Second lecture

1. Introduction

Machine parts fail when the stresses induced by external forces exceed their strength. The external loads cause internal stresses in the elements and the component size depends on the stresses developed. Stresses developed in a link subjected to uniaxial loading is shown in **figure-1**.

Loading may be due to:
a) The energy transmitted by a machine element.
b) Dead weight.
c) Inertial forces.
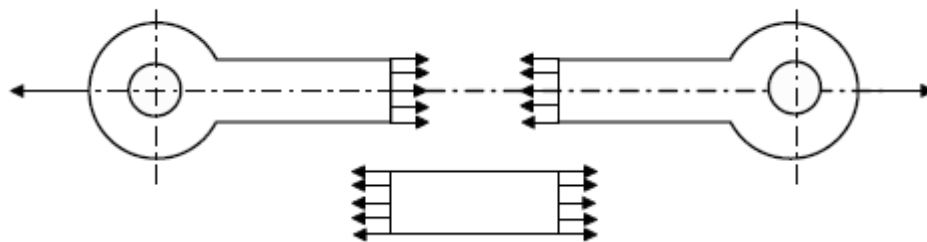d) Thermal loading.   e) Frictional forces.

figure-1. - *Stresses developed in a link subjected to uniaxial loading*

In another way, load may be classified as:
a) Static load- Load does not change in magnitude and direction and normally increases gradually to a steady value.
b) Dynamic load- Load may change in magnitude for example, traffic of varying weight passing a bridge. Load may change in direction, for example, load on piston rod of a double acting cylinder.
Vibration and shock are types of dynamic loading. **Figure.2** shows load vs time characteristics for both static and dynamic loading of machine elements.
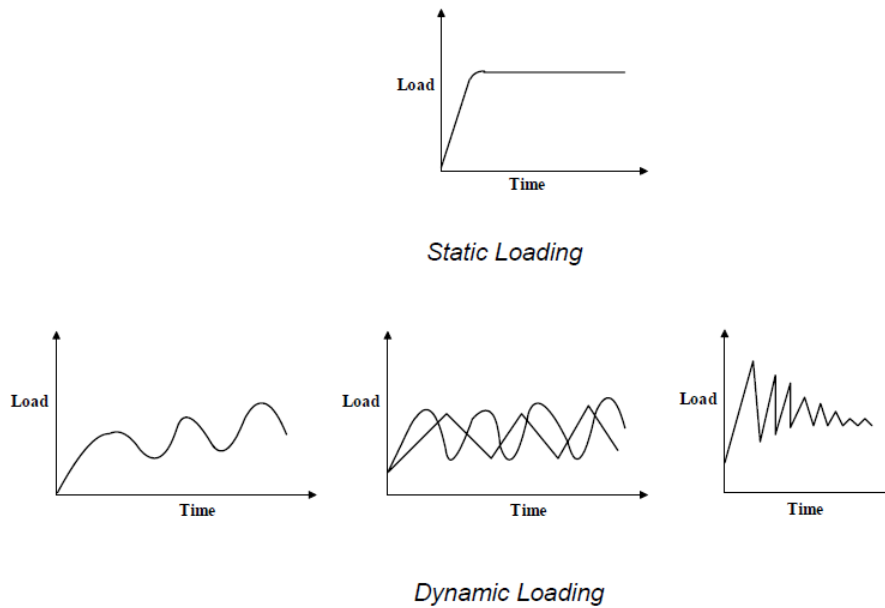
Figure.2 - *Types of loading on machine elements.*

2. Allowable Stresses: Factor of Safety

Determination of stresses in structural or machine components would be meaningless unless they are compared with the material strength. If the induced stress is less than or equal to the limiting material strength then the designed component may be considered to be safe and an indication about the size of the component is obtained. The strength of various materials for engineering applications is determined in the laboratory with standard specimens. For example, for tension and compression tests a round rod of specified dimension is used in a tensile test machine where load is applied until fracture occurs. The load at which the specimen finally ruptures is known as Ultimate load and the ratio of load to original cross-sectional area is the Ultimate stress.

Similar tests are carried out for bending, shear and torsion and the results for different materials are available in handbooks. For design purpose an allowable stress is used in place of the critical stress to take into account the uncertainties including the following:

1) Uncertainty in loading.
2) In homogeneity of materials.
3) Various material behaviors. e.g. corrosion, plastic flow, creep.
4) Residual stresses due to different manufacturing process.
5) Fluctuating load (fatigue loading): Experimental results and plot-ultimate strength depends on number of cycles.
6) Safety and reliability.

For ductile materials, the yield strength and for brittle materials the ultimate strength are taken as the critical stress.

An allowable stress is set considerably lower than the ultimate strength. The ratio of ultimate to allowable load or stress is known as factor of safety i.e.

$$\frac{\text{Ultimate Stress}}{\text{Allowable Stress}} = \text{F.S.}$$

The ratio must always be greater than unity. It is easier to refer to the ratio of stresses since this applies to material properties

3 .Theories of failure

When a machine element is subjected to a system of complex stress system, it is important to predict the mode of failure so that the design methodology may be based on a particular failure criterion. Theories of failure are essentially a set of failure criteria developed for the ease of design.

In machine design an element is said to have failed if it ceases to perform its function. There are basically two types of mechanical failure:

(a) **Yielding**- This is due to excessive inelastic deformation rendering the machine part unsuitable to perform its function. This mostly occurs in ductile materials.

(b) **Fracture**- in this case the component tears apart in two or more parts. This mostly occurs in brittle materials.

There is no sharp line of demarcation between ductile and brittle materials.

However a rough guideline is that if percentage elongation is less than 5% then the material may be treated as brittle and if it is more than 15% then the material is ductile. However, there are many instances when a ductile material may fail by fracture. This may occur if a material is subjected to:

(a) Cyclic loading.
(b) Long term static loading at elevated temperature.
(c) Impact loading.
(d) Work hardening.
(e) Severe quenching.

Yielding and fracture can be visualized in a typical tensile test .Typical engineering stress-strain relationship from simple tension tests for same engineering materials are shown in **figure- 3**.
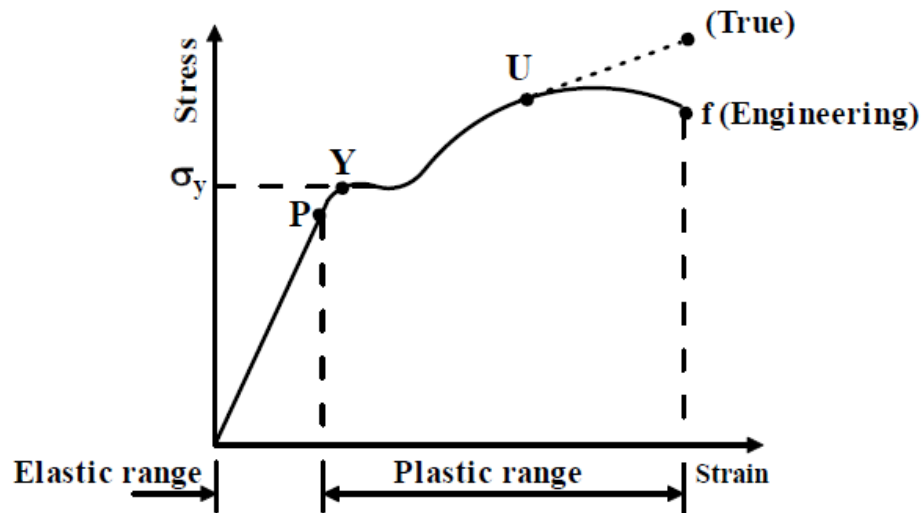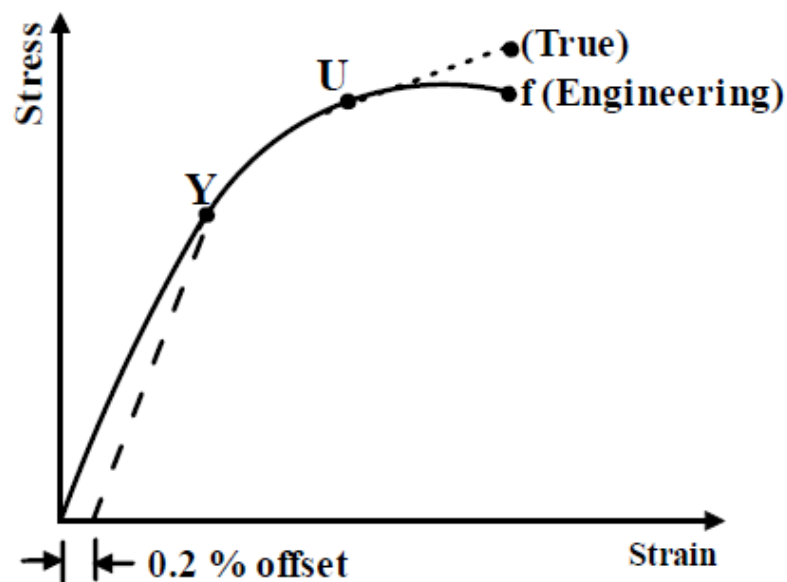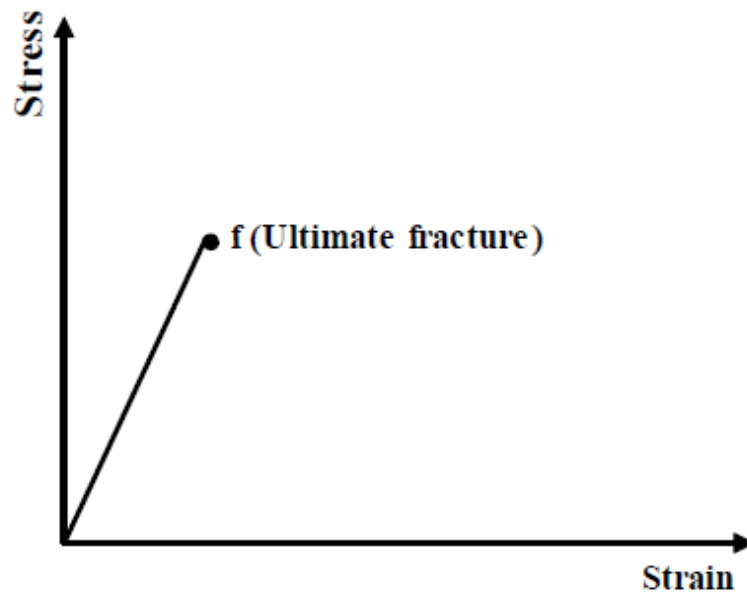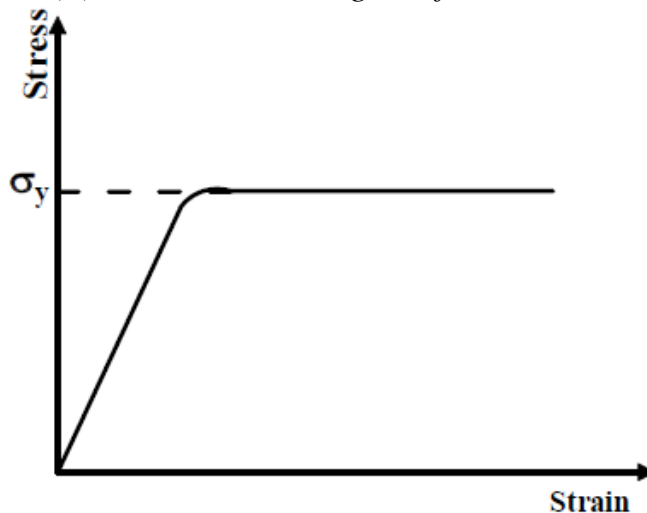

figure- 3. *(a) Stress-strain diagram for a ductile material e.g. low carbon steel.*

(b) Stress-strain diagram for low ductility.

(c) Stress-strain diagram for a brittle material.

(d) Stress-strain diagram for an elastic – perfectly plastic material.

For a typical ductile material as shown in **figure-3 (a)** there is a definite yield point where material begins to yield more rapidly without any change in stress level. Corresponding stress is σy . Close to yield point is the proportional limit which marks the transition from elastic to plastic range. Beyond elastic limit for an
elastic- perfectly plastic material yielding would continue without further rise in stress i.e. stress-strain diagram would be parallel to parallel to strain axis beyond the yield point. However, for most ductile materials, such as, low-carbon steel beyond yield point the stress in the specimens rises up to a peak value known as ultimate tensile stress σo . Beyond this point the specimen starts to neck-down i.e. the reduction in cross-sectional area. However, the stress-strain curve falls till a point where fracture occurs. The drop in stress is apparent since original cross-