

# PROPERTIES OF MATERIALS

## 1.1 PROPERTIES OF MATERIALS

Different materials possess different properties in varying degree and therefore behave in different ways under given conditions. These properties includes Mechanical properties, Electrical properties, Thermal properties, Chemical properties, Magnetic properties and Physical properties.

A design engineer is interested in the behaviour of materials under load which is mechanical in nature, for the design of machines & structures. Any material subjected to a load either deforms, yield, or break, depending upon the magnitude of the load.

We are basically interested in knowing as to how a particular material will behave under applied load i.e. in knowing the mechanical properties.

## 1.2 STRESS-STRAIN DIAGRAMS

The internal resistance of the material to counteract the applied load is called stress, and the deformation as strain. There are three types of stresses:

**Tensile stress:** force acts to pull materials apart;

**Compressive stress:** the force squeezes material;

**Shear stress:** the force causes one part to slide on another part.

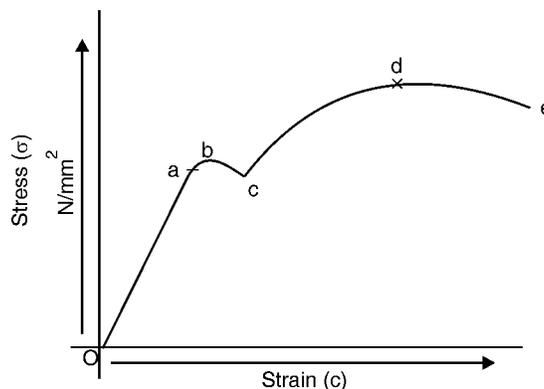
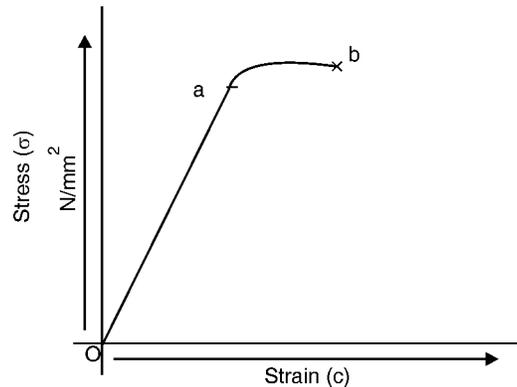


Fig. 1.1: Stress-Strain Diagram for Steel



**Fig. 1.2: Brittle Materials**

There are three types of corresponding strains.

The metals are tested on a Universal Testing Machine. The stress-strain diagram is a diagram with values of stress (load) as ordinate and strain (elongation, compression, deflection, twist etc.) as abscissa.

Mechanical properties depend upon the crystal structure, its bonding forces, and the imperfections which exist within the crystal.

The stress-strain diagram for steel is shown in Fig. 1.1(a). The salient points are:

**Point a:** Limit of proportionality. **0-a** is a straight line and stress is proportional to strain. The slope of the line gives the value of Young's Modulus of Elasticity; **E**. **Point b** gives the yield point of the material and is called the elastic limit. This is the greatest stress that the material can endure without taking up permanent set after load is removed. **Point c** is called lower yield point. **Point d** gives the maximum or ultimate stress. **Point e** is called the breaking point and material fails.

The various mechanical properties can be defined or understood with the help of the above diagram. This is drawn with data obtained from a test on Universal Testing Machine (UTM).

The stress-strain ( $\sigma - \epsilon$ ) diagram for high carbon steel, cast iron and other brittle materials are shown in Fig. 1.1(b).

**Point a** is the limit of proportionality and **point b** is the breaking point. The curve does not have a yield point.

### 1.3 PRINCIPAL MECHANICAL PROPERTIES

Those characteristics of the materials which describe their behaviour under external loads are known as Mechanical Properties. The most important and useful mechanical properties are:

#### 1.3.1 Strength

It is the resistance offered by a material when subjected to external loading. So, stronger the material the greater the load it can withstand.

Depending upon the type of load applied the strength can be tensile, compressive, shear or torsional.

The maximum stress that any material will withstand before destruction is called its ultimate strength. (Point d)

### **1.3.2 Elasticity**

Elasticity of a material is its power of coming back to its original position after deformation when the stress or load is removed. Elasticity is a tensile property of its material.

The greatest stress that a material can endure without taking up some permanent set is called elastic limit (Point a).

### **1.3.3 Stiffness (Rigidity)**

The resistance of a material to deflection is called stiffness or rigidity. Steel is stiffer or more rigid than aluminium.

Stiffness is measured by Young's modulus  $E$ . The higher the value of the Young's modulus, the stiffer the material.  $E$  is the ratio of stress over strain and is given by the slope of line 0-a.

### **1.3.4 Plasticity**

The plasticity of a material is its ability to undergo some degree of permanent deformation without failure. Plastic deformation will take place only after the elastic range has been exceeded, beyond point b.

Plasticity is an important property and widely used in several mechanical processes like forming, shaping, extruding and many other hot and cold working processes. In general, plasticity increases with increasing temperature and is a favourable property of material for secondary forming processes.

Due to this properties various metal can be transformed into different products of required shape and size. This conversion into desired shape and size is effected either by the application of pressure, heat or both.

### **1.3.5 Ductility**

Ductility of a material enables it to draw out into thin wire on application of the load. Mild steel is a ductile material. The wires of gold, silver, copper, aluminium, etc. are drawn by extrusion or by pulling through a hole in a die due to the ductile property. The ductility decreases with increase of temperature.

The per cent elongation and the reduction in area in tension is often used as empirical measures of ductility.

### **1.3.6 Malleability**

Malleability of a material is its ability to be flattened into thin sheets without cracking by hot or cold working. Aluminium, copper, tin, lead, steel, etc. are malleable metals.

Lead can be readily rolled and hammered into thin sheets but can not be drawn into wire. Ductility is a tensile property, whereas malleability is a compressive property. Malleability increases with increase of temperature.

### **1.3.7 Brittleness**

The brittleness of a material is the property of breaking without much permanent distortion. There are many materials, which break or fail before much deformation take place. Such materials are brittle e.g., glass, cast iron.

Therefore, a non-ductile material is said to be a brittle material. Usually the tensile strength of brittle materials is only a fraction of their compressive strength. A brittle material should not be considered as lacking in strength. It only shows the lack of plasticity. On stress-strain diagram, these materials don't have yield point and value of E is small.

### **1.3.8 Toughness**

The toughness of a material is its ability to withstand both plastic and elastic deformations. It is a highly desirable quality for structural and machine parts to withstand shock and vibration. Manganese steel, wrought iron, mild steels are tough materials.

For Ex: If a load is suddenly applied to a piece of mild steel and then to a piece of glass the mild steel will absorb much more energy before failure occurs. Thus, mild steel is said to be much tougher than a glass.

Toughness is a measure of the amount of energy a material can absorb before actual fracture or failure takes place. **“The work or energy a material absorbs is called modulus of toughness”**

Toughness is also resistance to shock loading. It is measured by a special test on Impact Testing Machine.

### **1.3.9 Hardness**

Hardness is closely related to strength. It is the ability of a material to resist scratching, abrasion, indentation, or penetration.

It is directly proportional to tensile strength and is measured on special hardness testing machines by measuring the resistance of the material against penetration of an indenter of special shape and material under a given load. The different scales of hardness are Brinell hardness, Rockwell hardness, Vicker's hardness, etc.

Hardness of a metal does not directly relate to the hardenability of the metal. Hardenability is indicative of the degree of hardness that the metal can acquire through the hardening process. i.e., heating or quenching.

### **1.3.10 Hardenability**

Hardenability is the degree of hardness that can be imparted to metal by process of hardening. A metal capable of being hardened throughout its structure is said to have high hardenability. The material is heated above a certain temperature and then suddenly quenched in a cold oil or water bath.

### **1.3.11 Impact Strength**

It can be defined as the resistance of the material to fracture under impact loading, i.e., under quickly applied dynamic loads. Two standard tests are normally used to determine this property.

1. The IZOD impact test.
2. The CHARPY test.

### **1.3.12 Resilience**

Resilience is the capacity of material to absorb energy elastically. On removal of the load, the energy stored is released as in a spring.

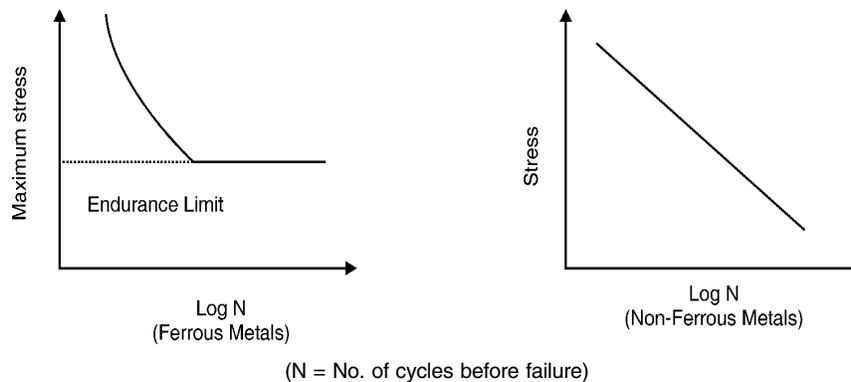
The maximum energy which can be stored in a body up to elastic limit is called the proof resilience. The quantity gives capacity of the material to bear shocks and vibrations. The strain energy stored in a material of unit volume gives proof resilience and is measured by work stretching.

## 1.4 FATIGUE AND FATIGUE TEST

The fatigue strength of a material is the maximum stress at which failure may occur after a certain number of cyclic load applications. A component is designed to give a certain length of service under a specified loading cycle. Many components of high speed aero and turbine engines are designed for fatigue strength.

The fatigue strength or endurance limit of material is used in the design of parts subjected to repeated alternating stresses over an extended period of time.

Specimens are tested to failure using different loads. The number of cycles is noted for each load. The results of such tests are plotted as graphs of applied stress against the logarithm of the number of cycles of failure. The curve is known as S-N curve. The tests are carried out on special fatigue testing machines.



**Fig. 1.3:** Fatigue Curves

## 1.5 CREEP AND CREEP TESTING

The slow and continuous elongation of a material with time at constant stress and high temperature below elastic limit is called creep. At high temperatures, stresses even below the elastic limit can cause some permanent deformation on stress-strain diagram.

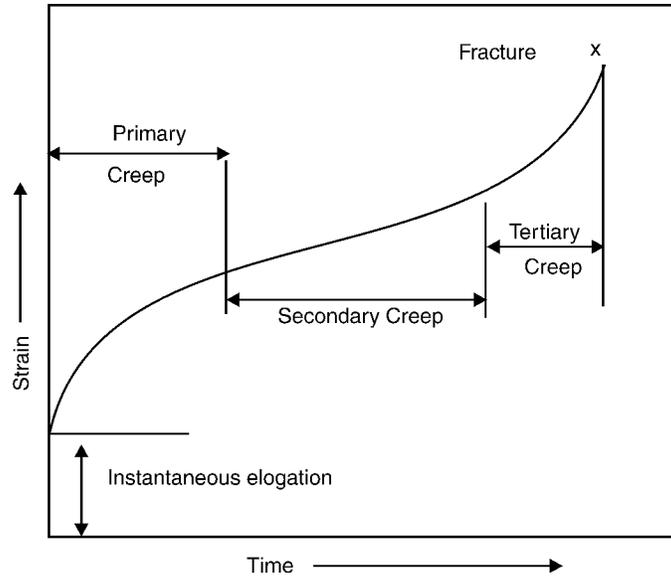
There are three stages of creep. In the first stage the material elongates rapidly but at a decreasing rate. In the second stage, the rate of elongation is constant. In third stage, the rate of elongation increases rapidly until the material fails. The stress for a specified rate of strain at a constant temperature is called creep strength.

Creep test is carried out at high temperature. A creep curve (Fig. 1.4) is a plot of elongation of a tensile specimen versus time, for a given temperature and under constant stress. Tests are carried out for a period of a few days to many years. The test can be carried out on Universal Testing Machine with special attachments.

Creep curve shows four stages of elongation:

- (a) Instantaneous elongation on application of load.
- (b) Primary creep: Work hardening decreases and recovery is slow.
- (c) Secondary creep: Rate of work hardening and recovery processes is equal.
- (d) Tertiary Creep: Grain boundary cracks. Necking reduces the cross-sectional area of the test specimen.

The creep strength is used for the design of blades and other parts of steam and gas turbines working at high temperatures.



**Fig. 1.4:** Creep Test Curve

## 1.6 IMPORTANT TERM

### 1.6.1 Simplification

It is the process through which a limited number of grades, types and size of a product are determined in order to have better control, minimise waste, simplify production and thus, reduces price. By eliminating unnecessary varieties, size and design it leads towards interchangeable manufacture of products.

### 1.6.2 Standardization

It is the second step towards interchangeable manufacture, increased output and higher economy. The process of standardization involves determining the best material, manufacturing processes and allied techniques for the manufacturing processes and allied techniques for the manufacture of a product.

### 1.6.3 Inspection and Quality Control

It is another important function of a production unit. If a manufacturing firm wants to maintain its reputation among the users, it should under all conditions, strive hard not only to keep up the standard of quality of its products once established but to improve upon the same. For this every concern, maintain a full-fledged inspection and quality control department which inspects the product at various stages of its production.

### 1.6.4 Interchangeability

It is a principle applied to the mass production of identical components such that any one of the

components, selected at random, will suit the assembly condition to meet the requirement of operation. For this, the components are allowed a predetermined amount of variation in their finished dimensions lie within these limits are acceptable components. This facilitates easy and quicker production, easy inspection, requires less skill on the part of worker and accommodates a slight inaccuracy in the machine as well, resulting in an overall reduction in the production cost of the component.

### **1.6.5 Mechanization**

It is the term which implies a trend towards minimizing the human efforts, to the extent it is possible, by adopting mechanical means or methods for different processes. Such a trend may be in material handling, loading and unloading of components. Actual operations done on the job or transportation, etc. But no feedback is provided by the process, operations or machine.

### **1.6.6 Automation**

It is a further extension of mechanization and involves adoption of automatic controls for the operations of different machines. This automatic control may be adopted for only a few operations or all the operations of a machine and accordingly the machine will be known as Semi-automatic or Fully-automatic.

### **1.6.7 Computer Aided Design(CAD)**

The CAD enables design engineers to rough out a particular product configuration and receive immediate feedback on its specification. In utilizing CAD, the computer draws pictures on the video screen. So, CAD can speed up the normally slow and laborious work of drafting.

### **1.6.8 Computer Aided Manufacturing(CAM)**

We have studied that the CAD function of their application fully takes care of product design, product research and analysis, preparation of assembly drawings, part drawings, bill of materials, make or buy decision, etc. Similarly, computers are being widely used in Numerical Control (NC) of machines. With similar advantages the computers are being used in almost all areas of actual manufacturing, including process optimization and production control, parts and material movement, material management, monitoring, scheduling etc., which is known as CAM.

### **1.6.9 Material Requirement Planning(MRP)**

Inventory management is another vital area where computers are widely used. MRP, which is based on production schedule, bill of materials and records of inventory in respect of raw materials, in-process materials, purchase parts and components, parts in-process, finished products, delivery schedules, etc.

### **1.6.10 Group Technology**

Group technology is a wide concept of manufacturing in which it is conceived that several problems have similar features which if solved together in a group, result in greater economy and efficiency. For the application of this concept to manufacturing different parts are analysed in respect of the similarities in their design features, manufacturing processes and the sequence of operations.

### 1.6.11 N.C.Machines

This term stands for NUMERICALLY CONTROLLED MACHINES, which implies controlling the relative movements of the cutting tool and work, cutting speeds, feeds and depths of cuts, sequencing of proper tools for a particular operation and almost all the machining parameters automatically with the help of a prearranged programme fed into the control unit. Such a control of machine tools enables higher accuracies, closer dimensional tolerances, enhanced productivity and reduction in production costs.

### THEORY QUESTIONS

1. *What is meant by mechanical properties of materials? State their importance in the design of a machine or structural element.*
2. *Explain the difference between malleability and ductility. Toughness, stiffness and strength.*
3. *Explain the term 'fatigue'. Also explain the term fatigue strength and fatigue limit related to fatigue.*
4. *Explain the difference between hardness and brittleness, strength and stiffness, elasticity and creep, malleability and ductility.*
5. *What do you understand from the term "Mechanical Properties of Materials"? On which factors does these properties mainly depend?*
6. *Explain the following in brief:*
  - (i) *Impact strength*
  - (ii) *Plasticity*
  - (iii) *Fatigue*
  - (iv) *Elasticity*
7. *Draw a typical "creep test" curve, showing different stages of elongation for a long time, high temperature creep test. State how the information is useful to the design engineers.*
8. *Differentiate between:*
  - (a) *Hardness and impact resistance*
  - (b) *Hardness and toughness*
9. *Explain: Brittleness, Stiffness and Ductility.*
10. *What property is dependent on time and temperature?*
11. *On what factors does the hardness of steel depend?*
12. *Briefly explain what do you understand by:*  
*Toughness, Fatigue, Creep, Hardness*
13. *Differentiate among strength, stiffness and toughness.*
14. *Explain (i) Elasticity (ii) Plasticity (iii) Toughness. (iv) Malleability*