7.16 MECHANICAL PROPERTIES

Mechanical properties are the most important requirements of materials from the engineering point of view in selecting them for the design purposes. Some important mechanical properties of materials are:

1. *Strength:* It is the ability of a material to resist externally applied load or forces without breaking. It is usually defined as tensile strength, compressive strength, proof stress, shear strength, etc.
2. *Hardness:* It is the property of the metal by virtue of which it can resist abrasion, indentation, machining and scratching. It is usually expressed in relation to the hardness of other materials. Hardness decreses by heating.
3. *Elasticity:* A material is said to be perfectly elastic if the deformation produced in it by external forces, completely disappears on the removal of external forces. This property by virtue of which certain materials return back to their original position after the removal of the external forces, is called elasticity.
   Examples: Steel, rubber
   Steel is said to be more elastic than rubber.
   There is a limiting value of force upto and within which, the deformation completely disappears on the removal of the force. The value of stress corresponding to this limiting force upto which the material is perfectly elastic is known as elastic limit.
4. *Plasticity:* Plasticity is the property of the material which enables the formation of permanent deformation.
   When each and every deformation without fracture, remains after removing the load, the material is called plastic.
   Examples: Gold, lead
5. *Ductility:* It is the property of a metal which enables it to be drawn out or elongated to an appreciable extent before rupture occurs. Ductile material must be strong and plastic. Ductility of a metal can be measured by the percentage of elongation and the percentage of reduction of area before rupture of a test piece.
   Ductility of a metal is usually much less when hot than when cold. Hence, wires are drawn cold.
6. *Brittleness:* It is the property of breaking of a material with little permanent distortion. Lack of ductility is brittleness.
   Metals having very little property of deformation, either elastic or plastic is called brittle. Usually the tensile strength of brittle materials is only a fraction of their compressive strength.
   Example: Cast Iron.
7. *Malleability:* The property of a metal by virtue of which it can be beaten or rolled into thin sheets without rupture is known as malleability. This property generally increases with increase of temperature.
8. *Toughness:* It is the property of a material to resist fracture due to high impact loads like hammer blows.
   It is measured by the amount of energy (in mN) that a unit volume of the metal has absorbed after being stressed upto the point of fracture. The area under the stress-strain curve indicates the toughness. Toughness decreases when material is heated.
   Examples: Mild steel, brass.

7.17 BEHAVIOUR OF DUCTILE METALS IN TENSILE TEST

The tensile test is carried out on a bar of uniform cross-section, usually circular, in a testing machine which indicates the tensile load being applied. For the very small strains involved in the early part of the test, the elongation of a measured length (called the gauge length) is recorded by an 'extensometer'.

If a specimen of mild steel is gripped between the jaws of a testing machine and the load and the extension in a gauge length are observed simultaneously we shall be able to plot these observations on a graph. This graph is drawn between the load and extension or between stress and strain. Figure 12, represents such a graph. The diagram in Fig. 12 is called a stress-strain diagram.

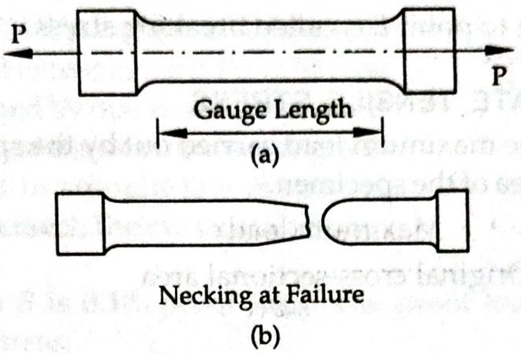

Fig. 11

7.18 STRESS-STRAIN DIAGRAM

For a mild steel (low carbon steel)

Point *A* = Proportional limit
B = Elastic limit
C = Yield point
D = Maximum stress
E = Breaking stress

The salient features of this curve are:

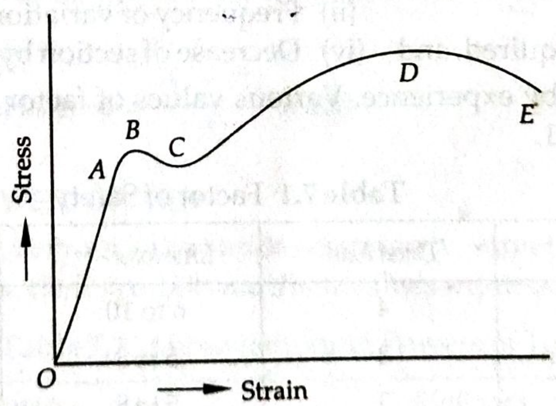

Fig. 12

1. **Proportional limit:** Point *A* is the limit of proportionality. From the origin O to a point *A*, stress strain diagram is a straight line i.e. stress is proportional to strain Hook's law holds good upto this point. Beyond this point, the stress is no longer proportional to the strain.
   Thus, proportional limit is the maximum stress at which stress remains directly proportional to strain.
2. **Elastic limit:** Point *B* is the elastic limit stage. Between *A* and *B* although the strain increases slightly more than the stress, yet the material is elastic, i.e. on removal of the load, the material will regain its shape and size. If the material is stressed beyond the point *B*, the plastic deformation will take place. The value of stress corresponding to point *B*, upto which material is completely elastic in behaviour is called elastic limit.
3. **Yield point:** Point C is the yield point, between *B* and C, the strain increases more quickly than the stress.

4. **Maximum stress point:** Beyond the point C, the load again starts increasing but the elongation now increases at a much faster rate than the load. As the test is continued, a point of maximum stress is reached at *D*. The stress at this point is called ultimate stress.
5. **Breaking point:** The reduction in area at the neck leads to a drop in the load. After point *D*, extension remains continuous even with lesser load and ultimately fracture occurs at point *E*. The stress corresponding to point *E* is called breaking stress.

7.19 MAXIMUM OR ULTIMATE TENSILE STRESS

It is calculated by dividing the maximum load carried out by the specimen during a tension test by the original cross-sectional area of the specimen.

$$\therefore \quad \text{Ultimate stress} = \frac{\text{Maximum load}}{\text{Original cross-sectional area}}$$

7.20 WORKING STRESS

The stress used in practical design is termed as the working stress. It is also called safe stress or allowable stress. This is obtained by dividing the ultimate stress of a material by the factor of safety.

$$\therefore \quad \text{Working stress} = \frac{\text{Ultimate stress}}{\text{Factor of safety}}$$

7.21 FACTOR OF SAFETY

The ratio of ultimate stress to working stress is called factor of safety

$$\therefore \quad \text{Factor of safety} = \frac{\text{Ultimate stress}}{\text{Working stress}}$$

It depends upon the following factors:

(i) Nature of loading
(ii) Frequency of variation of load
(iii) Degree of reliability required, and
(iv) Decrease of section by corrosion etc.

Factor of safety is decided by experience. Various values of factor of safety for different types of loading are given in Table 7.1.

Table 7.1 Factor of Safety

Material	*Dead load*	*Live load*	*Shock*
Cast Iron	4	6 to 10	10 to 15
Wrough Iron	3	5 to 8	9 to 13
Mild steel	3	5 to 8	9 to 13
Copper	5	6 to 9	10 to 15
Timber	5	9 to 14	14 to 20

7.22 BREAKING STRESS

It is determined by dividing the load at the time of fracture or breaking by the original cross-sectional area.

$$\therefore \quad \text{Breaking stress} = \frac{\text{Load at the breaking point}}{\text{Original cross-sectional area}}$$

7.23 PROOF STRESS

Proof stress is the stress necessary to cause a non-proportional or permanent extension equal to a defined percentage of gauge length. If the specified percentage is 0.1% of the gauge length, the corresponding proof stress is designed as 0.1% of proof stress. The stress-strain curve for most of non-ferrous metals like copper and their alloys do not have a definite yield point. In case of such metals and alloys the term proof stress is used instead of yield point.

Using 50 mm gauge length, 0.1% proof stress is the stress required to produce a permanent extension of 0.1% of 50 mm i.e. of 0.05 mm. This can be obtained by marking a point A at a distance of 0.05 mm (to a scale of extension) from the origin O and drawing a line AB parallel to straight line portion of load-extension curve which intersect, the curve at B. (Refer Fig. 13)

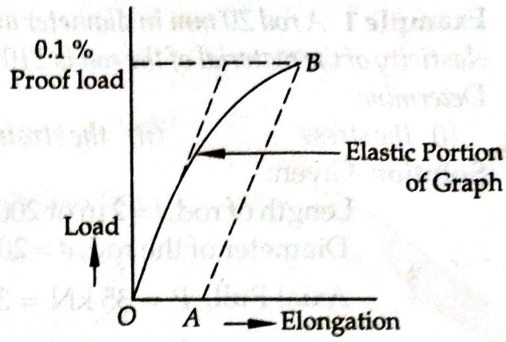

Fig. 13

The load corresponding to B is 0.1% proof load. The proof load divided by original cross-sectional area gives 0.1% proof stress.

7.24 PERCENTAGE ELONGATION

The percentage elongation is the percentage increase in length of the gauge length. If L_o is the original gauge length and L_f the final gauge length (measured after fracture), then

$$\text{Percentage elongation} = \frac{L_f - L_o}{L_o} \times 100$$

Material with more than 15% elongation are usually considered as ductile. Those with less than 5% elongation are considered as brittle. Those between 5% to15% are of intermediate ductility.

7.25 PERCENTAGE REDUCTION IN AREA

If the original cross-sectional area is A_o and final cross-sectional area is A_f (at the plane of failure), then

$$\text{Percentage reduction in area} = \frac{A_o - A_f}{A_o} \times 100$$

7.26 ABBREVIATIONS IN POWER OF TEN

In order to write very large and very small quantities compactly, sometimes we make use of certain prefixes. Table gives the prefixes, their symbols and their values expressed as powers of 10.

Table 7.2 Abbreviations in Powers of Ten

Sub-multiples			*Multiples*		
Prefix	*Symbol*	*Power of 10*	*Prefix*	*Symbol*	*Power of 10*
deci	d	10^{-1}	deca	da	10^{1}
centi	c	10^{-2}	hecto	h	10^{2}
milli	m	10^{-3}	kilo	k	10^{3}
micro	μ	10^{-6}	mega	M	10^{6}
nano	n	10^{-9}	giga	G	10^{9}
pico	p	10^{-12}	tera	T	10^{12}
femto	f	10^{-15}	peta	P	10^{15}
atto	a	10^{-18}	exa	E	10^{18}

Then compression in the aluminium cylinder

$$= (\delta - 0.20) \text{ mm}$$

$\therefore$ Strain in steel, $e_S = \dfrac{\delta}{500}$

Stress in aluminium, $e_a = \dfrac{\delta - 0.20}{500 - 0.20} = \dfrac{\delta - 0.20}{499.8}$

Strain in steel, $\sigma_S = E_S \times e_S$

$$= 210 \times 10^3 \times \frac{\delta}{500} = 420\delta \text{ N/mm}^2$$

Stress in aluminium, $\sigma_a = E_a \times e_a$

$$= 70 \times 10^3 \times \frac{\delta - 0.20}{499.8} = 140.06\ (\delta - 0.20)$$

Total load = Load on steel + Load on aluminium

$$400 \times 10^3 = \sigma_S A_S + \sigma_a A_a$$

$$= 420\delta \times 2827.43 \times 140.06(\delta - 0.20)$$

$$400 \times 10^3 = 1187520.6 + 140.06\delta - 28.01$$

$$400 \times 10^3 \times 28.01 = 1187660.7\delta$$

$$\delta = 0.337 \text{ mm}$$

$\therefore$ $\sigma_S = 420\ \delta = 420 \times 0.337 = 141.54 \text{ N/mm}^2$

and, $\sigma_a = 140.06\,(\delta - 0.20) = 140.06\,(0.337 - 0.20)$

$$= 19.19 \text{ N/mm}^2$$

7.29 FLEXURE LOADING

7.29.1 Beam

A structural member which carries lateral or transverse force (forces at right angles to the axis of the member) is termed as a beam or joist. Generally a beam is of moderate size and is made up of one piece. If the size is large and the beam is made of many parts joined together, than it is called girder.

7.29.2 Type of Beam

Depending upon the end conditions the various types of beams are:

1. Cantilever beam
2. Simply supported beam
3. Overhanging beam
4. Fixed beam, and
5. Continuous beam.

1. Cantilever Beam: A beam which is fixed at one end and free at the other end, is known as cantilever beam. (Fig. 31)

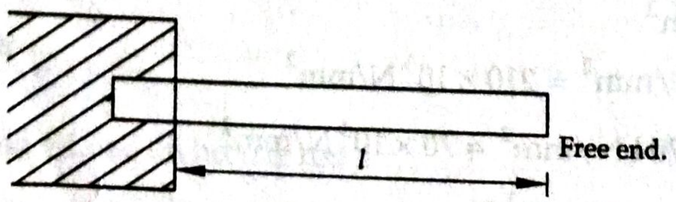

Fig. 31

where l = Length of Cantilever Beam.