Mechanical Testing: Tension Test and Stress-Strain Mechanisms

variety of simple mechanical tests used to evaluate material properties
→ include tension, compression, indentation, impact, bending, and torsion

Tension tests

frequently used to evaluate stiffness, strength, ductility, and other material charact.

Category	Engineering Property	True Stress–Strain Property
Elastic constants	Elastic modulus, E, E_t Poisson's ratio, ν	—
Strength	Proportional limit, σ_p Yield strength, σ_o Ultimate tensile strength, σ_u Engineering fracture strength, σ_f	True fracture strength, $\tilde{\sigma}_{fB}$ Strength coefficient, H
Ductility	Percent elongation, $100\varepsilon_f$ Reduction in area, $\%RA$	True fracture strain, $\tilde{\varepsilon}_f$
Energy capacity	Tensile toughness, u_f	True toughness, $\tilde{u}_f$
Strain hardening	Strain hardening ratio, σ_u/σ_o	Strain hardening exponent, n

Elastic Modulus, E, is a measure of stiffness + a fundamental elastic constant of the material

Yield strength σ_o characterizes resistance to the beginning of plastic deformation

ultimate tensile strength σ_u is the highest engineering stress that the material can withstand (prior to fracture)

Ductility is ability to resist deformation w/out fracture
↳ in a tension test, this is characterized by the percent elongation at fracture $100\varepsilon_f$ and by the percent reduction in area %RA

Material strength

strengths of engineering materials in bulk form are much lower than the theoretical strength to break chemical bonds

as a result of the structure of the material interacting w/ defects, a variety of behaviors are seen in tensile stress-strain curves of various metals
→ simplest case: linear behavior up to point of fracture (occurs in ceramics, glass, some metals, some polymers
↳ this brittle behavior caused by internal flaws, such as small cracks, pores, or other discontinuities that cause the material to fail before more ductile behavior can come into play

Plastic Deformation

ductile metals and ductile polymers are capable of large amounts of deformation before fracture

ductile metals – plastic deformation proceeds as result of the sliding of crystal planes caused by dislocation motion, w/ the strength + ductility being controlled by obstacles to this process such as impurity atoms, other dislocations, grain boundaries, and precipitate particles

ductile polymers – plastic deform. caused by rearrangement and relative sliding of the chain molecules, w/ strength + ductility being affected by the complexity of the molecule and features such as cross-linking

True Stresses + Strains

results of tension tests can be analyzed in terms of true stresses and strains which consider the finite changes in gage length and cross-sectional area that may occur

addt'l properties can be obtained, notably, the strain-hardening exponent n and the true fracture strength and strain

$\tilde{\sigma}_{fB}$ or $\tilde{\sigma}_{fm}$ $\qquad$ $\tilde{\varepsilon}_f$

Other

$$\sigma_u = \frac{P_{max}}{A_i}$$

engineering fracture strength σ_f is obtained from the force at fracture P_f even if this is not the highest force reached

$$\sigma_f = \frac{P_f}{A_i}$$

for brittle materials: $\sigma_u = \sigma_f$ $\qquad$ for ductile materials: $\sigma_u > \sigma_f$

yielding event can be characterized simplest by identifying the stress where the first departure from linearity occurs called the proportional limit σ_p

↳ difficult to precisely locate so use 0.2% offset method

offset yield strength σ_o where this dashed offset line intersects curve

→ note that the offset strain is a plastic strain such as $\varepsilon_{po} = 0.002$ as unloading from σ_o would follow a dashed line and this ε_{po} would be unrecovered strain

tensile toughness, u_f the area under the entire engineering stress-strain curve up to fracture

$$u_f \approx \varepsilon_f \left(\frac{\sigma_o + \sigma_u}{2}\right)$$

→ brittle materials have low tensile toughness despite high strength due to low ductility

→ to have high tensile toughness, both the strength + ductility must be high

→ tensile toughness should not be confused w/ fracture toughness, which is the resistance to failure in the presence of a crack

↳ tensile toughness used for comparing materials but fracture toughness used best/most in engineering purposes

Strain Hardening

Strain Hardening – the rise in the stress-strain curve following yielding as the material is ↑ its resistance w/ increasing strain

↳ a measure of the degree of strain hardening is the ratio of the ultimate tensile strength to the yield strength

$$\text{strain hardening ratio} = \frac{\sigma_u}{\sigma_o}$$

values > 1.4 for metals are high, values < 1.2 considered low