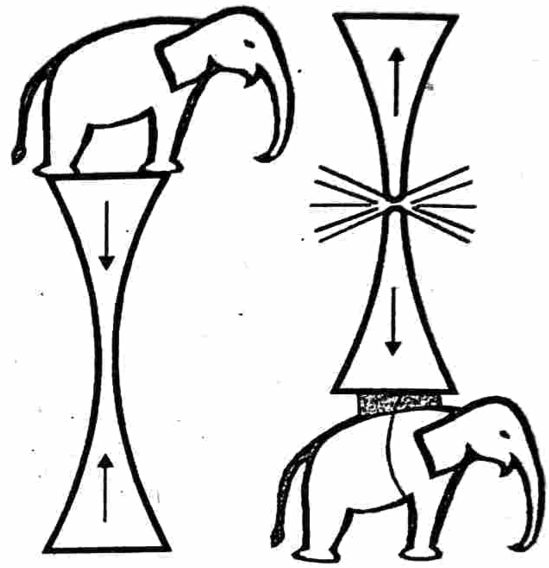
Chapter 9

Mechanical Properties of Solids

INSIDE

Curriculum Objectives

- To create knowledge of elastic properties, stress, strain, modulus of elasticity through group activities.
- To develop the concept of Hooke's law, stress-strain graph through experiments and discussions.



9.1 INTRODUCTION

Scientific progress has led to the very basic knowledge about the structure of matter in the microscopic level. The basic building blocks of matter are atoms. Molecules are the combination of atoms. Most of the matter in the universe is not in the form of atoms or molecules, but in the form of plasma.

You are all familiar with the vegetable, carrot. You go on chopping a carrot into smaller and smaller slices. At the end you reach a point where you can not cut the carrot further, but still the smallest piece possesses the same property of the carrot before chopping. The same explanation can be applied to substances like Aluminium, Copper, Salt ($NaCl$) etc.

The smallest particles of matter are called atoms. We cannot see or feel individual atoms or molecules at work. We can observe the result of a large number of atoms or molecules acting in a more or less organized manner, i.e., the macroscopic processes. The properties of matter in bulk are the results of these collective actions. A typical macroscopic system encountered in the every day life consists of about 10^{25} interacting atoms.

One can approach the description of the macroscopic behaviour of matter (called mechanics of solids and fluids) from two different approaches.

(i) Thermodynamics deals with the macroscopic view of matter, with measurements such as determining the volume, pressure and temperature changes of the substances.

(ii) To understand the behaviour of matter from a microscopic point of view, i.e., from the motion of atoms and molecules.

These two views together form a unified picture of the world.

e.g. Pressure of a gas is basically just the average of extremely large number of molecular impacts against the walls of the container.

9.2 ELASTIC BEHAVIOUR OF SOLIDS

9.2.1 Solids

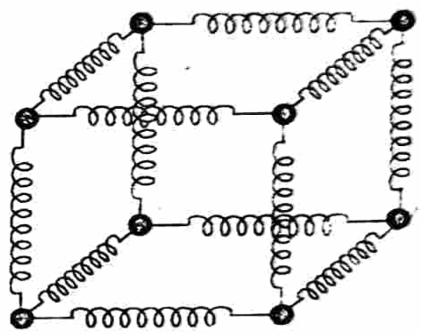


Fig. 1
Spring ball model for the illustration of elastic behaviour of solids

Our everyday experience tells us that a solid has a definite size and shape. All bodies are made up of atoms and molecules. The atoms in a solid are held more or less at specific positions with respect to one another by forces that are mainly electrical in origin. Because of thermal agitation, the atoms of a solid vibrate about their equilibrium positions. But at low temperatures their vibrations are very small and hence the atoms can be considered to be almost fixed. The vibrating motions of atoms in a solid can be picturised as that which would occur if the atoms were bound in their equilibrium positions by springs attached to the neighbouring atoms.

If a solid is compressed by some external forces, we can see that these external forces as compressing the internal springs and on removal of these forces, the solid tends to regain its original size and shape. Hence we can say that a solid exhibits elastic property.

Two surprising things about solids are (i) the extremely wide range of their properties and (ii) the amazing degree of regularity in their structure. The origin of all these properties are due to the interactions of electrons in the outer shells of the atoms, called valence electrons, among themselves and with the nuclei of the constituent atoms. The typical distances between nearest neighbouring atoms in solids range from 1.5 to 3 A°. The way in which these valence electrons interact, determines the atomic structure and the properties of solids such as electrical, magnetic, optical and thermal.

Based on the degree of regularity in the structure, solids are classified into two (i) Crystalline solids and (ii) Amorphous or glassy solids.

In crystalline solids, the atoms are arranged in a regular pattern and the array is periodic. Common salt, sugar, diamond etc. are some of the examples of crystalline substances.

In amorphous solids there is no regular array of atoms. Atoms are extensively disordered, non-periodic and only short range order. Glass, wood, plastic etc. are some of the examples of amorphous solids.

General properties of solids can be summarized as follows.

9.2.2 Properties of Solids

A. Solids have a definite shape and volume

The particles of a solid are held in place by relatively strong intermolecular forces.

B. Solids are crystalline or amorphous

If the particles are held together in a regular pattern, the solid will also have a regular pattern that we can see with our eyes. These are crystalline solids. Some common crystal patterns are cubes, needles, prisms, etc. Crystalline solids can be subdivided into:

i. **Ionic Solids**: Solids that are composed of alternating patterns of cations and anions. Some examples are : $NaCl$, $MgSO_4$, $CaCO_3$. These compounds are always very high melting points, i.e., > 500° C.

ii. **Molecular Solids**: Solids that are composed of molecules. Some examples are: $C_{12}H_{22}O_{11}$ (sugar), $H_3C_6H_5O_7$ (citric acid), $C_{18}H_{21}NO_3$ (codeine), etc. These compounds generally have melting points that are relatively low, i.e., < 300° C.

C. Solids are noncompressible

Because the particles of a solid are very close to each other, they cannot be forced together any closer.

D. The density of solids is slightly higher than their liquid states

When most liquids freeze, the particles move closer together and the density increases slightly.

E. The particles in a solid do not diffuse

Since the particles are very close to each other, they cannot move from one part of the sample to another.

9.2.3 Elasticity and Plasticity

Deforming force

When an external force is applied on a body, which changes its size or shape or both is called ***deforming force***. If this force is removed, the body may again acquire its original state.

Elasticity

The property of material of a body by virtue of which the body regains its original configuration (length, volume or shape) when the deforming force is removed is called ***elasticity.***

Perfectly elastic body

A body which regains its original configuration, immediately and completely after the removal of deforming force from it, is called ***perfectly elastic body.***

e.g. Quartz and Phosphor bronze are nearly perfectly elastic bodies.

Perfectly plastic body

A body which does not regain its original configuration at all on the removal of deforming force is called ***perfectly plastic body.***

e.g. Putty and wet mud are nearly perfectly plastic bodies.

Plasticity

The property of the material body by virtue of which it does not regain its original configuration when the deforming force acting on it is removed is called ***plasticity.***

9.3 Stress and Strain

9.3.1 Stress

We know that when deforming force is applied on a body, then the restoring force is developed inside the body.

The restoring force acting per unit area of a deformed body is called ***stress.***

$$\text{Stress} = \frac{\text{Restoring Force}}{\text{Area}} = \frac{F}{A}$$

If there is no permanent change produced in the configuration of the body, the restoring force is equal and opposite to the external deforming force applied.

$$\therefore \text{ Stress} = \frac{\text{Deforming Force}}{\text{Area}}$$

Unit

In S.I - Nm^{-2} or pascal (Pa)

In C.G.S - dyne cm^{-2}

Dimensional formula - $[M^1L^{-1}T^{-2}]$

Stress is a ***vector quantity.***

Types of Stress

i. Normal Stress

When a deforming force acts normally over an area of a body, then the internal restoring force developed per unit area of the body is called normal stress.

It is classified into two.

a. Tensile Stress

If there is an increase in length or extension of the body in the direction of force applied, the stress developed is called tensile stress or longitudinal stress or linear stress.

b. Compressional Stress

If there is a decrease in length of the wire or compression of the body due to force applied, the stress developed is called compressional stress.

ii. Tangential Stress

When a deforming force acting tangentially to the surface of a body produces a change in the shape of the body, then the stress developed in the body is called tangential stress.

9.3.2 Strain

The deforming force applied on a body produces generally a change in its dimensions and the body is said to be strained.

The ratio of change in configuration to the original configuration is called ***strain.***

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

Strain has no unit and dimension.

Types of Strain

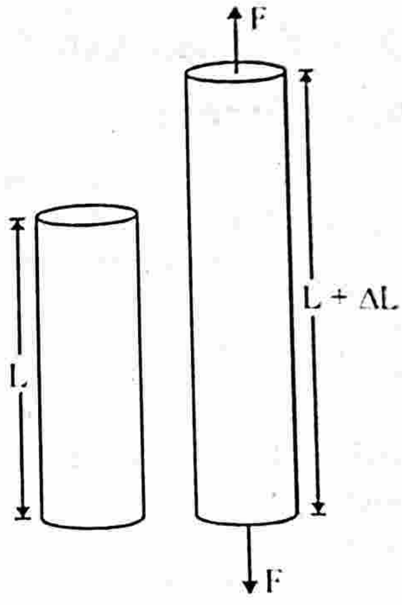


Fig.2 a

i. Longitudinal Strain

If the deforming force produces a change in length, the strain produced in the body is called ***longitudinal strain or tensile strain or linear strain.***

$$\text{Longitudinal Strain} = \frac{\text{Change in length}}{\text{Original length}} = \frac{\Delta L}{L}$$

where L is the original length and ΔL is the increase in length.

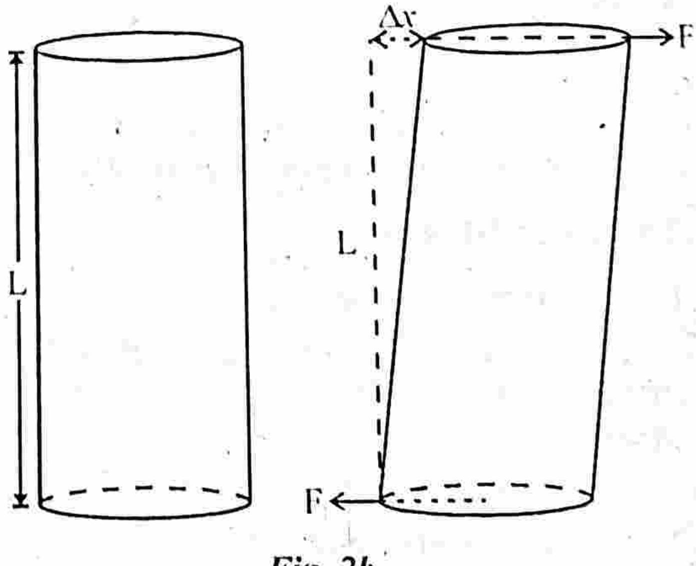


Fig. 2b

ii. Shearing Strain

If the deforming force produces a change in the shape of the body without changing its volume, the strain produced is called ***shearing strain.***

It is defined as the angle in radian through which a plane perpendicular to the fixed surface of the body gets tunred under the effect of tangential stress.

$$\text{Shear Strain} = \frac{\Delta x}{L} = \tan\theta \approx \theta.$$

[If $\theta = 10°$, there is only 1% difference between θ and $\tan\theta$]

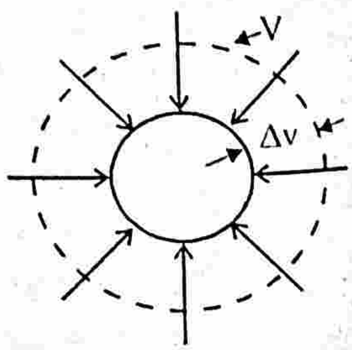


Fig. 2c

iii. Volume Strain

If the deforming force produces a change in volume alone, the strain produced in the body is called ***volume strain.***

$$\text{Volume strain} = \frac{\text{Change in volume}}{\text{Original volume}} = \frac{\Delta V}{V}$$