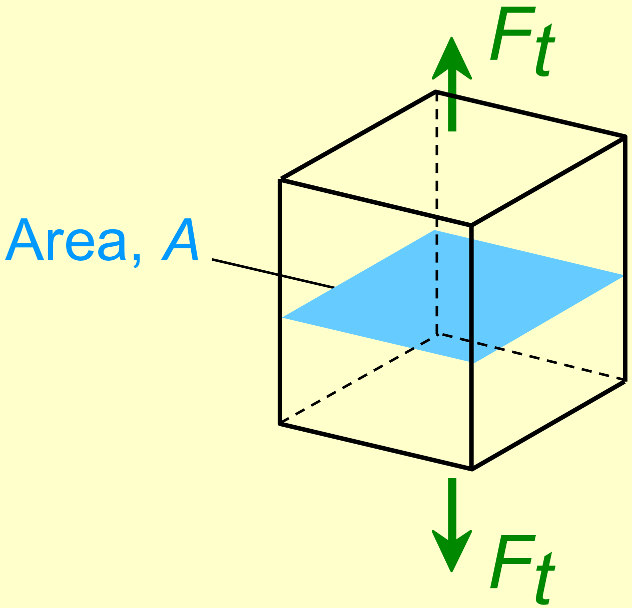
Chapter 6: Behavior Of Material Under Mechanical Loads = Mechanical Properties.

- Stress and strain:
  - What are they and why are they used instead of load and deformation
- Elastic behavior:
  - Recoverable Deformation of small magnitude
- Plastic behavior:
  - Permanent deformation We must consider which materials are most resistant to permanent deformation?
- Toughness and ductility:
  - Defining how much energy that a material can take before failure. How do we measure them?
- Hardness:
  - How we measure hardness and its relationship to material strength

Engineering Stress:

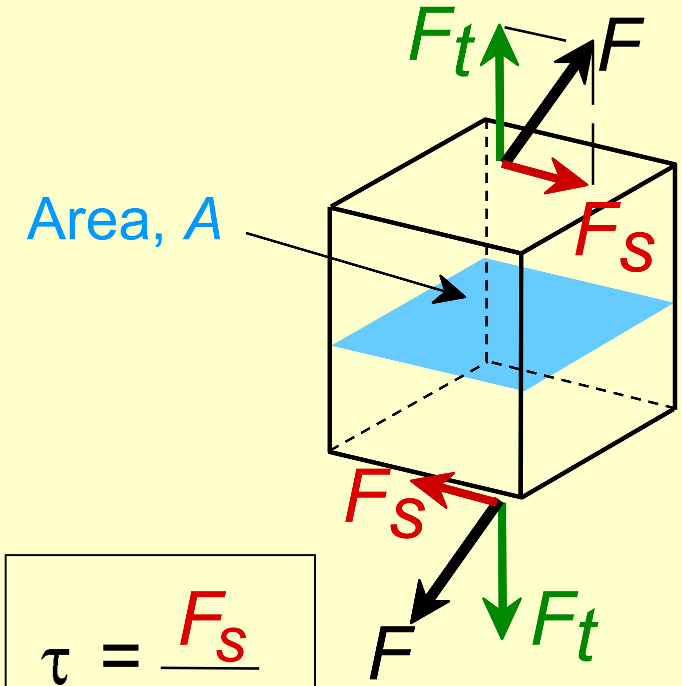
- Tensile stress, σ:



$$\sigma = \frac{F_t}{A_o} = \frac{lb_f}{in^2} \text{ or } \frac{N}{m^2}$$

original area
before loading

- Shear stress, τ:



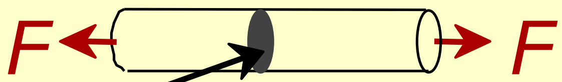
$$\tau = \frac{F_s}{A_o}$$

$\therefore$ Stress has units:
N/m^2 (Mpa) or $lb_f/in2$

we can also see the symbol ‘s’ used for engineering stress

Common States of Stress

- **Simple tension: cable**

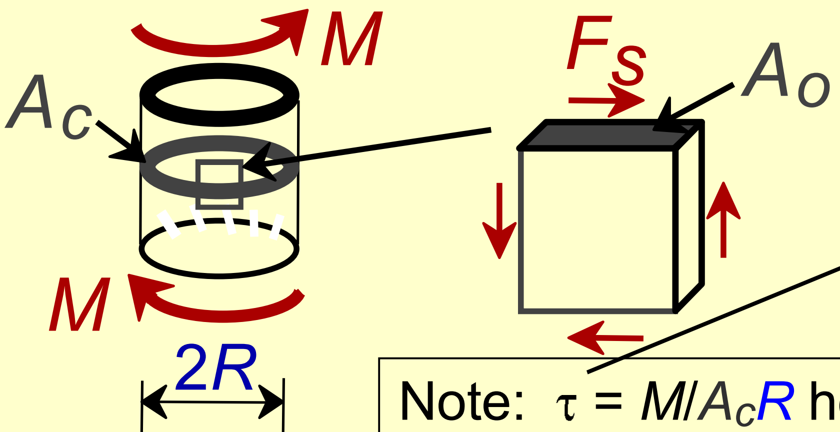


A_o = cross sectional area (when unloaded)

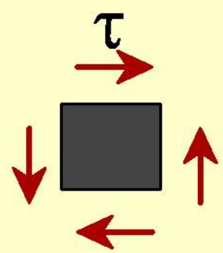
$$\sigma = \frac{F}{A_o}$$

Ski lift (photo courtesy P.M. Anderson)

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



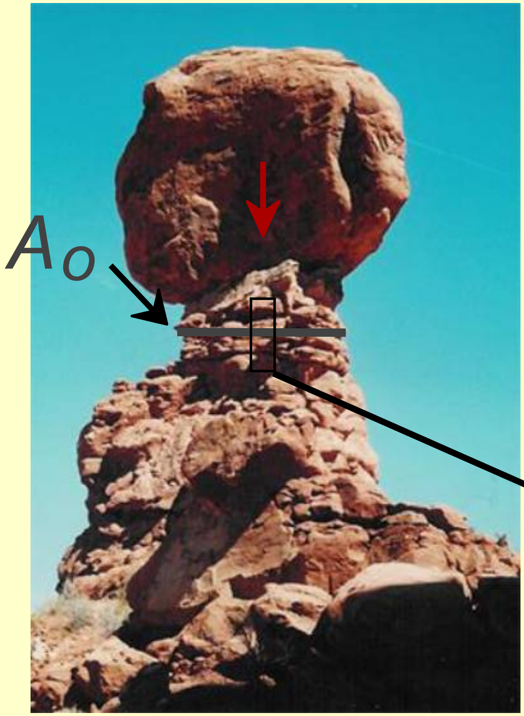
$$\tau = \frac{F_s}{A_o}$$



Note: $\tau = M/A_cR$ here.
Where M is the "Moment" A_c shaft area & R shaft radius

OTHER COMMON STRESS STATES (1)

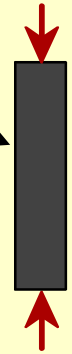
- **Simple compression:**



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

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

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

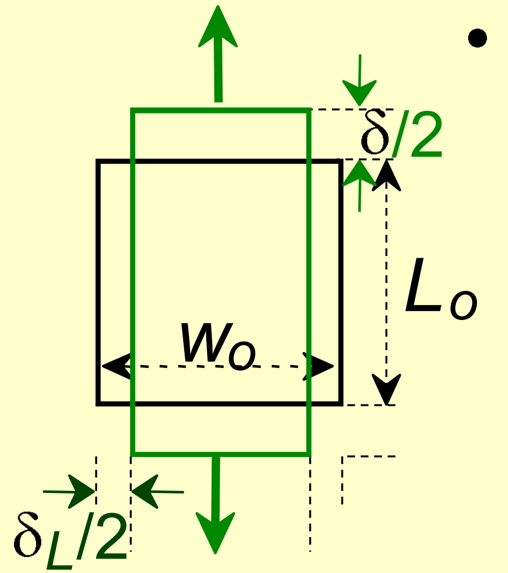


Note: compressive structure member (σ < 0 here).

Engineering Strain:

- **Tensile strain:**

$$\varepsilon = \frac{\delta}{L_o}$$



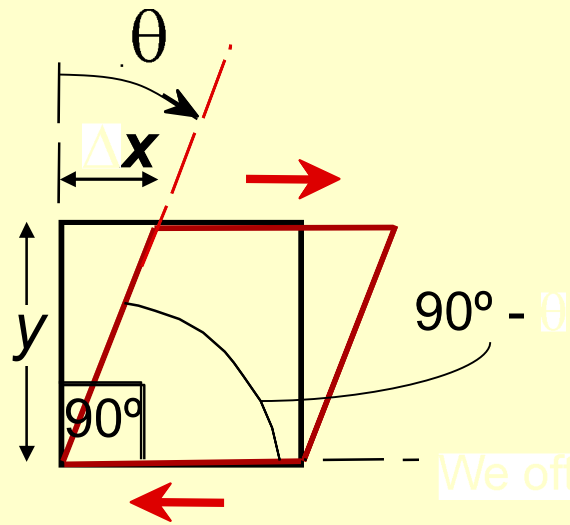
- **Lateral strain:**

$$\varepsilon_L = \frac{\delta_L}{w_o}$$

Here: The Black Outline is Original, Green is after application of load

Adapted from Fig. 6.1 (a) and (c), *Callister 7e.*

- **Shear strain:**



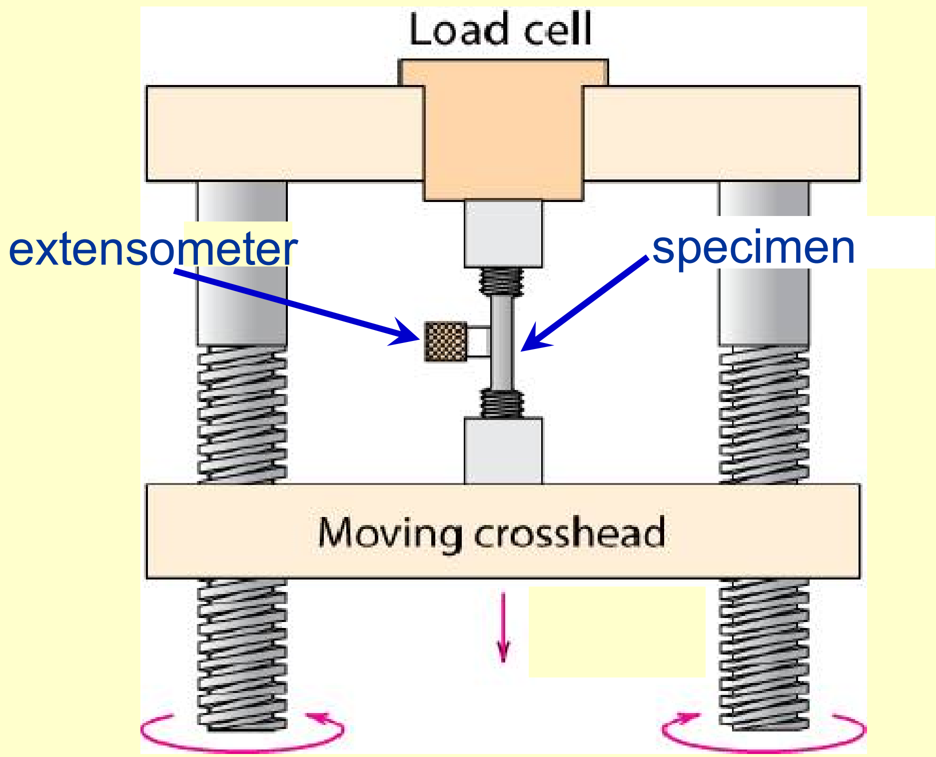
$$\gamma = \Delta x / y = \tan\theta$$

Strain is always Dimensionless!

We often see the symbol 'e' used for engineering strain

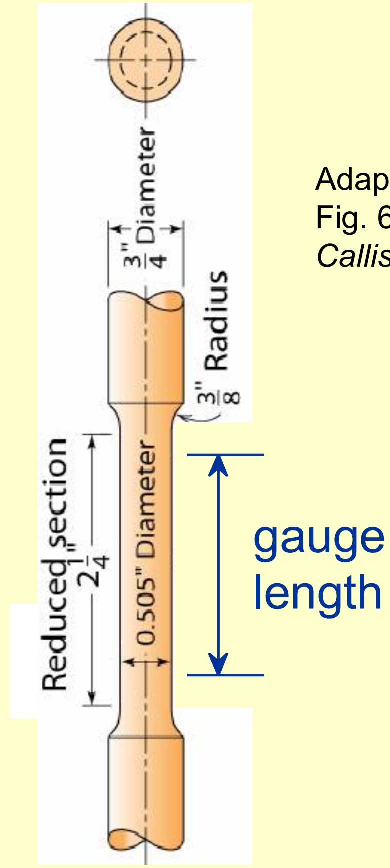
Stress-Strain: Testing Uses Standardized methods developed by ASTM for Tensile Tests it is ASTM E8

- **Typical tensile test machine**



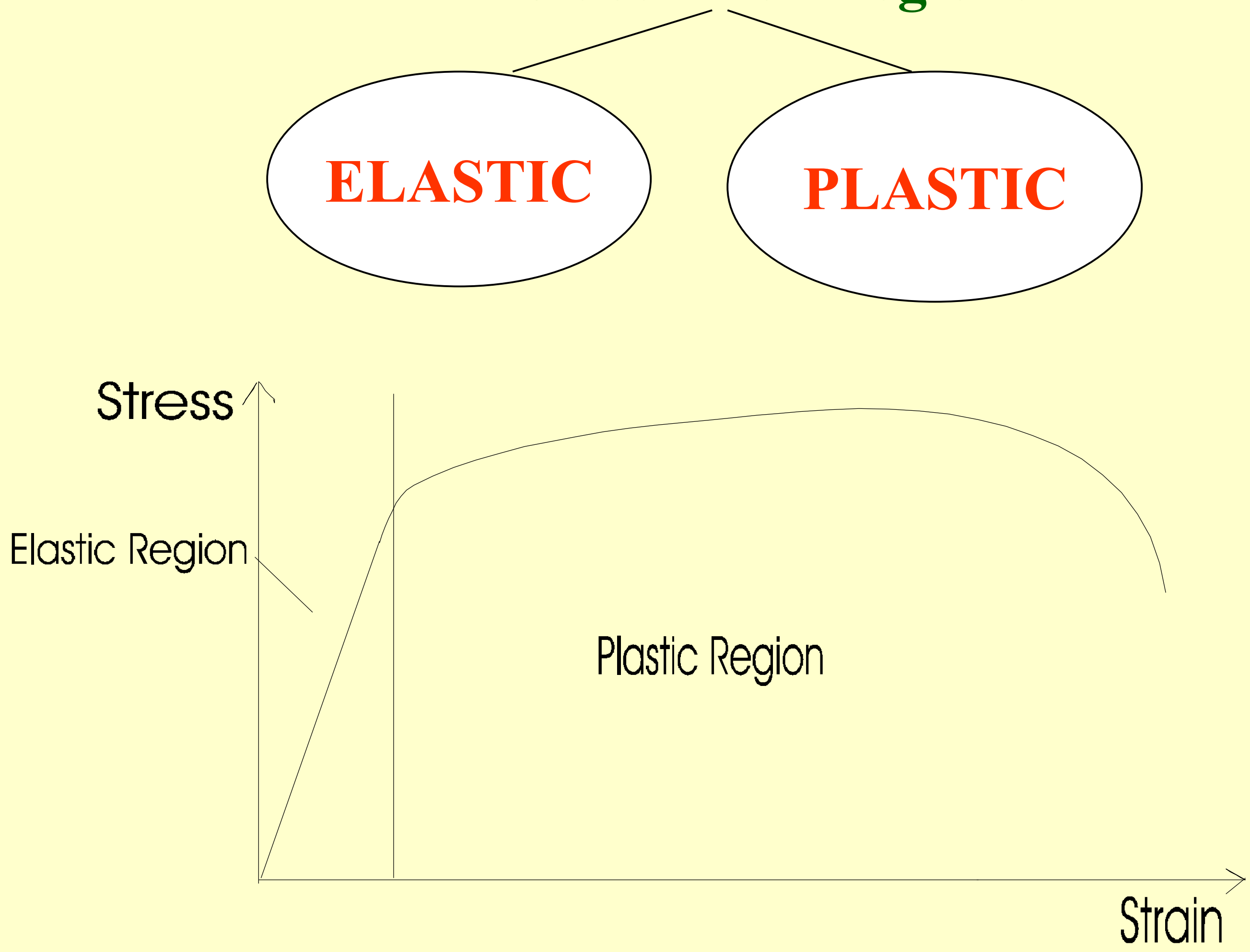
Adapted from Fig. 6.3, *Callister 7e.* (Fig. 6.3 is taken from H.W. Hayden, W.G. Moffatt, and J. Wulff, *The Structure and Properties of Materials*, Vol. III, *Mechanical Behavior*, p. 2, John Wiley and Sons, New York, 1965.)

- **Typical tensile specimen (ASTM A-bar)**



Adapted from Fig. 6.2, *Callister 7e.*

The Engineering Stress - Strain curve
Divided into 2 regions

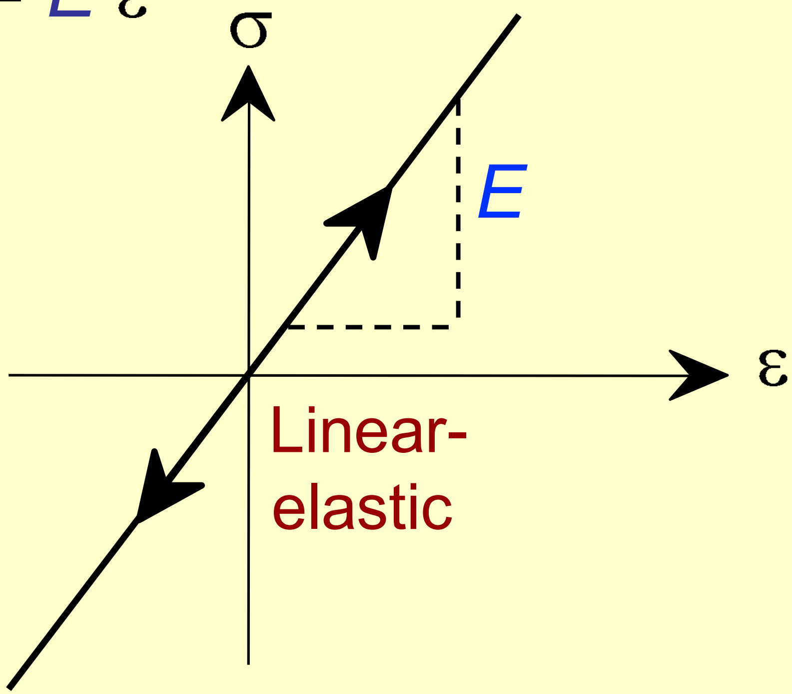


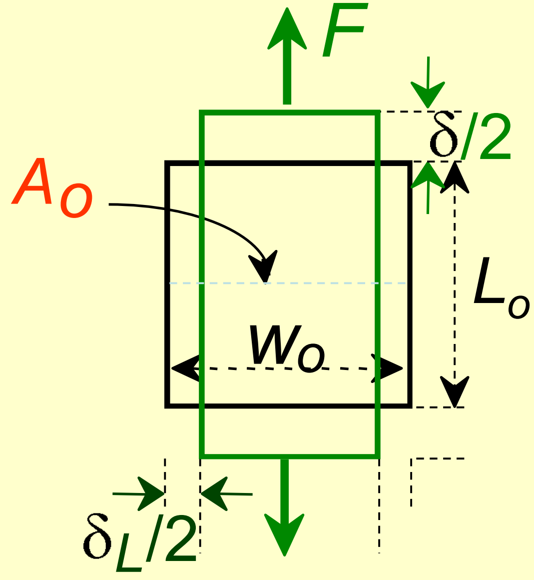
Linear: Elastic Properties

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

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

Units:
E: [GPa] or [psi]
σ: in [Mpa] or [psi]
ε: [m/m or mm/mm] or [in/in]





Here: The Black Outline is Original, Green is after application of load

Solving:

$$\sigma = F/A_0 = 66700N/\left(16.5*10^{-3}\right)^2 = 244.995MPa$$

$$\varepsilon = \Delta L/L_0 = 0.43mm/125mm = 0.00344$$

Because we are to assume all deformation is recoverable, Hooke's Law can be assumed:

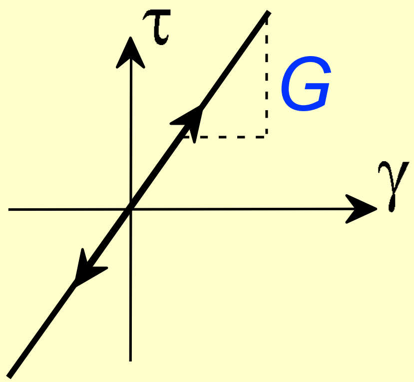
$$\sigma = E*\varepsilon \Rightarrow E = \sigma/\varepsilon = 244.995MPa/0.00344$$

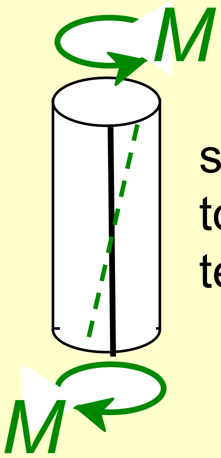
$$E = 71219.6\ MPa = 71.2\ GPa$$

Other Elastic Properties

- **Elastic Shear modulus, G:**

$$\tau = G\,\gamma$$

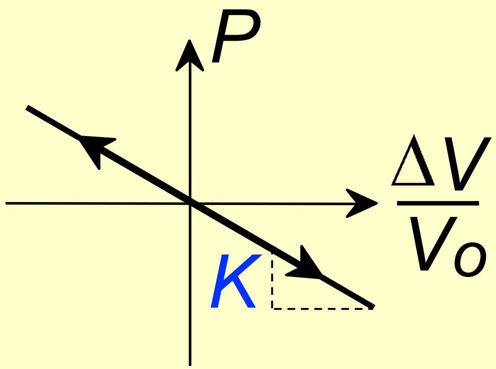


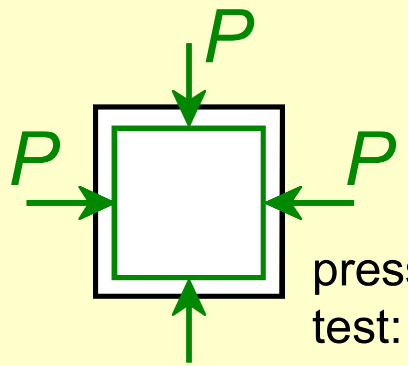


simple torsion test

- **Elastic Bulk modulus, K:**

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





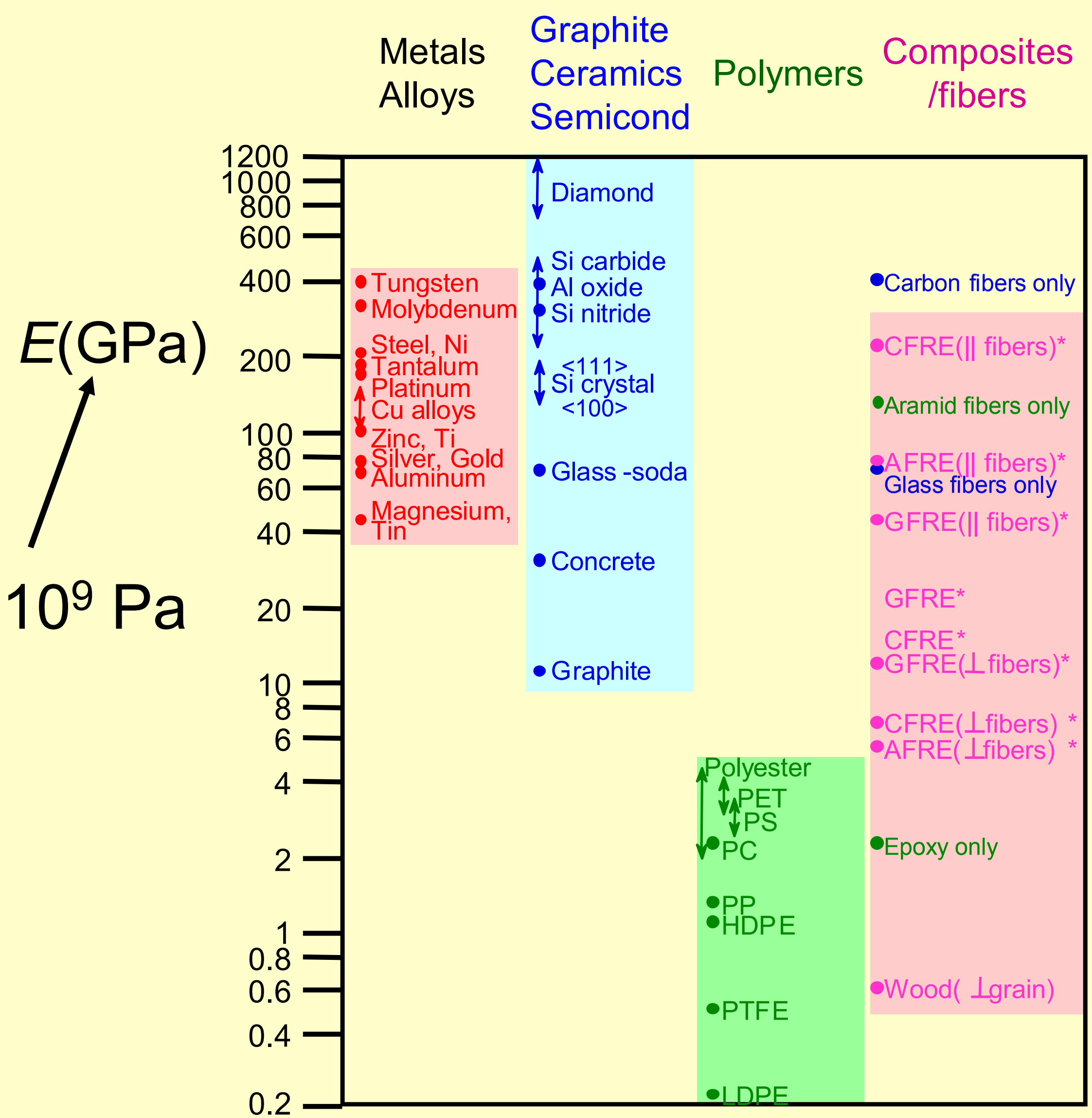
pressure test: Init. vol $= V_o$. Vol chg. $= \Delta V$

- Special relations for ***isotropic materials***:

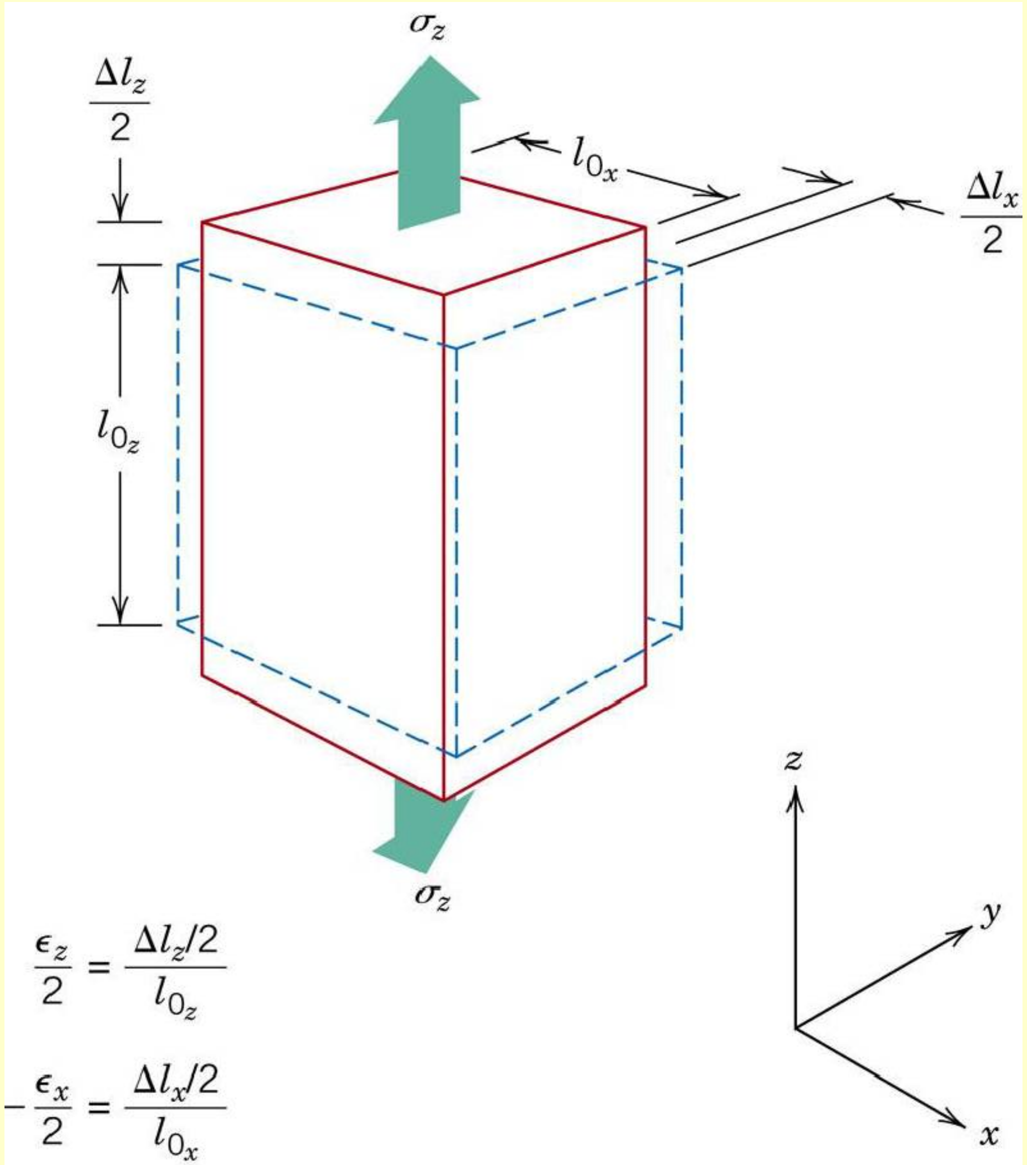
$$G = \frac{E}{2(1+\nu)} \qquad K = \frac{E}{3(1-2\nu)}$$

E is Modulus of Elasticity
ν is Poisson's Ratio

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.

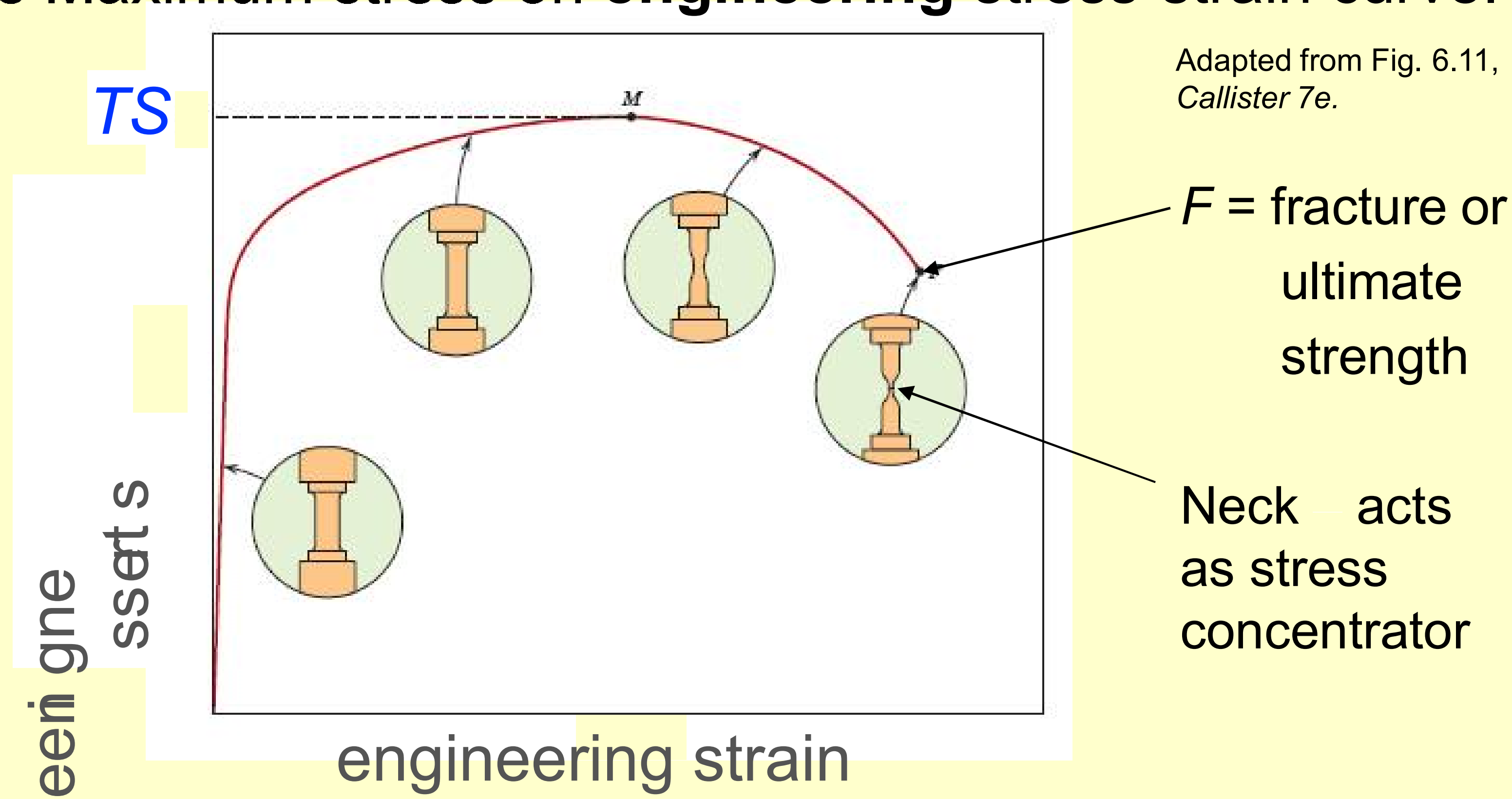


$$\frac{\epsilon_z}{2} = \frac{\Delta l_z/2}{l_{0_z}}$$

$$-\frac{\epsilon_x}{2} = \frac{\Delta l_x/2}{l_{0_x}}$$

Tensile Strength, TS

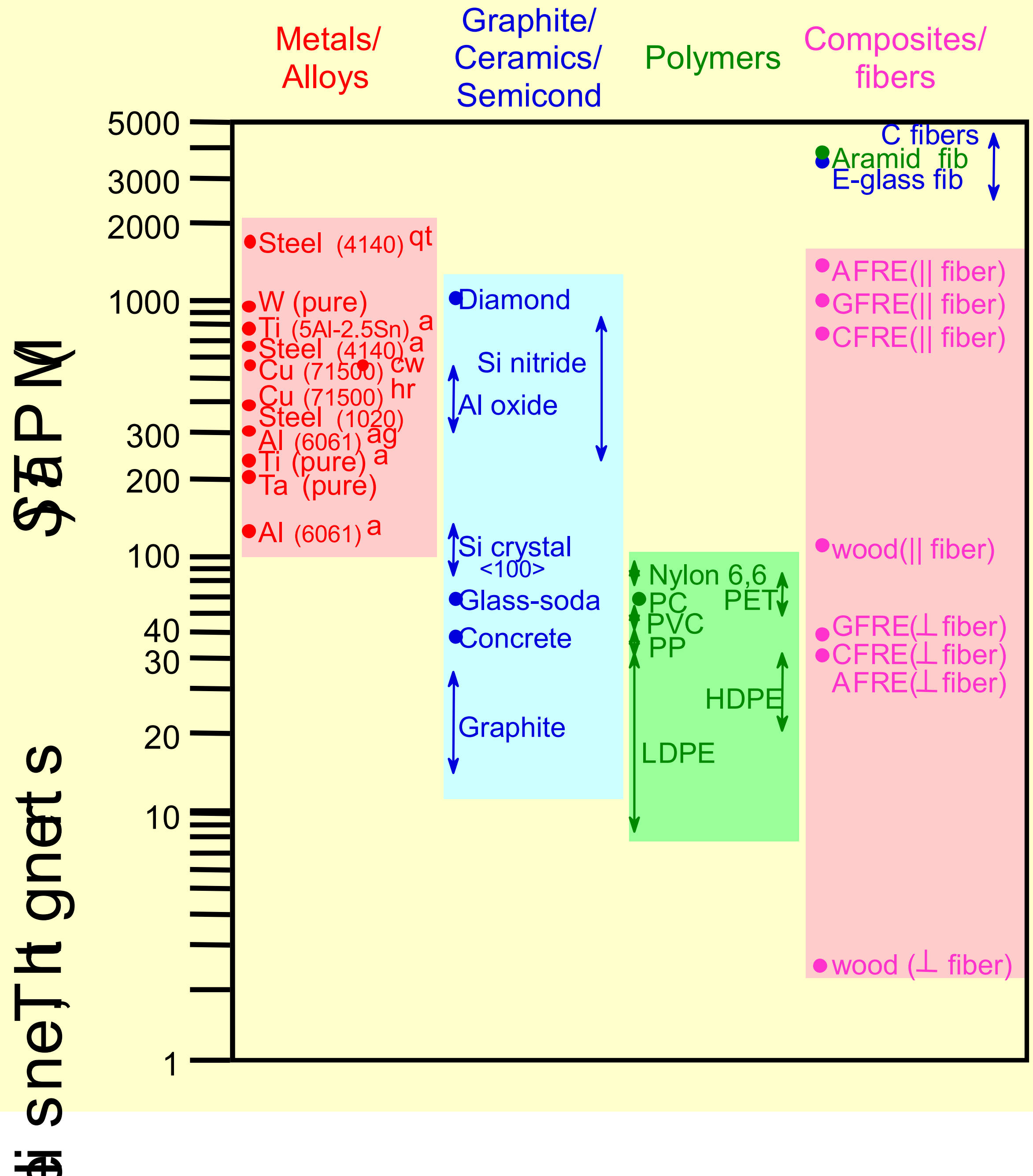
- TS is Maximum stress on **engineering** stress-strain curve.



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*.

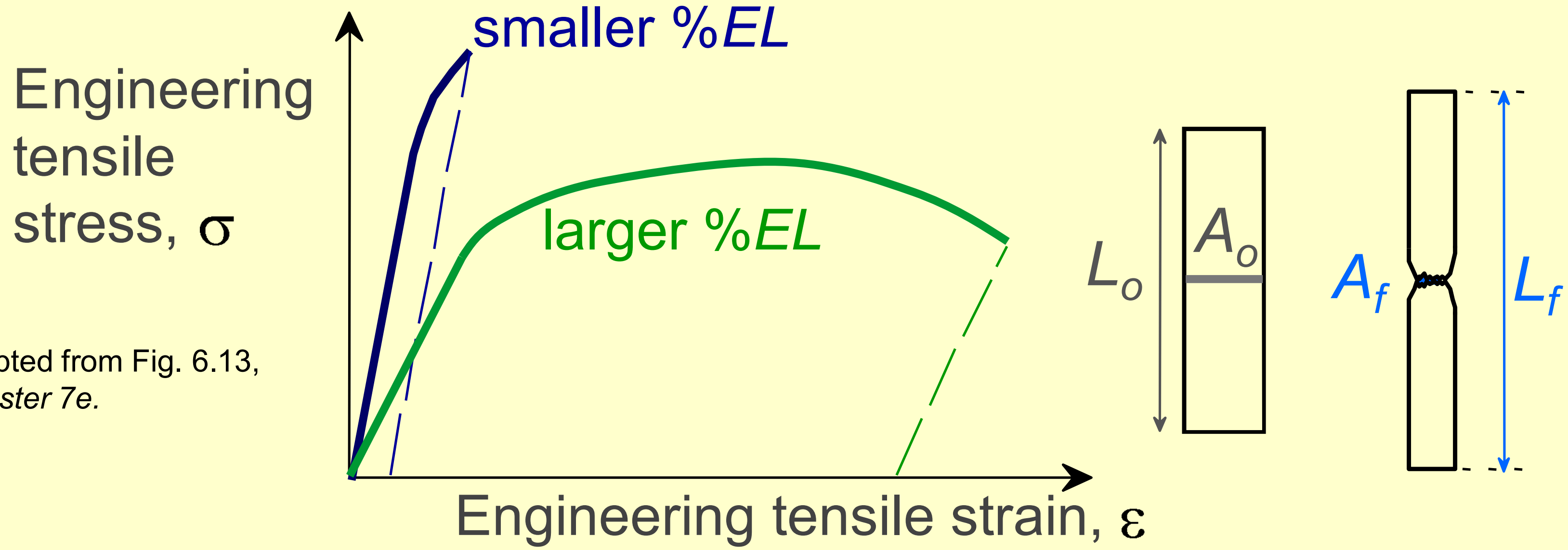
a = annealed
hr = hot rolled
ag = aged
cd = cold drawn
cw = cold worked
qt = quenched & tempered

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:

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

Lets Try one (like Problem 6.29)

GIVENS:

Load (N)	len. (mm)	len. (m)	Δl
0	50.8	0.0508	0
12700	50.825	0.050825	2.5E-05
25400	50.851	0.050851	5.1E-05
38100	50.876	0.050876	7.6E-05
50800	50.902	0.050902	0.000102
76200	50.952	0.050952	0.000152
89100	51.003	0.051003	0.000203
92700	51.054	0.051054	0.000254
102500	51.181	0.051181	0.000381
107800	51.308	0.051308	0.000508
119400	51.562	0.051562	0.000762
128300	51.816	0.051816	0.001016
149700	52.832	0.052832	0.002032
159000	53.848	0.053848	0.003048
160400	54.356	0.054356	0.003556
159500	54.864	0.054864	0.004064
151500	55.88	0.05588	0.00508
124700	56.642	0.056642	0.005842