Yield strength in uniaxial stress system is needed.Yield strength is assumed to be the same for both tension and compression.

Tresca Criteria

It is based on Max shear stress.

It states that yielding in the metal occurs in 3D stress system when the max.shear stress reaches the corresponding value of max.shear stress in uniaxial tension test.If σ1,σ2 and σ3 are the three principal stresses acting on an element in 3D (in a complex stress system) and σ1 > σ2 > σ3 in 3D and the corresponding value of max. shear stress in uniaxial stress system is given by $\sigma_o/2$ as $\sigma_1 = \sigma_o$ and

$\sigma_2 = \sigma_3 = 0$.

Hence, $(\sigma_1 - \sigma_3)/2 = \sigma_o/2$ ie., $\sigma_1 - \sigma_3 = \sigma_o$

then yielding will occur.

Von Mises Criteria

It is based on energy criteria.

It states that yielding in the metal occurs in 3D stress system when the strain energy reaches the corresponding value in uniaxial tension test.

$(1/12G)[(\sigma_1 - \sigma_2)2 + (\sigma_1 - \sigma_2)2 + (\sigma_1 - \sigma_3)2]$ …(1)

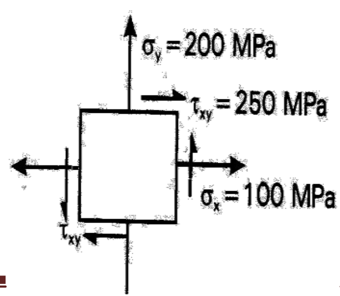
is the strain energy in 3D stress system and the corresponding value in 1D is given by allowing $\sigma_1 = \sigma_o$ $\sigma_2 = \sigma_3 = 0$ the value will be $\sigma_o2/6G$ …(2) for 1D stress system.

Equating equations 1 and 2 we get

$\sigma_o = 1/\mathrm{sqrt}2\ [\sum(\sigma_1 - \sigma_2)2]1/2$

Then Yielding will occur.

Problem: The state of stress at a point is given as shown in the figure. If the YS of the material is 475Mpa determine when the yielding will occur and if so according to which criteria**?**



$$\sigma_1 = 405 \text{ Mpa (Max)}$$
$$\sigma_2 = 0$$
$$\sigma_3 = -105 \text{ Mpa (Min)}$$
$$\tau_{max} = \frac{405-(-105)}{2} = 255 \text{ Mpa}$$

$$\sigma_{1,2} = \frac{100+200}{2} \pm \frac{1}{2}\sqrt{(100-200)^2 + 4(250)^2}$$
$$= 150 \pm 255$$
$$\sigma_1 = 405 \text{ Mpa } \sigma_2 = -105 \text{ Mpa}$$

$$= 0.707\,(164025 + 11025 + 260100)^{\frac{1}{2}}$$

1) As per Von Mises Criteria

$$\sigma_0 = \frac{1}{\sqrt{2}}\left[(\sigma_1-\sigma_2)^2 + (\sigma_2-\sigma_3)^2 + (\sigma_3-\sigma_1)^2\right]^{\frac{1}{2}}$$

τ_{max} at yield point in 1^D stress $= \frac{\sigma_y}{2} = \frac{475}{2}$

but in complex stress system $\tau_{max} = 255$ Mpa

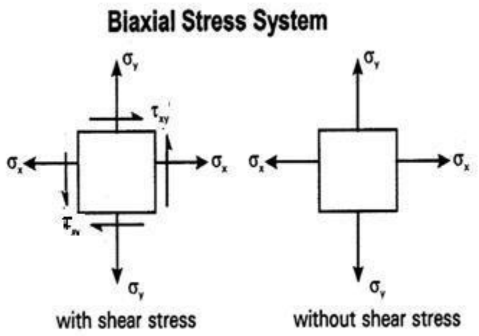
ie., 255 Mpa > 237.5 Mpa

ie., 466.38 Mpa < 475 Mpa

3^D Complex Stress System > Simple uniaxial test

Plane Stress

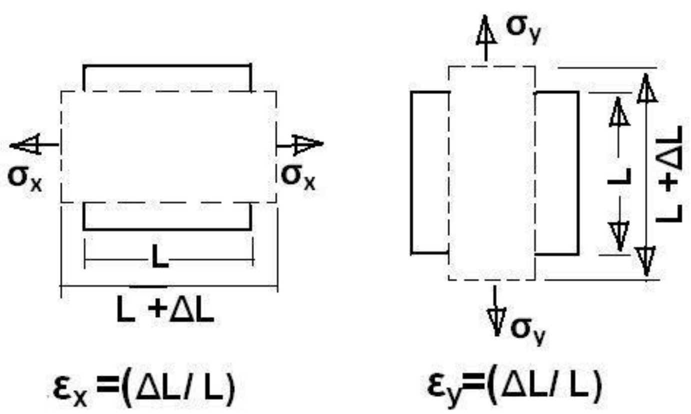
The type of stresses acting on a plane wherein the third direction does not exist is referred to as "Plane Stress". Only two normal stresses will be acting on the element with or without shear stress. σx and σy will be present and no σz.



Plane Strain

The strain existing on a plane element where there are only two normal stresses is referred to as "Plane Strain".

Corresponding to stresses σ_x and σ_y there will be strains εx and εy acting on the element.



Plane strain

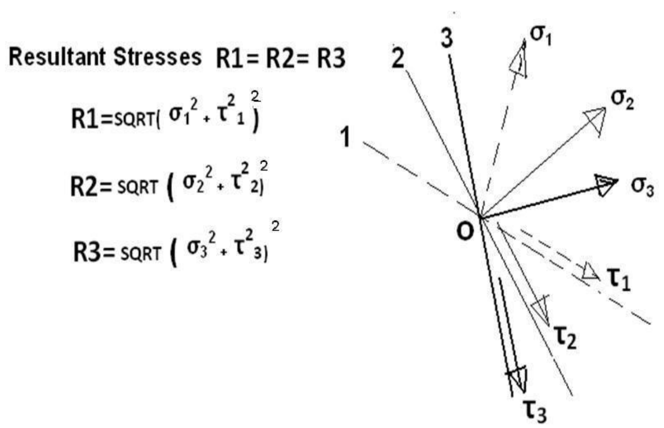
$$\sigma_{ij} = \begin{bmatrix} \sigma_x & \tau_{xy} & 0 \\ \tau_{xy} & \sigma_y & 0 \\ 0 & 0 & 0 \end{bmatrix} \qquad \sigma_{ij} = \begin{bmatrix} \sigma_x & 0 & 0 \\ 0 & \sigma_y & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

With Shear Stress   Without Shear Stress

Biaxial Stress System

Stress Tensor

At any given point in an element many planes may be drawn, but the resultant forces acting on theses planes are the same. Since the areas and inclinations of these planes are different, the normal and shear stresses on these planes are different.



In order to describe the stress completely

One has to specify the magnitude, direction, sense and also the surface on which it acts. Hence, stress is generally referred to as "Tensor" or "Stress Tensor".

On an element there will be 3 direct stresses and 6 shear stresses acting.

Remember that we learnt that a force can be resolved into one normal stress and two tangential forces on a given plane, hence the corresponding stresses.

In tensor notation, these can be represented by the tensor σij or τij where i=x,y,z and j=x,y,z.

$$\sigma_{ij},\tau_{i,j} = \begin{bmatrix} \sigma_x & \tau_{xy} & \tau_{xz} \\ \tau_{yx} & \sigma_y & \tau_{yz} \\ \tau_{zx} & \tau_{zy} & \sigma_z \end{bmatrix} \qquad \begin{matrix} \tau_{xy} = \tau_{yx} \\ \tau_{yz} = \tau_{zy} \\ \tau_{zx} = \tau_{xz} \end{matrix}$$

σ_{ij} and $\tau_{i,j}$ represents the state of the stress in a matrix form.

With shear stresses

$$\sigma_{ij} = \begin{bmatrix} \sigma_x & \tau_{xy} & \tau_{xz} \\ \tau_{yx} & \sigma_y & \tau_{yz} \\ \tau_{zx} & \tau_{zy} & \sigma_z \end{bmatrix} \qquad \begin{matrix} \tau_{xy} = \tau_{yx} \\ \tau_{yz} = \tau_{zy} \\ \tau_{zx} = \tau_{xz} \end{matrix}$$

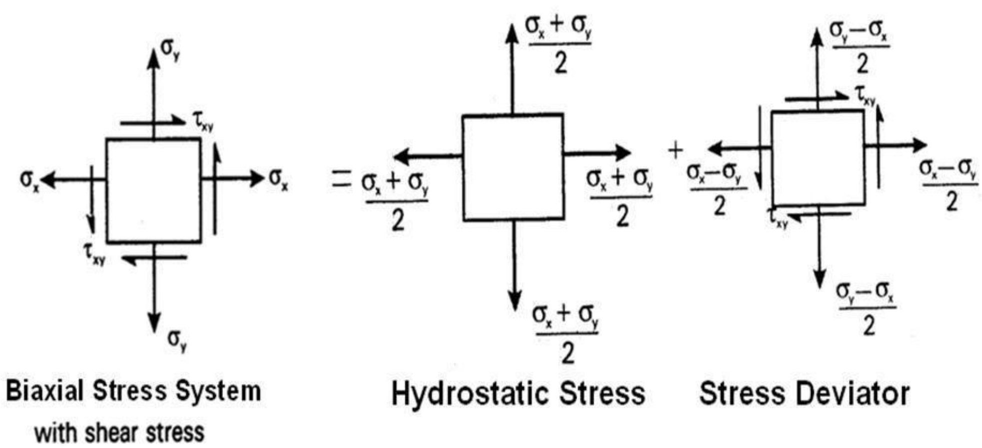
σ_{ij} represents the state of the stress in a matrix form.

2D Biaxial Stress and Its Composition

Total Biaxial Stress can be split into two parts as shown below. The first part is referred to as Hydrostatic stress (σm) and Stress Deviator (σij).

Total Biaxial	=	Hydrostatic	+	Deviator
Stress		Stress		Stress
σ		σm		σij

Hydrostatic Stress(σm) only causes elastic volume changes and does not cause plastic deformation.



Deviator Stress(σij) involves shear stress, causes plastic deformation, is very important in plastic deformation or mechanical working of metals.

It has been observed that the yield strength of metals is independent of hydrostatic stress, but the fracture strain is strongly influenced by hydrostatic stress.

Deformation of Metals

What is Deformation?

When an external load is applied on the material, it will undergo changes in the dimensions and change in shape will take place. As a result, strain will be induced in the material. The change in dimensions or the shape is referred to as “deformation”

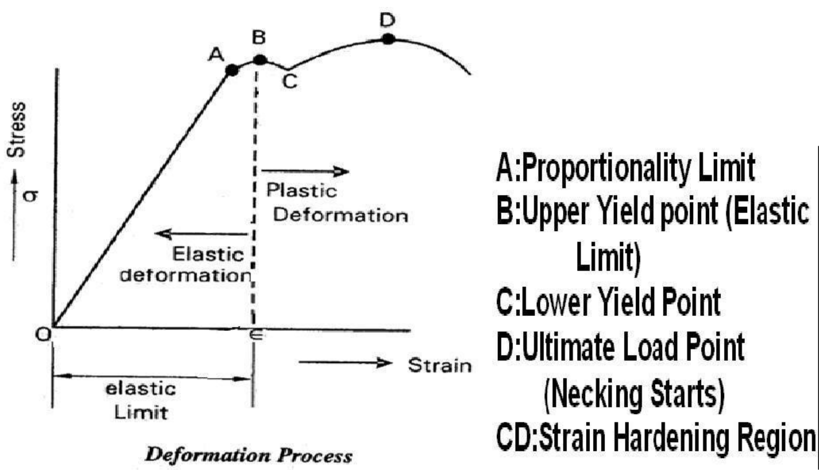
Deformation of metals may be

i)Excessive Elastic Deformation (EED)

This type of deformation is temporary. It is the deformation taking place within the elastic zone.Under the influence of external load the material will undergo changes.

As the magnitude of the load is increased the deformation becomes more and more and reaches a maximum value corresponding to the yield point.

Higher the load higher is the deformation and is referred to as excessive deformation.



Deformation Process

ii)Excessive Plastic Deformation(EPD)

This type of deformation is permanent in nature. It is the deformation taking place beyond the elastic zone. Under the influence of external load the material will undergo changes.As the magnitude of the load is increased the deformation becomes more and more and reaches a maximum value corresponding to the ultimate point.

Higher the load higher is the deformation and is referred to as excessive deformation. Beyond point B, is plastic deformation and the changes are permanent and the material cannot recover its strain free state.Once the external load is removed the material will not recover its free state. It will have induced strain in it.

Necking

Beyond the ultimate load the material undergoes deformation even without increasing the external load.The ultimate load point(D) is called as the point of instability. From point C to D the material shows increasing resistance to deformation.

The material will show continuous decrease in the cross section (when tensile load is applied) and reaches a very low value called as necking.

Beyond which it cannot offer any resistance at all. Once necking is initiated the material fails at any moment.

Once necking has been intiated, fracture propogates faster even when the load is reduced and separation occurs and the material breaks

Deformation Zone Geometry

For bringing about deformation in metals dies are used. Dies are flat or converging or conical shaped contours. They are made of hard materials. Through the dies external forces or stresses are induced on to the metal or work piece to bring about deformation. The basic features of the die is the ratio of the mean thickness(h) to the length(L) of deformation zone. This is referred to as Deformation Zone Geometry .

To reduce „ ‟ one can reduce the semi die angle ‟α‟ thereby increasing „L‟ or one can reduce the reduction „r‟ which decreases „h‟.

i) (h/L)

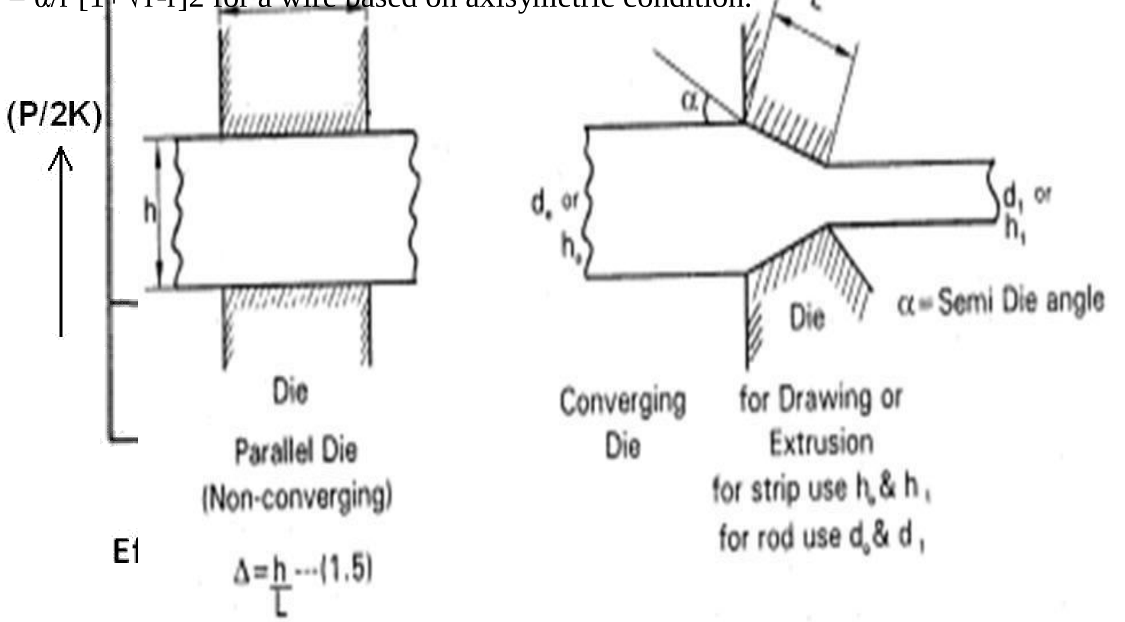
ii) $\alpha/r(2-r)$ for a strip based

on plane strain condition r =

(1- h1/h0) for a slab

r = 1- (d1/d0)2 for a wire or bar

= α/r [1+√1-r]2 for a wire based on axisymetric condition.



Deformation Geometry

Most of the deformation processes require the material to flow through an opening or a converging channel called as die.

A parameter which takes into account the thickness and length of deformation is used. This is related to the yield pressure. During the process, there will be some portion which will not be undergoing deformation.

This portion is referred to as redundant work.

In order to carry out successful deformation, the ratio of pressure applied to the Yield Stress in pure shear stress condition is given by (P/2K) has to be increased

There exists a relation betweendeformation geometry and yield pressure (P/2K). yield pressure increases with increase the die pressure increases.

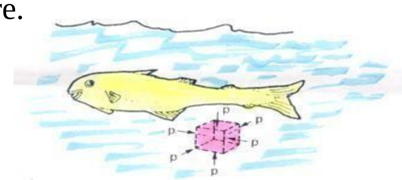
For Frictionless plane conditions:
Dependence of Yield Pressure on Deformation Zone Geometry,

*Increase in (P/2K) with is chiefly the result of increasing redundant work. *Die pressure increases with increase in value.

Smaller the value of , greater is the effect of friction at the tool work interface. *Internal cracks develop as a result of "Secondary Tensile Stresses" which occur with large values of.

Hydrostatic Pressure (Hydrostatic Compressive Stress)

Hydrostatic Pressure is the state of pressure on an element subjected to equal compressive pressure in all directions. A fish swimming under water is under the influence of hydrostatic pressure.



Hydrostatic Pressure

As already learnt earlier in the last class any stress system is composed of a hydrostatic stress and a stress deviator.In Mechanical Working of metals only the stress deviator will cause deformation. Hydrostatic stress(pressure) will cause uniform elastic deformation.

We shall consider the compressive Pressure acting on the metal in3D. This is referred to as triaxial compressive stress. In MW process hydrostatic pressure greatly reduces the cracking tendency of the metal. Due to the presence of hydrostatic pressure the metal will not undergo fracture at all. Infact the ductility of the metal is enhanced under the influence of hydrostatic pressure. Hence, the magnitude of hydrostatic pressure is important in this regard.

Hydrostatic stress is used in extrusion of brittle metals. Hydrostatic pressure enhances the limit of workability in metals. It closes small pores or discontinuities . It is used commercially in HIP(Hot Isostatic Pressing) to close the pores in casting and in Powder Metallurgy products there by increase the ductility and toughness.

Workability of Metals

Workability is defined as the extent to which a material be deformed in a specific metal working process without the formation of cracks. If ductility of the material is high the material can be mechanically worked with ease.

It is a complex technological concept that depends not only on the fracture resistance (ductility) of the material but also on the specific details of the deformation process**.**

Workability may be considered to be a function of

a. Fracture resistance viz., ductility of the material.
b. Parameters if deformation –friction, temperature, strain rate.

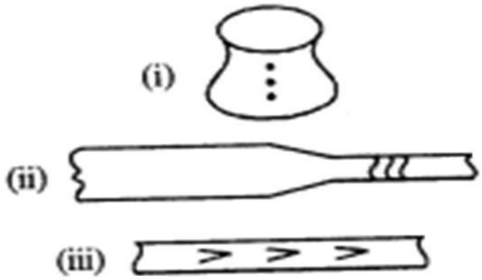
There exists friction between the metal and the die which influence deformation to a large extent. Higher the friction higher is the difficulty in deformation of metal and less is the workability. Use of lubricants helps minimize friction.

The die geometry or work piece geometry influence workability. Simple geometry show good workability and complex shapes will show poor workability in metals. Viz,. simple geometry can be easily worked as compared to complex shapes.

Temperature of working influence workability. Increase in temperature brings down strength values and increases ductility. Workability will be fairly improved as the temperature of working is higher.

As strain rate is increased ductility comes down and workability decreases and vice versa.

There is no test for assessing workability of metals. But upsetting of a cylindrical specimen under controlled strain rate conditions comes closest to the standard acceptable one.



Formation of cracks in metal working process can be grouped as:i)Cracks at a free surface, as in a bulge inupsetting a cylinder or in edge cracking in rolling.

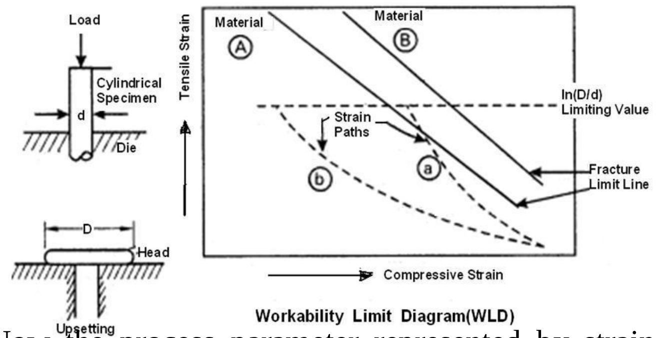
ii)Cracks that develop in a surface where iii) interface friction is high as in extrusion Internal cracks as in drawn bars.

Workability Limit Diagram (WLD)

There exists a unique correlation between tensile strain and compressive strains at fracture for each material, at room temperature as shown in figure . This relationship is used as the fracture criteria.

In the figure Strain Paths and Fracture Limit Line for a given material is plotted .

For different values of compression strain at fracture the corresponding tensile strain is obtained and is plotted for different materials to get the WLD.



Workability Limit Diagram(WLD)

Now the process parameter represented by strain paths at potential fracture sites in the material is plotted.Strain paths can be determined either experimentally or by using FEA models.

Soft materials like plasticine, lead or pure aluminium are taken and grids are placed on it and subjected to strain . The strain paths are determined from the path traced out by the deformation. These are then plotted in the diagram.

If the strain paths in the deformation of the material exceeds the fracture limit line, then fracture will occur.Strain paths depend on the die geometry, work piece geometry, lubrication condition and material property.

Consider cold upsetting of a cylinder into a blot head. A cylindrical specimen of dia „d" is upset to a head of diameter "D".

To form a head of diameter „D" from diameter „d" requires the material to withstand a circumferential surface strain of In(D/d).

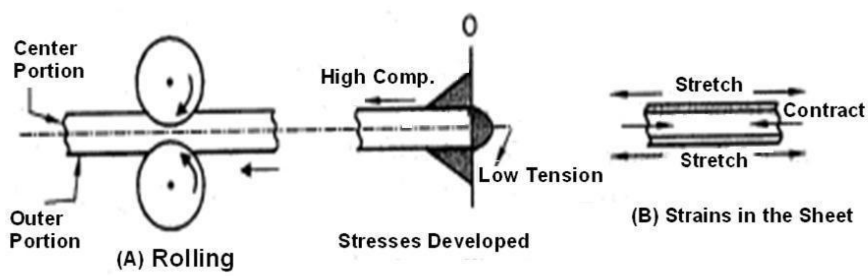
For workability of the material, the strain path must reach this limiting value of strain without crossing the fracture limit line.

In figure the strain path (a) meets the fracture limit line before reaching the limiting value. Fracture will take place in the material. By improving the lubrication the stress path can be shifted to (b) and the deformation can be achieved without fracture.

Alternately, deformation can be made with strain path (a) by changing the material from A to the more workable material B with fracture limit line as shown in the figure.

Residual Stresses in wrought Products

Residual stresses are due to the presence of stresses in the material after the completion of mechanical working. After mechanical working the desired shape in the metal is obtained, the external forces are removed. Now, if the mechanically worked metal has stresses in it then they are referred to as "Residual Stresses". These stresses are the result of non-uniform plastic deformation.



Deformation in Rolling of a sheet

For example, in rolling of sheets, plastic flow of metal occurs predominantly near the surface. Due to rolling action, the surface grains are deformed and elongated, while the grains at the center of the sheet are unaffected. Since the sheet must remain one continuous unit, the surface and center regions of the sheet must undergo strain accommodation.

The center fibers tries to restrain the outer fiber from stretching while the outer fibers tend to stretch the central fiber. This results in Residual Stresses which consists of a high compressive stress at the surface and a tensile residual stress at the center of the sheet. Inhomogeneous deformation has occurred In general, the direction of residual stresses induced in the metal (due to inhomogeneous deformation) will be opposite to the direction of plastic strain that produced residual stress.

Residual stresses are only elastic stresses. The maximum value it can reach is yield strength of the material.

Components with residual stresses can be stress relieved at a predetermined temperature. Even non uniform heating or cooling can produce residual stresses in the same way as non-uniform plastic deformation

Unit 3: Forging

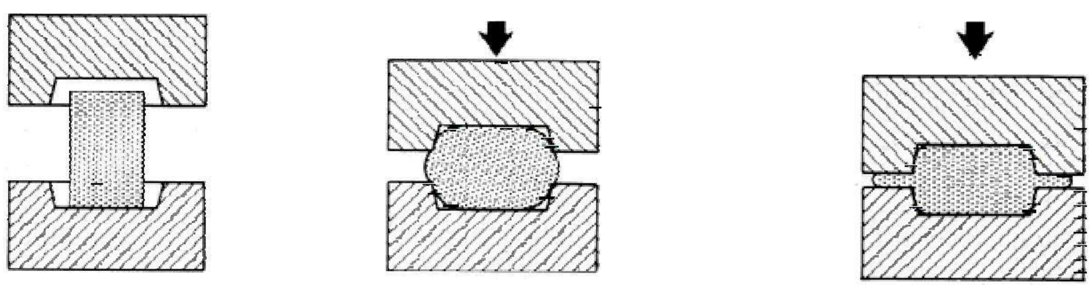
Definition:

Forging is a metal working process in which useful shape is obtained in solid state by hammering or pressing metal.

It is one of the oldest metalworking arts with its origin about some thousands of years back. Some examples of shapes obtained by forging process: Crane hook, connecting rod of IC engine, spanner, gear blanks ..etc.

Different Forging Operations

* **Upsetting**
  The thickness of the work reduces and length increases



Steps: (i) (ii) (iii) Final

Fig1. Upsetting

2. Edging

The ends of the bar are shaped to requirement using edging dies.

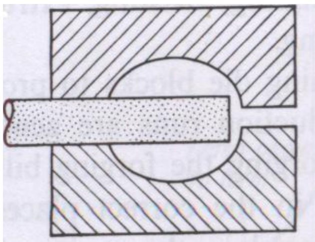


Fig 2. Edging

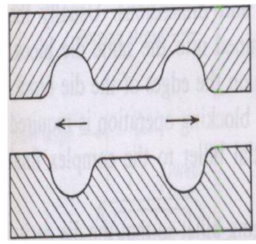


Fig 3. Fullering

3. Fullering

The cross sectional area of the work reduces as metal flows outward, away from centre.

4. Drawing

The cross sectional area of the work is reduced with corresponding increase in length using convex dies.

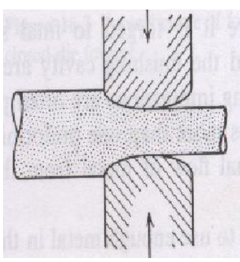


Fig 4. Drawing

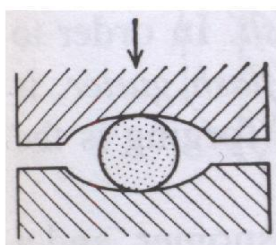
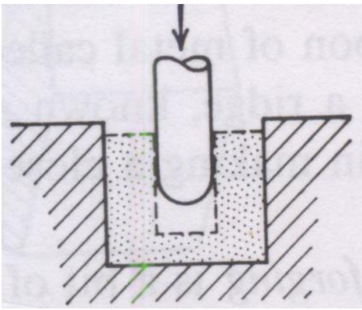


Fig 5. Swaging

5. Swaging: The cross sectional area of the bar is reduced using concave dies.

6. Piercing: The metal flows around the die cavity as a moving die pierces the metal.

7. **Punching:** It is a cutting operation in which a required hole is produced using a punching die.



Punch

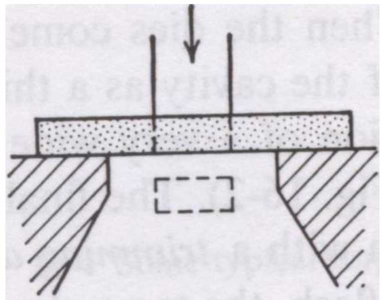


Fig 6. Piercing

Fig 7. Punching

8. Bending: The metal is bent around a die/anvil.

Classification of Forging Processes

Based on Temperature of the work piece:

1. Hot Forging: (most widely used)

Forging is carried out at a temperature above the recrystallization temperature of the metal.

Advantages:

- High strain rates and hence easy flow of the metal
- Recrystallization and recovery are possible
- Forces required are less

Disadvantages of Hot Working:

- Lubrication is difficult at high temperatures
- Oxidation and scaling occur on the work
- Poor surface finish
- Dies must withstand high working temperature

2. **Cold Forging**:

Forging is carried out at a temperature below the recrystallization temperature of the metal.

Advantages:

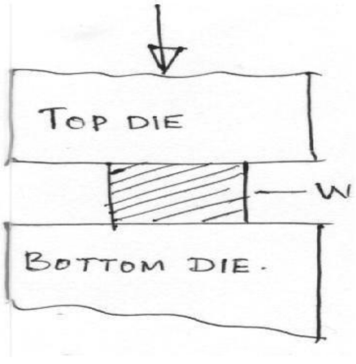
- Less friction between die surface and work piece
- Lubrication is easy
- No oxidation or scaling on the work
- Good surface finish

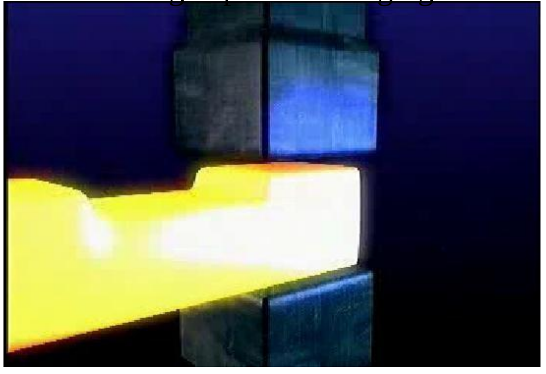
Disadvantages of Cold Working:

- Low strain rates, hence less reduction per pass.
- Recrystallization and recovery do not occur.
- Hence, annealing is required for further deformation in subsequent cycles.
- Forces required are high.

Classification of Forging Processes Based on Arrangement of Dies:

1. Open Die Forging: Flat dies of simple shape are used. Fig. Open Die Forging





Features of open die forging:

- Repeated impact blows are given on the work
- Less dimensional accuracy
- Suitable only for simple shapes of work
- Requires more skill of the operator

- Usually used for a work before subjecting it to closed die forging (to give approximate shape)
- Dies are simple and less expensive
- It can be analyzed much easily
- It is the simplest of all forging operations

2. Closed Die Forging:

Work piece is deformed between two dies with impressions (cavities) of the desired final shape on them.

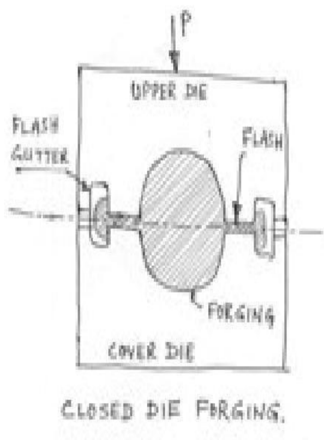
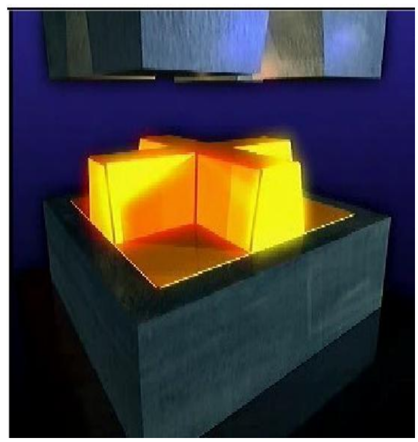


Fig. Closed Die Forgin



Features of Closed Die Forging:

Closed die forging involves two or more steps:

1. **i) Blocking Die**: Work is rough forged, close to final shape.
2. ii**) Finishing Die**: work is forged to final shape and dimensions.
3. Both Blocking Die and Finishing Die are machined into the same die block.
4. More number of dies are required depending on the complexity of the job.
5. Two die halves close-in & work is deformed under high pressure.
6. High dimensional accuracy / close control on tolerances.
7. Suitable for complex shapes.
8. Dies are complex and more expensive.
9. Large production rates are necessary to justify high costs.

Significance of Flash in Closed Die Forging:

- Excess metal is taken initially to ensure that die is completely filled with metal to avoid any voids.
- Excess metal is squeezed out of the die cavity as a thin strip of metal, called flash.
- A flash gutter is provided to reduce the area of flash.
    - Thin flash increases the flow resistance of the system & builds up the pressure to high values which ensures that all intricate shapes of cavity are filled.
    - Flash design is very critical and important step in closed die forging.
    - Extremely thin flash results in very high pressure build up which may lead to breaking of the dies.

Forging Equipment

They are classified based on the principle of operation.

1. **Forging Hammer**
    - The force is supplied by a falling weight of ram.
    - Deformation of work piece is due to the application of the kinetic energy of the ram.

Types of Forging Press

i) Mechanical board hammer:

- It is a stroke restricted machine.
- Repeatedly the board (weight) is raised by rolls and is dropped on the die.
- Rating is in terms of weight of the ram and energy delivered.

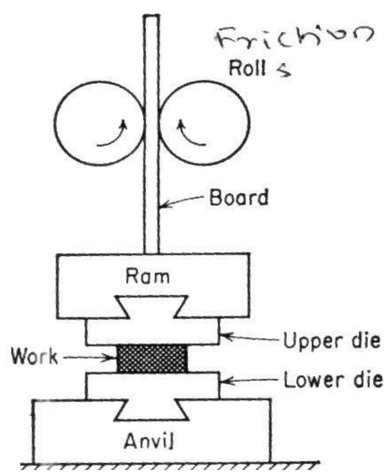


Fig. Mechanical Board Hammer

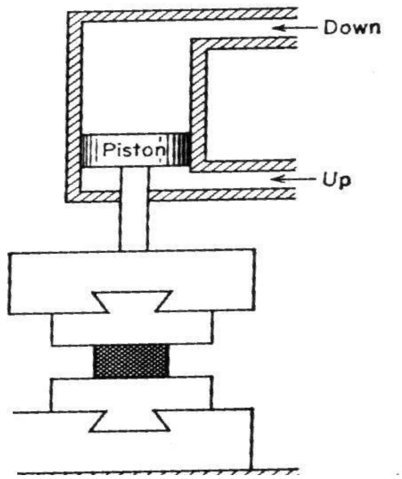


Fig. Steam Hammer

ii) Steam Hammer (Power Hammer) Range: 5 kN to 200 kN

- It uses steam in a piston and cylinder arrangement.
- It has greater forging capacity.
- It can produce forgings ranging from a few kgs to several tonnes.
- Preferred in closed die forging

The total energy supplied in a blow:

It is given by

: $W = 1/2mv^2 + pAH = (mg+pA)$

Where m= mass of ram

v= velocity of ram at the start of deformation

g= acceleration due to gravity

A= area of ram cylinder

H= height of ram drop

iii) Hydraulic Press:

- It is a load restricted machine.
- It has more of squeezing action than hammering action.
- Hence dies can be smaller and have longer life than with a hammer.

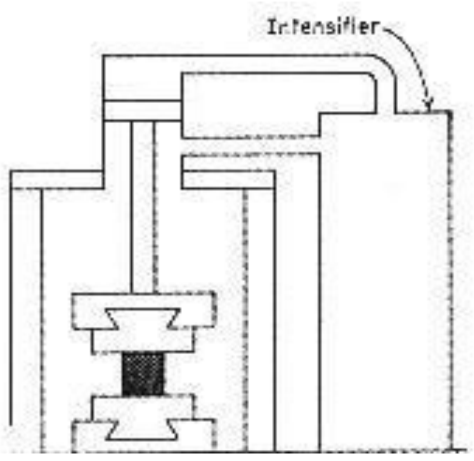


Fig. Hydraulic Press

Features of Hydraulic Press

- Full press load is available during the full stroke of the ram.
- Ram velocity can be controlled and varied during the stroke.
- It is a slow speed machine and hence has longer contact time and hence higher die temperatures.
- The slow squeezing action gives close tolerance on forgings.
- Initial cost is higher compared to hammers.

p= air/ steam pressure on ram on down stroke

Slab Analysis of Forging Operation

(Pre requisite: understanding of plane strain condition)

In a plane strain condition, the strain in one of the principal directions is zero.

During a forging process,

- the thickness of the work piece decreases
- the length of the work piece decreases
- The width remains unchanged

In a general condition of stress:

Let σ_1,σ_2, and σ_3 be the principal stresses, ε_1, ε_2 and ε_3 be the principal strains.

In a plane strain condition, ε_2=0 (as width remains constant).

In this condition, it can be shown that the principal stress σ_2, acting in a direction where ε_2=0, is the algebraic mean of the other two principal stresses.

This means,

$\sigma_2=(\sigma_1+\sigma_3)/2$

Applying Von-Mises‟ criteria for yielding, it can be shown that:

$(\sigma_1 - \sigma_3) = (2/\sqrt{3})\ \sigma_0$

$= \sigma_0^{/}$ (pronounced sigma not prime)

= yield stress under plane strain condition

Upset forging of a rectangular slab under plane strain condition, using a wide and flat die.

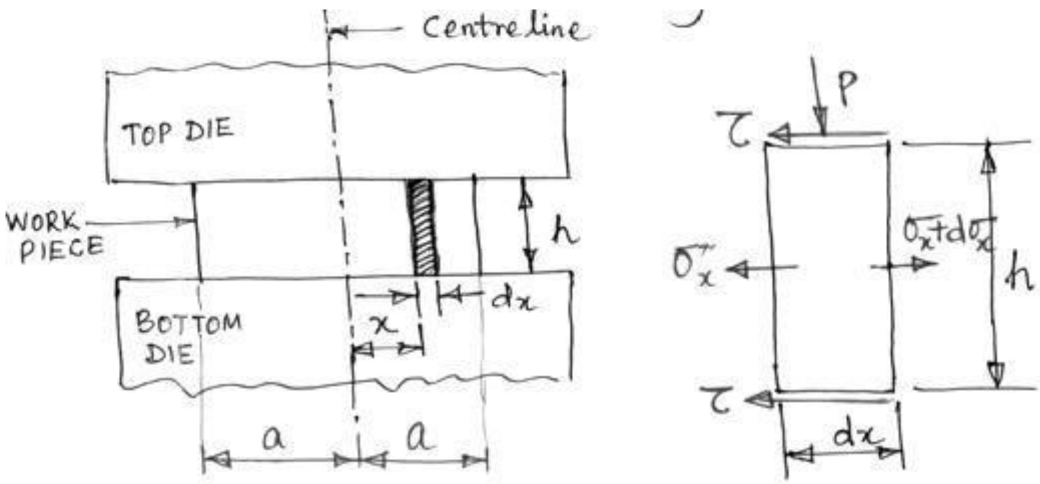


Fig.2. UPSET FORGING OF SLAB. Fig.3. ENLARGED ELEMENT

Consider a rectangular slab as shown in the above figure.

Let t = thickness of the work (decreases during forging)

L = length of the work (increases during forging)

W = width of the work (remains constant)

Consider an elemental volume in the work piece with length dx at a distance x from the centerline.

The stresses acting on the elemental volume are :

i) P = forging pressure
ii) σ_x= Longitudinal stress due to lateral flow of the metal
iii) τ =Shear stress due to friction between work and die surfaces

Under the equilibrium conditions, the summation of forces acting in a longitudinal direction must be zero.

Applying the above condition and conditions of plane strain, it can be shown that:

$$dP = -\frac{2\tau}{h} \cdot dx$$

The above equation is solved for different conditions as follows:

Case i): Sliding friction at the contact surface between work and die:
The solution to the above equation using boundary conditions, gives the following equation:

$$P = \sigma_0' \cdot e^{\frac{2\mu}{h}(a-x)}$$

This equation is the expression for forging pressure in upset forging under sliding friction condition. The forging pressure varies exponentially with length. The forging load is obtained by integrating the above equation.

Friction Hill for Sliding Friction Case:

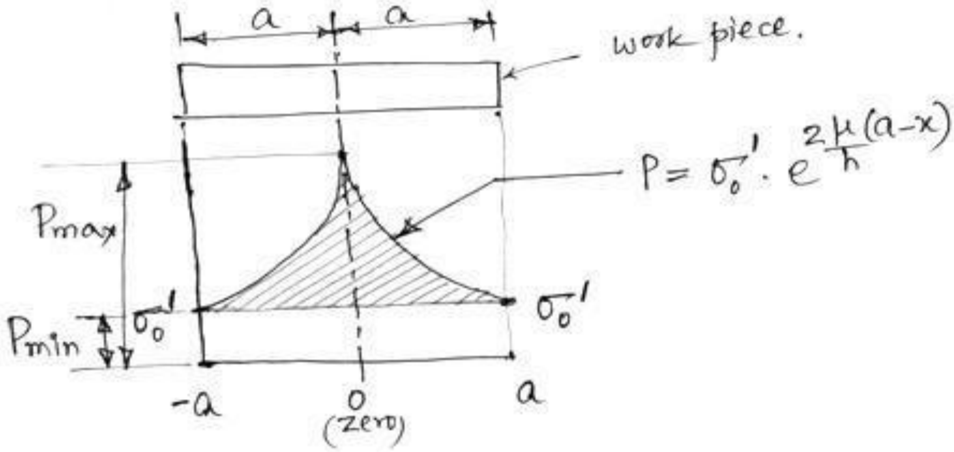


Fig: Friction Hill in Sliding Friction Condition

Case ii): Sticking friction at the work – die interface: This is a severe condition of friction. The solution to the general differential equation in this case with appropriate boundary conditions yields the equation:

$$\therefore \; P = \sigma_0' \left[1 + \frac{(a-x)}{h} \right]$$

The equation is a linear one, indicating linear variation of forging pressure with length. The forging load in this case is obtained by integrating the above equation

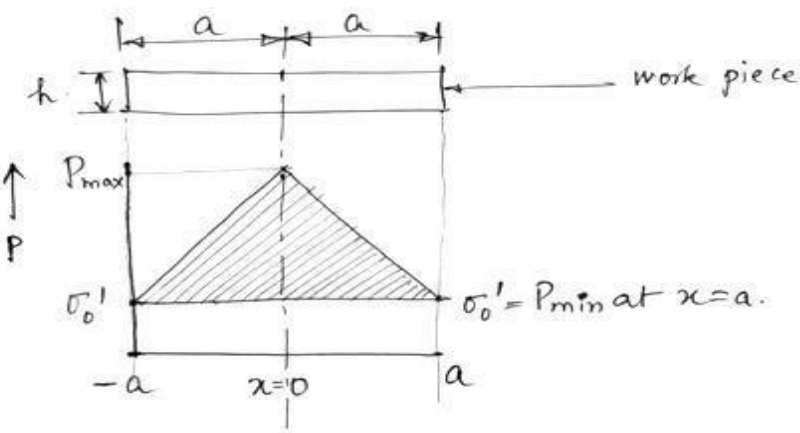


Fig. Friction Hill in Sticking Friction Condition

- **Example 1.**

  A steel slab is upset forged from: 50mmx200mmx100mm to 25mmx200mmx200mm. If the coefficient of friction between die and the material is 0.1 and yield strength of the steel is 250 N/mm^2, find the forging load.

- **Solution:**

Step i) to decide the dimensions to be used in the calculations:

Data: h=25mm

2a=200mm

w=200mm=constant

Step ii) to determine the condition of friction between die and work

Step iii) to determine the average forging pressure and forging load

Answer: Forging Load= 17.68MN/mm^2

Forging load= Pav x length x width

=39.8 MPa x 0.1m x 0.15m

=597kN

Upset forging of a circular disc in open die forging

Analysis involves cylindrical coordinates

The stresses acting on an elemental volume in a disc are:

σ_r = radial stress responsible for increase in the diameter of the disc

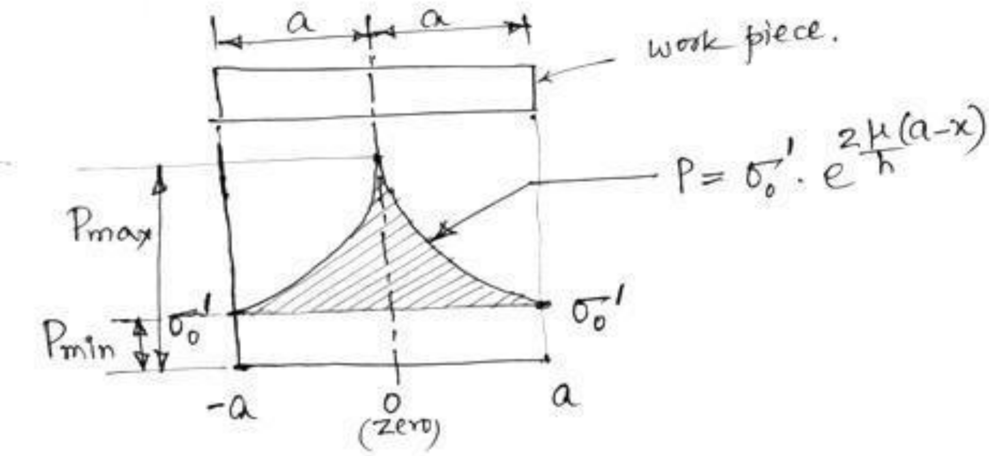
σ_θ = circumferential or tangential stress increasing the circumference of the disc Both σr and σθ are TENSILE in nature

lways,

$\sigma_r = \sigma_\theta$

This is called cylindrical state of stress

FRICTION HILL



Both forging pressure P and longitudinal stress (σ_x) build up to a maximum value at the centre of the plate(work), and reduce to a minimum value at the edge(end) of the plate. When this variation in P & (σ_x) is plotted over the entire length, L= 2a, a peak exists at the centre, resembling a "hill". This plot is called as friction hill.

NEUTRAL SURFACE

During forging, the metal is stationary at the centre line of the plate which defines the neutral surface. The flow of metal is always outwards, away from this neutral surface.

It is difficult to establish the neutral surface in a forging with a complex geometry.

FACTORS AFFECTING FRICTION HILL

1. **Nature of friction at the die/ work interface**

   a. Sliding Friction : exponential variation
   b. Sticking Friction : linear (more severe conditions of friction)
   c. Mixed Friction : linear at the middle where sticking friction exists and

exponential at the edge where sliding friction exists

2. **Lubrication :**(lubricants used : graphite powder, liquid glass) - If lubricant film is maintained, it gives sliding friction
   - Possible in cold forging
   - Under condition of high forging pressure and high temperature the lubricant is squeezed out or burnt
   - Leads to stitching friction and normally in hot forging

3. **Finish on die surface**: roughness on die adds to friction.
   - Proper selection of die material to retain finish is necessary.
4. **Working temperature**

   Hot Forging : lubrication difficult, easy flow of metal.

   Cold " : lubrication easy, less plastic flow.
5. **Nature of work surface:**
   a. Smooth/clean surface – less friction
   b. Scales/dirt/rough surface – more friction

FORGING PRESSURE / LOAD IN CLOSED DIE FORGING (CFD)

The deformation in closed die forging is highly complex and hence designing dies and intermediate steps is very critical and requires high skill.

The main objectives are: – complete die fill and closed dimensional tolerance. Important factors to be considered in CDF are:

1. Flash design : flash controls die fill and creates high forging loads
2. Proper understanding of the flow stress of the material: ensures successful forging operation
3. Frictional conditions
4. Optimal geometry of the die: Result of proper understanding of flow stress,

friction conditions and flow of the metal in the die

5. To prevent rapid cooling of the work piece by cold die‟s :
   - die‟s are preheated for many difficult aerospace applications- called isothermal heating
   - Results in lower flow stress and forging loads
   - Gives complete die fill and close dimensional tolerances

The design of a workpiece (part) made by CDF involves the prediction of the following:

1. Vol. and wt. of the workpiece
2. No. of pre-forming or intermediate steps and their configuration
3. Flash dimension in finishing die
4. Load & en-requirement for each operation

Forging load in CDF:

Prediction of forging load in CDF is quite difficult because of complexity involved Usual prediction methods are:

1. **Past Experience**:

   To estimate forging load of a new part/geometry: using information available from previous forging s of similar materials and shapes is used.

Using empirical relations:

One of the widely used equations is:

$P = \sigma.A_t C_1$

Where σ = effective true stress

A_t = cross sectional area of the forging at the parting line, including the flash

Where C_1 = a constant, depends on the complexity of the forging

C_1 = 1.2 to 2.5 for upsetting a cylinder between flat dies

= 3 to 8 for simple closed die forging

= 8 to 12 for more complex shapes

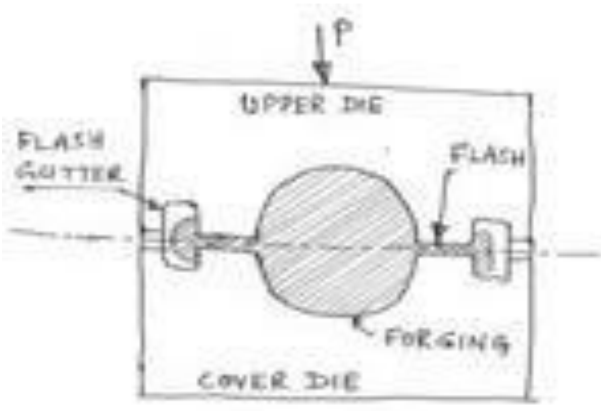
3. **Slab Analysis-** with suitable modifications for situations in CDF Basic approach:
   - The forging required is divided into simple geometric shapes, which are separately treated by slab analysis
   - The addition of all the loads of parts gives the total forging load

DIE DESIGN PARAMETERS

Die design depends on the forging required and its design requires the knowledge of:

i. Strength and ductility of work piece materials
ii. Sensitivity of the materials to the rate of deformation and temperature
iii. Frictional characteristics
iv. Shape and complexity of work piece
v. Die distortion under high forging loads- for close dimensional tolerance

Die Design Parameters



CLOSED DIE FORGING.

1. **Parting Line**

- is at the largest c/s of the part
- is a st. line at centre for simple shapes
- may not be in a single plane for complex shape

2. **Flash and Gutter**

- Flash material is allowred to flow into a gutter
- Prevents unnecessary increase of forging load (because of excess/ extra flash)

- Guidelines for flash and clearance between dies:

  - 3% of max. thickness of the forgings
  - The length of the land = 2 to 5 times the flash thickness

3. **Draft Angles**

- For easy removal of forgings from the die
- Similar to draft in casting design
- Internal draft angles are larger – 7^o- 10^o
- External draft angles are smaller – 3^o- 5^o

4. **Fillet :** It is a small radius provided at corners.

- To ensure smooth flow of metal into die cavity
- To improve die life
- As a general rule, should be as large as possible

- Small fillet radii lead to;

  - Improper metal flow

- Rapid wear of die
- Fatigue cracking of dies

5. **Die material : requirements are**
    - Strength and toughness at elevated temperature
    - Hardenability and ability to harden uniformly
    - Resistance to mechanical and thermal shocks
    - Wear resistance – to resist abrasion wear due to scales present on work piece

Selection of proper die material depends on :

- Die size
- Composition and properties of work piece
- Complexity of shape- no of performing steps
- Forging temperature
- Type of forging operation
- Cost of die material
- No. of forgings required
- Heat transfer from work piece to dies

- **Die materials used:**
- Tool and die steels with Cr, Ni, Mo, Va

Die Manufacturing: It consists of the following steps:

- -- Initially castings
- – then forged
- – finally machined and finished to required shape and surface finish

Material Flow Lines in Forgings:

Fig:Material Flow Lines

- The deformation produced by forging gives a certain degree of **directionality** to the microstructure of the work material.
- Due to this, second phases and inclusions are oriented parallel to the direction of greatest deformation.
- When magnified, this appears as flow lines or fiber structure, **a major characteristic** of all forgings.

Limitation of flow lines:

- Flow lines (fiber structure) lead to lower tensile ductility and lower fatigue properties in the direction normal to it (in transverse direction).
- Hence **optimal balance** between ductility in longitudinal and transverse directions is very essential. (Deformation limited to 50% to 70% reduction in c/s area.

Forging defects

1.**Incomplete forging penetration:**

- Dendritic ingot structure at the interior of forging is not broken. Actual forging takes place only at the surface.

- Cause: Use of light rapid hammer blows
- Remedy: To use forging press for full penetration.

2. Surface Cracking

- Cause: Excessive working on the surface and too low temperature. High sulfur in furnace leading to hot shortness
- Remedy: To increase the work temperature

3. Cracking at the flash:

- This crack penetrates into the interior after flash is trimmed off.
- Cause: Very thin flash
- Remedy:-Increasing flash thickness, relocating the flash to a less critical region of the forging, hot trimming and stress relieving.

4. **Cold shut (Fold)**

- Two surfaces of metal fold against each other without welding completely
- Cause: Sharp corner (less fillet), excessive chilling, high friction
- Remedy: increase fillet radius on the die

5. Scale pockets and Underfills:

- They are loose scale/ lubricant residue which accumulate in deep recesses of the die.
- Cause: Incomplete descaling of the work
- Remedy: Proper decaling of work prior to forging

6. Internal cracks

Cause: Secondary tensile stresses developed during forging

Remedy: Proper die design

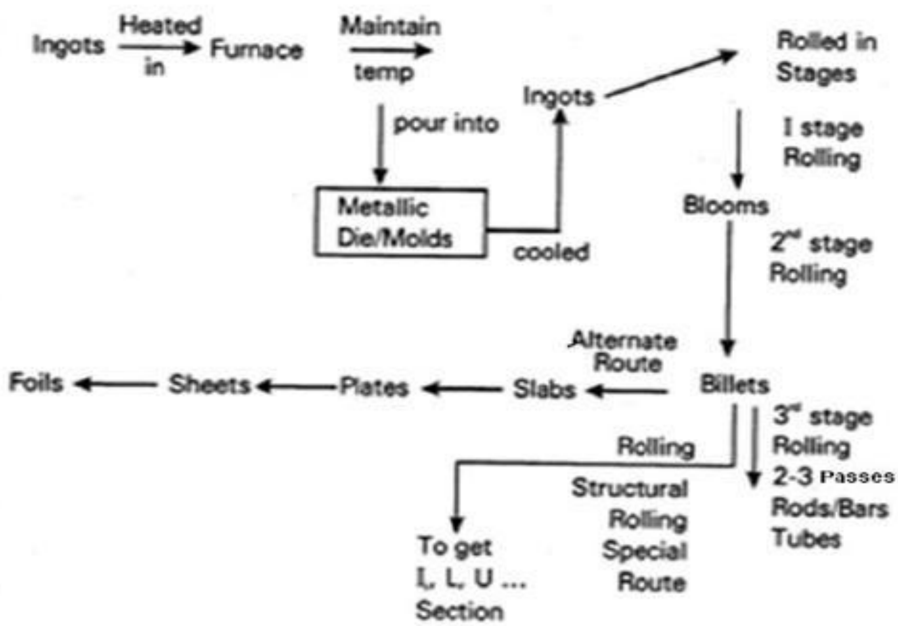
Residual stresses in Forging:

Causes: Inhomogeneous deformation and improper cooling (quenching) of forging. Remedy: Slow cooling of the forging in a furnace or under ash cover over a period of time.

UNIT 4: ROLLING

Rolling

The work piece is subjected to compressive forces and is deformed plastically. The cross section decreases and length gets elongated whereas the total volume remains constant. It is the main metal working process and offers itself to mass production. Close control of the final product is possible. Rotating rolls will squeeze the work piece inducing direct compressive stress in it. Friction dominates the process. Rolling of work piece can be carried out in hot or cold condition. Components produced through rolling have higher mechanical properties than cast products. Slabs, Sheets, Bars, Rods, Structural components like I, U, L etc., in long lengths can be produced easily.



Flow chart for Rolling Process

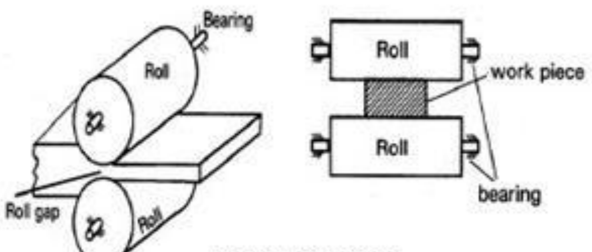
Steps in Rolling Process

The starting raw material in rolling is the ingot which is obtained by using a metal die.

Ingot will have a length of about 1 meter and a cross section of 100x100mm or 250x250mm etc,. Ingot may have any geometrical cross section. The details of Ingot production are:*Prepare molten metal in a furnace.

*Pour clean well prepared molten metal with correct temperature into a metal die cavity and allow it to cool.

Take out the solid metal. This solid metal is referred to as Ingot or Ingot casting.*The ingot is then passed through the rolls to get the next set of products blooms, billets, bars, slabs, plates, sheets or Structural components. The same is shown in the flow chart.



Typical Rolling Process

Classification of Rolling Process

Rolling Process can be classified either

i)based on the temperature of the metal during rolling or

ii) based on the arrangement of the rolls and their number or

iii)based on the Products rolled.

i**) Based on the temperature:** Rolling can be classified as Hot Rolling or Cold Rolling. Hot rolling is carried out above RCT and cold rolling is carried out below RCT.

Hot rolling is used to convert ingots to blooms and blooms to billets to slabs to plates, billets to bars, and billets to structural shapes. It is used for heavy or thick sections. Surface finish will be poor but the mechanical properties will be uniform.

Cold rolling is used for converting small sections plates to sheets to foils or bars to wires. Good surface finish is obtained with enhanced properties.

ii)Based on Roll arrangement: The minimum number of rolls required for rolling to take place is two and the higher end is dictated by the amount of reduction required, type of metal being rolled, configuration of the product etc., The rolls are cylindrical shaped may be plain or may have grooves cut on it.

The arrangement of rolls could be:

2 high roll mill- two rolls are used here.

*3 high roll mill- three rolls are used here.

*4 high roll mill- four rolls are used here.

*Cluster roll mill- a number of rolls are used in conjunction.

*Planetary roll mill- rolls are arrangement in the form of planetary movement.

Tandem roll mill- continuous arrangement of rolls are used for continuous rolling.

*Sendizmer roll mill-similar to a cluster mill but large number of rolls are used.
Greatest reduction in the material is obtained.

***All these arrangement are discussed below:**

The term"mill" is generally used while referring to while referring to the type of rolling process. It signifies the station involving the arrangement of rolls contributing for rolling and type of rolling operation carried out.

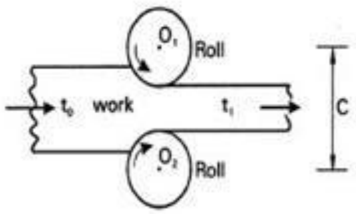
The term "high" signifies that the rolls are placed above the ground level.

As already discussed the starting raw material is the ingot. Ingot is rolled to blooms-billets-rods-wires in the first route.In the second route Ingot-bloom-slab-plate-sheet-foil is obtained. In the third route Ingot-bloom-structural configuration like I, U, V etc. is obtained.

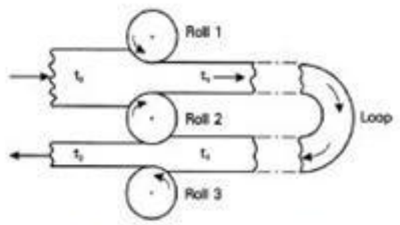
Two high mills

It consists of two rolls located one above the other with their centers in vertical plane. A controlled opening or gap is provided between the rolls. This gap represents the required thickness of the product. The rolls are cylindrical and mounted on bearings.

They are driven by motor and rotate in opposite directions as shown.



Two high mill



Three High roll Mill

The rolling direction can be changed by changing the direction of rotation of the rolls. The center distance between the rolls (C) can be changed to change the roll gap to vary the thickness of the product. This is mainly used for producing blooms and billets.

Three high mills

The arrangement consists of three rolls located one above the other, with their centers in a vertical plane. Outer rolls will be rotating in one direction and the center one will be rotating in the opposite direction. Here two passes of the work is possible unlike one pass in two roll mill. Work piece is fed between the gap of top set of rolls and its thickness is reduced. The output of this is fed into the gap between the bottom set of rolls.

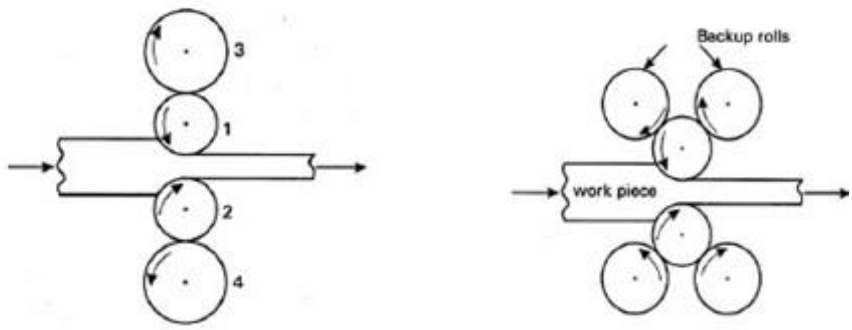
One reduction in thickness of the work piece is obtained. Thus rolling will take place in both directions. Since the output of one is taken and fed into the second set of rolls, the work forms a loop as shown. Hence, it is also named as looping mill.

The mill has higher output. Gap between roll1 and roll2= t1 and between roll2 and roll3=t2. Where t1 > t2

Four high mill

Here four rolls are used.

Two smaller form the main rolls and come in contact with the work piece and cause deformation. These rolls are backed up by larger diameter rolls. Thus the mill is more rigid and can be used for higher reductions in the work. Back up rolls prevent roll deflection.



Four high mill Cluster Mill

Cluster mill

Here the main rolls are small and are backed up by two sets of rolls on each side. Higher rigidity and stability is imparted to the mill. Higher reductions are possible. Better deformation will take place.

Planetary Mill

Here the large roll has very small rolls located along the circumference. A number of them will be arranged on each roll of a virtually two high roll mill. The arrangement looks like planets on the rolls. Hence, the name planetary mill. In fact the small rolls come in contact with the work piece and the big roll act as back up roll.

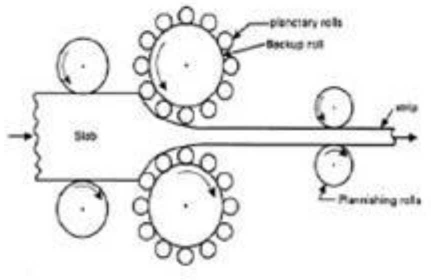
Higher reduction of the order 25:1 is possible in one pass.

The mill provides forging action as well as rolling action at the same time.

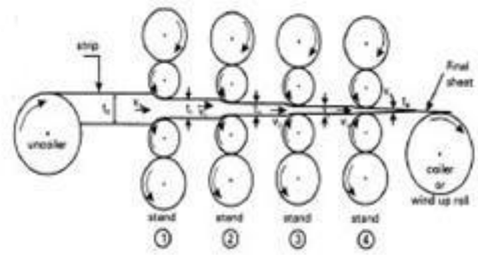
There will be two high mill at the beginning feeding the work piece to the planetary mill.

At the out let end there will be another set of two high mill to take the out coming work. This arrangement provides roll tension at the beginning and at the out let.

The mill is mainly used for converting slab to sheet or strip.



Planetary Mill



Tandem Mill

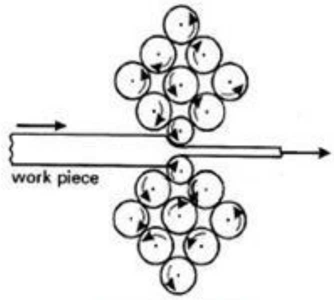
Tandem Mill

A series of four high mills are used one after the other. The work piece passes through each one of them. Reduction in the thickness will take place at each point. Each one of the mill is referred to as stand. There may be as many stands as necessary. This arrangement is referred to as “Tandem Mill”. Continuous reduction will take place at each stand.

There will be coiler and uncoiler which provides winding up of the work at the out let
end and act as feed roll by releasing the work piece.Normally this arrangement is used for converting thick sheet to very thin sheet and is a cold roll mill. Coiler and uncoiler provide the necessary tension in the work piece. Very smooth and good surface is obtained in the work piece.

Sendizmer Mill

- It is basically a cluster mill.
- It is used to produce thin sheets and foils.
- Very strong metals can be rolled very easily.
- Basically a cold rolling mill.
- Stainless steels, Alloy steels etc., can be rolled easily.
- Very high reduction ratio is obtained.



Sendizmer Mill

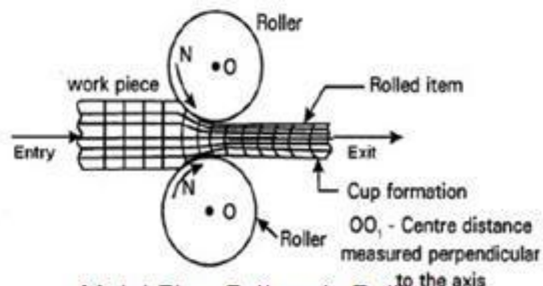
iii)Based on the product

•**Blooming Mill-** Here only blooms are produced from the Ingot. Blooms will have a dimension of approx.150x150mm.•Billet Mill- Here Billets are produced from Blooms. Billet will have a dimension of approx. 100x100mm.Rod/Bar Mill - Here bars or rods are produced from billets. Bar will have a dimension of 40x40mm.

•**Slab Mill-** Here slab is produced from the bloom. t>b and b=100mm•Plate Mill- Here plate is produced from the slab. t>4mm.•Sheet Mill – Here sheet is produced from plate. t<4mm.Structural Mill- Here structural shapes like I, U,L or channel sections are produced.

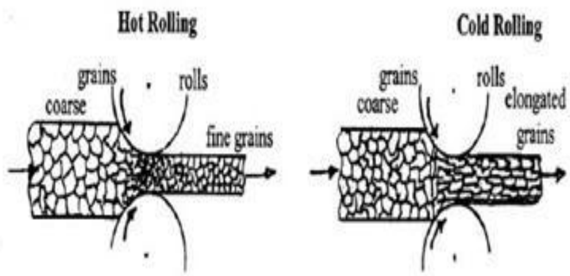
Metal flow pattern in Rolling

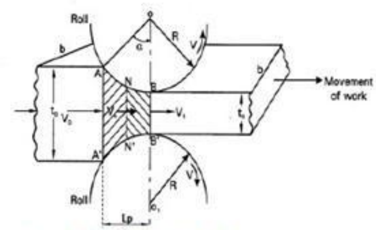
When the metal is rolled it is seen that the outer surface of the metal is deformed to a greater extent. This is due to the fact that the metal will be in direct contact with the roll surface. The frictional forces will be dragging it in the direction of rolling. The center portion of the metal is not at all deformed as it is free from any contact with the roll surface. To study the effect of rolling on the deformation process grid markings are made in the vertical and horizontal directions. The deformation pattern is observed after rolling. It is observed that distance between the horizontal grids decreases and they come closer. The distance between the vertical grids increases and are bent forward in the direction of rolling.



Metal Flow Pattern in Rolling

The velocity of the work piece as it leaves the rolls is greater than the circumferential velocity of the rolls due to stretching of the layers. Thickness of the work piece is reduced and the length is increased as it passes out of the roll gap.





Geometric Relationship in Rolling

Let a slab of constant width '*b*' enter the gap between the rolls and leave it with the same width '*b*'

R - is the radius of the rolls

V - is the surface velocity of the rolls

AA^1 - is the entry plane of the slab

BB^1 - is the exit plane of the slab

t_0 - is the thickness of the slab at the entrance

t_1 - is the thickness of the slab at the exit

V_0 - is the velocity of the slab at the entrance

V_1 - is the velocity of the slab at the exit

NN' - is the neutral plane

The velocity of the work piece increases steadily from entrance to the exit. At one point along the contact surface of the roll and work, the surface velocity of the roll will be equal to the velocity of the work. This point is referred to as “Neutral point” or “No Slip Point

V_x - is the velocity of the slab at the neutral plane

α - angle of contact or angle of bite

$\widehat{AB}$ - arc of contact

L_p - Projected length of arc of contact

$(t_0 - t_1)$ - is the draft

b - is the constant width of the slab at the entrance and at the exit.

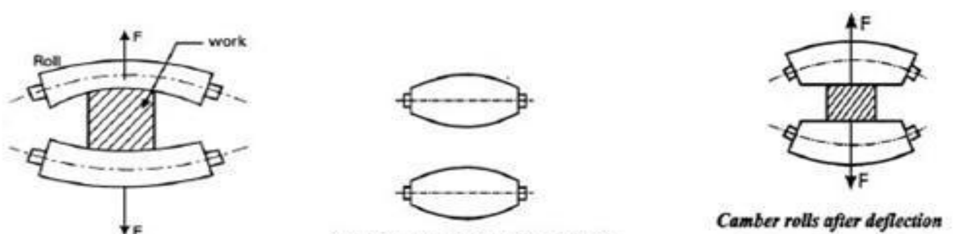
00_1 - is the plane corresponding to the line joining the centers of the rolls.

AA^1B^1B - is the deformation zone

AA^1N^1N - is the Lagging zone $V_0 < V_x$

Roll Camber

For a given reduction in thickness of the work piece the roll separating force (influencing roll bending) increases linearly with roll radius. Forces will be set up along the length of the roll and try to deflect and separate the rolls.



Flat rolls undergoing deformation

Rolls with convex surface ie. camber before rolling

Camber rolls after deflection experiencing roll separating force

The convex contour provided on the rolls is called “Roll Camber”. Without Roll Camber the thickness of the work piece is more at the centre than at the ends. But with Roll Camber, uniform thickness is maintained across the width of the work.

The Main Parameters in Rolling

The parameters are:

- Roll diameter
- Friction between rolls and work piece
- Deformation resistance of the metal as influenced by metallurgy, temperature and strain rate Presence of roll tensions

Roll Diameter:

*Rolling load increases with roll diameter at a rate greater than D1/2

*We know Rolling load P = p.b.√R.Δt but R=D/2 Therefore P = p.b.√D/2.Δt or P α√D

*As roll diameter decreases both rolling load and length of arc of contact decreases.

*Small diameter rolls supported by large back up rolls can produce greater reduction and keep the work flat.

Friction:

*Frictional force is needed to pull the metal into the rolls.*Large fraction of rolling load comes from the frictional force.*Friction varies from point to point along the arc of contact of the roll, it will be acting from entry to neutral point long the direction of roll rotation and from neutral point to exit point it will be opposing the direction of roll rotation. High friction results in high rolling load and a steep friction hill will be realized.

*Since it is very difficult to measure the variation in coefficient of friction „μ" it is assumed that „μ" is constant. For cold rolling it is taken as 0.05-0.1 and for hot rolling it is taken as >= 0.2.*Coeff.of friction is inversely proportional to the rolling speed. As μ decreases rolling speed increases. From F= μ/N μ = F/N Thinner gage sheet can be produced in cold rolling as coeff.of friction is smaller.

Deformation resistance of metal:

Deformation resistance indicate how much a given metal offers resistance to deformation.

Deformation resistance is the resistance offered by the metal for external load.

Higher the deformation resistance higher is the difficulty to deform.

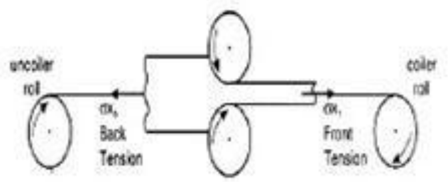
Coarser grains in the metal offer less resistance for deformation and vice versa.

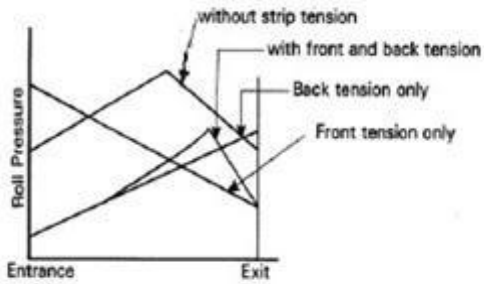
Higher the dislocation density higher is the deformation resistance.

Higher the working temperature lesser is the deformation resistance.

Strip Tension:

The presence of tension in the plane of the sheet can reduce the rolling load. Front tension can be controlled by the coiler where as back tension can be created by controlling the speed of the uncoiler relative to the roll speed.





Variation of Roll Pressure

Tension reduces wear of the rolls. Improves flatness in the sheet, induces uniform thickness across the width of the sheet. Tension is used to shift the neutral point towards the exit plane.

Pressure Distribution in Rolling:

*The roll pressure "p" increases continuously from the entry to the neutral point there after it decreases continuously.*The peak pressure at the neutral point is normally called as the "Friction Hill"*This peak pressure increases with increasing coefficient of friction.

It can be concluded that as the roll tension is increased at the front and back the roll pressure can be reduced along the arc of contact. *Peak pressure is reduced and shifted towards the entry side. *As a result the load required for rolling gets reduced.

Defects in Metal Working Process

Defects in the Final Product of Mechanically worked metal may have originated from any one or a combination of the following:The ingot used for MW may contain defects (pores, microcracks or inclusions) which may remain as such or get aggravated during working operation.

Operational Parameters Localized to a particular type of MW process (not following the proper practice).

Defects in Rolled Products

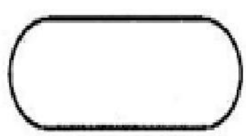
The defects may arise due to

i) Surface irregularities: The ingot or the raw material may be having irregularities due to scaling which will get trapped in the metal and remain inside the metal surface as laps. This needs to be removed by grinding and there will be metal loss. If the defect is deep and severe the product may get rejected.

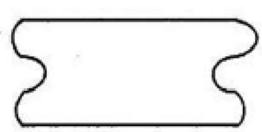
ii) Non-metallic inclusions: The inclusions may results from oxides or nitrides or silicates etc., especially in steels. These are present in the molten metal during the preparation. If less in volume may cause small cracks in the metal and if more in volume will result in severe cracks called crocodile cracks separating the product into two halves.

iii)Internal Pores: There may be pores in the product due to the presence of gases like hydrogen,oxygen,nitrogen etc., If too much gases are present leads to elongation of the pores and the product may become weaker. Sometimes separation may take place resulting in cracks.

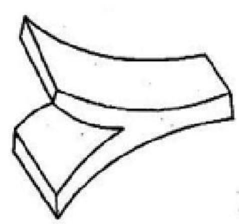
iv)Barrel: Due to friction at the edges of the product barrel action takes place. Surface in contact experience severe friction as compared to center of the work. Hence, with heavy reduction in the work the center tends to expand laterally more than the outer surfaces in contact with the dies and produces barreled edges.



Barelling



Non uniform defomation



Alligator Cracks

ii) Non uniform deformation: When the rolling conditions a re such that only surface of the work piece is deformed. The cross section of the slab is deformed into the shape as shown.

The middle portion is less deformed as compared to the outer surface.

This may be due to variation in temperature in the metal. Surface temperature being more than the inside temperature of the slab.

iii) Alligator Cracks: If there is any metallurgical weakness in the metal (due to the presence of inclusions) along the centre line of the slab, fracture will occur. This results in the separation of the layer giving rise to opening of the slab which looks like an alligator mouth in opening position. Hence, the name.

Others:

i) **Hydrogen cracks:** During preparation of the melt in the furnace several gases tries to get into the melt. Out of this Hydrogen gas diffuses into the melt to a large extent and is retained in the solid metal. Due the presence of hydrogen in excess internal cracks appear through the cross section during rolling and cannot be used. It is a major problem with alloy steels especially.

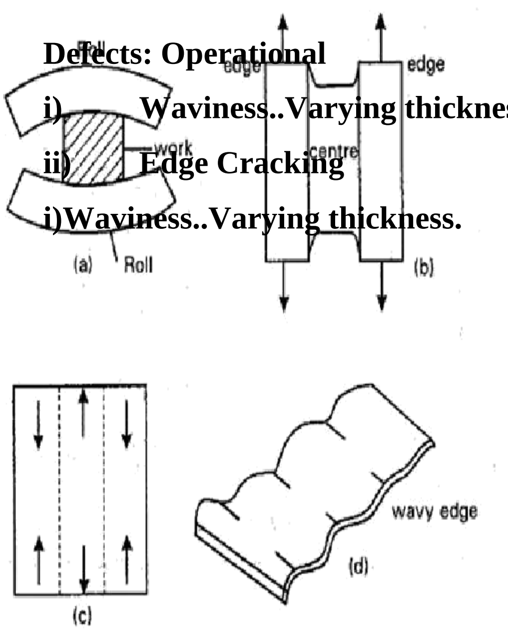
ii) Non metallic inclusion: Inclusions are non metallics appearing in the metal as a result of entrapment. During the preparation of the molten metal non metallic like oxides, nitrides, silicates enter the melt and remain as such in the solid metal. These are discontinuities in the metal and reduce the properties of the metal. On rolling they may result in cracks which may reach a critical value and make the product rejectable.

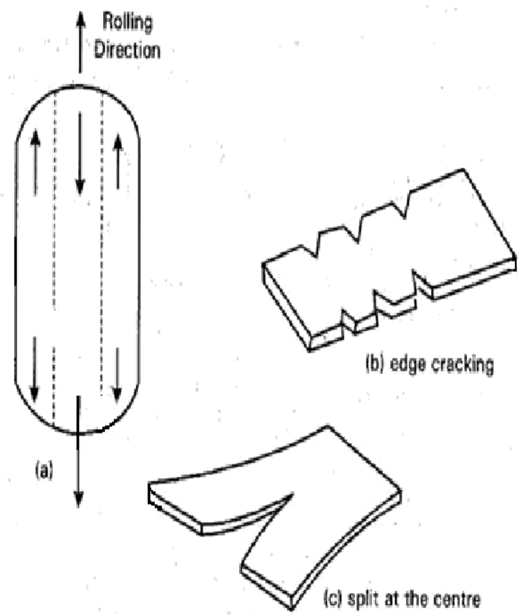
Defects: Operational

i) Waviness..Varying thickness.

ii) Edge Cracking

i)Waviness..Varying thickness.





Variation in the work across the width in sheet rolling occurs because the roll gap is not perfectly parallel (a).

Since width and volume are constant and thickness is varying, the edges elongate more than the center (b).

But the sheet is a continuous body; the strains readjust to maintain continuity. Thus the center portion is in tension and the edges are in compression (c). The result is a wavy edge (d)

ii)Edge Cracking

The length of the center portion increases but the edges are prevented due to frictional force. As a result the material gets rounded off (a). The edges are strained in tension leading to edge cracking along the width of the slab (b).

When the difference in the strains become excess i.e. under severe condition, split at the center of the slab occurs (c).

Numericals

Prob,1. Determine the max. possible reduction for cold rolling a 300mm thick slab when μ=0.08 and the roll diameter is 600mm.

i) $t)_{max}$= ? for cold rolling t=300mm

R=600/2 = 300mm

ii) for hot rolling $t)_{max}$= ?

iii) %reduction=?

i) Max.Possible reduction i) Cold rolling

We know $t)_{max} = \mu^2.R$

Substituting the values we get

$= (0.08)^2.(300)$

Max.Possible reduction = 1.92mm

ii) hot rolling

$t)_{max} = \mu^2.R$

$= (0.5)^2.(300)$

Max.Possible reduction = 75mm

ii) %reduction

Cold rolling= (t/t).100

= (1.92/300).100

= 0.64%

Hot rolling = (75/300).100

= 25%

Prob.2. If the max. reduction in rolling of slab is from 25 to 20 mm, calculate the value of coeff.friction. Take the roll diameter as 500mm. Also find the length of projection of arc of contact.

Given: t_0 =25mm t_1=20mm 2R=500mm μ=? L_p=?

R=250mm

Max.reduction t = 25-20 = 5mm

From $\cos\alpha = (1- t/2R)$

$= (1- 5/500)$

$\cos\alpha = 0.99$

Angle of bite $\alpha = 8.11^0$

We know $\mu = \tan\alpha = \tan(8.11)$

Coeff.of friction $\mu = 0.1425$

Length of Projection of arc of contact L_p

$L_p = \sqrt{(R. t)}$

$= \sqrt{(250)(5)}$

$L_p = 35.35$mm

Prob.3. If the coeff. Of friction in cold rolling is 0.08,determine the i) length of projection of arc of contact ii) the velocity of the slab at the exit iii) specific roll pressure. Neglect lateral spread. Use the following data.

Width of the slab=b=80mm, Roll radius=800mm thickness of the slab=t_o=400mm, velocity of the slab at the entry=V_o=200mm/sec, Rolling load=P=14MN.

from $t)_{max} = \mu^2.R$

$= (0.08)^2.(800) = 5.12$mm

i)$L_p = \sqrt{(R. t_{max})} = \sqrt{(800)(5.12)} = 64$mm we need to calculate

thickness of the slab after rolling

$t_{max}=(t_o-t_f)$

$5.12 = 400- t_f$

$t_f = 400-5.12 = 394.88mm$

ii) Specific roll pressure is given by

$p= (P/b. L_p)$

$= (14x10^6/800.64) = 273.44$ N/mm2

= 273.44 Mpa

iii)The velocity of the slab at the exit

we know for constant volume of the metal in rolling assuming constant width

$bV_0t_0 = bV_ft_f$

$200(400)= V_f (394.88)$

$V_f = 202.593$ mm

Prob.4. Aluminium strip of 400mm wide and 25 mm thick is rolled using a 1800mm dia. Roll at 250rpm. The thickness is reduced to 20mm. If λ is 0.5 for hot rolling and 0.45 for cold rolling, calculate the torque and power required to roll the metal. Take the specific roll pressure 250Mpa for hot rolling and 300 Mpa for cold rolling.

Given: b=400mm, R=D/2 =1800/2 =900mm

t_o=25mm, t_f=20mm, p=250Mpa (hot rolling) and p= 300Mpa (for cold rolling)

N=250rpm=(250/60), λ =0.5 for hot rolling

=0.45 for cold rolling

Torque M_t=? Power =?

a=distance from the center of the roll where total rolling load is assumed to be concentrated.

We know

λ = (a/L_p) = (a/√R. t)

=a/√900(25-20)=a/(67.08)

For hot rolling substitute λ =0.5

0.5= a/67.08

therefore a= 33.54mm

again p= (P/b. L_p)

250 = P/(400.33.54)

Rolling load=67080000N or 6.708 MN

Torque Mt = 2P.a

- 2(6.708)(33.54)/1000

0.45MNm

Work done = 2 (2.π.a).P = 4Pπ.a

= 4π(33.45)6.708/1000

= 2.83MNm

Power = Work done/sec= (4P.π.a)N/60

= (2.83x250)/60

= 11.79MW For cold rolling λ= a/(67.08)

0.45= a/67.08

a= 30.186mm or 0.030m again from p= (P/b. L_p)

300= P/(400x67.08)

P= 8049600 N =8.05MN

Torque M_t = 2P.a

=2x8.05x0.03=0.483 MNm Work done= 4Pπ.a =4π(8.05)(0.03)

= 3.035 MNm

Power required = (4P.π.a)N/60

= 3.035x 250/60

= 12.648MW

Equations used in Rolling Process

i) Maximum draft t)$_{max}$=μ^2R , μ=tanα and t)$_{max}$=t_o-t_f

ii) Cosα=1- t/2R

iii)Length of arc of contact Lp=√R. t iv)Specific Roll Pressure p=P/b.Lp

v)Constant Volume Rate , $bV_o t_o$= $bV_1 t_1$= constant vi)Torque M_t=2Pa λ=a/Lp

λ =0.50 hot rolling =0.45 cold rolling

vii)Power required=(2.2πa.P)N/60 =(4πa.P)(N/60)

viii)Forward slip=(V_1-V_n)/ V_1

x)Backward slip=(V_n-V_0)/ V_0

xi)Volume rate of deformation is the ratio of volume of the work to the time for deformation

={b(t_o- t_1) Lp}/T

Unit 5: Drawing

Drawing is a metalworking process which uses tensile forces to stretch metal. As the metal is **drawn** (pulled), it stretches thinner, into a desired shape and thickness. Drawing is classified in two types: sheet metal drawing and wire, bar, and tube drawing. The specific definition for sheet metal drawing is that it involves plastic deformation over a curved axis. For wire, bar, and tube drawing the starting stock is drawn through a die to reduce its diameter and increase its length. Drawing is usually done at room temperature, thus classified a cold working process, however it may be performed at elevated temperatures to hot work large wires, rods or hollow sections in order to reduce forces.[1][2] Drawing is one type of extrusion.

Drawing differs from rolling in that the pressure of drawing is not transmitted through the turning action of the mill but instead depends on force applied locally near the area of compression. This means the amount of possible drawing force is limited by the tensile strength of the material, a fact that is particularly evident when drawing thin wires

Sheet metal

The success of forming is in relation to two things, the flow and stretch of material. As a die forms a shape from a flat sheet of metal, there is a need for the material to move into the shape of the die. The flow of material is controlled through pressure applied to the blank and lubrication applied to the die or the blank. If the form moves too easily, wrinkles will occur in the part. To correct this, more pressure or less lubrication is applied to the blank to limit the flow of material and cause the material to stretch or thin. If too much pressure is applied, the part will become too thin and break. Drawing metal is the science of finding the correct balance between wrinkles and breaking to achieve a successful part.

Deep drawing

Sheet metal drawing becomes *deep drawing* when the workpiece is drawing longer than its diameter. It is common that the workpiece is also processed using other forming processes, such as piercing, ironing,necking, rolling, and beading.

Bar, tube & wire

Bar, tube, and wire drawing all work upon the same principle: the starting stock drawn through a die to reduce the diameter and increase the length. Usually the die is mounted on a draw bench. The end of the workpiece is reduced or pointed to get the end through the die. The end is then placed in grips and the rest of the workpiece is pulled through the die. Steels, copper alloys, and aluminium alloys are common materials that are drawn.

Drawing can also be used to produce a cold formed shaped cross-section. Cold drawn cross-sections are more precise and have a better surface finish than hot extruded parts. Inexpensive materials can be used instead of expensive alloys for strength requirements, due to work hardening.

Bar drawing

Bars or rods that are drawn cannot be coiled therefore straight-pull draw benches are used. Chain drives are used to draw workpieces up to 30 m (98 ft). Hydraulic cylinders are used for shorter length workpieces.

The reduction in area is usually restricted to 20 to 50%, because greater reductions would exceed the tensile strength of the material, depending on its ductility. To achieve a certain size or shape multiple passes through progressively smaller dies or intermediate anneals may be required.[6]

The Cold Drawing Process for Steel Bars and Wire

Carbide Die Cross Section

Raw Stock: Hot rolled steel bar or rod coils are used as raw material. Because the hot rolled products are produced at elevated temperatures (1700 - 2200 Deg. F. i.e. hot rolling), they generally have a rough and scaled surface and may also exhibit variations in section and size.

Cleaning: Abrasive scale (iron oxide) on the surface of the hot rolled rough stock is removed.

Coating: The surface of the bar or coil is coated with a drawing lubricant to aid cold drawing.

Pointing: Several inches of the lead ends of the bar or coil are reduced in size by swaging or extruding so that it can pass freely through the drawing die. Note: This is done because the die opening is always smaller than the original bar or coil section size.

Cold Drawing Process: In this process, the material being drawn is at room temperature (i.e. Cold-Drawn). The pointed/reduced end of the bar or coil, which is smaller than the die opening, is passed through the die where it enters a gripping device of the drawing machine. The drawing machine pulls or draws the remaining unreduced section of the bar or coil through the die. The die reduces the cross section of the original bar or coil, shapes the profile of the product and increases the length of the original product.

Finished Product: The drawn product, which is referred to as Cold Drawn or Cold Finished, exhibits a bright and/or polished finish, increased mechanical properties, improved machining characteristics and precise and uniform dimensional tolerances.

Multi-Pass Drawing: The cold drawing of complex shapes/profiles may require that each bar/coil be drawn several times in order to produce the desired shape and tolerances. This process is called multi-pass drawing and involves drawing through smaller and smaller die openings. Material is generally annealed between each drawing pass to remove cold work and to increase ductility.

Annealing: This is a thermal treatment generally used to soften the material being drawn, to modify the microstructure, the mechanical properties and the machining characteristics of the steel and/or to remove internal stresses in the product. Depending on the desired characteristics of the finished product, annealing may be used before, during (between passes) or after the cold drawing operation, depending on material requirements. by shangar hawrami

Tube drawing

Tube drawing is very similar to bar drawing, except the beginning stock is a tube. It is used to decrease the diameter, improve surface finish and improve dimensional accuracy. A mandrel may or may not be used depending on the specific process used.

Wire drawing

This technique has long been used to produce flexible metal wire by drawing the material through a series of dies of decreasing size. These dies are manufactured from a number of materials, the most common being tungsten carbide and diamond.

Plastic drawing

Plastic drawing, sometimes referred to as *cold drawing*, is the same process as used on metal bars, but applied to plastics.

Cold drawing is primarily used in manufacturing plastic fibers. The process was discovered by Julian Hill (1904–1996) in 1930 while trying to make fibers from an early polyester.[8] It is performed after the material has been "spun" into filaments; by extruding the polymer melt through pores of a spinneret. During this process, the individual polymer chains tend to somewhat align because of viscous flow. These filaments still have an amorphous structure, so they are drawn to align the fibers further, thus increasing crystallinity, tensile strength and stiffness. This is done on a draw twister machine.

For nylon, the fiber is stretched four times its spun length. The crystals formed during drawing are held together by hydrogen bonds between the amide hydrogens of one chain and the carbonyl oxygens of another chain

Metal drawing is a manufacturing process that forms metal work stock by reducing its cross section. This is accomplished by forcing the work through a mold, (die), of smaller cross sectional area than the work. This process is very similar to metal extrusion, the difference being in the application of force. In extrusion the work is pushed through the die opening, where in drawing it is pulled through. The basic concept of metal drawing is illustrated in the following figure.

Unit 6: Extrusion

Extrusion is a process used to create objects of a fixed cross-sectional profile. A material is pushed or pulled through a die of the desired cross-section. The two main advantages of this process over other manufacturing processes are its ability to create very complex cross-sections, and to work materials that are brittle, because the material only encounters compressive and shear stresses. It also forms parts with an excellent surface finish.

Extrusion may be continuous (theoretically producing indefinitely long material) or semi-continuous (producing many pieces). The extrusion process can be done with the material hot or cold.

Commonly extruded materials include metals, polymers, ceramics, concrete, play dough, and foodstuffs. The products of extrusion are generally called "extrudates". Drawing metal is the main way to produce wire and sheet, and bar and tube are also often drawn.

Hollow cavities within extruded material cannot be produced using a simple flat extrusion die, because there would be no way to support the center barrier of the die. Instead, the die assumes the shape of a block with depth, beginning first with a shape profile that supports the center section. The die shape then internally changes along its length into the final shape, with the suspended center pieces supported from the back of the die.

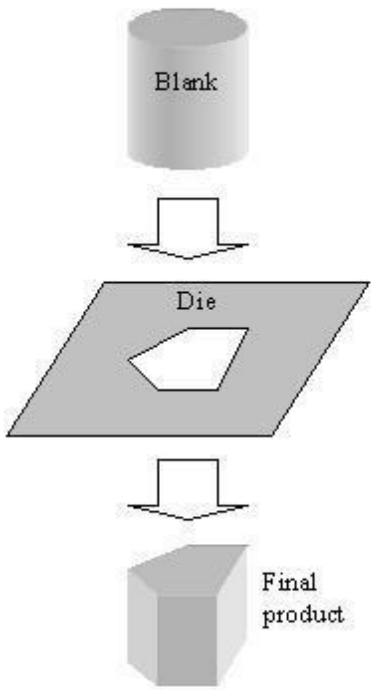
The extrusion process in metals may also increase the strength of the material.

The process begins by heating the stock material (for hot or warm extrusion). It is then loaded into the container in the press. A dummy block is placed behind it where the ram then presses on the material to push it out of the die. Afterward the extrusion is stretched in order to straighten it. If better properties are required then it may be heat treated orcold worked.[2]

The extrusion ratio is defined as the starting cross-sectional area divided by the cross-sectional area of the final extrusion. One of the main advantages of the extrusion process is that this ratio can be very large while still producing quality parts.

Hot extrusion

Hot extrusion is a hot working process, which means it is done above the material's recrystallization temperature to keep the material from work hardening and to make it easier to push the material through the die. Most hot extrusions are done on horizontal hydraulic presses that range from 230 to 11,000 metric tons (250 to 12,130 short tons). Pressures range from 30 to 700 MPa (4,400 to 101,500 psi), therefore lubrication is required, which can be oil or graphite for lower temperature extrusions, or glass powder for higher temperature extrusions. The biggest disadvantage of this process is its cost for machinery and its upkeep



The extrusion process is generally economical when producing between several kilograms (pounds) and many tons, depending on the material being extruded. There is a crossover point where roll forming becomes more economical. For instance, some steels become more economical to roll if producing more than 20,000 kg (50,000 lb)

Cold extrusion

Cold extrusion is done at room temperature or near room temperature. The advantages of this over hot extrusion are the lack of oxidation, higher strength due to cold working, closer tolerances, better surface finish, and fast extrusion speeds if the material is subject to hot shortness. Materials that are commonly cold extruded include: lead, tin, aluminum, copper, zirconium, titanium, molybdenum, beryllium, vanadium, niobium, and steel.

Examples of products produced by this process are: collapsible tubes, fire extinguisher cases, shock absorber cylinders and gear blanks.

Warm extrusion

Warm extrusion is done above room temperature, but below the recrystallization temperature of the material the temperatures ranges from 800 to 1800 °F (424 to 975 °C). It is usually used to achieve the proper balance of required forces, ductility and final extrusion properties.[3]

Extrusion defects

- Surface cracking occurs when the surface of an extrusion splits. This is often caused by the extrusion temperature, friction, or speed being too high. It can also happen at lower temperatures if the extruded product temporarily sticks to the die.
- Pipe – A flow pattern that draws the surface oxides and impurities to the center of the product. Such a pattern is often caused by high friction or cooling of the outer regions of the billet.
- Internal cracking – When the center of the extrusion develops cracks or voids. These cracks are attributed to a state of hydrostatic tensile stress at the centerline in the deformation zone in the die. (A similar situation to the necked region in a tensile stress specimen)

- **Surface lines –** When there are lines visible on the surface of the extruded profile. This depends heavily on the quality of the die production and how well the die is maintained, as some residues of the material extruded can stick to the die surface and produce the embossed lines.

- **Equipments**

A horizontal hydraulic press for hot aluminum extrusion (loose dies and scrap visible in foreground)

There are many different variations of extrusion equipment. They vary by four major characteristics:

1. Movement of the extrusion with relation to the ram. If the die is held stationary and the ram moves towards it then it is called "direct extrusion". If the ram is held stationary and the die moves towards the ram it is called "indirect extrusion".
2. The position of the press, either vertical or horizontal.
3. The type of drive, either hydraulic or mechanical.
4. The type of load applied, either conventional (variable) or hydrostatic.

A single or twin screw auger, powered by an electric motor, or a ram, driven by hydraulic pressure (often used for steel and titanium alloys), oil pressure (for aluminium), or in other specialized processes such as rollers inside a perforated drum for the production of many simultaneous streams of material.

Typical extrusion presses cost more than $100,000, whereas dies can cost up to $2000.

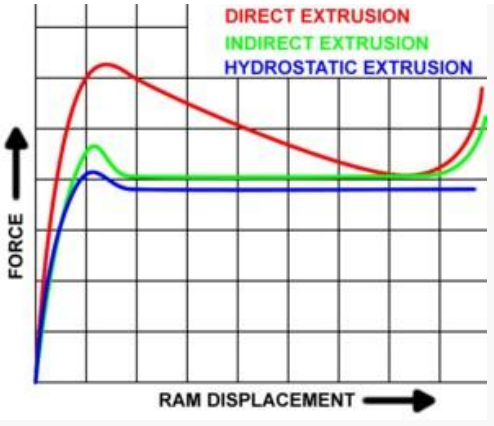
Forming internal cavities

Two-piece aluminum extrusion die set (parts shown separated.) The male part (at right) is for forming the internal cavity in the resulting round tube extrusion.

There are several methods for forming internal cavities in extrusions. One way is to use a hollow billet and then use a fixed or floating mandrel. A fixed mandrel, also known as a German type, means it is integrated into the dummy block and stem. A floating mandrel, also known as a French type, floats in slots in the dummy block and aligns itself in the die when extruding. If a solid billet is used as the feed material then it must first be pierced by the mandrel before extruding through the die. A special press is used in order to control the mandrel independently from the ram.[1] The solid billet could also be used with a spider die, porthole die or bridge die. All of these types of dies incorporate the mandrel in the die and have "legs" that hold the mandrel in place. During extrusion the metal divides, flows around the legs, then merges, leaving weld lines in the final product.[4]

Direct extrusion

Direct extrusion, also known as forward extrusion, is the most common extrusion process. It works by placing the billet in a heavy walled container. The billet is pushed through the die by a ram or screw. There is a reusable dummy block between the ram and the billet to keep them separated. The major disadvantage of this process is that the force required to extrude the billet is greater than that needed in the indirect extrusion process because of the frictional forces introduced by the need for the billet to travel the entire length of the container



Plot of forces required by various extrusion processes.

. Because of this the greatest force required is at the beginning of process and slowly decreases as the billet is used up. At the end of the billet the force greatly increases because the billet is thin and the material must flow radially to exit the die. The end of the billet (called the butt end) is not used for this reason.

Indirect extrusion

In indirect extrusion, also known as backwards extrusion, the billet and container move together while the die is stationary. The die is held in place by a "stem" which has to be longer than the container length. The maximum length of the extrusion is ultimately dictated by the column strength of the stem. Because the billet moves with the container the frictional forces are eliminated. This leads to the following advantages:

- A 25 to 30% reduction of friction, which allows for extruding larger billets, increasing speed, and an increased ability to extrude smaller cross-sections
- There is less of a tendency for extrusions to crack because there is no heat formed from friction
- The container liner will last longer due to less wear
- The billet is used more uniformly so extrusion defects and coarse grained peripherals zones are less likely.

The disadvantages are:

- Impurities and defects on the surface of the billet affect the surface of the extrusion. These defects ruin the piece if it needs to be anodized or the aesthetics are important. In order to get around this the billets may be wire brushed, machined or chemically cleaned before being used.
- This process isn't as versatile as direct extrusions because the cross-sectional area is limited by the maximum size of the stem.

Hydrostatic extrusion

In the hydrostatic extrusion process the billet is completely surrounded by a pressurized liquid, except where the billet contacts the die. This process can be done hot, warm, or cold, however the temperature is limited by the stability of the fluid used. The process must be carried out in a sealed cylinder to contain the hydrostatic medium. The fluid can be pressurized two ways:

1. *Constant-rate extrusion*: A ram or plunger is used to pressurize the fluid inside the container.
2. *Constant-pressure extrusion*: A pump is used, possibly with a pressure intensifier, to pressurize the fluid, which is then pumped to the container.

The advantages of this process include:

- No friction between the container and the billet reduces force requirements. This ultimately allows for faster speeds, higher reduction ratios, and lower billet temperatures.
- Usually the ductility of the material increases when high pressures are applied.
- An even flow of material.
- Large billets and large cross-sections can be extruded.
- No billet residue is left on the container walls.

The disadvantages are:

- The billets must be prepared by tapering one end to match the die entry angle. This is needed to form a seal at the beginning of the cycle. Usually the entire billet needs to be machined to remove any surface defects.
- Containing the fluid under high pressures can be difficult.

Drives

Most modern direct or indirect extrusion presses are hydraulically driven, but there are some small mechanical presses still used. Of the hydraulic presses there are two types: direct-drive oil presses and accumulator water drives.

Direct-drive oil presses are the most common because they are reliable and robust. They can deliver over 35 MPa (5000 psi). They supply a constant pressure throughout the whole billet. The disadvantage is that they are slow, between 50 and 200 mm/s (2–8 ips).

Accumulator water drives are more expensive and larger than direct-drive oil presses, and they lose about 10% of their pressure over the stroke, but they are much faster, up to 380 mm/s (15 ips). Because of this they are used when extruding steel. They are also used on materials that must be heated to very hot temperatures for safety reasons.

Hydrostatic extrusion presses usually use castor oil at pressure up to 1400 MPa (200 ksi). Castor oil is used because it has good lubricity and high pressure properties.

Die design:

The design of an extrusion profile has a large impact on how readily it can be extruded. The maximum size for an extrusion is determined by finding the smallest circle that will fit around the cross-section, this is called the *circumscribing circle*. This diameter, in turn, controls the size of the die required, which ultimately determines if the part will fit in a given press. For example, a larger press can handle 60 cm (24 in) diameter circumscribing circles for aluminium and 55 cm (22 in). diameter circles for steel and titanium.[1]

The complexity of an extruded profile can be roughly quantified by calculating the *shape factor*, which is the amount of surface area generated per unit mass of extrusion. This affects the cost of tooling as well as the rate of production.[9]

Thicker sections generally need an increased section size. In order for the material to flow properly legs should not be more than ten times longer than their thickness. If the cross-section is asymmetrical, adjacent sections should be as close to the same size as possible. Sharp corners should be avoided; for aluminium and magnesium the minimum radius should be 0.4 mm (1/64 in) and for steel corners should be 0.75 mm (0.030 in) and fillets should be 3 mm (0.12 in). The following table lists the minimum cross-section and thickness for various materials

UNIT 7: Sheet Metal Forming

Introduction

Sheet metal is simply metal formed into thin and flat pieces. It is one of the fundamental forms used in metalworking, and can be cut and bent into a variety of different shapes. Countless everyday objects are constructed of the material. Thicknesses can vary significantly, although extremely thin thicknesses are considered foil or leaf, and pieces thicker than 6 mm (0.25 in) are considered plate.

Metal Forming Process

Forming can be defined as the process in which the desired size and shape of the object are obtained through plastic deformation of material. The stresses induced during the process are greater than yield strength but should be less than the fracture strength. Different types of loading may be used depending on the process. Tensile Compressive Shear, Bending

Classification of Metal Working Process

Metal working process may be classified as the ease with which metal may be formed into useful shapes by-

Plastic deformation process and Metal removal process

1. **Plastic Deformation Process**

In this the volume and the mass of the metal are conserved and the metal is displaced from one location to another.

2. **Metal Removal Process**

In this the material is removed from the stock in order to give it required shape.

Classification of Metal Forming Process

Metal forming process may be classified on the basis of type of forces applied to the work piece as it is formed into direct shape. These categories are:

Direct compression type process (e.g.-Forging, Rolling)

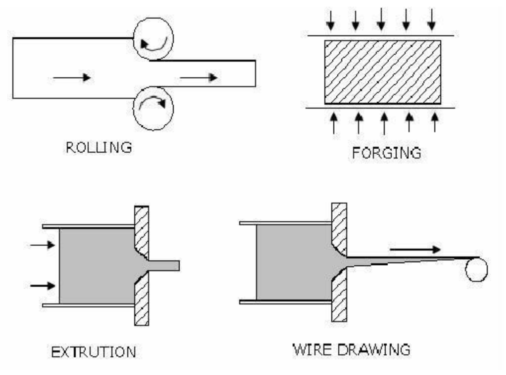
Indirect – compression processes (e.g.-Extrusion, Wire Drawing)

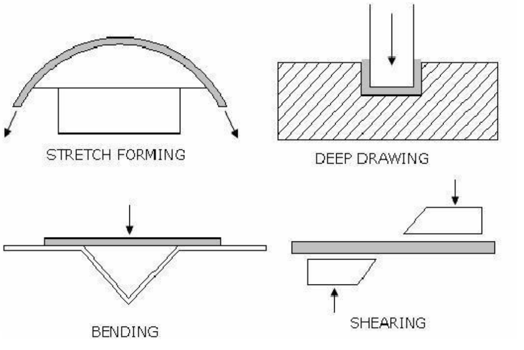
Tension type processes e.g.-Stretch forming)

Bending processes

Shearing processes

Bending process Shearing process





Sheet metal processing

The raw material for sheet metal manufacturing processes is the output of the rolling process. Typically, sheets of metal are sold as flat, rectangular sheets of standard size. If the sheets are thin and very long, they may be in the form of rolls. Therefore the first step in any sheet metal process is to cut the correct shape and sized „blank" from larger sheet.

Sheet metal forming processes

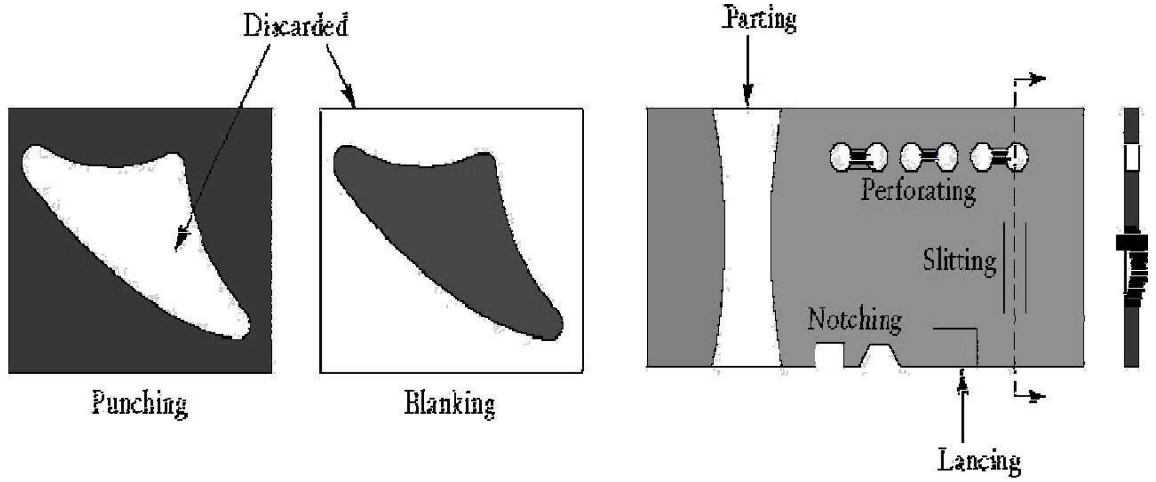
Sheet metal processes can be broken down into two major classifications and one minor classification

- **Shearing processes** -- processes which apply shearing forces to cut, fracture, or separate the material.
- **Forming processes** -- processes which cause the metal to undergo desired shape changes without failure, excessive thinning, or cracking. This includes bending and stretching.
- **Finishing processes** -- processes which are used to improve the final surface characteristics.

Shearing Process

1. **Punching:** shearing process using a die and punch where the **interior** portion of the sheared sheet is to be **discarded.**

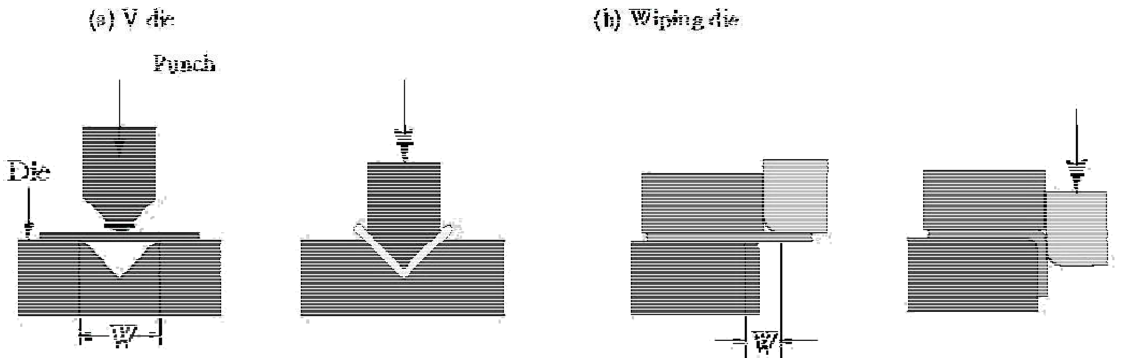
2. **Blanking:** shearing process using a die and punch where the **exterior** portion of the shearing operation is to be **discarded**.
3. **Perforating**: punching a number of holes in a sheet
4. **Parting:** shearing the sheet into two or more pieces
5. **Notching:** removing pieces from the edges
6. **Lancing:** leaving a tab without removing any material



Shearing Operations: Punching, Blanking and Perforating

Forming Processes

- **Bending:** forming process causes the sheet metal to undergo the desired shape change by bending without failure. Ref fig.1



Stretching: forming process causes the sheet metal to undergo the desired shape change by stretching without failure. Ref fig.2

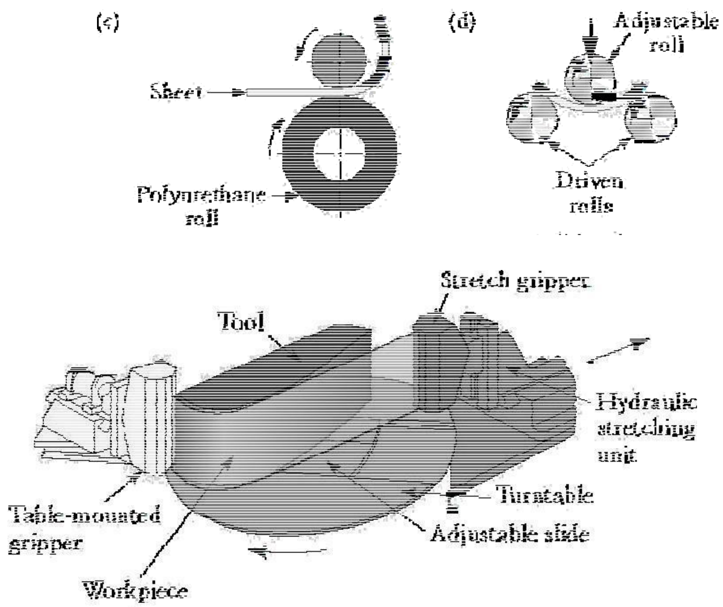


Fig.2 Schematic illustration of a stretch-forming process.

- **Deep Drawing:** forming process causes the sheet metal to undergo the desired shape change by drawing without failure. Ref fig.3

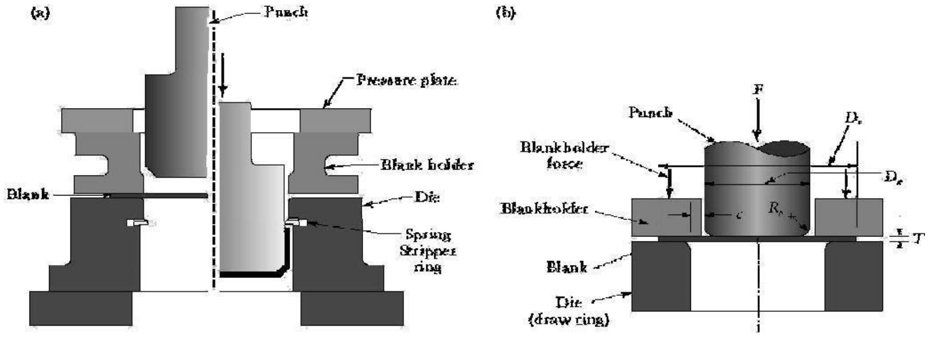


Fig. 3 Schematic of the Drawing process

- **Roll forming:** Roll forming is a process by which a metal strip is progressively bent as it passes through a series of forming rolls. Ref fig.4

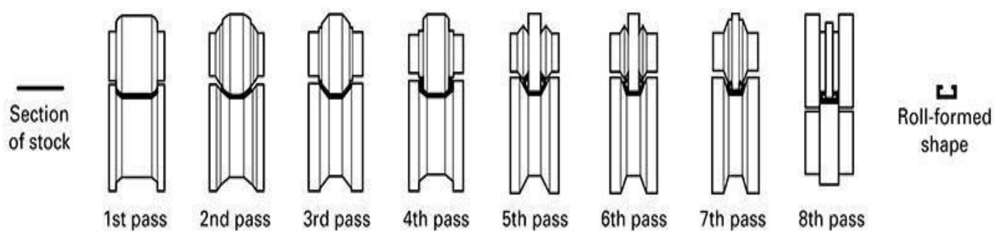
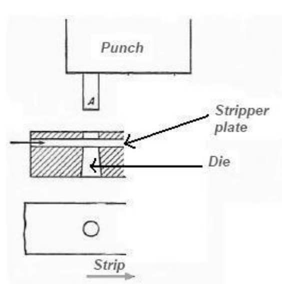
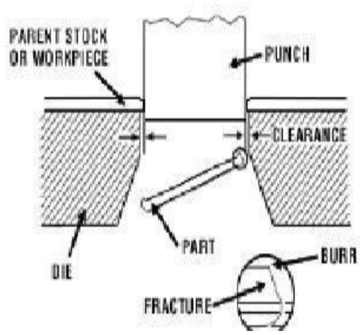


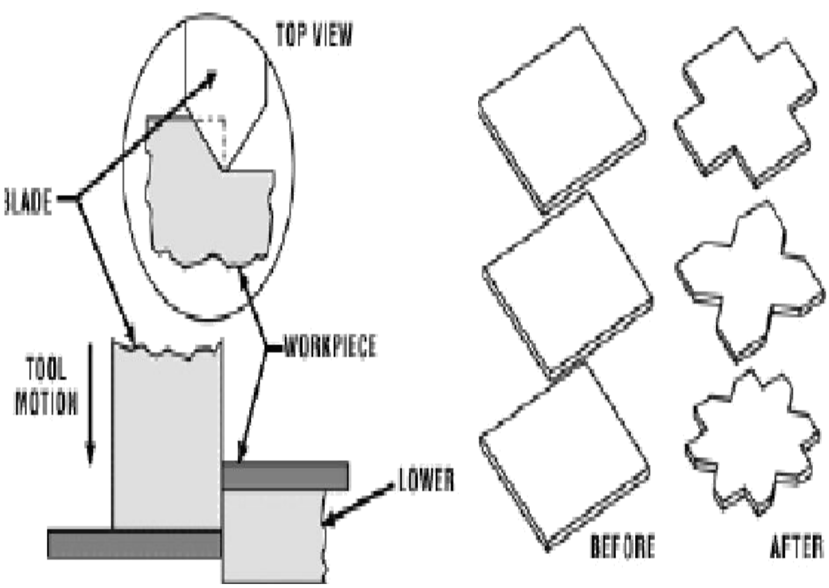
Fig. 4 Eight-roll sequence for the roll forming of a box channel

- **Punching or piercing :** The shearing of the material when the metal inside the contour is discarded. The punch A is piercing the hole for the washer.



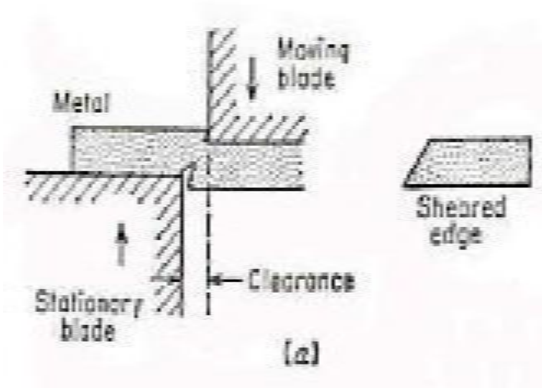
- **Blanking:** The shearing of close contours, when the metal inside the contour is the desired part

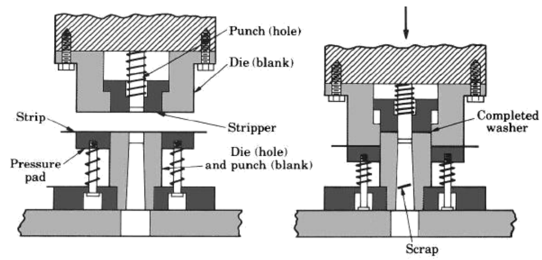




- **Notching:** The punch removes material from the edge or corner of a strip or blank or part.

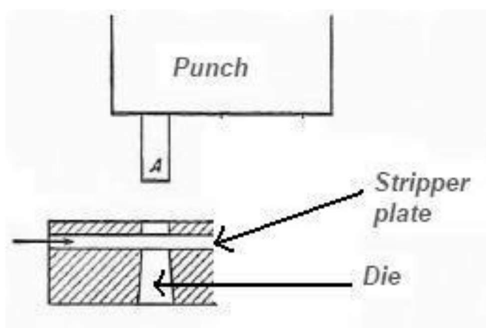
- **Shearing:** The separation of metal by the movement of two blades operated based on shearing forces.





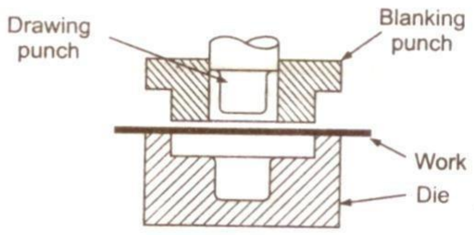
Dies and Punches

Simple- single operation with a single stroke

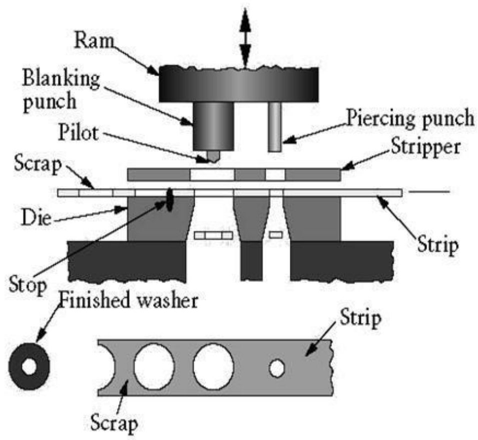


Compound- two operations with a single stroke

Combination- two operations at same station.



Progressive- two or more operations at two or more stations with each press stroke, creates what is called a strip development Punches and dies are designed so that successive stages in the forming of the part are carried out in the same die on each stroke of the press. Progressive dies are also known as multi-stage dies.



Limiting draw ratio (LDR)

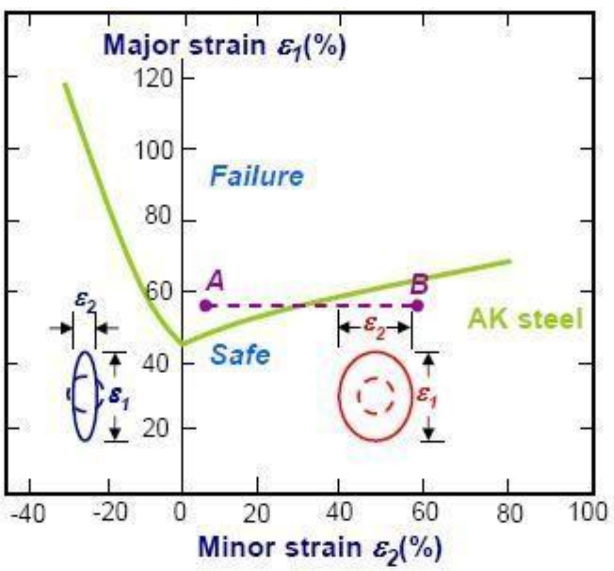
Drawability is a ratio of the initial blank diameter (Do) to the diameter of the cup drawn from the blank to punch diameter (DP)

$$LDR \approx \left(\frac{D_o}{D_p}\right)_{max} \approx e^{\eta}$$

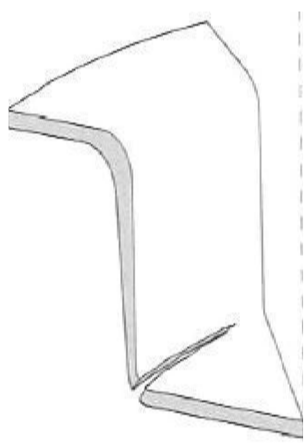
Where η, is an efficiency term accounting for frictional losses. Normally the average maximum reduction in deep drawing is ~ 50%.

Forming limit criteria

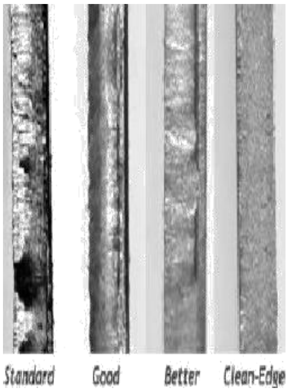
Tensile test only provides ductility, work hardening, but it is in a uniaxial tension with frictionless, which cannot truly represent material behaviours obtained from unequal biaxial stretching occurring in sheet metal forming. Sheet metal formability tests are designed to measure the ductility of a material under condition similar to those found in sheet metal forming.



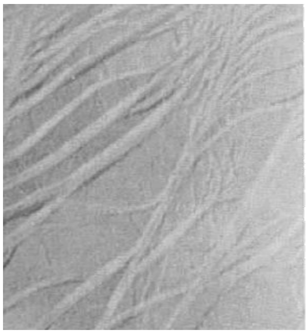
Defects in Forming



Cracks



Edge Forming



Strain on surface

- Radial cracks in the flanges and edge of the cup due to not sufficient ductility to withstand large circumferential shrinking.
- Wrinkling of the flanges or the edges of the cup resulting from buckling of the sheet (due to circumferential compressive stresses) solved by using sufficient hold-down pressure to suppress the buckling.
- Surface blemishes due to large surface area. EX: orange peeling especially in large grain sized metals because each grain tends to deform independently use finer grained metals.
- Mechanical fibering has little effect on formability.
- Crystallographic fibering or preferred orientation may have a large effect. Ex: when bend line is parallel to the rolling direction, or earing in deep drawn cup due to anisotropic properties.

Simple Calculation Formulas:

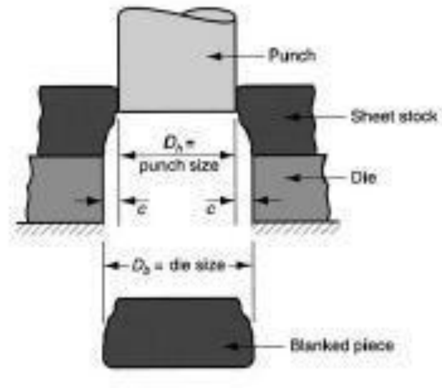
Clearance in Sheet Metal Cutting

- Distance between the punch and die
- Typical values range between 4% and 8% of stock thickness

– If too small, fracture lines pass each other, causing double burnishing and larger force

– If too large, metal is pinched between

Cutting edges and excessive burr results



where c = clearance

Die size determines blank size D_b; punch size determines hole size

- *Low "c" for soft materials*
- *High "c" for hard materials*

For a round *blank* of diameter D_b:

Blanking punch diameter = $D_b - 2c$

Blanking die diameter = D_b

For a round *hole* of diameter D_h: Hole punch diameter = D_h

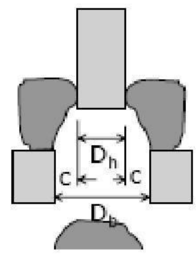
Hole die diameter = $D_h + 2c$

- Recommended clearance can be calculated by: c = *at;* where c = clearance; *a* = allowance; and *t* = stock thickness
- Allowance *a* is determined according to type of metal

Metal group	*a*
1100S and 5052S aluminum alloys, all tempers	0.045
2024ST and 6061ST aluminum alloys; brass, soft cold rolled steel, soft stainless steel	0.060

Cold rolled steel, half hard; stainless steel, half hard and full hard	0.075

Cutting Forces



*F=S*t*L; Where: S= Shear strength; t=thickness; L=length of cutting edge; Important to determine the press capacity (tonnage)If shear strength is not known cutting force can be estimated as: F=0.7*TS*t*L Where TS =Ultimate tensile strength*

$$BA = 2\pi \frac{A}{360}(R + K_{ba}t)$$

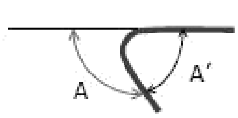
- If $R < 2t$, $K_{ba} = 0.33$
- If $R \geq 2t$, $K_{ba} = 0.50$

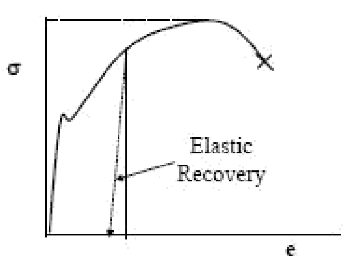
Stretching during Bending

• If bend radius is small relative to stock thickness, metal tends to stretch during bending

• Important to estimate amount of stretching, so that final part length = specified dimension

• Problem: to determine the length of neutral axis of the part before bending Where, *BA* = bend allowance; *A* = bend angle; *R*= bend radius; *t* = stock thickness and *Kba* is factor to estimate stretching





$$SB = \frac{A' - A'_b}{A'_b}$$

A' = included angle of the sheet metal part

A'_b = included angle of the bending tool

Bending Force

Maximum bending force estimated as follows: Where,

F = bending force

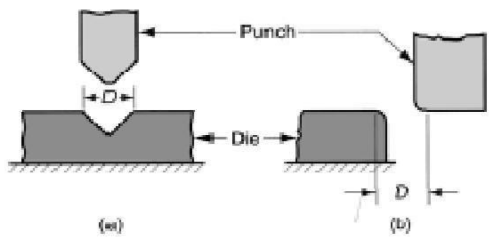
TS = tensile strength of sheet metal

w = part width in direction of bend axis *t* = stock thickness

D = die opening dimension

$$F = \frac{K_{bf} TS w t^2}{D}$$

- For V- bending, $K_{bf} = 1.33$
- For edge bending, $K_{bf} = 0.33$



UNIT 8: High Energy Rate Forming (HERF) Processes

Introduction:

The forming processes are affected by the rates of strain used.

Effects of strain rates during forming:

- The flow stress increases with strain rates
- The temperature of work is increases due to adiabatic heating.
- Improved lubrication if lubricating film is maintained.
- Many difficult to form materials like Titanium and Tungsten alloys, can be deformed under high strain rates.

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.
- **Advantages of HERF Processes**

i) Production rates are higher, as parts are made at a rapid rate.

ii) Die costs are relatively lower.

iii) Tolerances can be easily maintained.

iv) Versatility of the process – it is possible to form most metals including difficult to form metals.

v) No or minimum spring back effect on the material after the process.

vi) Production cost is low as power hammer (or press) is eliminated in the process. Hence it is economically justifiable.

vii) Complex shapes / profiles can be made much easily, as compared to conventional forming.

viii) The required final shape/ dimensions are obtained in one stroke (or step), thus eliminating intermediate forming steps and pre forming dies.

ix) Suitable for a range of production volume such as small numbers, batches or mass production.

Limitations:

i) Highly skilled personnel are required from design to execution.

ii) Transient stresses of high magnitude are applied on the work.

iii) Not suitable to highly brittle materials

iv) Source of energy (chemical explosive or electrical) must be handled carefully.

v) Governmental regulations/ procedures / safety norms must be followed.

vi) Dies need to be much bigger to withstand high energy rates and shocks and to prevent cracking.

vii) Controlling the application of energy is critical as it may crack the die or work.

viii) It is very essential to know the behavior or established performance of the work metal initially.

Applications:

i) In ship building – to form large plates / parts (up to 25 mm thick).

ii) Bending thick tubes/ pipes (up to 25 mm thick).

iii) Crimping of metal strips.

iv) Radar dishes

v) Elliptical domes used in space applications.

vi) Cladding of two large plates of dissimilar metals.

Explosive Forming

Introduction:

A punch in conventional forming is replaced by an explosive charge.

Explosives used can be:

- High energy chemicals like TNT, RDX, and Dynamite.
- Gaseous mixtures
- Propellants.

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.

Types of explosive forming:

1) Unconfined type or Stand off technique
2) Confined type or Contact technique
3) Unconfined type (or Stand off technique)

Principle: The work is firmly supported on the die and the die cavity is evacuated. A definite quantity of explosive is placed suitably in water medium at a definite stand off distance from the work. On detonation of the explosive charge, a pressure pulse (or a shock wave) of very high intensity is produced.

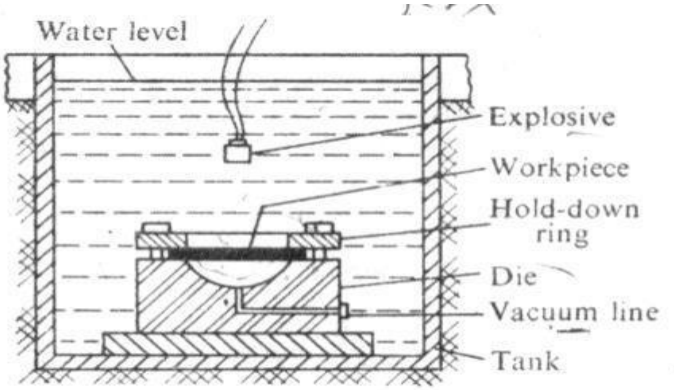


Fig. Unconfined Type Explosive Forming

A gas bubble is also produced which expands spherically and then collapses. When the pressure pulse impinges against the work (plate or sheet0, the metal is deformed into the die with a high velocity of around 120 m/s (430km/h).

The vacuum is necessary in the die to prevent adiabatic heating of the work which may lead to oxidation or melting.

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 sis available.
- Standoff 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

Advantages;

- Shock wave is efficiently transmitted through water and energy is transmitted effectively on the work
- Less noise
- Less probability of damage to work.
- Large and thick parts can be easily formed
- Economical, when compared to a hydraulic press

Limitations:

- Optimum SOD is essential for proper forming operation.
- Vacuum is essential and hence it adds to the cost.
- Dies must be larger and thicker to withstand shocks.
- Not suitable for small and thin works.
- Explosives must be carefully handled according to the regulations of the government.

Applications:

- Ship building,
- Radar dish,
- Elliptical domes in space applications

2) Confined System (or Contact Technique)

Principle: The pressure pulse or shock wave produced is in direct contact with the work piece (usually tubular) and hence the energy is directly applied on the work without any water medium. The tube collapses into the die cavity and is formed. It is used for bulging and flaring operations.

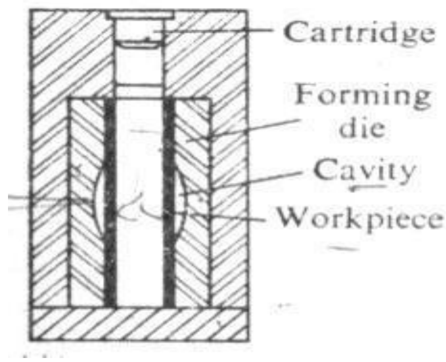


Fig. Confined (Contact) type Explosive Forming

Advantages:

- Entire shock wave front is utilized as there is no loss in water.
- More efficient as compared to unconfined type.

Disadvantages:

- More hazard of die failure
- Vacuum is required in the die
- Air present in the work piece (tube) is compressed leading to heating.
- Not suitable for large and thick plates.

Applications; Bulging and flaring of tubes.

(II) **Electro hydraulic Forming**

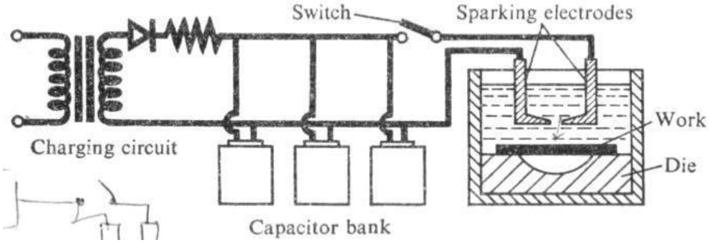


Fig. Electro Hydraulic Forming

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. The characteristics of this process are similar to those of explosive forming. The major difference, however, is that a chemical explosive is replaced by a capacitor bank, which stores the electrical energy.

The 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. The energy released is much lesser than that released in explosive forming.

Process Characteristics:

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

Advantages:

i) Better control of the pressure pulse as source of energy is electrical- which can be easily controlled.
ii) Safer in handling than the explosive materials.
iii) More suitable if the work size is small to medium.
iv) Thin plates can be formed with smaller amounts of energy.
v) The process does not depend on the electrical properties of the work material.

Limitations:

i) Suitable only for smaller works
ii) Need for vacuum makes the equipment more complicated.
iii) Proper SOD is necessary for effective process.

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

Electromagnetic forming

The electrical energy stored in a capacitor bank is used to produce opposing magnetic fields around a tubular work piece, surrounded by current carrying coils. The coil is firmly held and hence the work piece collapses into the die cavity due to magnetic repelling force, thus assuming die shape.

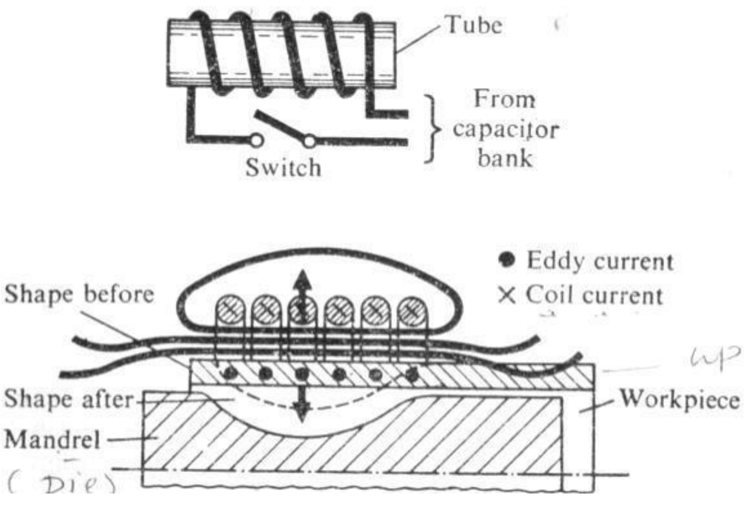


Fig. Electro Magnetic Forming

Process details/ Steps:

i) The electrical energy is stored in the capacitor bank

ii) The tubular work piece is mounted on a mandrel having the die cavity to produce shape on the tube.

iii) A primary coil is placed around the tube and mandrel assembly.

iv) When the switch is closed, the energy is discharged through the coil

v) The coil produces a varying magnetic field around it.

vi) In the tube a secondary current is induced, which creates its own magnetic field in the opposite direction.

vii) The directions of these two magnetic fields oppose one another and hence the rigidly held coil repels the work into the die cavity.

viii) The work tube collapses into the die, assuming its shape.

Process parameters:

i) Work piece size

ii) Electrical conductivity of the work material.

iii) Size of the capacitor bank

iv) The strength of the current, which decides the strength of the magnetic field and the force applied.

v) Insulation on the coil.

vi) Rigidity of the coil.

Advantages:

i) Suitable for small tubes

ii) Operations like collapsing, bending and crimping can be easily done.

iii) Electrical energy applied can be precisely controlled and hence the process is accurately controlled.

iv) The process is safer compared to explosive forming.

v) Wide range of applications.

Limitations:

i) Applicable only for electrically conducting materials.

ii) Not suitable for large work pieces.

iii) Rigid clamping of primary coil is critical.

iv) Shorter life of the coil due to large forces acting on it.

Applications:

i) Crimping of coils, tubes, wires

ii) Bending of tubes into complex shapes

iii) Bulging of thin tubes.

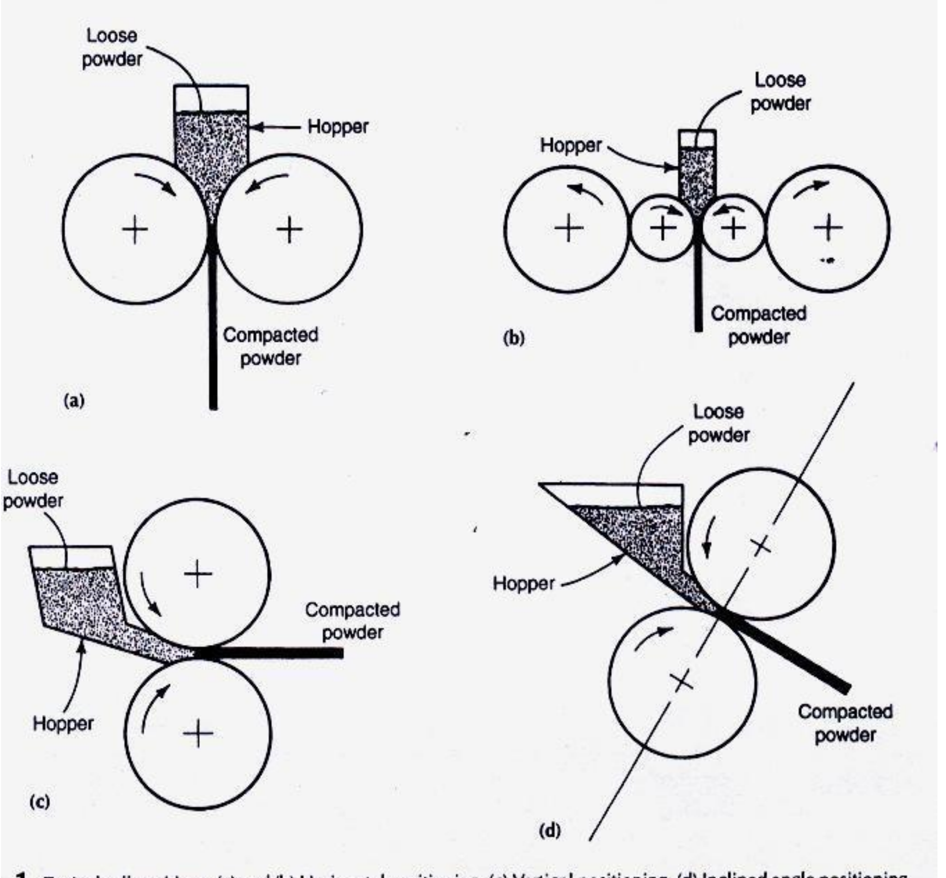
Powder Metallurgy

Powder Production Reduction,Electrolytic deposition, Pulverization, Mechanical Alloy and othersBlending of powdersCompaction of Powders Punch and Die,Rolling, Extrusion, Injection Moulding, Isostatic Pressing SinteringTypical Sintering set up

Powder Rolling

*In powder rolling (powder compaction) the powder is fed into the roll gap in a two high rolling mill and is compacted into a continuous strip at speeds up to 0.5m/s.*The process can be carried out at room temperature or at elevated temperatures.

*Sheet metal for electrical and electronic components, coins can be made by powder rolling.



. 1 Typical roll positions. (a) and (b) Horizontal positioning. (c) Vertical positioning. (d) Inclined angle positioning

Powder Extrusion

*Powders can be compacted by extrusion.*The metal powder is encased in a container and extruded.

*After sintering, preformed PM parts may be rolled or forged in a closed die to their shape.

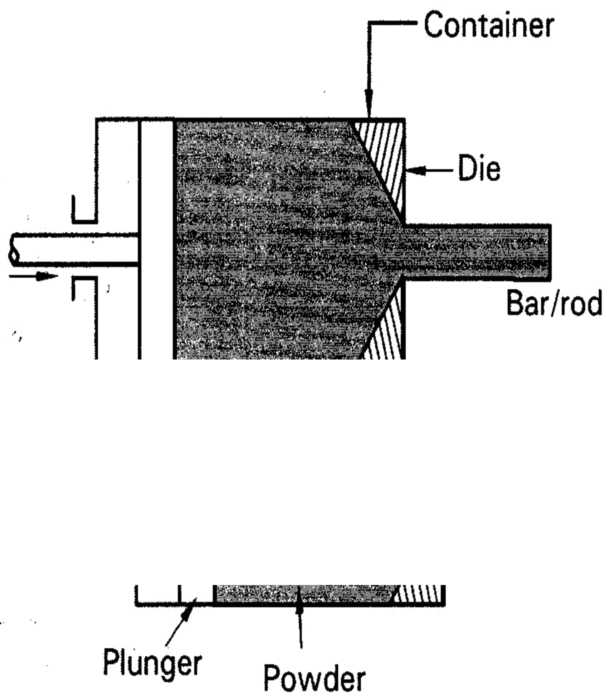
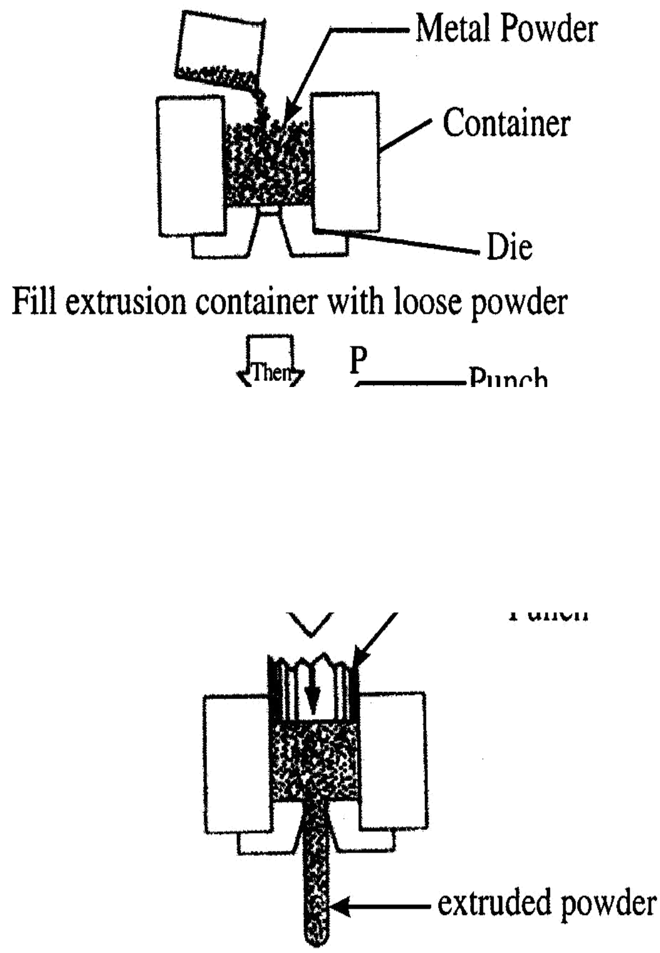


Fig. 8.11 Powder Extrusion

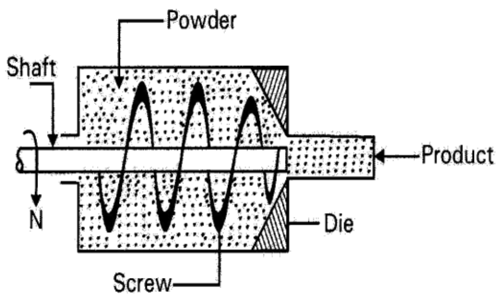


Hot extrusion methods for metal powders

Powder Injection Moulding

*It is also called metal injection moulding.*Very fine metal powders (<10µm) are blended with a polymer or a wax based binder.*The blended mixture undergoes compaction due to pressure.*The green compacts are heated in a oven at low temperature to burn off plastic and then sintered in a furnace.

Pressing can be carried out either at room temperature or at elevated temperature. *The powder must flow easily into the die cavity.*The density of the green compact, depends on pressure applied during compaction.*By using particles of different shape, very close packing of the metal powder can be achieved*Higher density results in higher strength and higher elastic modulus of the components.



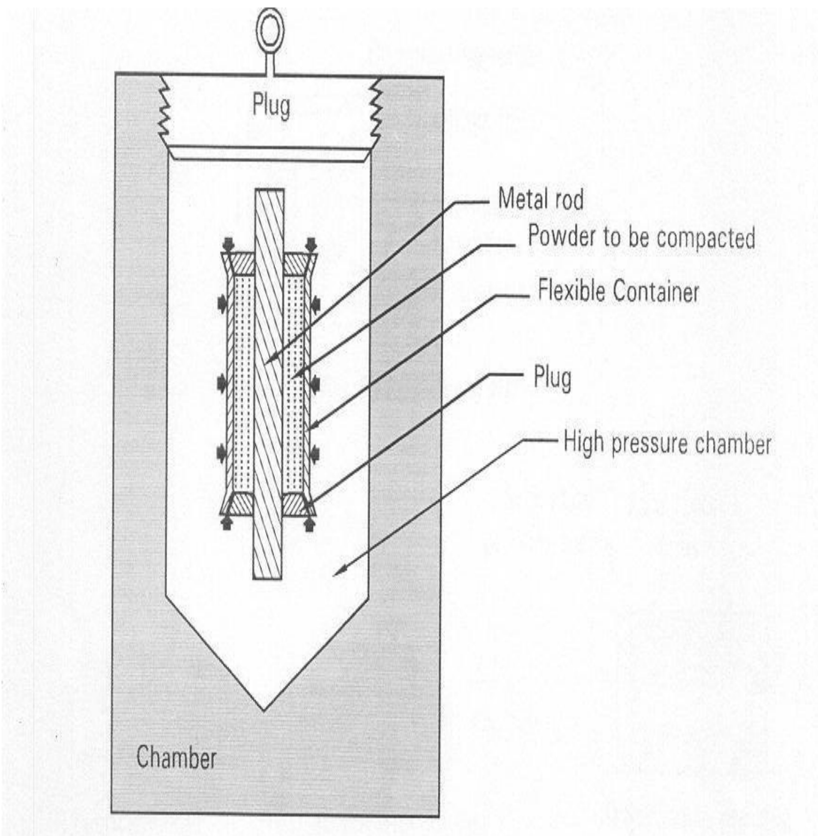
The normal compaction pressure ranges from 70Mpa for aluminium to 800Mpa for iron parts.*Crank or eccentric type mechanical presses are used for small tonnage.*Toggle or knuckle joint presses are used for higher capacities.
*Hydraulic process (450MN) are employed for large components. Compaction can also be carried out by a number of other processes such as isostatic pressing, rolling and forging.*Since the density of the compacted powders can vary significantly, green compacts are subjected to hydrostatic pressures in order to achieve more uniform density.

Isostatic pressing:

*This type of operation is used for compaction of powders. *The process is similar to pressing using cupped hands for making snow balls.

Cold Isostatic Pressing

*In cold isostatic pressing (CIP) the metal powder is placed in a flexible mould made of rubber or Urethane or PVC.*The assembly is then pressurize hydrostatically in a chamber usually using water. *Pressures of 400 to 1000MPa are used.



Cold Isostatic Pressing

The powder is enclosed in flexible container around a solid core rod. Pressure is applied isostatically to the assembly inside a high pressure chamber. The powder gets compacted and the green compact is taken out and sintered.

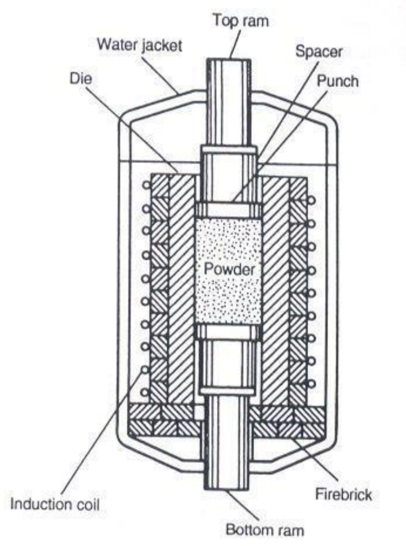
Hot Isostatic Pressing

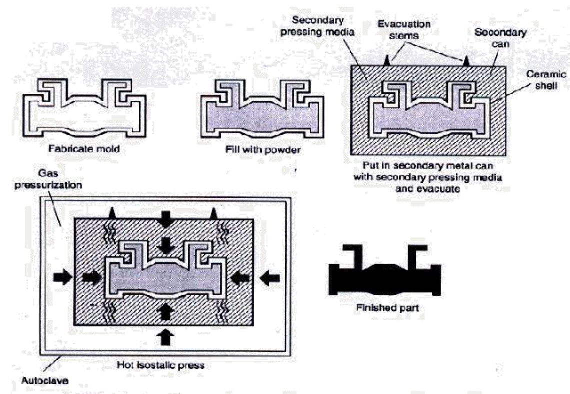
In Hot Isostatic Pressing (HIP) a metal powder is stressed using inert gas in a metal container. *Pressure of 100MPa at 1000oC is used.*Here a container made of very high melting point metal is used.*An inert gas is used as the pressuring media.The main advantage of HIP is its ability to produce compacts with essentially 100% density, good

metallurgical bonding among the particles with good mechanical properties*HIP process is relatively expensive and is used for making super alloy components for aerospace industry.

*It is regularly used for the densification of WC cutting tools and PM tool steels.

HIP is also used to close the internal porosity and improve properties in superalloy and Ti alloy castings for the aerospace industry.The main advantage of isostatic pressing is the absence of wall friction as pressure is being applied from all directions.It produces compacts of practically uniform grain structure and density irrespective of shape.

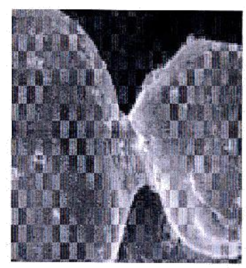




Schematic diagram of ceramic mold process for producing fully dense P/M shapes. Source: Ref 24

Step 4: Sintering

- It is the heating of the compacted metal powders to a temperature above their recrystallisation temperature but below their melting point.


Sintering or consolidation at high temperatures

Hot Isostatic Pressing

Figure shows the details of producing PM component.Here a mold is used into which metal powder is filled.This is then surrounded by a secondary pressing media.Then vacuum is applied.The entire assembly is kept in an autoclave Chamber and subjected to HIP.Necessary pressure is applied through the chamber and temperature is maintained at a known value. As a result the compacted metal powder gets sintered finally the component is taken out of the system to get the finished.`