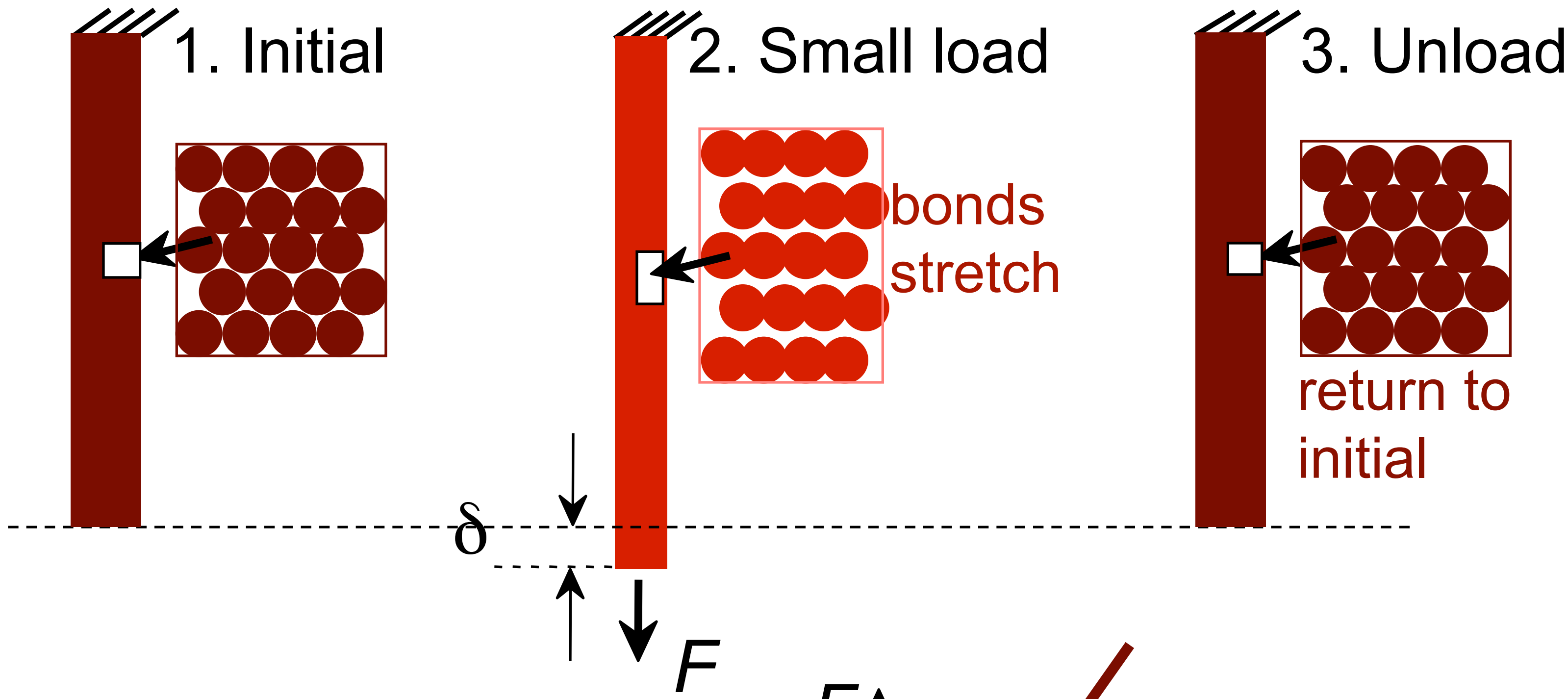
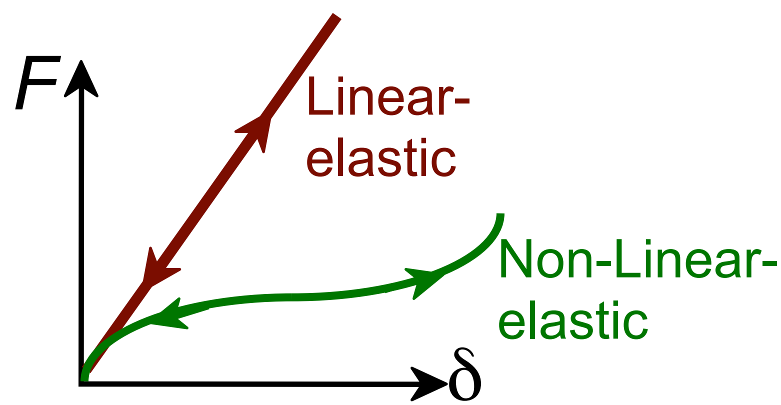
Chapter 6:
Mechanical Properties

- Elastic behavior: When loads are small, how much deformation occurs? What materials deform least?
- Stress and strain: What are they and why are they used instead of load and deformation?
- Plastic behavior: At what point does permanent deformation occur? What materials are most resistant to permanent deformation?
- Toughness and ductility: What are they and how do we measure them?

Elastic Deformation



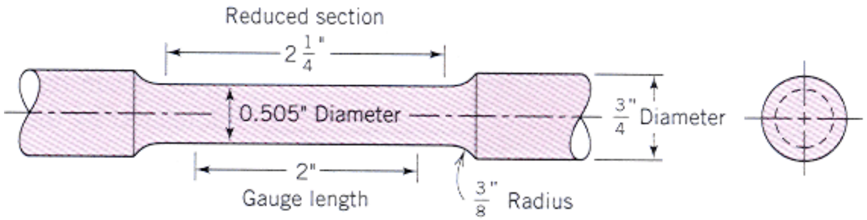
Elastic means reversible!

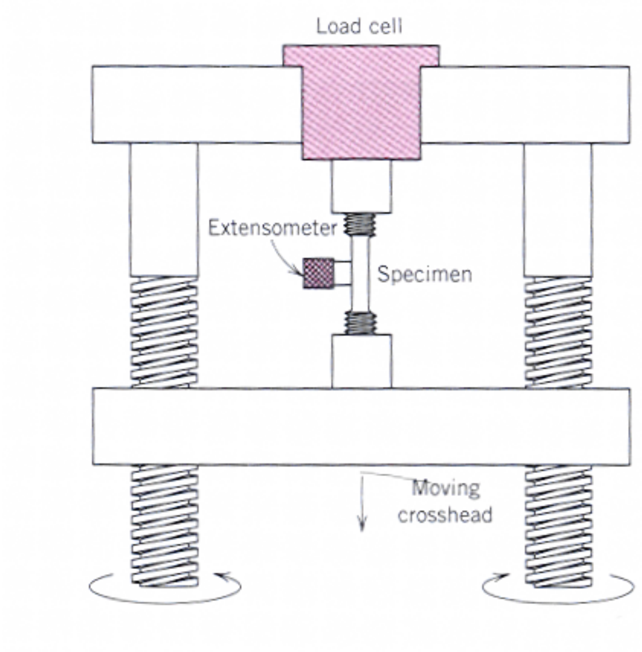


Concepts of stress and strain

- **Tension tests**
  - **engineering stress** $$\sigma = \frac{F}{A_0}$$
  - **engineering strain**

$$\varepsilon = \frac{l_i - l_0}{l_0} = \frac{\Delta l}{l_0}$$



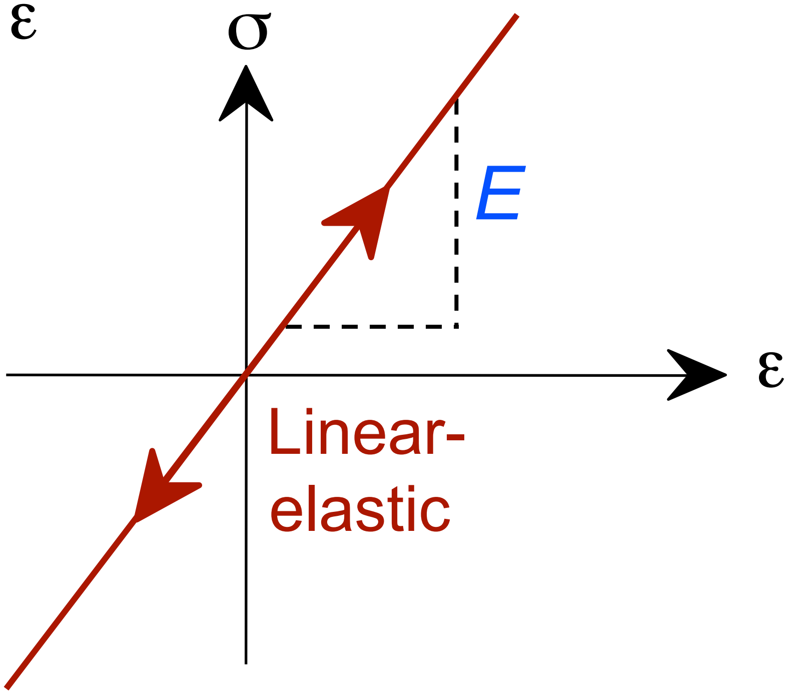


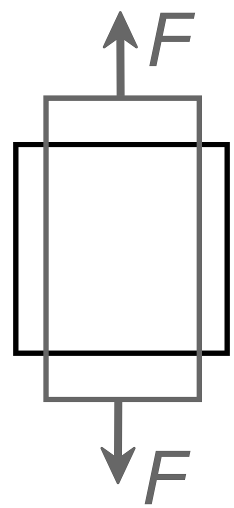
- **Compression tests**

Linear Elastic Properties

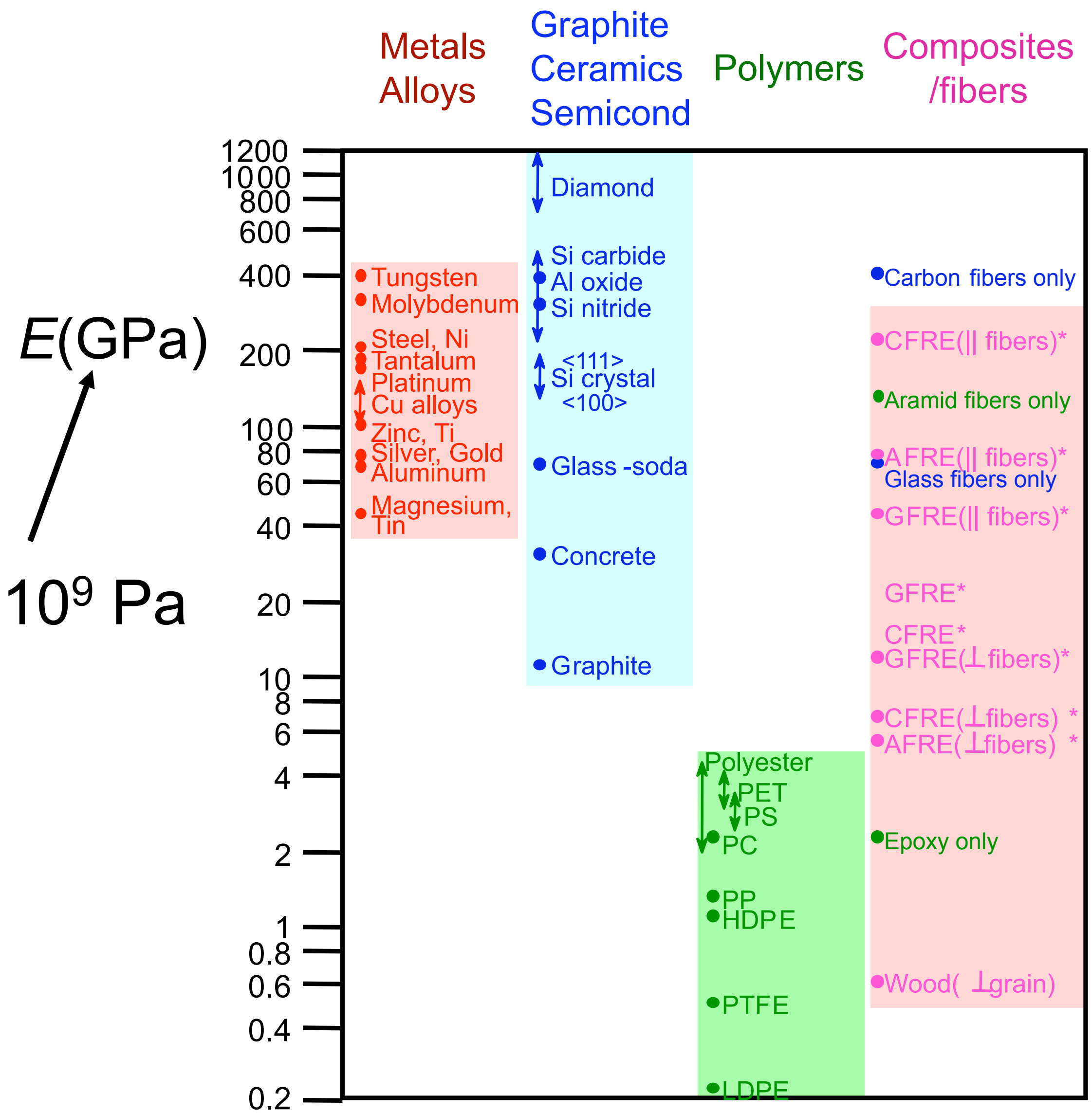
- **Modulus of Elasticity, *E*:**
  (also known as Young's modulus)
- **Hooke's Law:**

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





Young's Moduli: Comparison

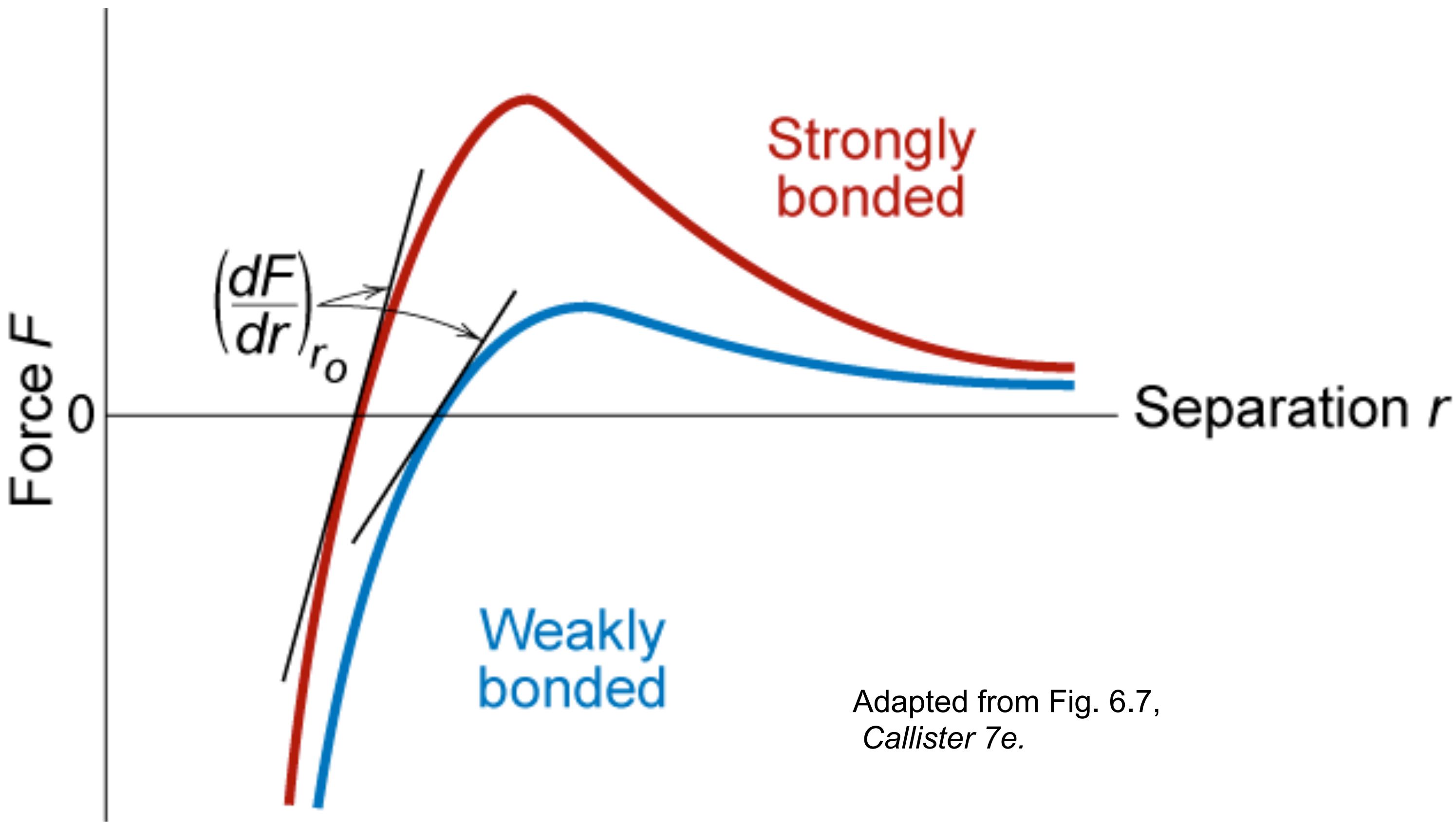


Based on data in Table B2, *Callister 7e*.

Composite data based on reinforced epoxy with 60 vol% of aligned carbon (CFRE), aramid (AFRE), or glass (GFRE) fibers.

Mechanical Properties

- Slope of stress strain plot (which is proportional to the elastic modulus) depends on dF/dr

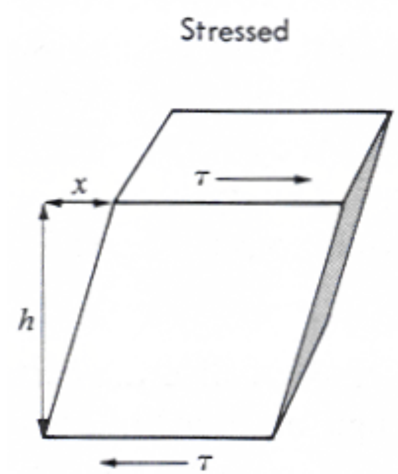


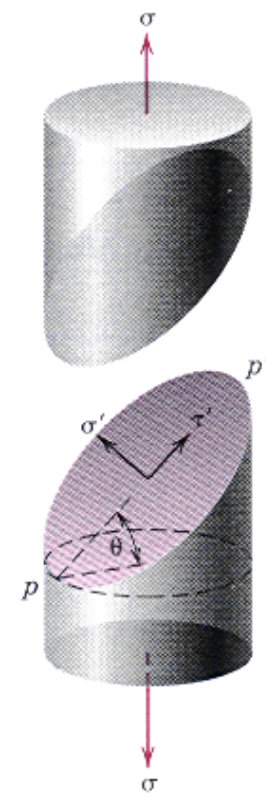
Adapted from Fig. 6.7, *Callister 7e.*

Concepts of stress and strain (*continued*)

- **Shear and torsional tests**
  - **Shear stress** $$\tau = \frac{F}{A_0} = G\gamma$$
  - **Shear strain** $$\gamma = \frac{x}{h}$$

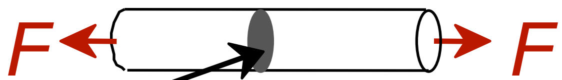
- **Geometric considerations of the stress state**





Common States of Stress

- **Simple tension: cable**

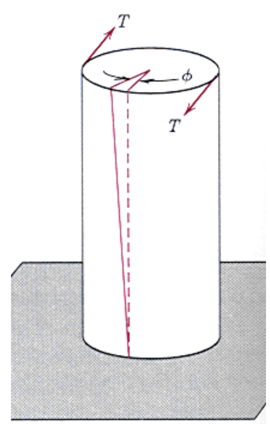


A_o = cross sectional area (when unloaded)

$$\sigma = \frac{F}{A_o}$$

Ski lift (photo courtesy P.M. Anderson)

- **Torsion (a form of shear): drive shaft**



(d)

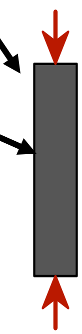
OTHER COMMON STRESS STATES (1)

- **Simple compression:**

Balanced Rock, Arches National Park
(photo courtesy P.M. Anderson)

Canyon Bridge, Los Alamos, NM
(photo courtesy P.M. Anderson)

$$\sigma = \frac{F}{A_o}$$



Note: compressive structure member ($\sigma < 0$ here).

Poisson's ratio, ν

- **Poisson's ratio, ν:**

$$\nu = -\frac{\varepsilon_L}{\varepsilon}$$

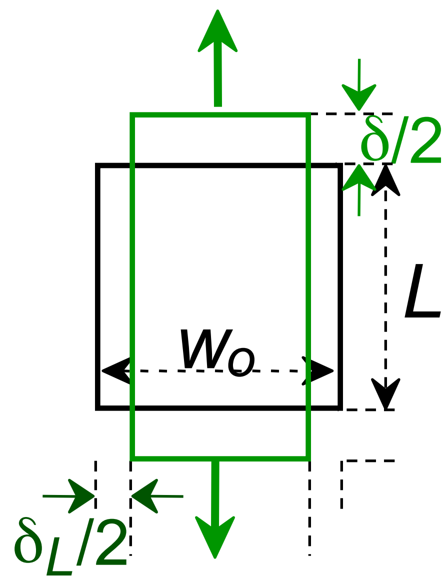
metals: ν ~ 0.33
ceramics: ν ~ 0.25
polymers: ν ~ 0.40

Relation of elastic properties
for isotropic materials

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

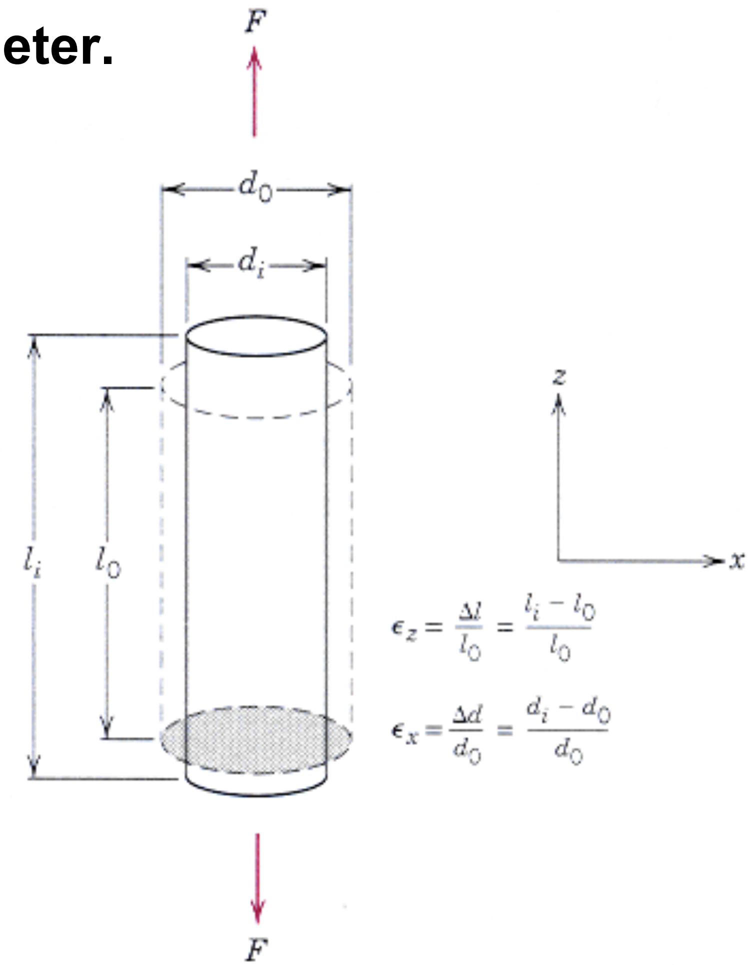
- **Tensile strain:** $\varepsilon = \dfrac{\delta}{L_o}$

- **Lateral strain:** $\varepsilon_L = \dfrac{-\delta_L}{w_o}$

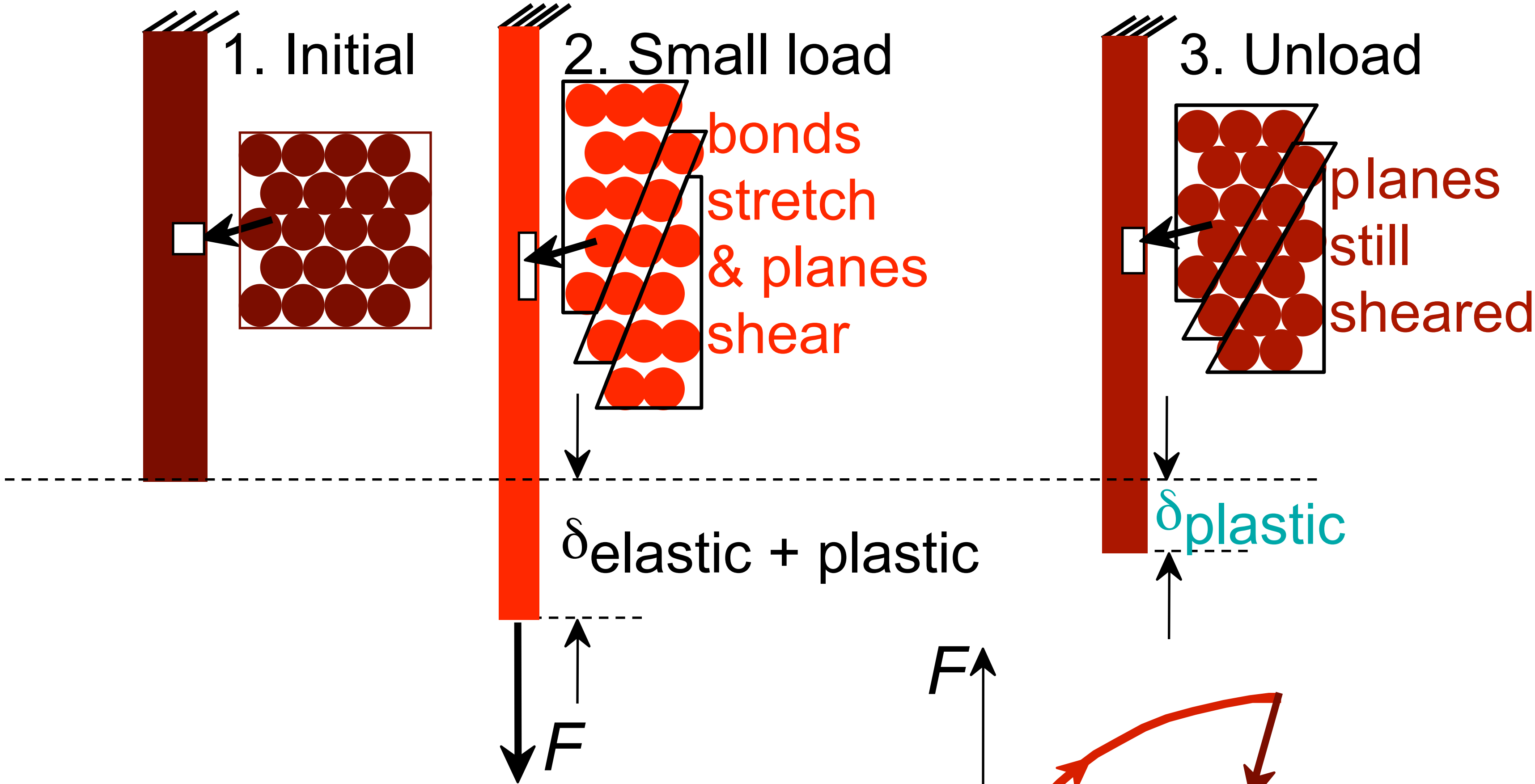


Examples

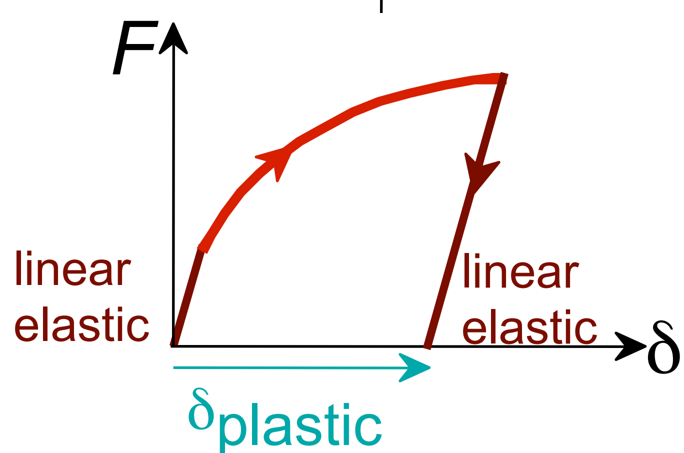
- **Determine the load required to produce a 2.5x10^{-3} mm change in diameter. D$_0$=10mm, Poisson's ratio for brass is 0.34**



Plastic Deformation (Metals)



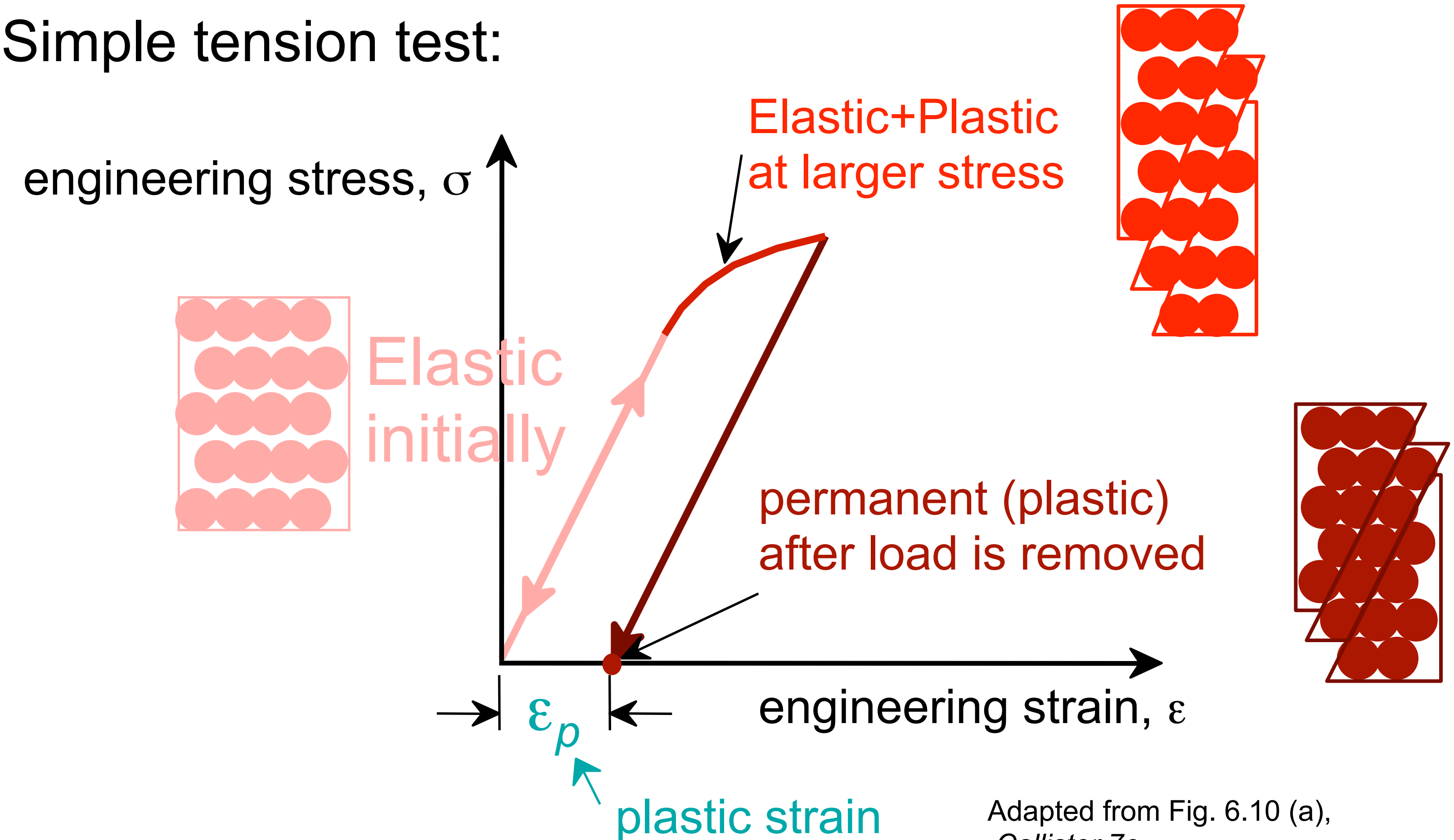
Plastic means permanent!



Plastic (Permanent) Deformation

(at lower temperatures, i.e. $T < T_{melt}/3$)

- Simple tension test:

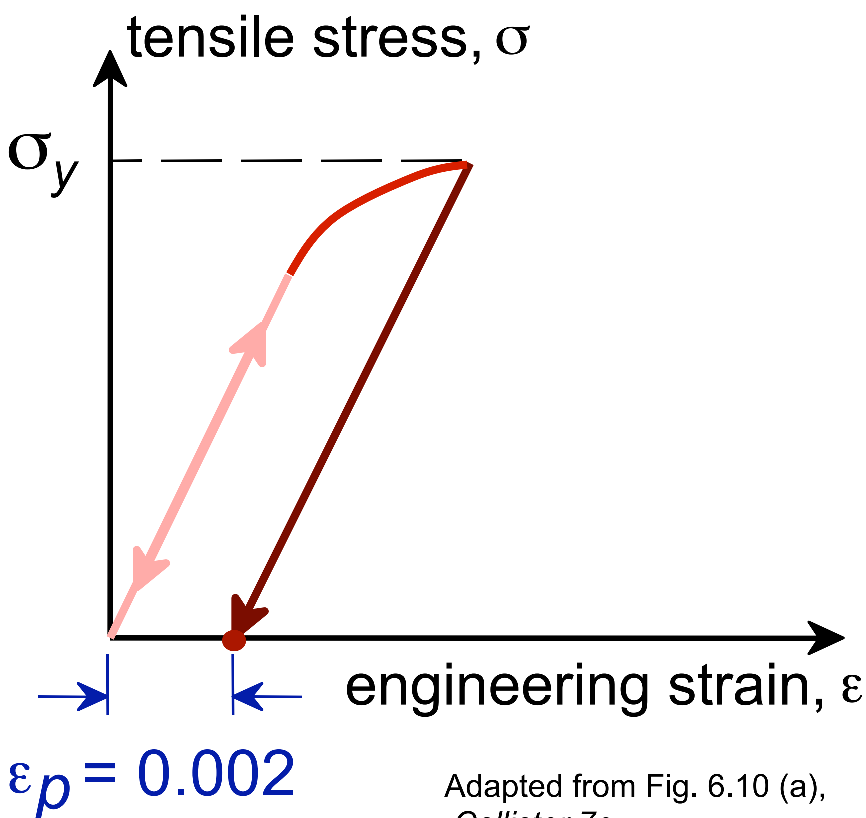


Adapted from Fig. 6.10 (a), *Callister 7e.*

Yield Strength, σ_y

- **Stress at which *noticeable* plastic deformation has occurred.**

when $\varepsilon_p = 0.002$



Adapted from Fig. 6.10 (a), *Callister 7e.*

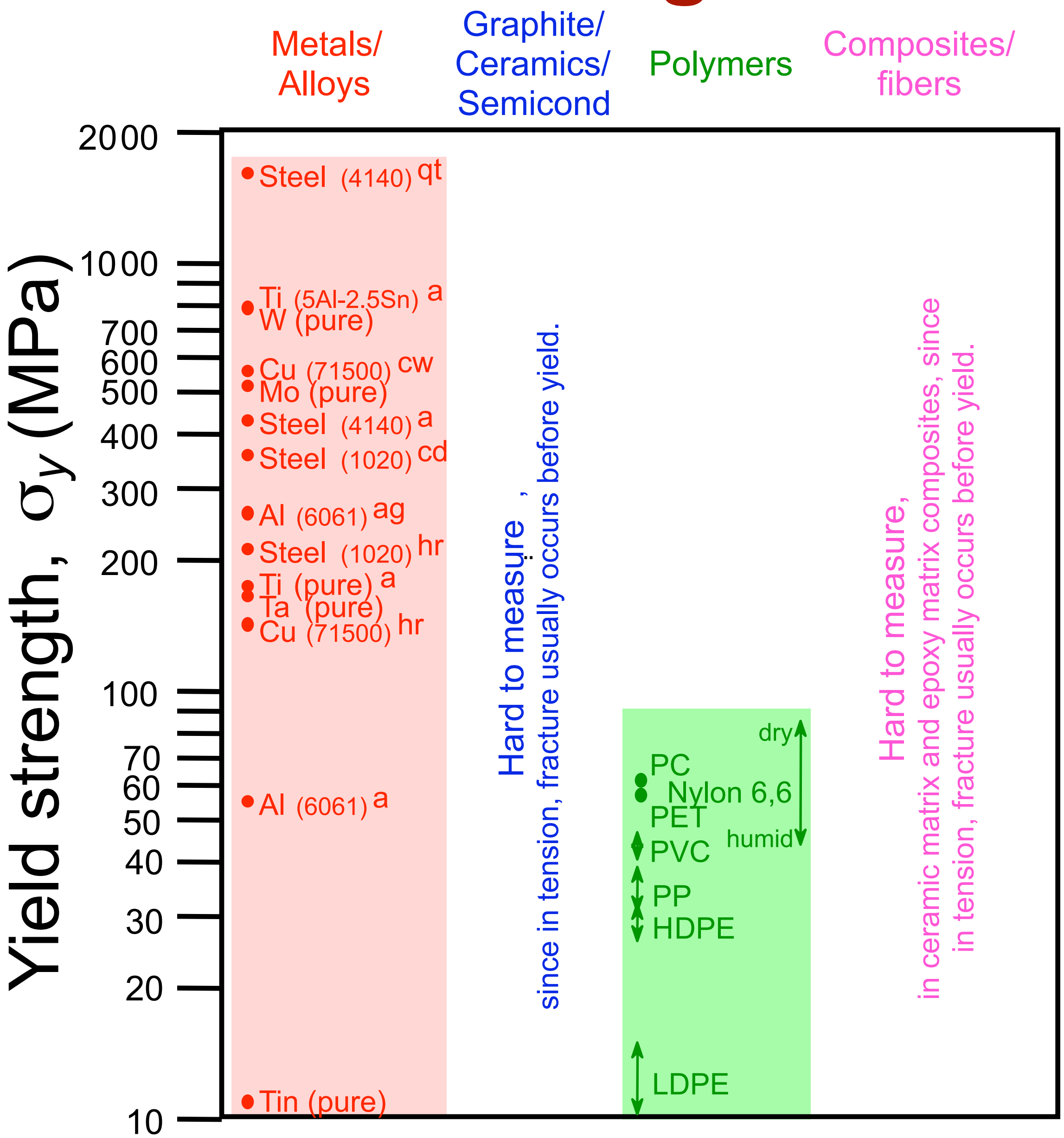
σ_y = yield strength

Note: for 2 inch sample

$\varepsilon = 0.002 = \Delta z/z$

$\therefore\ \Delta z = 0.004$ in

Yield Strength : Comparison



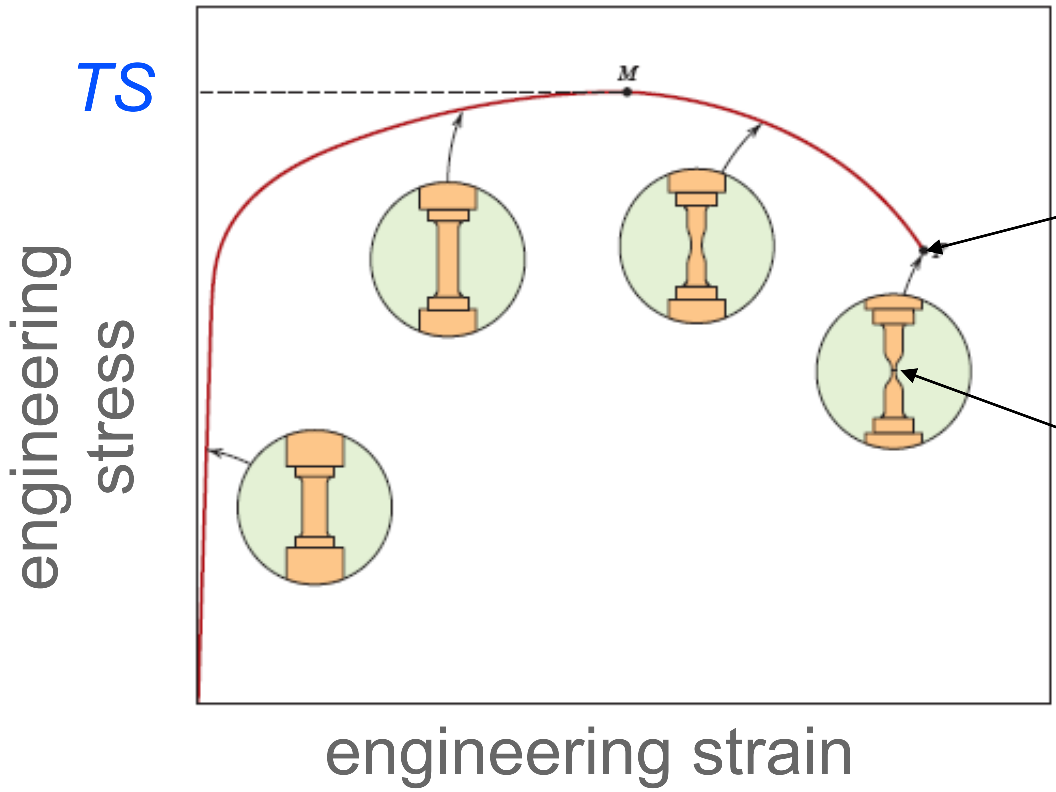
Room *T* values

Based on data in Table B4, *Callister 7e*.

a = annealed
hr = hot rolled
ag = aged
cd = cold drawn
cw = cold worked
qt = quenched & tempered

Tensile Strength, TS

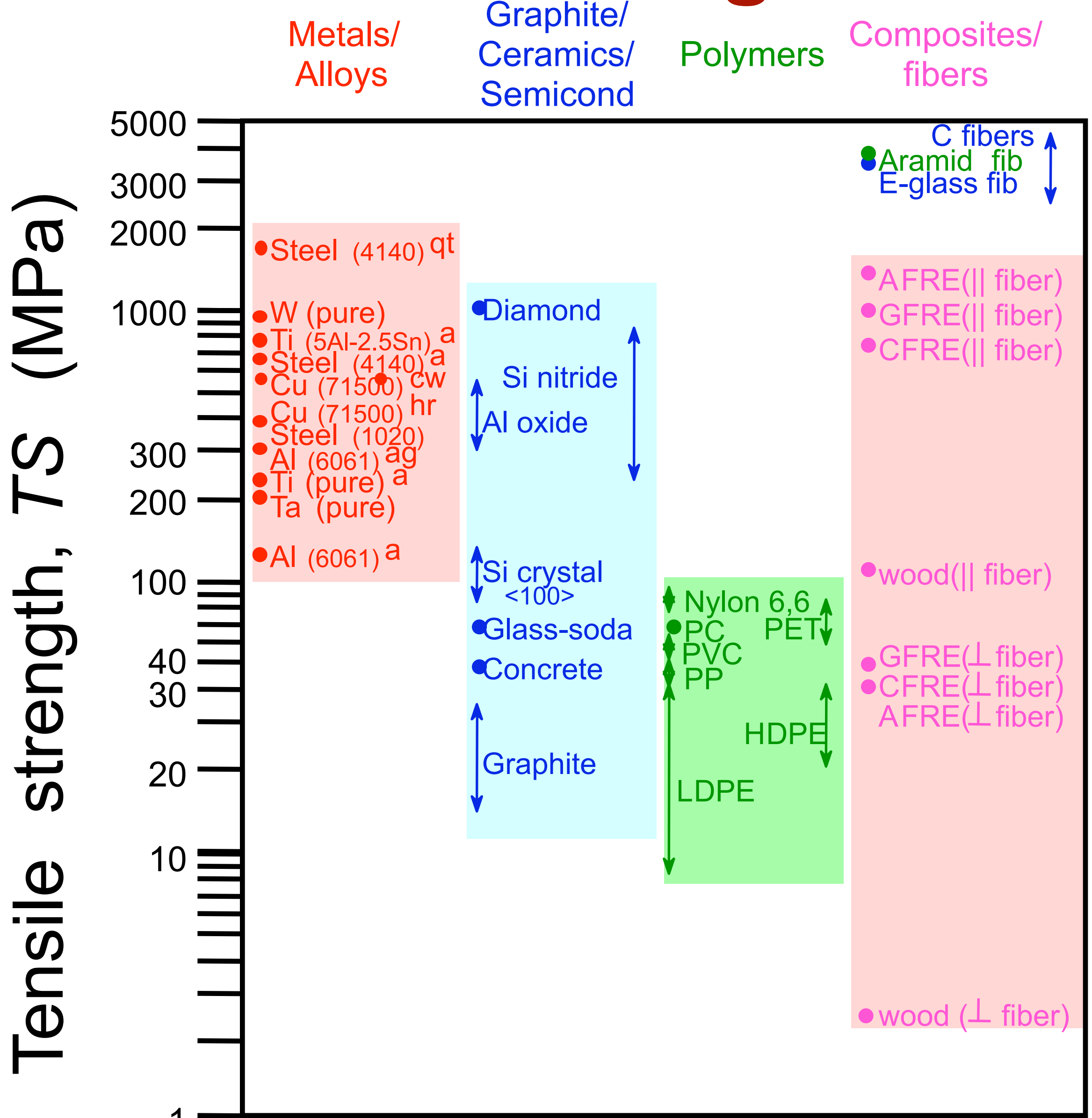
- Maximum stress on engineering stress-strain curve.



Adapted from Fig. 6.11, *Callister 7e.*

- Metals: occurs when noticeable necking starts.
- Polymers: occurs when polymer backbone chains are aligned and about to break.

Tensile Strength : Comparison



Room Temp. values

Based on data in Table B4, *Callister 7e*.

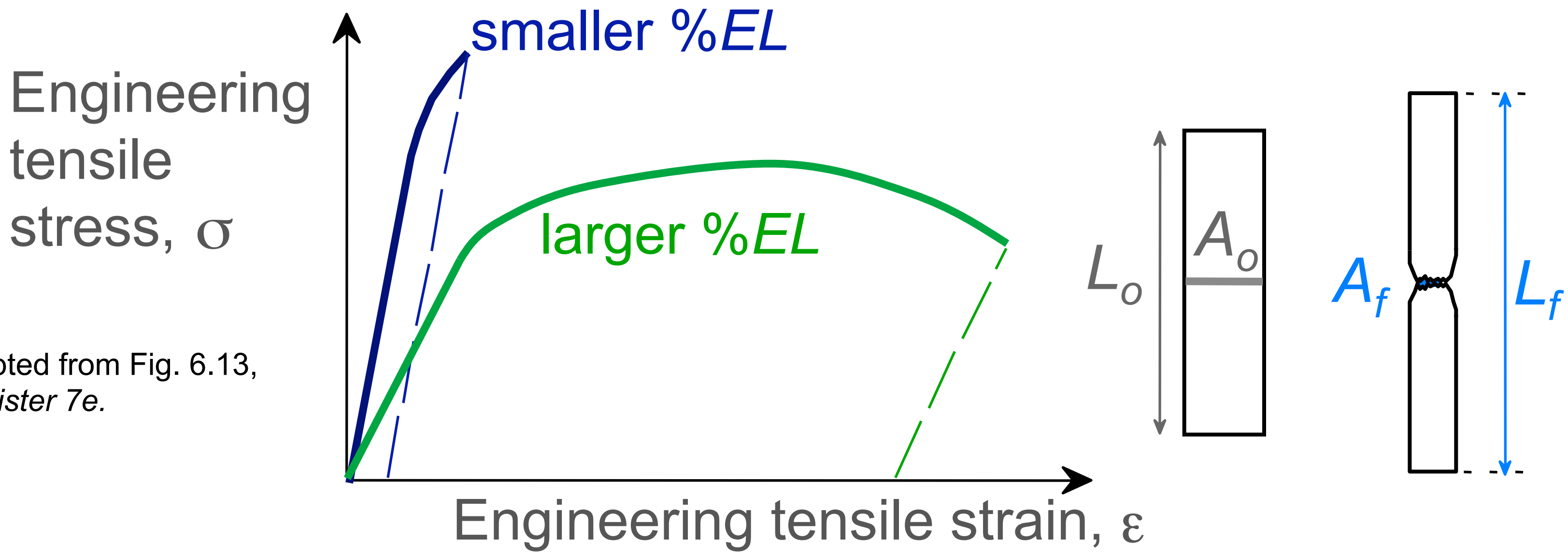
a = annealed
hr = hot rolled
ag = aged
cd = cold drawn
cw = cold worked
qt = quenched & tempered

AFRE, GFRE, & CFRE = aramid, glass, & carbon fiber-reinforced epoxy composites, with 60 vol% fibers.

Ductility

- Plastic tensile strain at failure:

$$\%EL = \frac{L_f - L_o}{L_o} \times 100$$



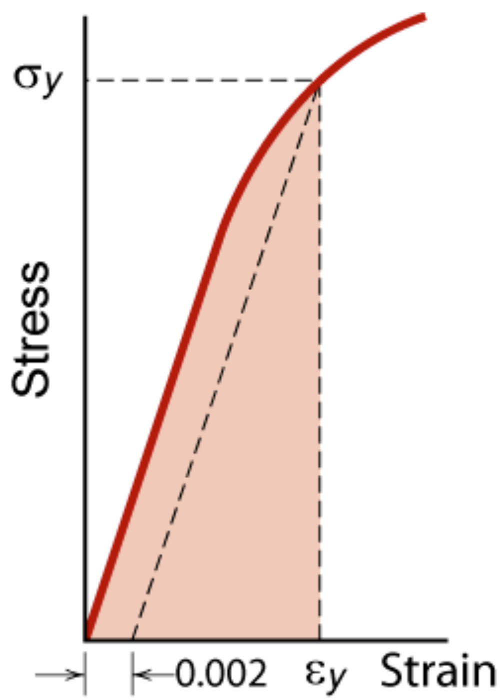
Adapted from Fig. 6.13, *Callister 7e.*

- Another ductility measure:

$$\%RA = \frac{A_o - A_f}{A_o} \times 100$$

Resilience, U_r

- Ability of a material to store energy
  - Energy stored best in elastic region



Adapted from Fig. 6.15, *Callister 7e.*

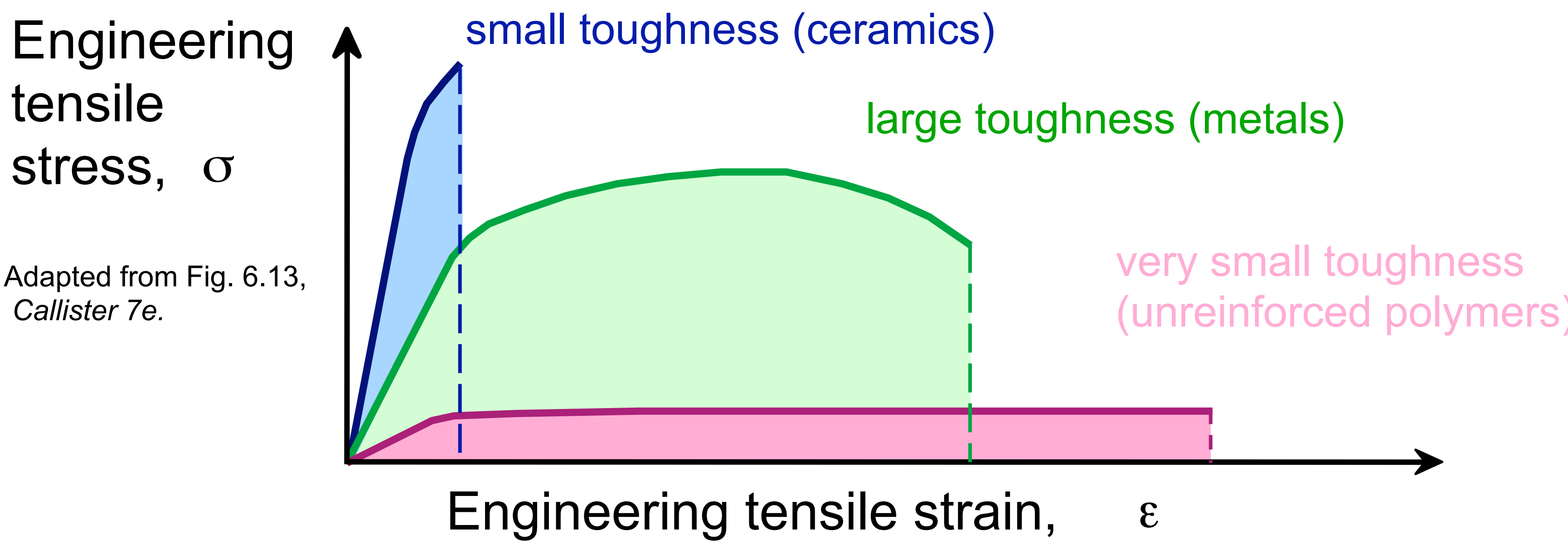
$$U_r = \int_0^{\varepsilon_y} \sigma d\varepsilon$$

If we assume a linear stress-strain curve this simplifies to

$$U_r \cong \frac{1}{2}\sigma_y \varepsilon_y$$

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.