

METAL FORMING PROCESSES

UNIT - I

stress

- * The force of resistance per unit area, offered by a body against deformation is known as stress.
- * The external force acting on the body is called the load or force.
- * The load is applied on the body while the stress is induced in the material of the body.
- * A loaded member remains in equilibrium when the resistance offered by the member against the deformation and the applied load are equal.

mathematically stress is written as,

$$\sigma = \frac{P}{A}$$

where, σ = stress (also called intensity of stress),

P = External force or load, and

A = cross-sectional area.

In the S.I. units, the force is expressed in newtons (written as N) and the area is expressed as m^2 . Hence unit of stress becomes as N/m^2 . The area is also expressed in millimetre square then unit of force becomes as N/mm^2 .

strain :-

- * When a body is subjected to some external force, there is some change of dimension of the body.
- * The ratio of change of dimension of the body to the original dimension is known as strain. strain is dimensionless.

strain may be:

- ① Tensile strain
- ② Compressive strain
- ③ Volumetric strain, and
- ④ shear strain.

- * If there is some increase in length of a body due to external force, then the ratio of increase of length to the original length of the body is known as tensile strain.
- * But if there is some decrease in length of the body, then the ratio of decrease of the length of the body to the original length is known as compressive strain.
- * The ratio of change of volume of the body to the original volume is known as volumetric strain.
- * The strain produced by shear stress is known as shear strain.

Types of stresses:

- ① Tensile stress
- ③ Shear stress.

- ② Compressive stress

- * The stress may be normal stress or shear stress.
- * Normal stress is the stress which acts in a direction perpendicular to the area. It is represented by σ (sigma).
- * The normal stress is further divided into tensile stress and compressive stress.

① Tensile stress

* The stress induced in a body, when subjected to two equal and opposite pulls as shown in figure (1) as a result of which there is an increase in length, is known as tensile stress.

* The tensile stress acts normal to the area and it pulls on the area.

Let, P = pull (or force) acting on the body,

A = Cross-sectional area of the body,

L = Original length of the body,

ΔL = Increase in length due to pull P acting on the body,

σ = stress induced in the body, and

ϵ = strain (i.e., tensile strain)

* Fig.(1) shows a bar subjected to a tensile force P at its ends.

* Consider a section $X-X$, which divides the bar into two parts.

* The part left to the section $X-X$, will be in equilibrium if $P = R$. This is shown in fig(1)(b).

* Similarly the part right to the section $X-X$, will be in equilibrium if $P = R$ as shown in fig(1)(c).

* This resisting force per unit area is known as stress (σ) or intensity of stress.

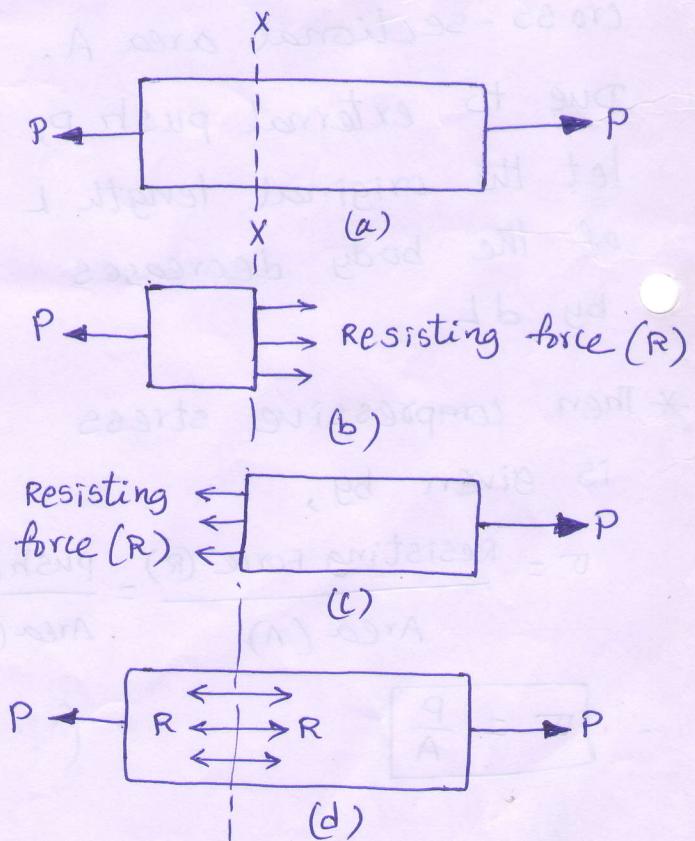


Figure (1)

$$\therefore \text{Tensile stress, } \sigma = \frac{\text{Resisting force (R)}}{\text{Cross-sectional area}} = \frac{\text{Tensile load (P)}}{A}$$

$$\boxed{\sigma = \frac{P}{A}}$$

$$(\because P = R)$$

② Compressive stress :-

- * The stress induced in a body, when subjected to two equal and opposite pushes as shown in figure (2), as a result of which there is a decrease in length of the body, is known as compressive stress.
- * The compressive stress acts normal to the area and it pushes on the area.

- Let an axial push P is acting on a body in cross-sectional area A .

Due to external push P , let the original length L of the body decreases by dL .

* Then compressive stress is given by,

$$\sigma = \frac{\text{Resisting Force (R)}}{\text{Area (A)}} = \frac{\text{Push (P)}}{\text{Area (A)}}$$

$$\therefore \boxed{\sigma = \frac{P}{A}} \quad (\because R = P)$$

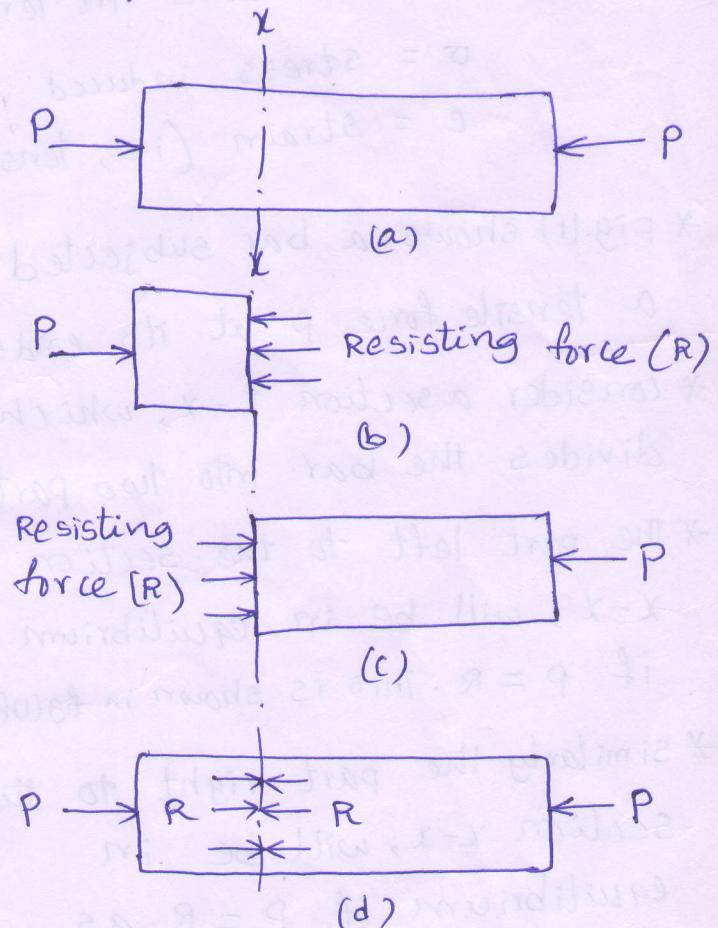
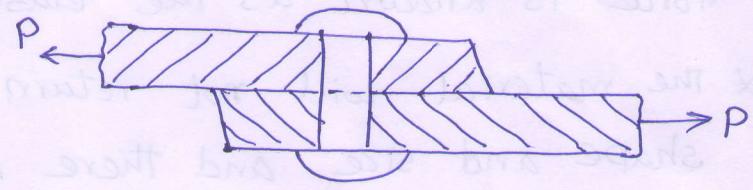


Figure (2)

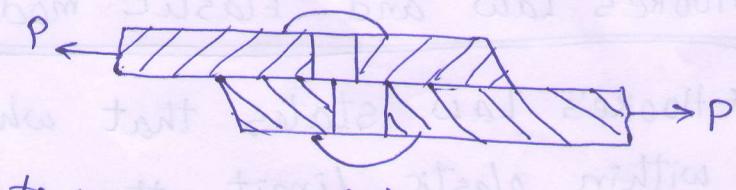
③ shear stress :-

* The stress induced in a body, when subjected to two equal and opposite forces which are acting tangentially across the resisting section as shown in Fig.(3). as a result of which the body tends to shear off across the section, is known as shear stress.



(a)

* The corresponding strain is known as shear strain.



(b)

* The shear stress is the stress which acts tangential to the area. It is represented by τ .

Figure. (3)

$$\therefore \text{shear stress, } \tau = \frac{\text{shear resistance}}{\text{shear area}} = \frac{R}{A} = \frac{P}{A}$$

$$\therefore \boxed{\tau = \frac{P}{A}}$$

$\because (R=P)$

Elasticity and Elastic Limit :-

* When an external force acts on a body, the body tends to undergo some deformation. If the external force is removed and the body come back to its original shape and size, the body is known as elastic body.

* The body will regain its previous shape and size only when the deformation caused by the external force, is within a certain limit.

- * Thus there is a limiting force value of force up to and within, which the deformation completely disappears on the removal of the force.
- * The value of stress corresponding to this limiting force is known as the elastic limit of the material.
- * The material will not return to its original ~~shape~~ shape and size and there will be a residual deformation in the material.

Hooke's Law and Elastic modulus:

- * Hooke's Law states that when a material is loaded within elastic limit, the stress is proportional to the strain produced by the stress. This means the ratio of the stress to the corresponding strain is a constant within the elastic limit.
- * This constant is known as modulus of elasticity (or) modulus of Rigidity (or) Elastic modulus.

Modulus of Elasticity (or) Young's modulus:

- * The ratio of tensile stress (or) compressive stress to the corresponding strain is a constant. It is denoted by E.

$$\therefore E = \frac{\text{Tensile stress}}{\text{Tensile strain}} \quad (\text{or}) \quad \frac{\text{Compressive stress}}{\text{Compressive strain}}$$

$$- \therefore E = \frac{\sigma}{\epsilon}$$

Modulus of Rigidity (or) Shear modulus:

- * The ratio of shear stress to the corresponding shear strain within the elastic limit.

Factor of safety :-

It is defined as the ratio of ultimate tensile stress to the working (or permissible) stress.

$$\therefore \text{Factor of safety} = \frac{\text{ultimate stress}}{\text{permissible stress}}$$

Longitudinal strain :-

* When a body is subjected to an axial tensile load, there is an increase in the length of the body. But at the same time there is a decrease in other dimensions of the body at right angles to the line of action of the applied load.

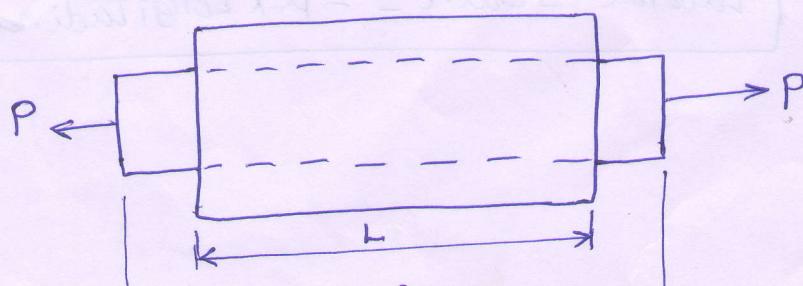
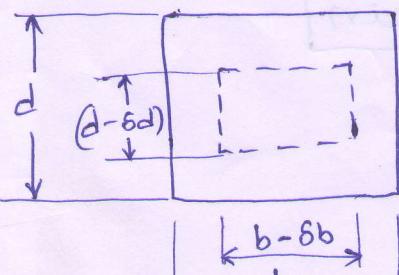
* Thus the body is having axial deformation and also deformation at right angles to the line of action of the applied load (i.e., lateral deformation).

* The ratio of axial deformation to the original length of the body is known as longitudinal (or linear) strain.

$$\therefore \text{Longitudinal strain} = \frac{\delta L}{L}$$

Lateral strain :-

* The strain at right angles to the direction of applied load is known as lateral strain.



* Let a rectangular bar of length L , breadth b and depth d is subjected to an axial tensile load P as shown in figure.

* The length of the bar will increase while the breadth and depth will decrease.

Let δL = Increase in length

δb = Decrease in breadth, and

δd = Decrease in depth.

Then longitudinal strain = $\frac{\delta L}{L}$

and Lateral strain = $\frac{\delta b}{b}$ or $\frac{\delta d}{d}$

Poisson's ratio :-

* The ratio of lateral strain to the longitudinal strain is a constant for a given material, when the material is stressed within the elastic limit. It is denoted by μ . Hence mathematically,

Poisson's ratio, $\mu = \frac{\text{Lateral strain}}{\text{Longitudinal strain}}$.

(01) Lateral strain = $\mu \times$ Longitudinal strain.

* As lateral strain is opposite in sign to longitudinal strain, hence algebraically, lateral strain is written as

Lateral strain = $-\mu \times$ Longitudinal strain

One-Dimensional stress analysis :-

- * The relationship between stress and strain for a unidirectional stress (i.e., for normal stress in one direction only) is given by Hooke's law, which states that when a material is loaded within its elastic limit, the normal stress developed is proportional to the strain produced.
- * This means that the ratio of the normal stress to the corresponding strain is a constant within the elastic limit.
- * This constant is represented by E and is known as Young's modulus of elasticity.

$$\therefore \frac{\text{normal stress}}{\text{corresponding strain}} = \text{constant} \quad (\text{or}) \quad \frac{\sigma}{e} = E$$

$$(\text{or}) \quad e = \frac{\sigma}{E}$$

The above equation gives the stress and strain relation for the normal stress in one direction.

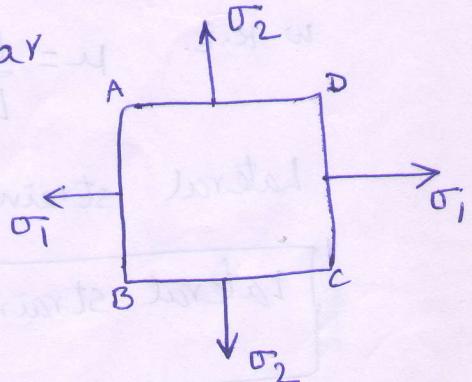
Two-Dimensional stress analysis :-

- * Consider a two-dimensional figure ABCD, subjected to two mutually perpendicular stresses σ_1 and σ_2 .

Refer to figure (i).

Let σ_1 = normal stress in x-direction

σ_2 = normal stress in y-direction.



Consider the strain produced by σ_1

* The strain in the direction of x

$$\text{Young's modulus, } E = \frac{\sigma_1}{e}$$

$$\therefore e_{x0} = \frac{\sigma_1}{E}$$

* The strain in the direction of y

$$\text{w.r.t. Poisson's ratio, } \mu = \frac{\text{Lateral strain}}{\text{Longitudinal strain}}$$

$$\text{Lateral strain} = -\mu \times \text{Longitudinal strain}$$

$$\text{Lateral strain} = -\mu \times \frac{\sigma_1}{E}$$

* ~~Total strain in the direction of x~~

~~Strain~~

Consider the strain produced by σ_2

* The strain in the direction of y

$$\text{Young's modulus, } E = \frac{\sigma_2}{e}$$

$$\therefore e_{y0} = \frac{\sigma_2}{E}$$

* The strain in the direction of x

$$\text{w.r.t. } \mu = \frac{\text{lateral strain}}{\text{Longitudinal strain}}$$

$$\text{Lateral strain} = -\mu \times \text{Longitudinal strain}$$

$$\text{Lateral strain} = -\mu \times \frac{\sigma_2}{E}$$

\therefore now total strain in the direction of x due to stresses σ_1 and σ_2 .

$$e_1 = \frac{\sigma_1}{E} - \mu \cdot \frac{\sigma_2}{E}$$

\therefore similarly total strain in the direction of y due to stresses σ_1 and σ_2

$$e_2 = \frac{\sigma_2}{E} - \mu \cdot \frac{\sigma_1}{E}$$

The above two equations gives the stress and strain relationship for the two-dimensional stress analysis.

In the above equations, tensile stress is taken to be positive whereas the compressive stress negative.

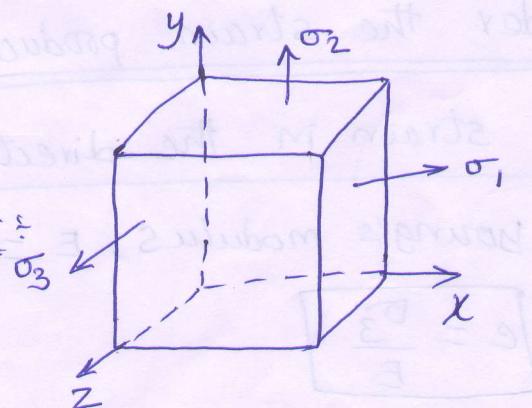
Three-Dimensional stress analysis

* Figure (1) shows a three-dimensional body subjected to three orthogonal normal stresses $\sigma_1, \sigma_2, \sigma_3$ acting in the directions of x, y and z respectively.

* Consider the strains produced by each stress separately.

Consider the strain produced by σ_1 :

* The strain in the direction of x



$$\text{Young's modulus, } E = \frac{\sigma_1}{e}$$

$$\therefore e = \frac{\sigma_1}{E}$$

Fig(1).

* The strain in the direction of y and z:

w.k.t. poisson's ratio, $\mu = \frac{\text{Lateral strain}}{\text{Longitudinal strain}}$

Lateral strain = $-\mu \times \text{Longitudinal strain}$

$$\boxed{\text{Lateral strain} = -\mu \times \frac{\sigma_1}{E}}$$

Consider the strain produced by σ_2 :

* The strain in the direction of y:

young's modulus, $E = \frac{\sigma_2}{e}$

$$\boxed{e = \frac{\sigma_2}{E}}$$

* The strain in the direction of x and z:

w.k.t $\mu = \frac{\text{lateral strain}}{\text{Longitudinal strain}}$

Lateral strain = $-\mu \times \text{longitudinal strain}$

$$\boxed{\text{Lateral strain} = -\mu \times \frac{\sigma_2}{E}}$$

Consider the strain produced by σ_3

* The strain in the direction of z:

young's modulus, $E = \frac{\sigma_3}{e}$

$$\therefore \boxed{e = \frac{\sigma_3}{E}}$$

* The strain in the direction of x and y:

w.k.t $\mu = \frac{\text{lateral strain}}{\text{Longitudinal strain}}$

\therefore Lateral strain = $-\mu \times \text{longitudinal strain}$

∴ Total strain in the direction of x due to stresses

σ_1, σ_2 and σ_3 .

$$e_1 = \frac{\sigma_1}{E} - \mu \cdot \frac{\sigma_2}{E} - \mu \cdot \frac{\sigma_3}{E}$$

∴ similarly total strain in the direction of y due to stresses σ_1, σ_2 and σ_3 .

$$e_2 = \frac{\sigma_2}{E} - \mu \cdot \frac{\sigma_3}{E} - \mu \cdot \frac{\sigma_1}{E}$$

∴ similarly total strain in the direction of z due to stresses σ_1, σ_2 and σ_3

$$e_3 = \frac{\sigma_3}{E} - \mu \cdot \frac{\sigma_1}{E} - \mu \cdot \frac{\sigma_2}{E}$$

The above three equations give the stress and strain relationship for the three orthogonal normal stress system.

Relation between Engineering stress and True stress :

when a ductile material is subjected to tensile stress, beyond a certain stress, the cross sectional area of the material decreases at a particular position in the specimen; i.e., a constriction develops at a particular position. This is called necking. The area of the load is increased.

The true stress at any ~~time~~ time of loading, is the force divided by the instantaneous

at the instant of time (at the neck); i.e.,

$$\boxed{\text{True stress } (\sigma_T) = \frac{F}{A_i}} \quad ①$$

The engineering stress, on the other hand, is the force divided by the original area of cross-section i.e.,

$$\boxed{\text{Engineering stress } (\sigma) = \frac{F}{A_0}}$$

Relation between engineering stress (σ) and true stress (σ_T) is :

Assuming that there is no volume change during deformation

$$\boxed{A_0 L_0 = A_i L_i}$$

$$A_i = \frac{A_0 L_0}{L_i} \quad (or)$$

$$\boxed{A_i = A_0 \left[\frac{L_0}{L_i} \right]} \quad \text{so that}$$

we know that

$$\text{True stress, } \sigma_T = \frac{F}{A_i}$$

substitute the value "A_i" in equation ①

$$\sigma_T = \frac{F}{A_0 \left[\frac{L_0}{L_i} \right]} \Rightarrow \sigma_T = \frac{F \cdot L_i}{A_0 \cdot L_0}$$

$$\therefore \sigma_T = \frac{F}{A_0} \cdot \frac{L_i}{L_0}$$

$$\left[\because \sigma = \frac{F}{A_0} \right]$$

$$\therefore \sigma_T = \sigma \left[\frac{L_i}{L_0} \right]$$

Relation between Engineering strain and True strain

- * When a ductile material is subjected to some external force, there is some change of dimension of the body.
- * The ratio of change of dimension of the body to the original dimension is known as Engineering strain.

$$\therefore \text{Engineering strain, } e = \frac{L_i - L_0}{L_0}$$

$$e = \frac{L_i - L_0}{L_0} \Rightarrow e = \frac{L_i}{L_0} - 1$$

$$e = \frac{L_i}{L_0} - 1 \Rightarrow e + 1 = \frac{L_i}{L_0} \quad (1)$$

$$\Rightarrow \boxed{\frac{L_i}{L_0} = e + 1} \quad (1)$$

where,
 L_i = Instantaneous length of the specimen.
 L_0 = original length of the specimen.

- * True strain is defined as the instantaneous elongation per unit length of the specimen.

$$\therefore \text{True strain, } e_T = \int_{L_0}^{L_i} \frac{1}{x} dx = (\log x) \Big|_{L_0}^{L_i} = \log L_i - \log L_0$$

$$\boxed{e_T = \ln \left[\frac{L_i}{L_0} \right]} \quad (2)$$

Relation between Engineering strain, e and True strain, e_T is:

using eqn. (2)

$$e_T = \ln \left[\frac{L_i}{L_0} \right]$$

Substitute the value $\frac{L_i}{L_0}$ in eqn. (2)

$$\boxed{e_T = \ln [e + 1]} \quad (1+1)$$

yield criteria and yield locus :-

- * A yield criteria is a hypothesis is defining the limit of elasticity in a material and the onset of plastic deformation under any possible combination of stress.
- * yielding will occur when the maximum shear stress reaches the values of the maximum shear stress occurring under simple tension.
- * yield locus is a point where the maximum shear stress exist due to which fatigue failure of the component exerts.

Metal Forming :-

- * Forming is the process in which the desired shape and size are obtained through the plastic deformation of a material. The stresses induced during the process are greater than the yield strength, but less than the fracture strength, of the material.

classification of metal forming :-

① Hot working :-

- * In hot working process is carried above the recrystallization temperature with or without actual heating.

- * In hot working, the temperature at which the working is completed is important because any extra heat

Advantages of Hot working :

- * As the material is above the recrystallization temperature, any amount of working can be imparted since there is no strain hardening taking place.
- * At high temperature, the material would have higher amount of ductility and therefore there is no limit on the amount of hot working that can be done on a material. Even brittle materials can be hot worked.
- * Since the shear stress gets reduced at higher temperatures, hot working requires much less force to achieve the necessary deformation.
- * It is possible to continuously reform the grains in metal working and if the temperature and rate of working are properly controlled, a very favourable grain size could be achieved giving rise to better mechanical properties.

Disadvantages of Hot working :

- * Some metals cannot be hot worked because of their brittleness at high temperatures.
- * Higher temperatures of metal give rise to scaling of the surface and as result, the surface finish obtained is poor.
- * Because of the thermal expansion of metals, the dimensional accuracy in hot working is hard to achieve since it is difficult to control the temperature of workpieces.
- * Handling and maintaining of hot metal is difficult and troublesome.

② Cold working :

when the material is deformed below recrystallization temperature. The recrystallization temperature generally varies between one-third to half the melting point of most of the metals.

Advantages of cold working :

- * cold working increases the strength and hardness of the material due to strain hardening. Further, there is no possibility of decarburization of the surface.
- * since the working is done in the cold state, no oxide would form on the surface and consequently, good surface finish is obtained
- * better dimensional accuracy is achieved
- * It is far easier to handle cold parts and also is economical for smaller sizes.

Disadvantages of cold working :

- * Since the material has higher yield strength at lower temperatures, the amount of deformation that can be given to it is limited by the capability of the presses or hammers used.
- * Since the material gets strain hardened, the maximum amount of deformation that can be given is limited. Any further deformation can be given after annealing.
- * Some materials which are brittle cannot be cold worked.