University of Anbar
College of Science
Department of Physics

فيزياء المواد

Physics of Materials

المرحلة الثالثة
الكورس الاول

اعداد
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1. Mechanical properties الخواص الميكانيكية

Many materials are subjected يسلط عليها to forces or loads احمال; examples use the aluminum alloy سبيكة الالومنيوم in an airplane wing جناح الطائرة and the steel in an automobile axle محور السيارة . It is necessary to know the characteristics الخصائص of the material and to design وتصميم the member العضو from which it is made الذي صنعت منه such that any resulting deformation يحدث تشوه فيه. Mechanical design properties are **stiffness صلابة, strength قوة**, **hardness صلادة**, **ductility ليونة**, and **toughness متانة**.

If a load حمل is static ثابتا or changes relatively slowly يتغير ببطء with time and is applied uniformly يسلط باتجاه احادي over a cross section مقطع عرضي or surface سطح of a member العضو, the mechanical behavior السلوك الميكانيكي may be ascertained يحقق by a simple **stress–strain test**; these are most commonly conducted الأكثر شيوعًا for metals at room temperature في حرارة الغرفة. There are three principal ways توجد ثلاث طرق in which a load may be applied لتسليط الحمل: tension الشد, compression الانضغاط, and shear القص (Figures 6.1a, b, c).

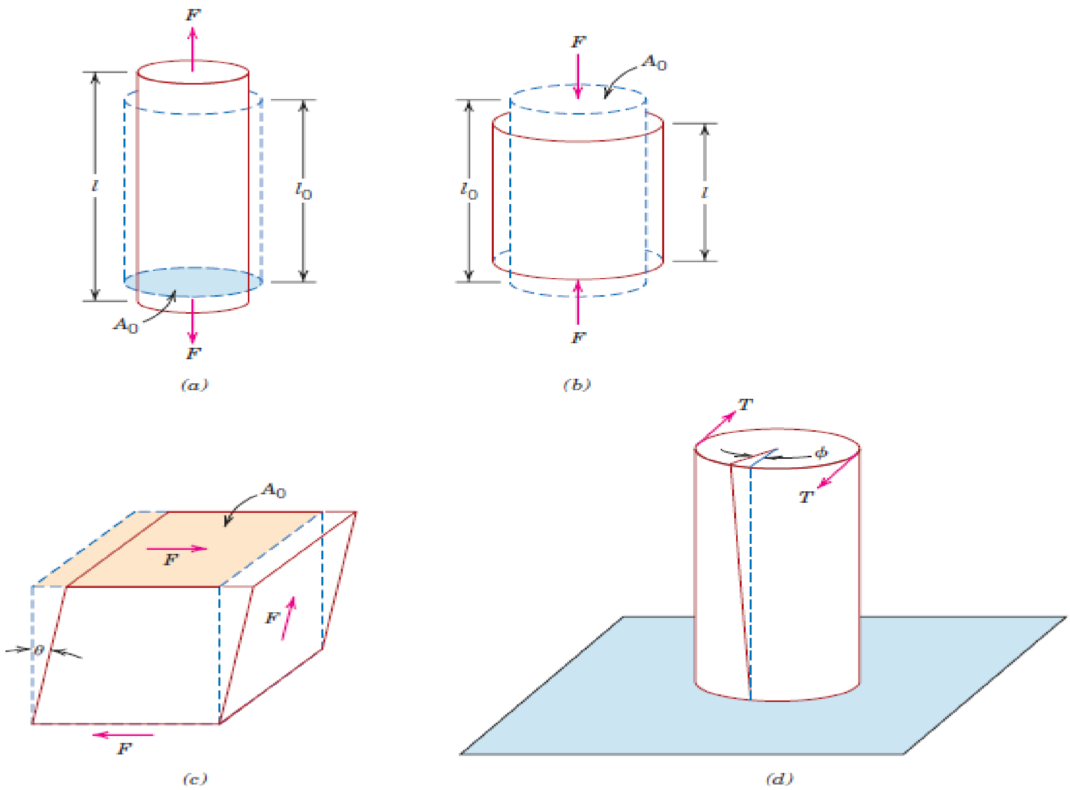


Figure 6.1

There are different types توجد انواع مختلفة of **forces** or "**stresses**" that are encountered واجهت in dealing التعامل with mechanical properties of materials. In general بصورة عامة, we define **stress** as the force acting per unit area over which the force is applied. **Tensile**, **compressive**, and **shear** stresses are illustrated in Figure 6.1. **Strain** is defined as the change تغير in dimension في الابعاد per unit length لوحدة الطول. Stress is typically expressed in psi (pounds per square inch) or Pa (Pascals). **Strain** has no dimensions and is often expressed as in./in. or cm/cm.

Tensile and compressive stresses are normal stresses. A normal stress arises when the applied force acts perpendicular عمودي to the area.

6.1 Tension Tests اختبار الشد

One of the most common mechanical stress–strain tests is performed يتم ادائها in **tension الشد** . The tension test can be used to ascertain لتحقق من several mechanical properties of materials that are important in design التصميم. A specimen العينة is deformed تتشوه, usually to fracture عادة الى حد الكسر, with a gradually increasing زيادة تدريجية tensile load that is applied uniaxially باتجاه واحد along the long axis of a specimen. A standard tensile specimen عينة شد قياسية is shown in Figure 6.2. Normally, the cross section is circular دائري, but rectangular مستطيلة specimens are also used. The technique used التقنية المستخدمة to test the tensile is shown in figure 6.3.

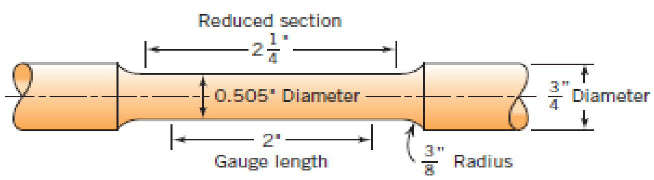


Figure 6.2

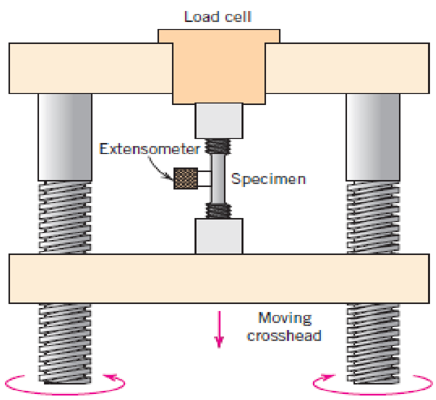


Figure 6.3 Schematic representation of the apparatus used to conduct tensile

stress–strain tests اختبار اجهاد-انفعال

The stress σ is defined by the relationship

$$\sigma = \frac{F}{A_0} \tag{6.1}$$

Where F is the instantaneous load applied perpendicular to the specimen cross section, in units of newtons (N), and A_0 is the original cross sectional area before any load is applied (m^2 or $in.^2$).The units of stress are megapascals, MPa (SI) (where 1 MPa 106 N/m^2),

Also, the strain ϵ is defined according to

$$\epsilon = \frac{l_i - l_0}{l_0} = \frac{\Delta l}{l_0} \tag{6.2}$$

Where l_0 is the original length before any load is applied and l_i is the instantaneous length.

6.2 Compression Tests اختبار الانضغاط

Compression stress–strain tests may be conducted if in-service forces are of this type. A compression test is conducted in a manner similar to the tensile test, except that the force is compressive and the specimen contracts along the direction of the stress. Equations 6.1 and 6.2 are utilized to compute compressive stress and strain, respectively. a compressive force is taken to be negative, which yields a negative stress. because l_0 is greater than l_i, compressive strains computed from Equation 6.2 are also negative.

6.3 Shear and Torsional Tests اختبار القص والالتواء

For tests performed using a pure shear force as shown in Figure 6.1c, the shear stress τ is computed according to

$$\tau = \frac{F}{A_0} \tag{6.3}$$

where F is the load or force imposed parallel to the upper and lower faces, each of which has an area of A_0. The shear strain γ is defined as the tangent of the strain angle , as indicated in the figure

Torsion is a variation of pure shear, wherein a structural member is twisted in the manner of Figure 6.1d; torsional forces produce a rotational motion about the longitudinal axis of one end of the member relative to the other end.

Torsional tests are normally performed on cylindrical solid shafts or tubes. A shear stress τ is a function of the applied torque T, whereas shear strain γ is related to the angle of twist ϕ, in Figure 6.1d.

6.4 Elastic Deformation التشوه المرن

The degree to which a structure deforms, or strains depends on the magnitude of an imposed stress. For most metals that are stressed in tension and at relatively low levels, stress and strain are proportional to each other through the relationship

$$\sigma = E\epsilon \tag{6.5}$$

This is known as Hooke's law, and the constant of proportionality E (GPa)is the **modulus of elasticity** معامل المرونة, or **Young's modulus** معامل يونك.

Deformation التشوه in which stress and strain are proportional is called elastic deformation تشوه مرن; a plot of stress versus strain results in a linear relationship علاقة خطية, as shown in Figure 6.4 .The slope الميل of this linear segment corresponds to the modulus of elasticity E.

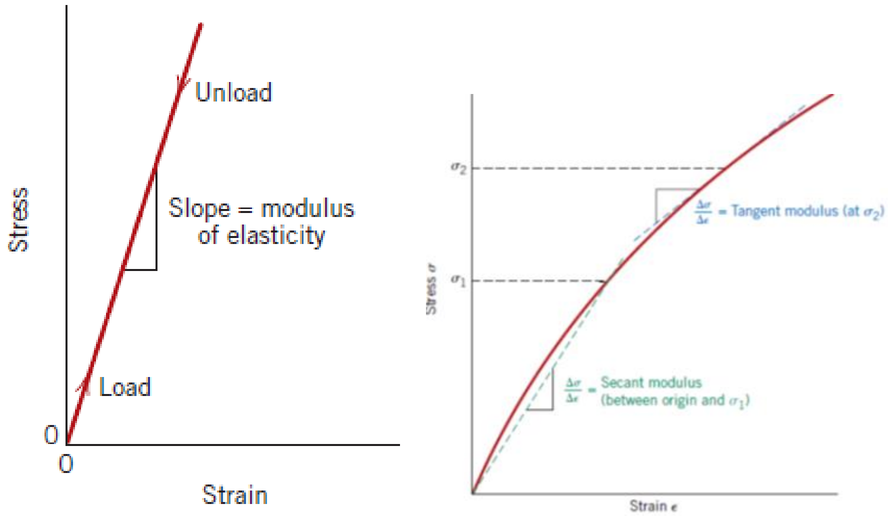


Fig. a　　　　fig. b

Figure 6.4 Schematic stress–strain diagram showing (a) linear elastic (b) nonlinear elastic deformation for loading and unloading cycles.

Shear stress and strain are proportional to each other through the expression

$$\tau = G\gamma \tag{6.7}$$

where G is the shear modulus معامل القص, the slope of the linear elastic region of the shear stress–strain curve.

EXAMPLE PROBLEM 6.1

Elongation (Elastic) Computation

A piece of copper originally 305 mm (12 in.) long is pulled in tension with a stress of 276 MPa (40,000 psi). If the deformation is entirely elastic, what will be the resultant elongation?

Solution

Because the deformation is elastic, strain is dependent on stress according to Equation 6.5. Furthermore, the elongation Δl is related to the original length l_0 through Equation 6.2. Combining these two expressions and solving for Δl yields

$$\sigma = \epsilon E = \left(\frac{\Delta l}{l_0}\right)E$$

$$\Delta l = \frac{\sigma l_0}{E}$$

The values of σ and l_0 are given as 276 MPa and 305 mm, respectively, and the magnitude of E for copper from Table 6.1 is 110 GPa (16×10^6 psi). Elongation is obtained by substitution into the preceding expression as

$$\Delta l = \frac{(276\ \text{MPa})(305\ \text{mm})}{110 \times 10^3\ \text{MPa}} = 0.77\ \text{mm}\ (0.03\ \text{in.})$$

6.5 Elastic Properties Of Materials الخواص المرنة للمواد

When a tensile stress is imposed on a metal specimen, an elastic elongation استطالة مرنة and accompanying strain ϵ_z result in the direction of the applied stress, as indicated in Figure 6.5. As a result of this elongation, there will be constrictions in the lateral (x and y) directions perpendicular to the applied stress; from these contractions, the compressive strains ϵ_x and ϵ_y can be determined. If the applied stress is uniaxial (only in the z direction), and the material is isotropic, then $\epsilon_x = \epsilon_y$ x y. A parameter termed **Poisson's ratio** v is defined as the ratio of the lateral and axial strains,

$$\nu = -\frac{\epsilon_x}{\epsilon_z} = -\frac{\epsilon_y}{\epsilon_z} \tag{6.8}$$

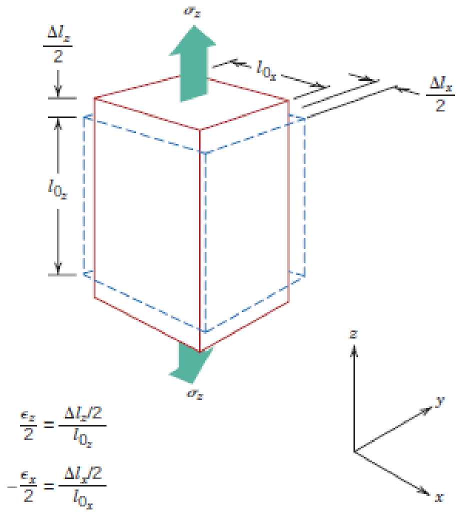


Figure 6.5

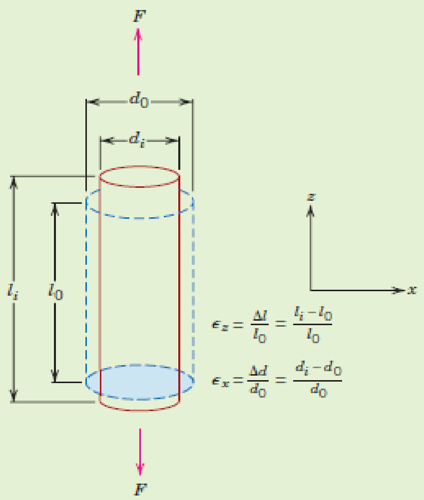
EXAMPLE PROBLEM 6.2

Computation of Load to Produce Specified Diameter Change

A tensile stress is to be applied along the long axis of a cylindrical brass rod that has a diameter of 10 mm (0.4 in.). Determine the magnitude of the load required to produce a 2.5×10^{-3} mm (10^{-4} in.) change in diameter if the deformation is entirely elastic.

Solution

This deformation situation is represented in the accompanying drawing.



When the force F is applied, the specimen will elongate in the z direction and at the same time experience a reduction in diameter, Δd, of 2.5×10^{-3} mm in the x direction. For the strain in the x direction,

$$\epsilon_x = \frac{\Delta d}{d_0} = \frac{-2.5 \times 10^{-3}\text{ mm}}{10\text{ mm}} = -2.5 \times 10^{-4}$$

which is negative, because the diameter is reduced.

It next becomes necessary to calculate the strain in the z direction using Equation 6.8. The value for Poisson's ratio for brass is 0.34 (Table 6.1), and thus

$$\epsilon_z = -\frac{\epsilon_x}{\nu} = -\frac{(-2.5 \times 10^{-4})}{0.34} = 7.35 \times 10^{-4}$$

The applied stress may now be computed using Equation 6.5 and the modulus of elasticity, given in Table 6.1 as 97 GPa (14×10^6 psi), as

$$\sigma = \epsilon_z E = (7.35 \times 10^{-4})(97 \times 10^3\text{ MPa}) = 71.3\text{ MPa}$$

Finally, from Equation 6.1, the applied force may be determined as

$$F = \sigma A_0 = \sigma \left(\frac{d_0}{2}\right)^2 \pi$$

$$= (71.3 \times 10^6\text{ N/m}^2)\left(\frac{10 \times 10^{-3}\text{ m}}{2}\right)^2 \pi = 5600\text{ N}\,(1293\text{ lb}_f)$$

6.6 Plastic Deformation التشوه اللدن غير مرن

For most metallic materials, elastic deformation persists only to strains of about 0.005. As the material is deformed beyond this point, the stress is no longer proportional to strain or plastic deformation occurs (Hooke's law, Equation 6.5, ceases to be valid) and permanent, nonrecoverable, or plastic deformation occurs. Figure 6.6 plots schematically the tensile stress–strain behavior into the plastic region for a typical metal. The transition from elastic to plastic is a gradual one for most metals; some curvature results at the onset of plastic deformation, which increases more rapidly with rising stress.

From an atomic perspective, plastic deformation corresponds to the breaking of bonds with original atom neighbors and then re-forming bonds with new neighbors as large numbers of atoms or molecules move relative to one another; upon removal of the stress they do not return to their original positions.

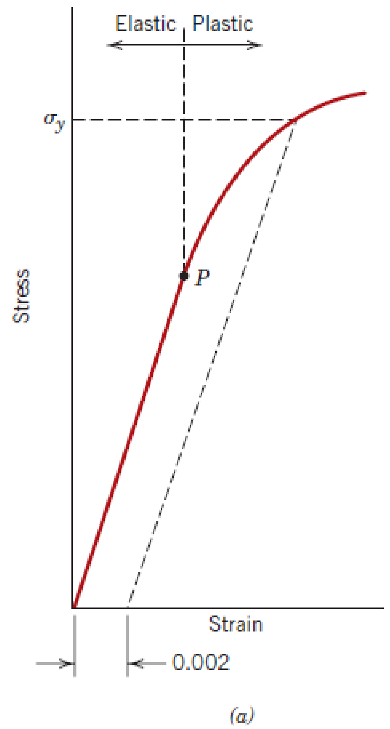


Figure 6.6

6.7 Yielding and Yield Strength الخضوع وقوة الليونة

Most structures are designed to ensure that only elastic deformation will result when a stress is applied. A structure or component that has plastically deformed, or experienced a permanent change in shape, may not be capable of functioning as intended. It is therefore desirable to know the stress level at which plastic deformation begins, or where the phenomenon of **yielding** occurs. For metals that experience this gradual elastic–plastic transition, the point of **yielding** may be determined as the initial departure from linearity of the stress–strain curve.

The stress corresponding to the intersection of this line and the stress–strain curve as it bends over in the plastic region is defined as the **yield strength** . This is demonstrated in Figure 6.6, the units of **yield strength** are MPa.

6.8 Tensile Strength قوة الشد

After yielding, the stress necessary to continue plastic deformation in metals increases to a maximum, point M in Figure 6.7, and then decreases to the eventual fracture, point F. The tensile strength TS (MPa) is the stress at the maximum on the stress–strain curve (Figure 6.7). This corresponds to the maximum stress that can be sustained by a structure in tension; if this stress is applied and maintained, fracture will result.

All deformation up to this point is uniform throughout the narrow region of the tensile specimen. However, at this maximum stress, a small constriction or neck begins to form at some point, and all subsequent deformation is confined at this neck, as indicated by the schematic specimen insets

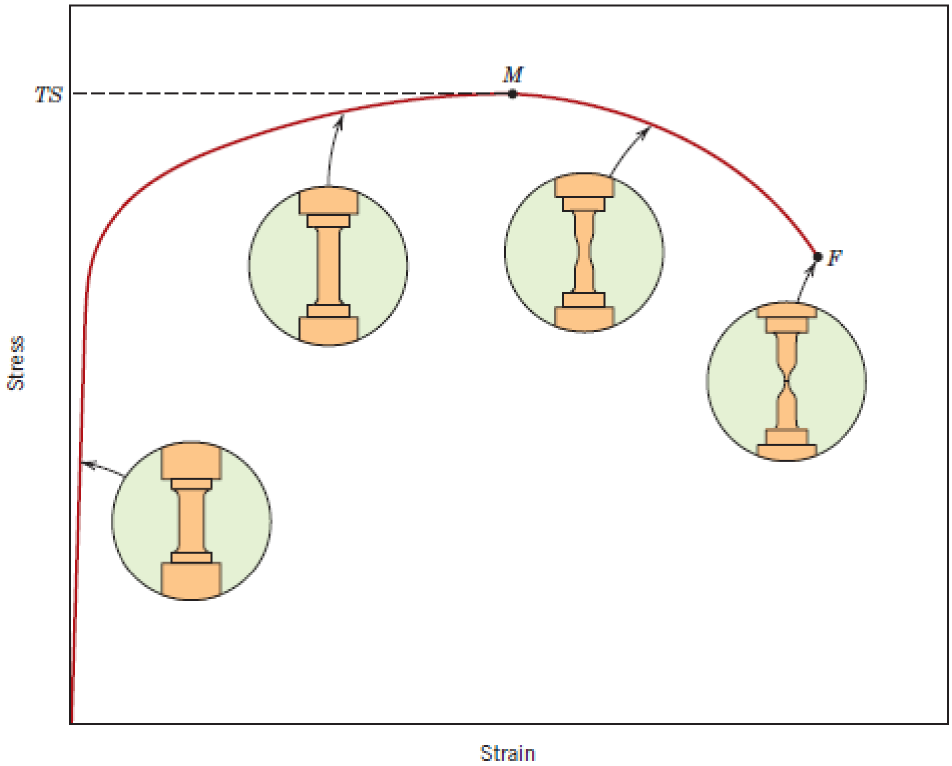


Figure 6.7

6.9 Ductility الليونة

Ductility is another important mechanical property. It is a measure of the degree of plastic deformation that has been sustained at fracture. A metal that experiences very little or no plastic deformation upon fracture is termed brittle. The tensile stress–strain behaviors for both ductile and brittle metals are schematically illustrated in Figure 6.7.

Ductility may be expressed quantitatively as either percent elongation or percent reduction in area. The percent elongation %EL is the percentage of plastic strain at fracture,

$$\%\mathrm{EL} = \left(\frac{l_f - l_0}{l_0}\right) \times 100 \tag{6.11}$$

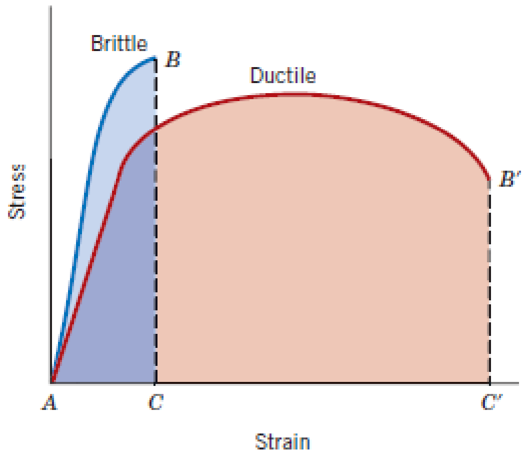


Figure 6.7

References

1- Fundamentals of Materials Science and Engineering, William D. Callister, Jr. David G. Rethwisch
2- Materials _Science_ and _Engineering_9th . William D. Callister, Jr. David G. Rethwisch