2 Properties of materials

Before appropriate materials for the manufacture of a given product are chosen, a careful evaluation of the properties of all available materials is usually advisable. Among the properties which may need to be considered are mechanical properties, physical properties, and chemical properties.

Mechanical properties

Foremost among the properties that should be considered are mechanical properties like strength, hardness, ductility, and toughness. A very important way of assessing some of the mechanical properties of a material is by means of a Young’s modulus experiment. A brief description of such an experiment is given below.

Young’s modulus experiment for a uniform metal specimen

In this experiment, a piece of material of uniform cross-section is subjected to a tensile load which increases the length of the specimen. The load is gradually increased from zero to a value at which the specimen breaks. The following physical quantities are used to study the behaviour of the specimen quantitatively.

- **Longitudinal stress** = Tensile force / cross-sectional area \( \text{N/m}^2 \)
- **Longitudinal strain** = Increase in length / original length (No units)
- **Young’s modulus** \( E \) = Stress / Strain \( \text{N/m}^2 \)

If a graph between stress and strain is plotted (after the experiment has been completed), a curve similar to that in Fig. 2.1 is obtained. In the region OA, the strain is proportional to the stress. If the load is removed at this stage, the specimen will revert to its original shape and size. The behaviour of the material in this region is said to be elastic, and the change in shape it undergoes when loaded is called elastic deformation. The stress corresponding to the point A where the proportional region ends, is called the yield strength.

At higher values of stress beyond A, the slope of the curve changes, and the deformation is no longer proportional and elastic. The specimen does not return to
its original size and shape when the load is removed, and is said to have undergone \textit{plastic deformation}.

In the region BC, the specimen \textit{elongates permanently} and at the same time its \textit{cross-section} becomes \textit{reduced uniformly} along its length. The material becomes stronger and is said to be \textit{strain hardened} or \textit{work hardened}.

Beyond the point C, the cross-section of the specimen \textit{decreases} only at its \textit{weakest point}. This process is called \textit{necking} (see Fig. 2.1 (b)), and the load that can be sustained decreases. Finally at point C \textit{fracture occurs}. The stress at the maximum load (point B) is called the \textit{ultimate tensile strength (UTS)} or the tensile strength (TS). The stress at point C is called the \textit{breaking strength}.

\textbf{Elastic and plastic deformation in engineering applications}

Elastic and plastic deformation are both useful in engineering applications. In \textit{structural applications} like columns and machine frames, loads must be kept well within the \textit{elastic range} so that \textit{no permanent deformation occurs}. In applications like the bending, stretching, and the deep drawing of metal, \textit{plastic deformation has to take place} if the shape of the metal is to be changed.

\textbf{Some important mechanical properties}

- \textit{Strength} refers to the ability of a material to \textit{resist tensional} or \textit{compressional stresses}. The yield strength and the ultimate tensile strength of a material are important quantities in engineering design.

- \textit{Elasticity} is the ability of a material to return to its original shape and dimensions after load has been removed.

- \textit{Plasticity} is the ability of a material to be permanently deformed without breaking.

- \textit{Ductility} refers to the property of a metal which allows it to be \textit{plastically deformed} and to be \textit{drawn into wire} without breaking.

- \textit{Toughness} refers to the ability of a material to \textit{withstand bending} (or the application of shear stresses) \textit{without breaking}. Copper is extremely tough, while cast iron is extremely brittle.