*Third lecture*

# *CHARACTERIZATION OF MATERIALS —1*

*Fourth Stage*

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# CHARACTERIZATION OF MATERIALS —1

The characterization of materials is an important step to be taken before utilizing the materials for any purpose. Depending on the purpose one can subject the material to mechanical, thermal, chemical, optical, electrical, and other characterizations to make sure that the material under consideration can function without failure for the life of the final product.

## 1. MECHANICAL PROPERTIES

Among the most important properties for the application of materials in medicine and dentistry are the mechanical properties. We will study the fundamental mechanical properties that will be used in later.

### 1.1. Stress-Strain Behavior

For a material that undergoes a mechanical deformation, the stress is defined as a force per unit area, which is usually expressed in Newton's per square meter (Pascal, Pa)

$$\text{Stress } (\sigma) = force \;/\; cross\text{-}sectional\ area\ (N/m2)$$

A load (or force) can be applied upon a material in tension, compression, and shear or any combination of these forces (or stresses). Tensile stresses are generated in response to loads (forces) that pull an object apart (Figure 1a), while compressive stresses squeeze it together (Figure 1b). Shear stresses resist loads that deform or separate by sliding layers of molecules past each other on one or more planes (Figure 1c). The shear stresses can also be found in uniaxial tension or compression since the applied stress produces the maximum shear stress on planes at 45° to the direction of loading (Figure 1d).

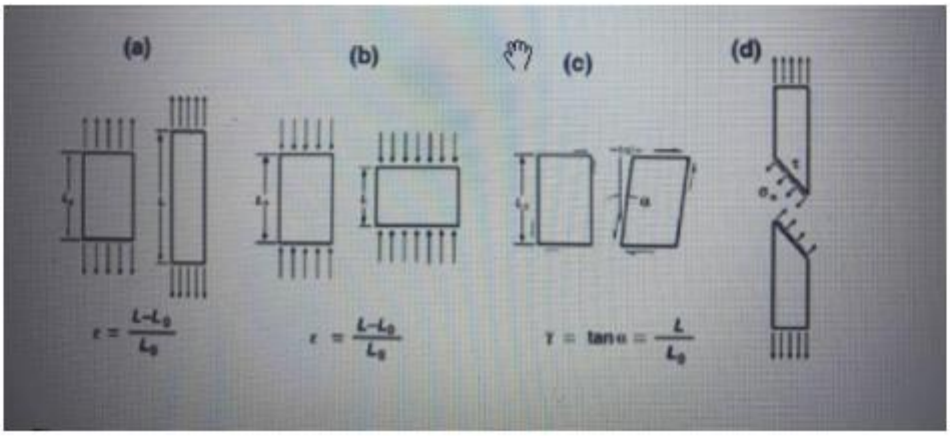



Figure 1. There different modes of deformation: (a) tension, (b) compression, (e) shear, and (d) shear in tension.

The deformation of an object in response to an applied load is called strain;

**Strain (α) = (deformed length - original length) / original length (m/m)**

It is also possible to denote strain by the stretch ratio, i.e., deformed length/original length. The deformations associated with different types of stresses are called tensile, compressive, and shear strain (Figure 1).

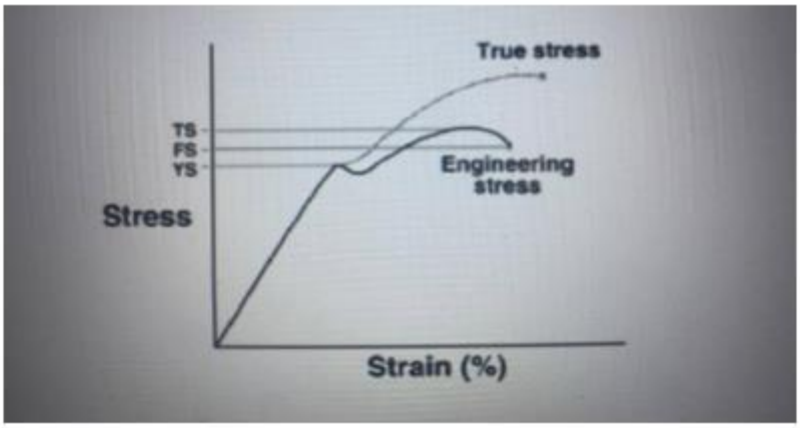



Figure 2. Stress-strain behavior of an idealized material.

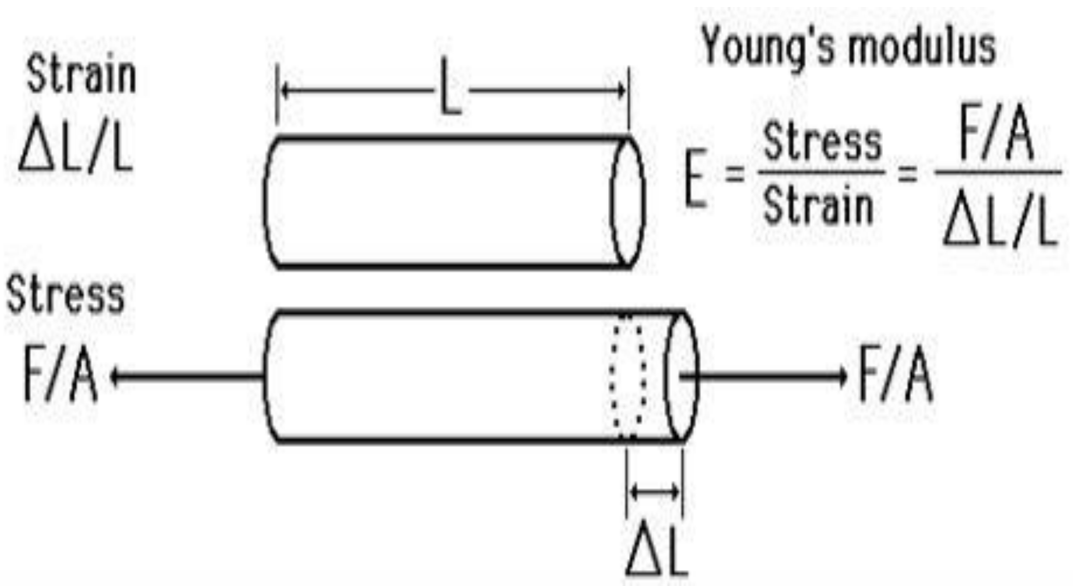
If the stress-strain behavior is plotted on a graph, a curve that represents a continuous response of the material toward the imposed force can be obtained, as shown in Figure 2. The stressstrain curve of a solid sometimes can he demarcated by the yield point (σ, or YP) into clastic and plastic regions. In the elastic region, the strain Ɛ increases in direct proportion to the applied stress σ (Hooke's law):

**σ = E Ɛ stress = (initial slope) × (strain).**

The slope (E) or proportionality constant of the tensile/compressive stress strain curve is called Young's modulus or the modulus of elasticity. It is the value of the increment of stress over the increment of strain. The stiffer a material is, the higher the value of E and the more difficult it is to deform. Similar analysis can be performed for deformation by shear, in which the shear modulus (G) is defined as the initial slope of the curve of shear stress versus shear strain. The unit for the modulus is the same as that of stress since strain is dimensionless. The shear modulus of an isotropic material is related to its Young's modulus by

$$E=2G\ (1+\ v)$$

in which v is the Poison's ratio of the material. Poison's ratio is defined as the negative ratio of the transverse strain to the longitudinal strain for tensile or compressive loading of a bar. Poison's ratio is close to 1/3 for common stiff materials, and is slightly less than 1/2 for rubbery materials and for soft biological tissues. For example, stretch a rubber band by 10% of its original length and the cross-sectional dimensions will decrease by about 5%.



**Example** :

A steel bar with a cross-sectional area of 10 mm^2 is subjected to a tensile load of 500 N. The length of the bar is 2 meters, and after the load is applied, the length of the bar increases to 2.002 meters. Calculate Young's modulus of the steel bar.

**Solution**:

Young's modulus, E = stress/strain

stress = Force/Area = 500 N / 10 mm^2 = 50 MPa

strain = (final length – initial length) / initial length

= (2.002 m – 2 m) / 2 m = 0.001

Young's modulus = stress/strain

= 50 MPa / 0.001 = 50,000 MPa

Therefore, Young's modulus of the steel bar is 50,000 MPa.

## *1.2. Mechanical Failure*

### *1.2.a. Static failure*

Mechanical failure usually occurs by fracture. The fracture of a material can be characterized by the amount of energy per unit volume required to produce the failure. The quantity is called toughness and can be expressed in terms of stress and strain:

$$\textbf{Toughness} = \int \sigma d\varepsilon = \int \sigma \, dl/l$$

**1.2.b. Dynamic fatigue failure**

When a material is subjected to a constant or a repeated load below the fracture stress, it can fail after some time. This is called static or dynamic (cyclic) fatigue respectively, the effect of cyclic stresses (Figure3) is to initiate micro cracks at centers of stress concentration within the material or on the surface, resulting in the growth and propagation of cracks, leading to failure. The rate of crack growth can he plotted in a log-log scale versus time. The most significant portion of the curve is the crack propagation stage, which can be estimated as follows:

$$da/dN = A(\Delta K)^m$$

where a, N, and ΔK are the crack length, number of cycles, and range of stress intensity factor.

$$AK = A\sigma \sqrt{\pi a}$$

and m are the intercept and slope of the linear portion of the curve. This is called the Paris equation.

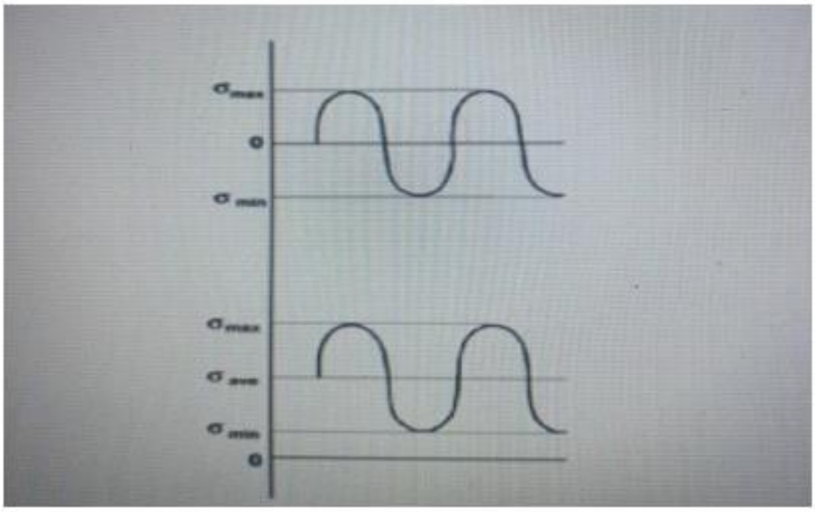


Figure 3, Cyclic stresses. σ max and σ min are the maximum and minimum values of the cyclic stresses, The range of stresses $\Delta \sigma = \sigma_{max} - \sigma_{min}$ and average stress $\sigma_{ave} = (\sigma_{max} + \sigma_{min})/2$. The top curve is fluctuating, and the bottom curve is for reversed cycle loading.