The bodies like chewing gum, lead solder, putty dough (wet mida) and wax which get permanently deformed under the action of forces are called as plastic bodies.

Stress

When an external force F is applied to a body, it gets deformed. Then, the forces of reaction is set within the body to restore the body to its original condition.

The restoring force acting per unit area inside the body is defined as stress.

This restoring force is equal and opposite to the applied force F. Therefore, stress is also defined as

The deforming force per unit cross sectional area of the body.

i.e., $\boxed{\text{Stress} = \dfrac{\text{Deforming force}}{\text{Area}} = \dfrac{F}{A}}$

SI unit for force is newton (N) and that of area is metre^2 (m^2)

$$\therefore \text{ SI unit of stress} = \frac{\text{newton (N)}}{\text{metre}^2\ (\text{m}^2)} = \text{N}/\text{m}^2 \text{ (or) N m}^{-2}.$$

Types of stresses

It is found that the deforming forces may change length or shape or volume of the body. Accordingly, there are three types of stresses namely

(i) **Linear or longitudinal stress**

(ii) **Shearing or tangential stress**

(iii) **Volume or Bulk stress**

Strain

The change in dimension or shape of a body due to the deforming force results in strain.

The strain is measured by the ratio of change in dimension to original dimension. i.e.,

$$\boxed{\text{Strain} = \frac{\text{Change in dimension}}{\text{Original dimension}}}$$

The strain has no unit since it is the ratio of same physical quantities.

Types of strains

According to the changes in length or area (shape) or volume, there are three types of strains namely,

(i) **Linear strain (change in length per unit length)**

(ii) **Shearing strain (change in area per unit area)**

(iii) **Volume or bulk strain (change in volume per unit volume)**

Elastic limit

The maximum stress upto which a body exhibits the property of elasticity is called elastic limit or limit of elasticity.

Hooke's Law

Robert Hooke an English Physicist in the year 167 had given a relation between stress and strain. Thi relation is known as Hooke's law.

Statement

It states that ***"within the elastic limit, stress in a boc is directly proportional to strain produced on it".***

$$\text{Stress} \propto \text{Strain}$$

$$\text{Stress} = \text{Constant} \times \text{Strain}$$

$$\boxed{\frac{\text{Stress}}{\text{Strain}} = \text{E (Constant)}}$$

In other words, the ratio between stress and strain is a constant. **This constant of proportionality is known as coefficient of elasticity or modulus of elasticity.**

E is different for different materials.

1.2 STRESS - STRAIN DIAGRAM AND ITS USES

Consider a wire which is rigidly fixed at one end. It is loaded at the other end. The strains produced for the different loads are noted until the wire breaks down.

A graph is drawn between strain along X-axis and stress along Y-axis. This graph is known as stress - strain diagram or graph (fig. 1.1).

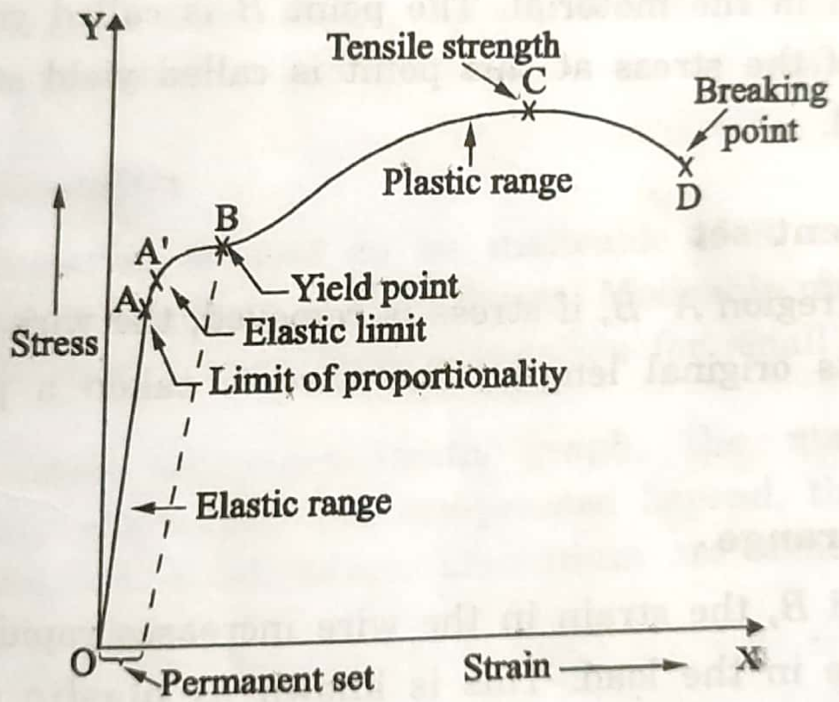

Fig. 1.1 Stress - Strain diagram for low carbon steel wire

The following useful informations regarding the behaviour of solid materials is studied from this diagram.

1. Hooke's law

The portion OA of the curve is a straight line. In this region, stress is directly proportional to strain. This means that upto OA, the material obeys Hooke's law. The wire is perfectly elastic. The point A is called the limit of proportionality.

2. Elastic limit

The stress is further increased till a point A'. The point A', lying near to A denotes the elastic limit.

Upto this point A', the wire regains its original length if the stress is removed. If the wire is l aded beyond the elastic limit, then it will not restore its original length.

3. Yield point

On further increasing the stress beyond the elastic limit, the curve bends and a point B is reached.

In this region $A'B$, a slight increase in stress produces a larger strain in the material. The point B is called yield point. The value of the stress at this point is called yield strength of the material.

4. Permanent set

In the region $A'B$, if stress is removed, the wire will never return to its original length. The wire is taken a permanent set.

5. Plastic range

Beyond B, the strain in the wire increases rapidly without any increase in the load. This is known as **plastic range**.

6. Ultimate tensile strength

If the wire is further loaded, a point C is reached after which the wire begins to neck down. Hence, its cross sectional area is no longer remains uniform.

At this point C, the wire begins to thin down at some point and it finally breaks. At the point C, the stress developed is maximum and it is called ultimate tensile strength or simply tensile strength of the given material.

7. Breaking point

The point 'D' is known as the breaking point where the wire breaks down completely. The stress at the point D is called breaking stress.

Other Elasticity related Material Properties

(i) Ductility

A material is said to be ductile if it can be readily drawn into wires. In terms of stress-strain curve, the materials show ductility behaviour when they are extended beyond yield limit.

It is the property related to elongation when the material becomes plastic. Gold, silver, copper, iron etc. are some examples of ductile materials.

(ii) Malleability

A material is said to be malleable if it can readily be beaten out in the form of thin sheets. Malleable material should be soft. It should have large elongation for small stress.

In terms of stress-strain graph, the materials show malleability when they are compressed beyond, the yield point for compression. Gold, silver, aluminium are some examples of malleable materials.

(iii) Brittleness

Most of the materials first pass through elastic region and then through plastic region before they break.

However, there is a type of materials known as brittle materials which break even before entering the plastic region.

A brittle material fractures and breaks into pieces under the influence of large forces but it remains elastic till it breaks. Glass, ceramics and cast iron are good examples of brittle materials.

Tensile Strength and Safety Factor

Tensile Strength

It is defined as the maximum value of tensile stress withstand by the material before fracture under a steady load.

i.e. $$\text{Tensile strength} = \frac{\text{Maximum tensile load}}{\text{Original cross–sectional area}}$$

- Usually the tensile strength of metals and alloys increases on cooling and decreases on heating.
- Normally the working stress of a body is kept far below the ultimate tensile stress and it is never allowed to cross the elastic limit.
- The above fact is practiced by all design engineers to get higher stability and reliability of the structures.

Safety Factor

The ratio between the ultimate tensile stress and the working stress is called the safety factor.

i.e. $$\text{Safety factor} = \frac{\text{Ultimate tensile stress}}{\text{working stress}}$$

Working load or working stress is determined by the designer on the basis of his experience and knowledge. Thus the safety factory depends upon the engineering material and the standard of workmanship.

- The good values of safety factor are always adopted to keep the structure for long life. For dead loads, live loads and alternating kind of loads, the safety factors are 4, 6 and 9 respectively.
- For steel structures, the safety factor is about 4 since the steel is a very good engineering material. But for brick structures, it is about 10 since it is not a very good elastic material.

Uses of stress - strain diagram

1. It is used to measure the elastic strength, yield strength and tensile strength of metals.
2. It is used to estimate the working stress and safety factor of an engineering material.

   The lower values of safety factor are adopted to keep the structure for long life. The safety factor helps the design engineer in determining the degree of safety, the economy of design, the dependability of material and the permanency of design.
3. The area under the curve in the elastic region gives the energy required to deform it elastically. The area under the curve upto Ultimate Tensile strength (UTS) gives the energy required to deform it plastically.
4. This diagram is also used to identify the ductile and brittle materials.

Types of Moduli of Elasticity

There are three types of moduli of elasticity corresponding to three types of strains. They are

1. **Young's modulus** of elasticity corresponding to linear strain.
2. **Rigidity modulus or shear modulus** of elasticity corresponding to shearing strain.
3. **Bulk modulus or volume modulus** of elasticity corresponding to volume strain.

Young's modulus of elasticity (Y)

Within the elastic limit, the ratio of linear stress to linear strain is called Young's modulus of elasticity.

It is denoted by the letter Y.

$$\boxed{\textbf{Young's modulus of elasticity } (Y) = \frac{\text{Linear stress}}{\text{Linear strain}}}$$

1.3 FACTORS AFFECTING ELASTIC MODULUS AND TENSILE STRENGTH

Metals are just an assembly of large number of fine crystals that is, they are in polycrystalline state.

The elastic nature of a material is linked up with its grain size. ***The metal of smaller grains has better elasticity than the same metal of larger grains.***

The following factors affect the elastic modulus and tensile strength of the materials. They are

1. **Effect of stress**
2. **Effect of change in temperature**
3. **Effect of impurities**
4. **Effect of hammering, rolling and annealing**
5. **Effect of crystalline nature**

1. Effect of stress

With a small load (within the elastic limit) is applied on the body, elongation occurs immediately on loading and goes back to the original length on removal of the load.

With a higher load, the body continues to stretch, and if the load is removed, a permanent elongation remains.

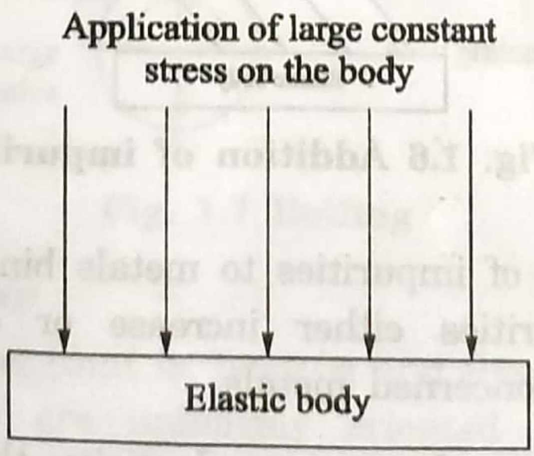

Fig. 1.5 Elasticity decreases due to application of large constant stress

Hence, the application of large constant stress or repeated number of cycles of stress acting on a body decreases the elasticity of the body gradually. (Fig.1.5).

2. Effect of change in temperature

A change in temperature affects the elastic properties of a material. A rise in temperature usually decreases the elasticity of the material.

This is due to ***increase of grain size*** with rise of temperature. With rise in temperature, the ***distance between atoms also increases*** and so the elastic restoring force decreases. This in turn decrease the elasticity.

A carbon filament which is highly elastic at normal temperature becomes plastic at high temperature.

Similarly, a decrease in temperature will increase the elastic property. Lead is not a very good elastic material. But at low temperature, it becomes a very good elastic material.

However, in some cases like the invar steel, the elasticity is not affected by any change in temperature.

3. Effect of impurities

The elastic property of a material is either increased or decreased due to the addition of impurities (Fig.1.6). It depends upon the elastic or plastic properties of the impurities added.

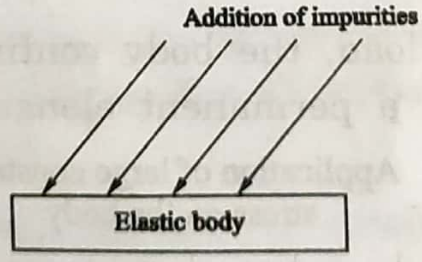

Fig. 1.6 Addition of impurities

The addition of impurities to metals binds the crystal grai better. The impurities either increase or decrease the elas properties of the concerned metals.

If the impurity has more elasticity than the material which it is added, it increases the elasticity. If the impurity less elastic than the material, it decreases the elasticity.

If minute quantities of carbon is added with molten iron, the elastic properties of iron are increased enormously. If more carbon is added, its elastic properties are decreased.

Similarly the addition of potassium or copper in gold increases the elastic properties of gold.

4. Effect of hammering, rolling and annealing

We know that a metal with smaller grains has better elasticity than the same metal of larger grains.

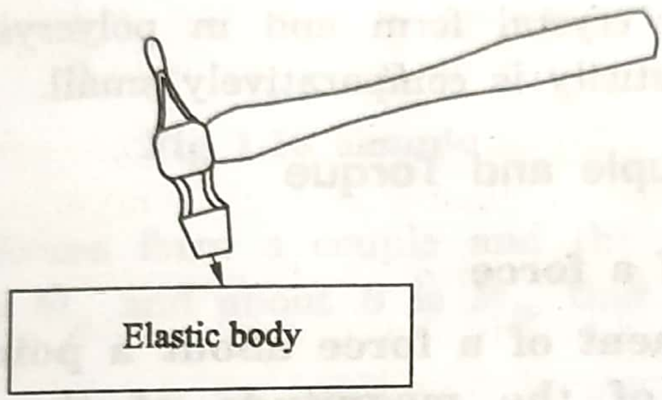

Fig. 1.6 Hammering

While being hammered or rolled, ***crystal grains break into smaller grains*** resulting in increase of their elastic properties.

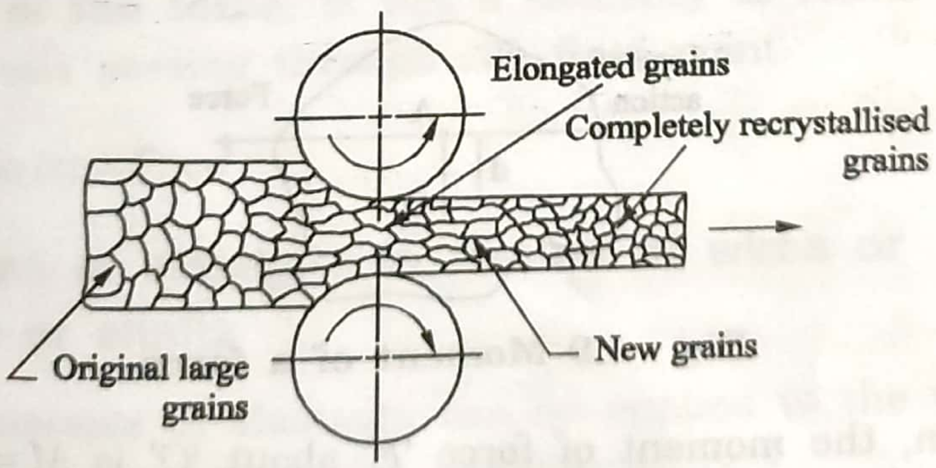

Fig. 1.7 Rolling

Effect of annealing

While annealing (that is, heating and then cooling gradually) constituent crystals are uniformly oriented and ***form larger crystal grains***. This results in decrease in their elastic properties.

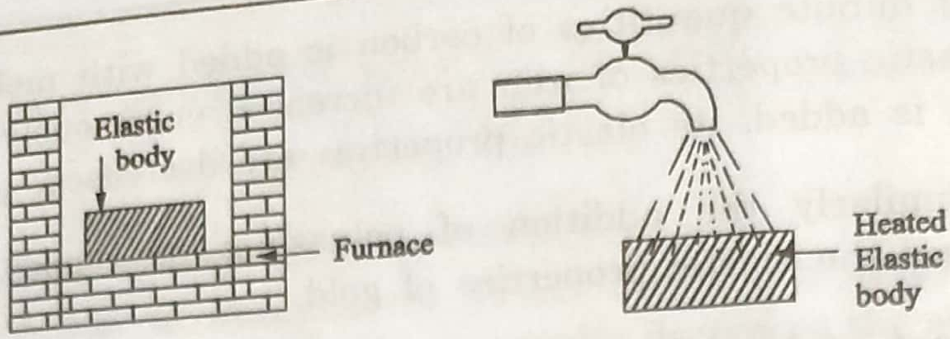

Fig. 1.8 Annealing

5. Effect of crystalline nature

For a given metal, the modulus of elasticity is more when it is in single crystal form and in polycrystalline state, its modulus of elasticity is comparatively small.

Moment, Couple and Torque

(i) Moment of a force

The moment of a force about a point is defined as the product of the magnitude of the force and the perpendicular distance from the point to the line of action of force.

Let 'F' be the force acting on a body, at A as shown in fig 1.9.

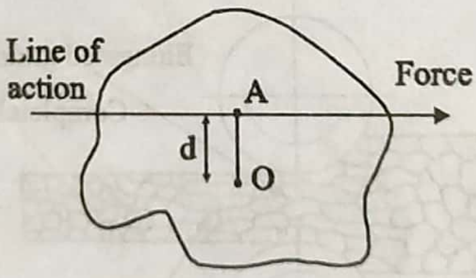

Fig : 1.9 Moment of a force

Then, the moment of force 'F' about 'O' is $M = F \times d$

where 'd' is the perpendicular distance from the point 'O' to the line of action of force F.

(ii) Couple

A couple constitutes a pair of two equal and opposite forces acting on a body, in such a way that the lines of action of the two forces are not in the same straight line