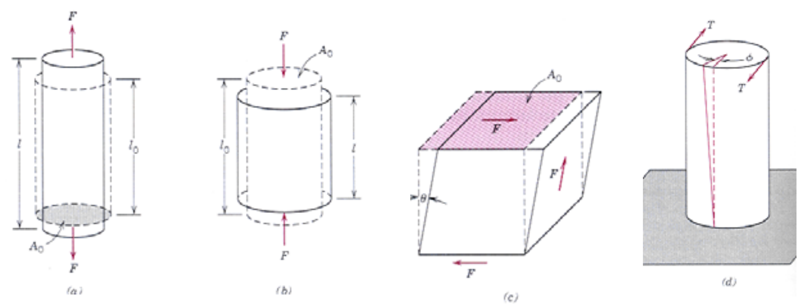
Chapter 6: Mechanical properties of metals

Outline

- Introduction
- Concepts of stress and strain
- Elastic deformation
  - Stress-strain behavior
  - Elastic properties of materials
- Plastic deformation
  - Yield and yield strength
  - Ductility
  - Resilience
  - Toughness

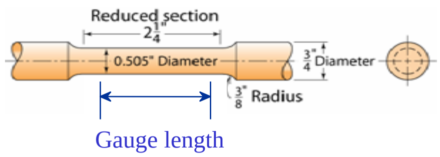
Concepts of stress and strain

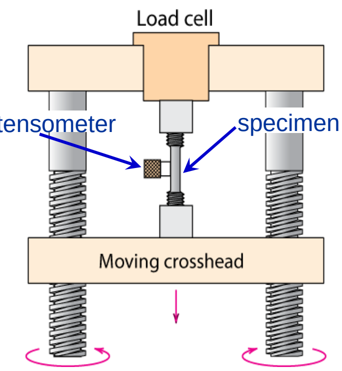
- Tension, compression, shear, and torsion



Stress-strain testing

- Tension tests
  - engineering stress $\sigma = \dfrac{F}{A_0}$
  - engineering strain $\varepsilon = \dfrac{l_i - l_0}{l_0} = \dfrac{\Delta l}{l_0}$

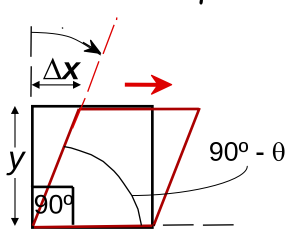


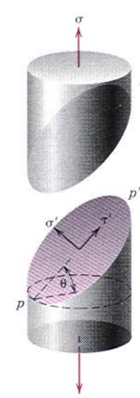


- Compression tests

Shear stress

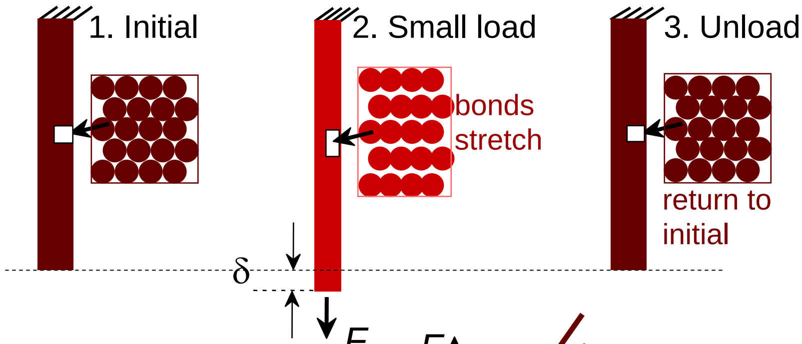
- Shear and torsional tests
  - Shear stress $\tau = \dfrac{F}{A_0} = G\gamma$
  - Shear strain $\gamma = \Delta x / y = \tan\theta$



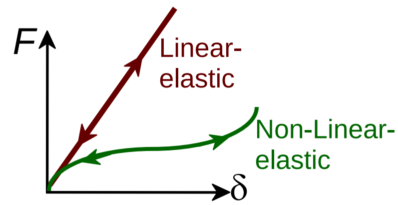


- Geometric considerations of the stress state

Elastic deformation



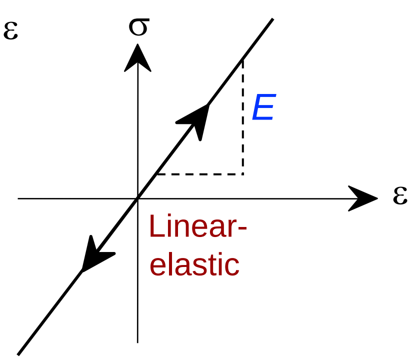
Elastic means reversible!

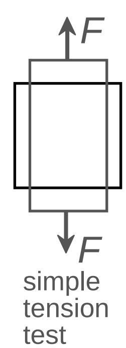


Linear elastic properties

- Modulus of Elasticity, *E*:
  (also known as Young's modulus)
- Hooke's Law:

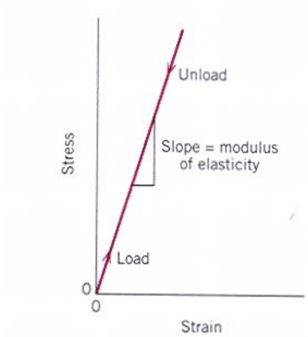
$$\sigma = E\,\varepsilon$$

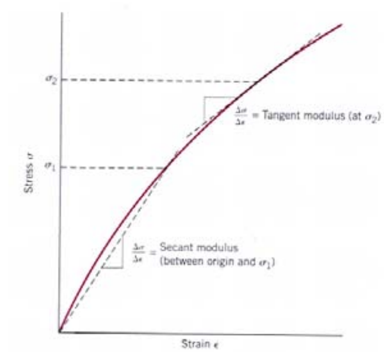




Stress-strain behavior

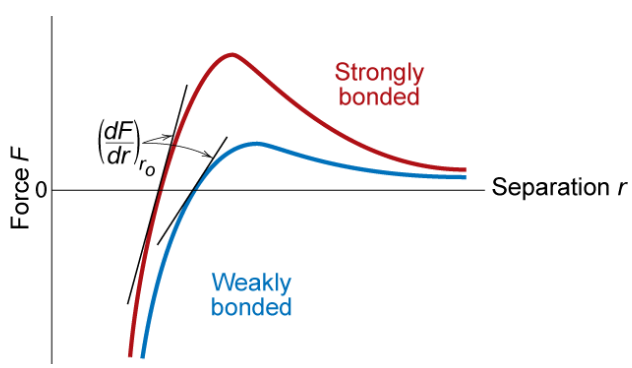
- Stress-strain for linear elastic deformation
- Stress-strain for non-linear elastic deformation





Stress-strain behavior(*continue*)

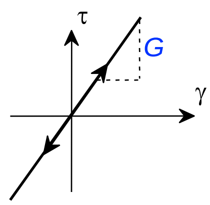
- Modulus of elasticity E is proportional to $(dF/dr)_r$
- Slope of stress strain plot (which is proportional to the elastic modulus) depends on bond strength of metal

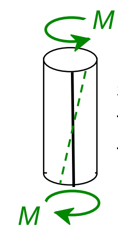


Other elastic properties

- **Elastic Shear modulus, G:**

  $\tau = G\gamma$

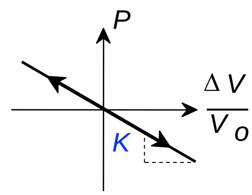


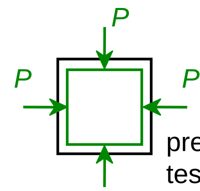


simple torsion test

- **Elastic Bulk modulus, K:**

  $P = -K\dfrac{\Delta V}{V_o}$





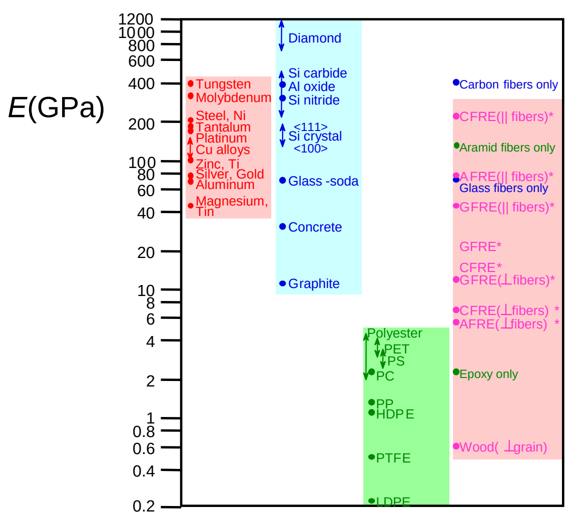
pressure test: Init. vol $=V_o$. Vol chg. $=\Delta V$

- **Special relations for isotropic materials:**

$$G = \frac{E}{2(1+\nu)} \qquad K = \frac{E}{3(1-2\nu)}$$

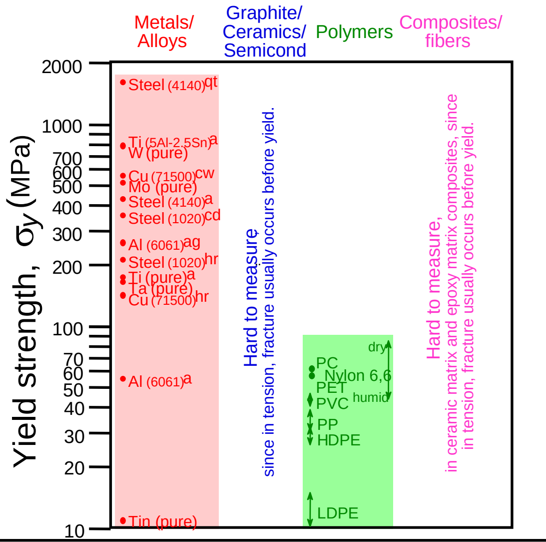
Comparison of Young's moduli

$E_{ceramics} > E_{metals} >> E_{polymers}$



Comparison of yield strength

σ_y(ceramics) >> σ_y(metals) >> σ_y(polymers)



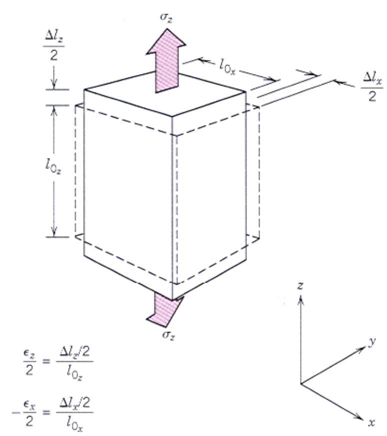
Elastic properties of materials

- Poisson's ratio

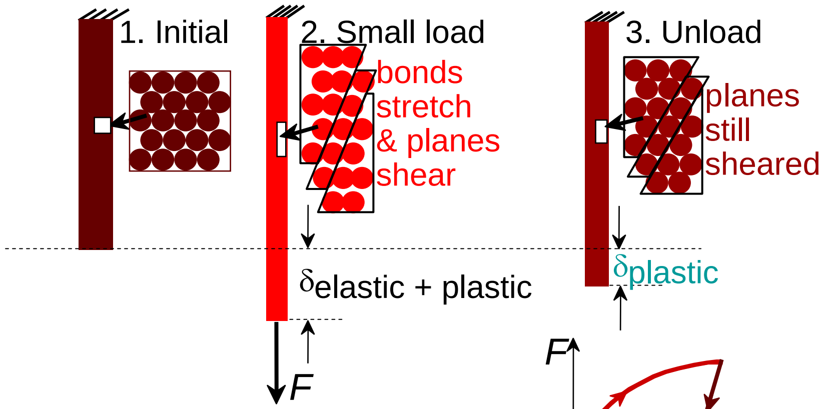
$$\nu = -\frac{\varepsilon_x}{\varepsilon_z} = -\frac{\varepsilon_y}{\varepsilon_z}$$

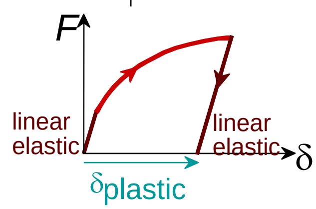
metals: ν ~ 0.33
ceramics: ν ~ 0.25
polymers: ν ~ 0.40

Units:
E: [GPa] or [psi]
ν: dimensionless



Plastic Deformation (Metals)

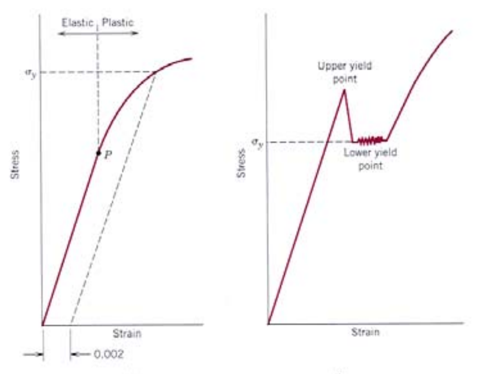




Plastic means permanent!

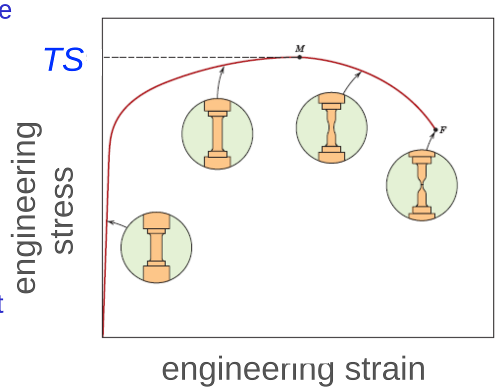
Plastic deformation: yield and yield strength

- Yielding
- Proportional limit
- Yield strength



Tensile strength

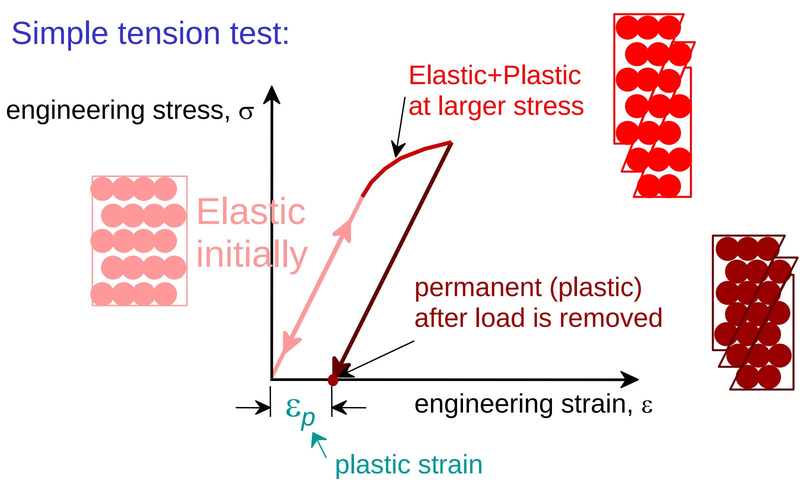
- Tensile strength: the stress at the maximum on the engineering stress-strain curve
- Metals: occurs when noticeable "necking" starts
- Ceramics: occurs when crack propagation starts
- Polymers: occurs when polymer backbones are aligned and about to break



Plastic (permanent) deformation

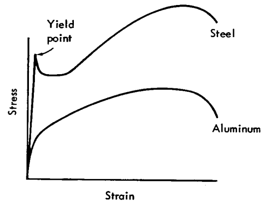
(At lower temperature: T< Tmelt/3)

- Simple tension test:

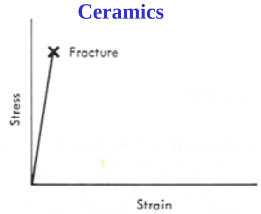


Elastic and plastic deformations

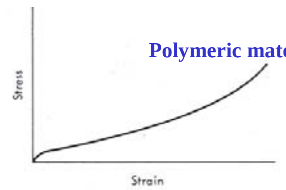
- Stress-strain relations under uniaxial loading



Ceramics



Polymeric material

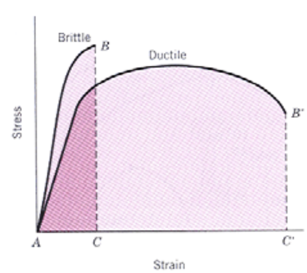


Ductility

- Ductility: a measure of the degree of plastic deformation that has been sustained at fracture

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

$$\%RA = \left(\frac{A_0 - A_f}{A_0}\right) \times 100$$



Mechanic properties of typical metals

Table 6.2 Typical Mechanical Properties of Several Metals and Alloys in an Annealed State

Metal Alloy	*Yield Strength MPa (ksi)*	*Tensile Strength MPa (ksi)*	*Ductility, %EL [in 50 mm (2 in.)]*
Aluminum	35 (5)	90 (13)	40
Copper	69 (10)	200 (29)	45
Brass (70Cu–30Zn)	75 (11)	300 (44)	68
Iron	130 (19)	262 (38)	45
Nickel	138 (20)	480 (70)	40
Steel (1020)	180 (26)	380 (55)	25
Titanium	450 (65)	520 (75)	25
Molybdenum	565 (82)	655 (95)	35

Resilience

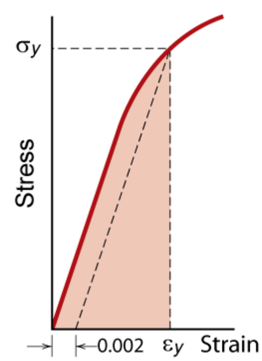
- Resilience: is the capacity of a material to absorb energy when it is deformed elastically and then, upon unloading, to have this energy recovered.

Resilience

$$U_r = \int_0^{\epsilon_y} \sigma \, d\epsilon$$

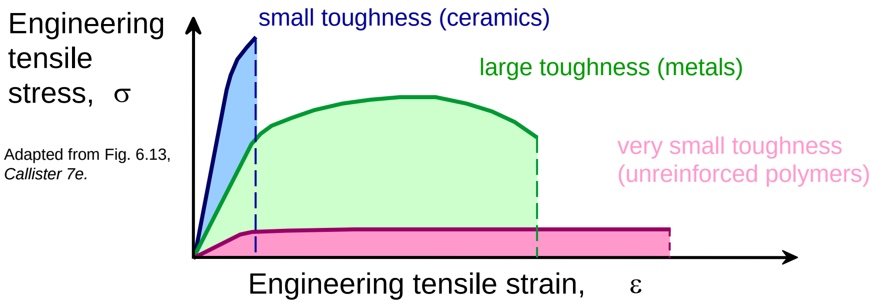
$$U_r = \tfrac{1}{2}\sigma_y \epsilon_y$$

$$U_r = \tfrac{1}{2}\sigma_y \epsilon_y = \tfrac{1}{2}\sigma_y \left(\frac{\sigma_y}{E}\right) = \frac{\sigma_y^2}{2E}$$



Toughness

- Energy to break a unit volume of material
- Approximate by the area under the stress-strain curve



Adapted from Fig. 6.13, *Callister 7e.*

Brittle fracture: elastic energy
Ductile fracture: elastic + plastic energy

Summary

- Stress and strain: These are size-independent measures of load and displacement, respectively.
- Elastic behavior: This reversible behavior often shows a linear relation between stress and strain. To minimize deformation, select a material with a large elastic modulus (*E* or *G*).
- Plastic behavior: This permanent deformation behavior occurs when the tensile (or compressive) uniaxial stress reaches σ_y.
- Toughness: The energy needed to break a unit volume of material.
- Ductility: The plastic strain at failure.