Chemical Engineering 378

Science of Materials Engineering

Lecture 12

Mechanical Properties

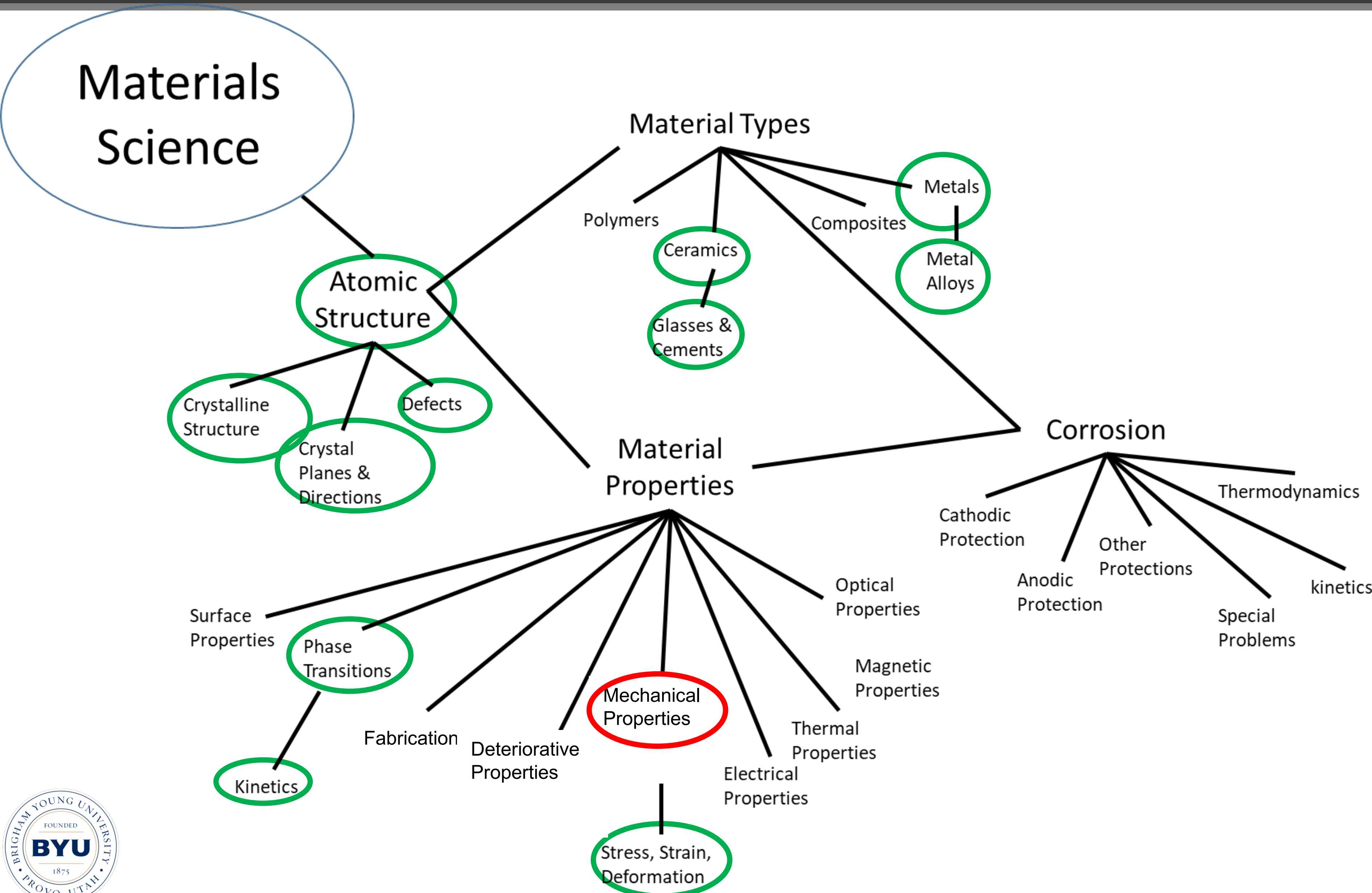
(Tensile Properties, Hardness)

Spiritual Thought

"The gift I am thinking of is more important than any of the inventions that have come out of the industrial and technological revolutions. This is a gift of greater value to mankind than even the many wonderful advances we have seen in modern medicine. It is of greater worth to mankind than the development of flight or space travel. I speak of the gift of the Book of Mormon, given to mankind 156 years ago."

-President Ezra Taft Benson

Materials Roadmap



Mechanical Properties

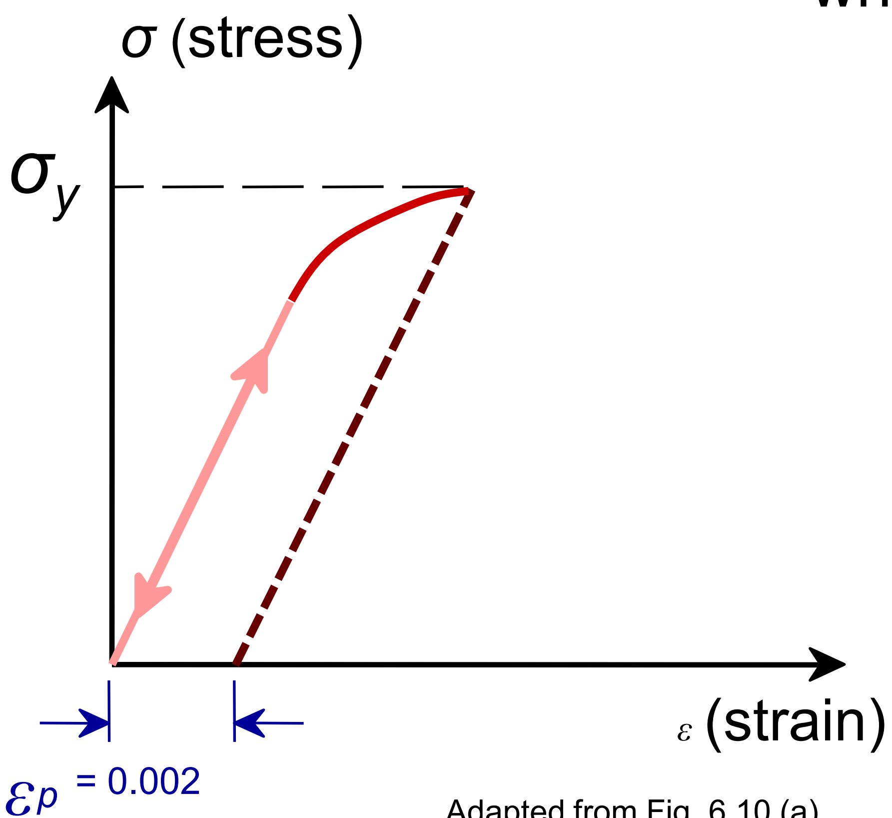
Property	Symbol	Measure of
Modulus of elasticity	E	Stiffness—resistance to elastic deformation
Yield strength	σ_y	Resistance to plastic deformation
Tensile strength	TS	Maximum load-bearing capacity
Ductility	%EL, %RA	Degree of plastic deformation at fracture
Modulus of resilience	U_r	Energy absorption—elastic deformation
Toughness (static)	–	Energy absorption—plastic deformation
Hardness	e.g., HB, HRC	Resistance to localized surface deformation

Yield Strength

- Transition from elastic to plastic deformation is gradual
- Yield strength = stress at which *noticeable* plastic deformation has occurred

when $\varepsilon_p = 0.002$

σ_y = yield strength



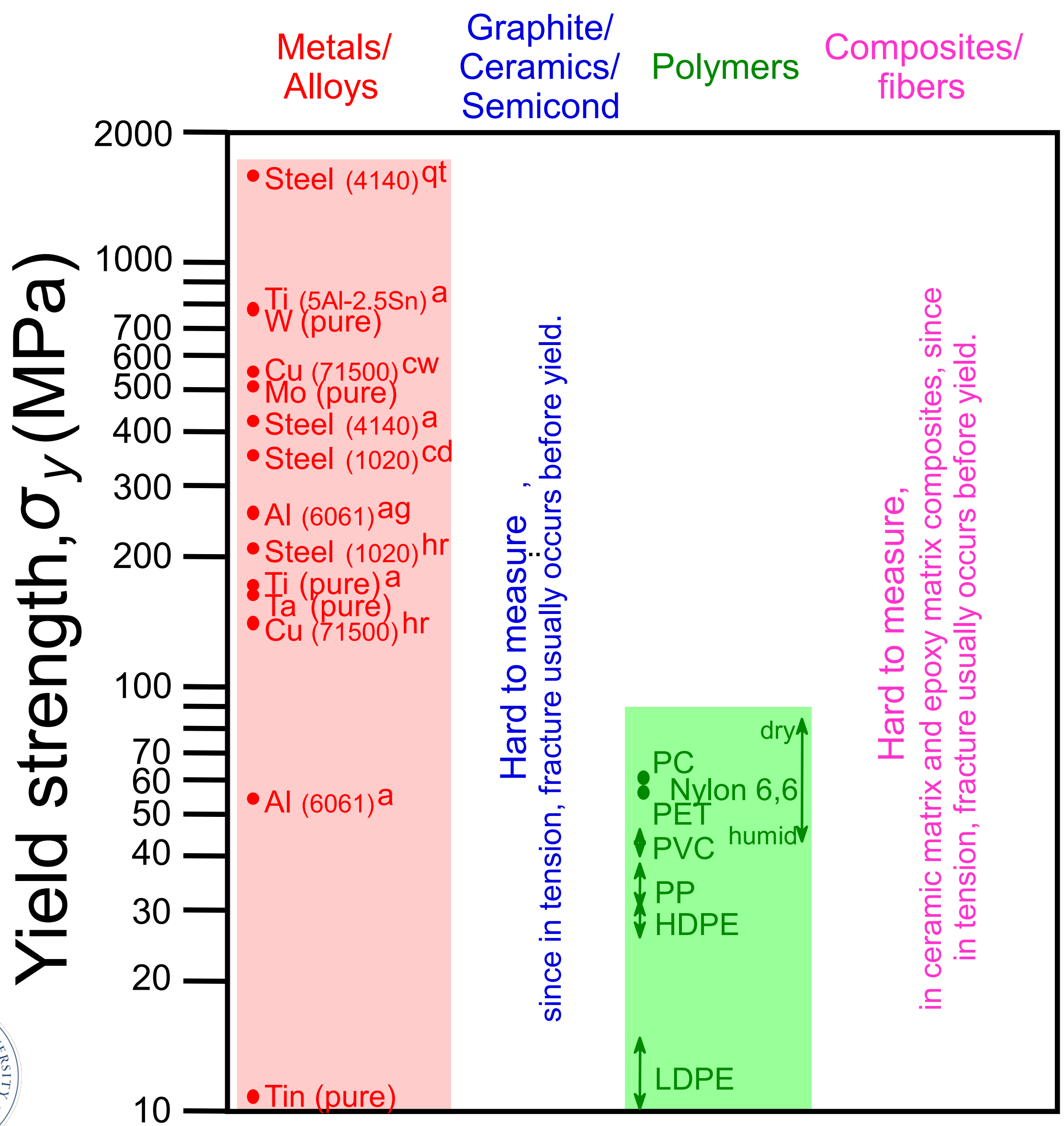
Note: for 5 cm sample

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

$\Delta z = 0.01$ cm

Adapted from Fig. 6.10 (a), *Callister & Rethwisch 10e.*

Yield Strength – Comparison of Material Types



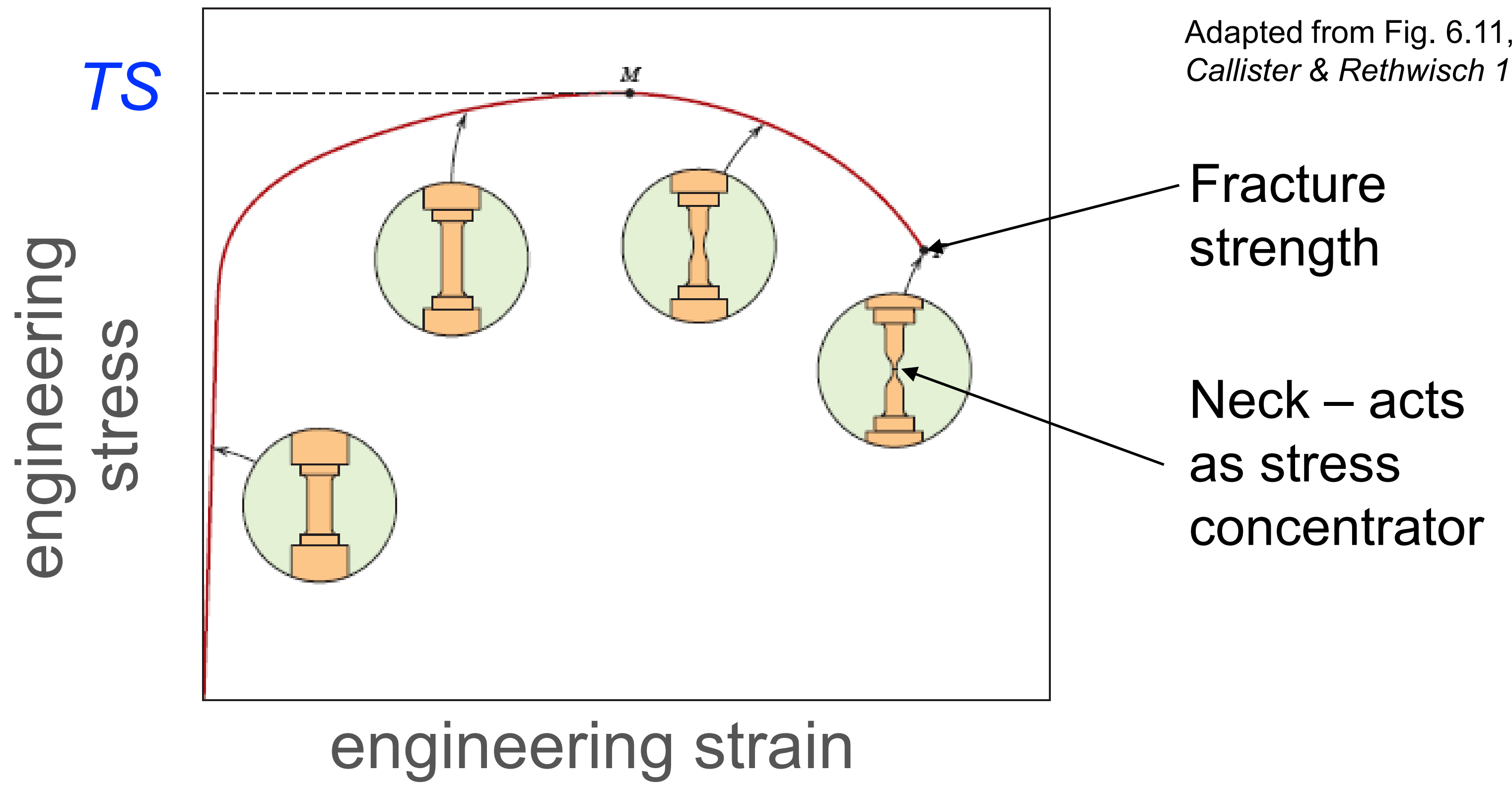
Room temperature values

Based on data in Table B.4, *Callister & Rethwisch 10e.*

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

Tensile Strength

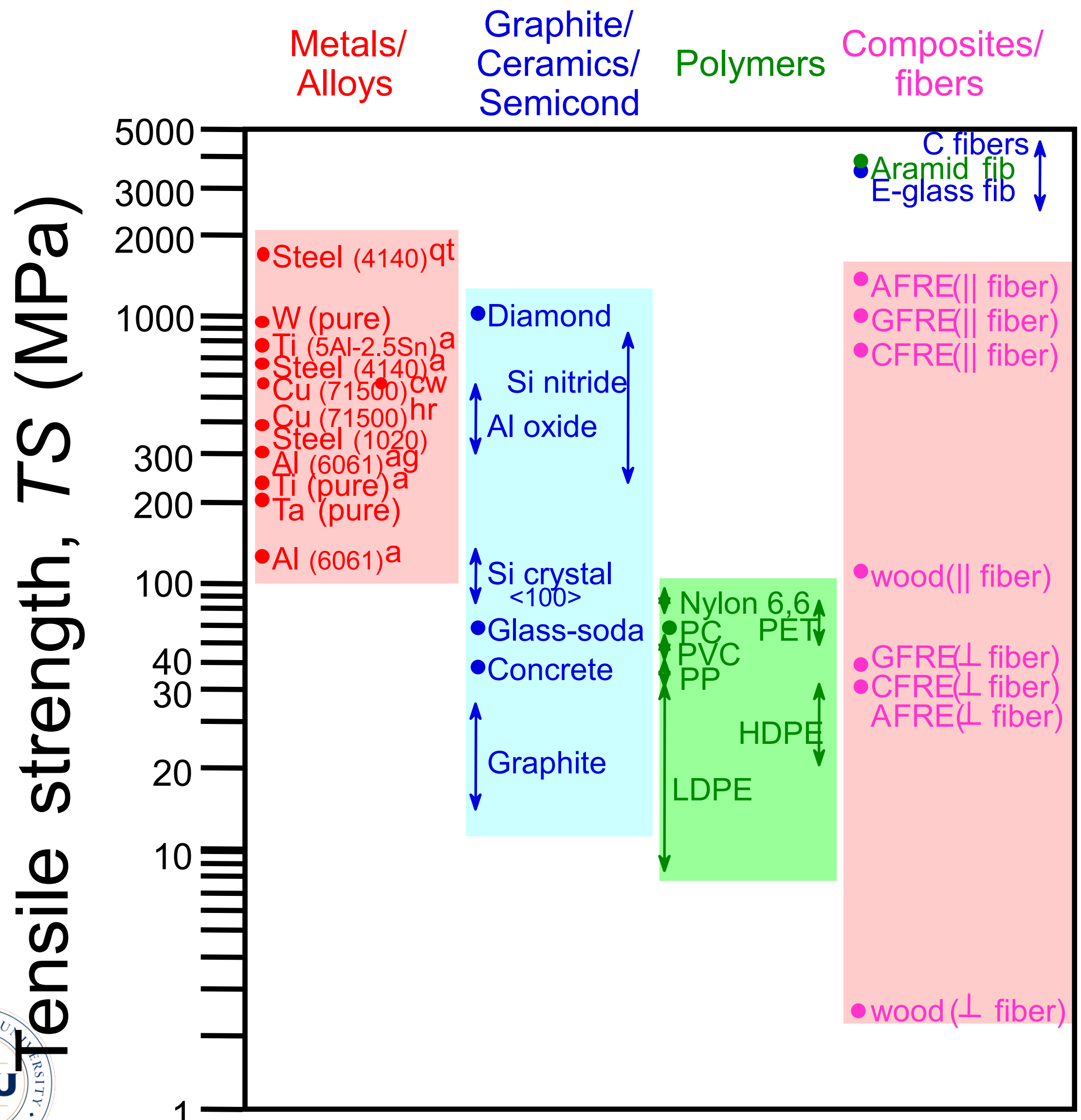
- Tensile strength (*TS*) = maximum stress on engineering stress-strain curve.



Adapted from Fig. 6.11, *Callister & Rethwisch 10e.*

- Metals: Maximum on stress-strain curve appears at the onset of noticeable necking

Tensile Strength: Comparison of Material Types



Room temperature values

Based on data in Table B4, *Callister & Rethwisch 10e.*

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

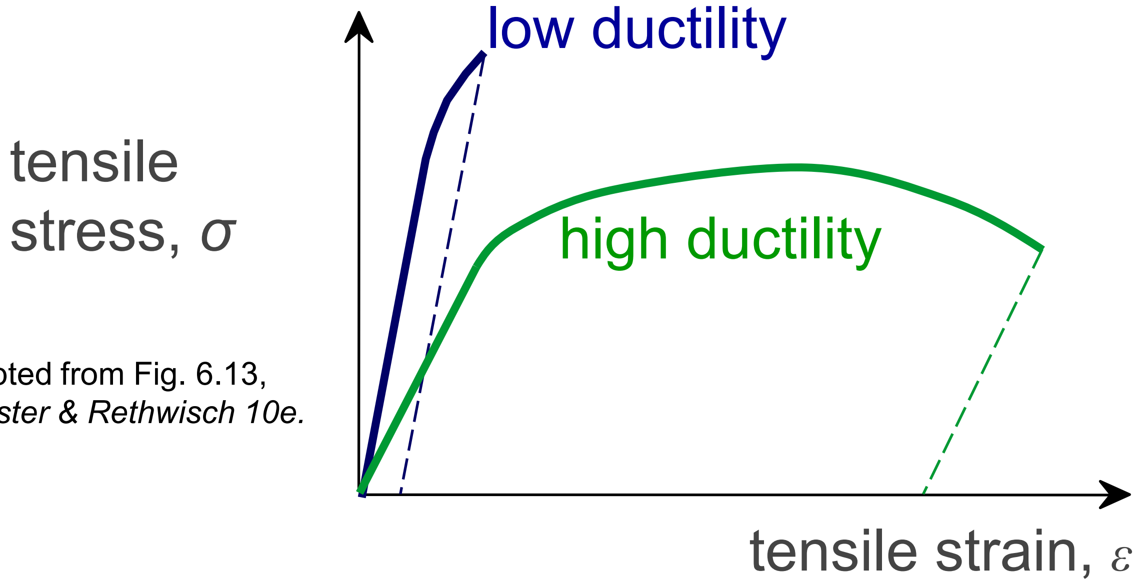
Ductility

- Ductility = amount of plastic deformation at failure:
- Specification of ductility
  - -- Percent elongation:

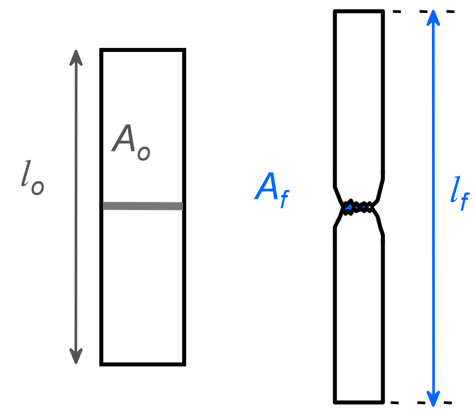
$$\%EL = \frac{l_f - l_0}{l_0} \text{ x } 100$$

  - -- Percent reduction in area:

$$\%RA = \frac{A_0 - A_f}{A_0} \text{ x } 100$$



Adapted from Fig. 6.13, *Callister & Rethwisch 10e.*



Resilience

- Resilience—ability of a material to absorb energy during elastic deformation
- Energy recovered when load released
- Resilience specified by modulus of resilience, U_r

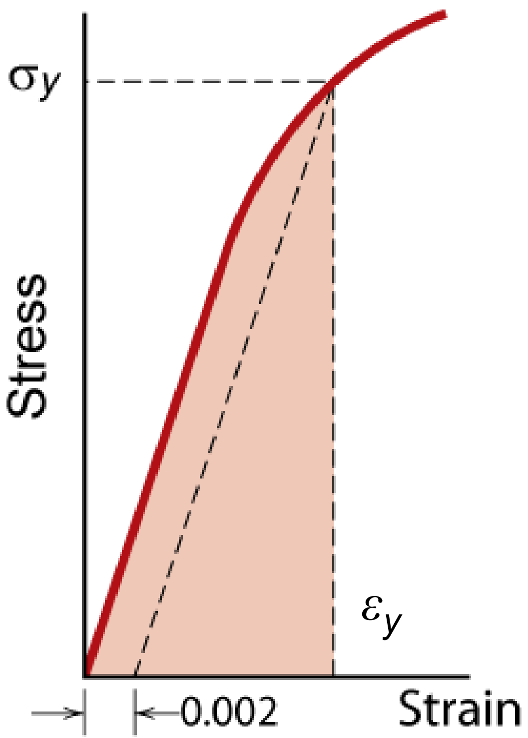


Fig. 6.15, *Callister & Rethwisch 10e.*

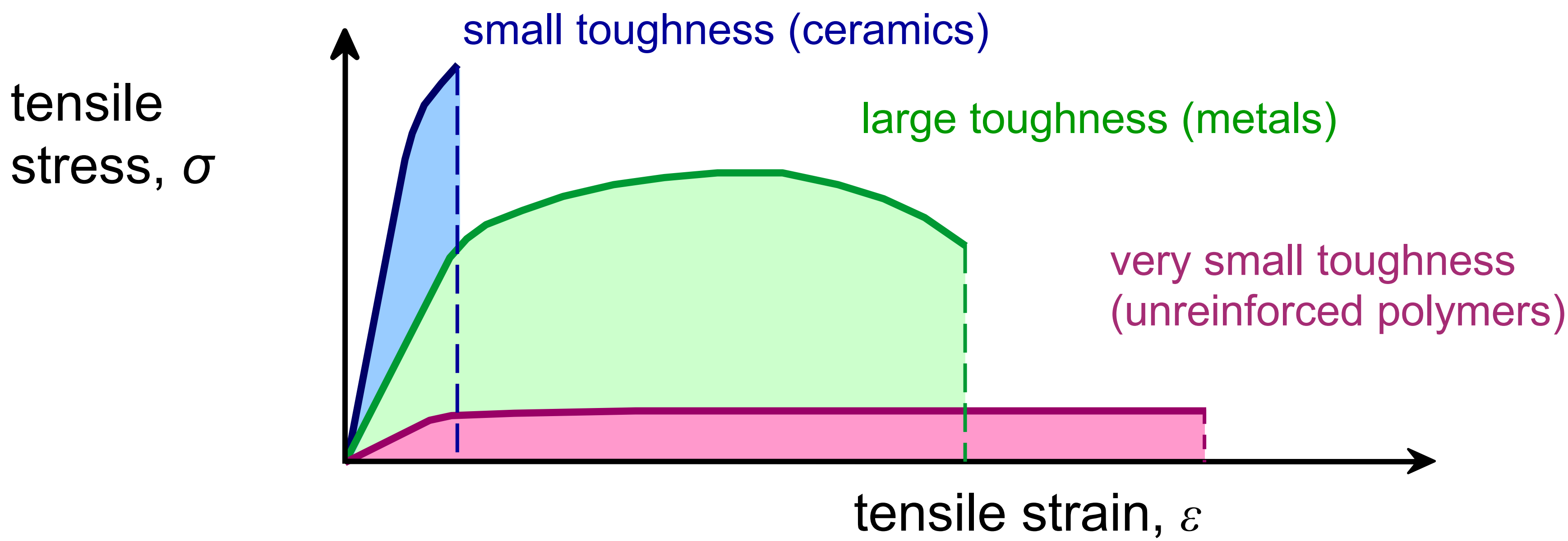
U_r = Area under stress-strain curve to yielding $= \int_0^{\varepsilon_y} \sigma \, d\varepsilon$

If assume a linear stress-strain curve this simplifies to

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

Toughness

- Toughness of a material is expressed in several contexts
- For this course, toughness = amount of energy absorbed before fracture
- Approximate by area under the stress-strain curve—units of energy per unit volume

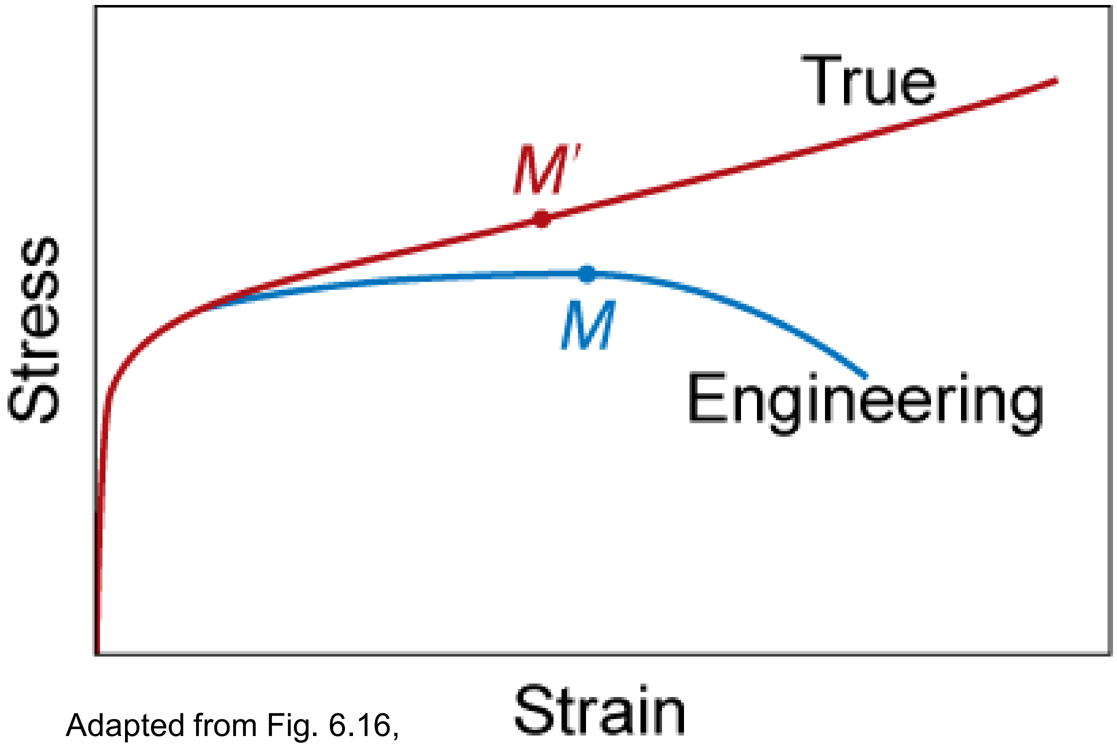


Brittle fracture: small toughness
Ductile fracture: large toughness

True Stress & Strain

- True stress $\sigma_T = F/A_i$
- True strain $\varepsilon_T = \ln(\ell_i/\ell_o)$

where A_i = instantaneous cross-sectional area



Adapted from Fig. 6.16, *Callister & Rethwisch 10e.*

Conversion Equations: valid only for the onset of necking

$$\sigma_T = \sigma(1+\varepsilon)$$

$$\varepsilon_T = \ln(1+\varepsilon)$$

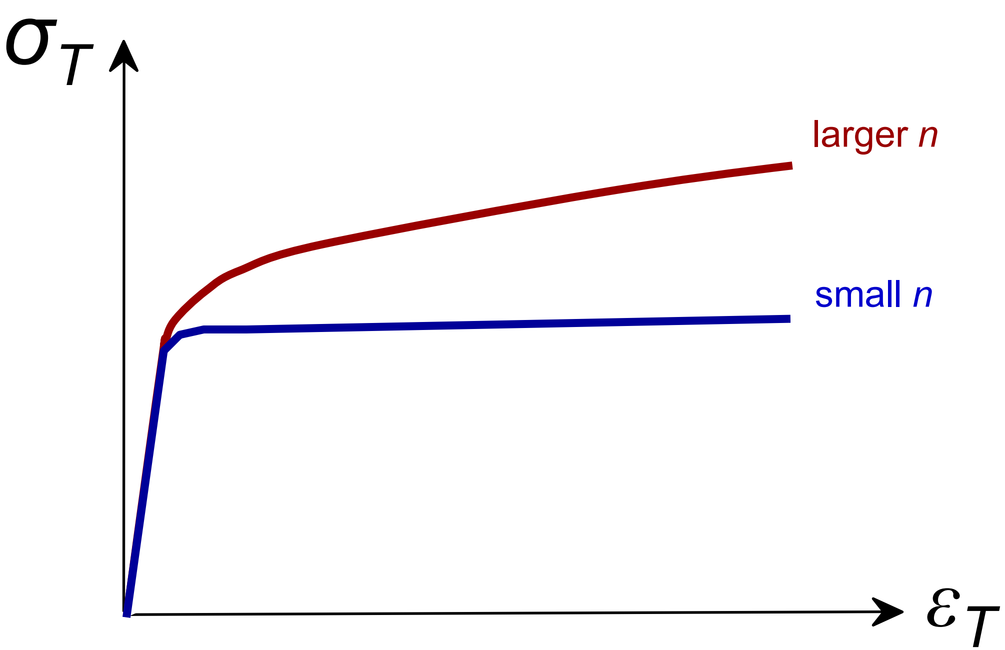
True Stress-True Strain Relationship

- Most alloys, between point of yielding and onset of necking

$$\sigma_T = K\left(\varepsilon_T\right)^n$$

— *n* and *K* values depend on alloy and treatment
— *n* = strain-hardening exponent
— $n < 1.0$

- σ_T vs. ε_T -- influence of *n*.



Elastic Strain Recovery

yield strength for 2nd deformation = σ_{y_i}

initial yield strength = σ_{y_o}

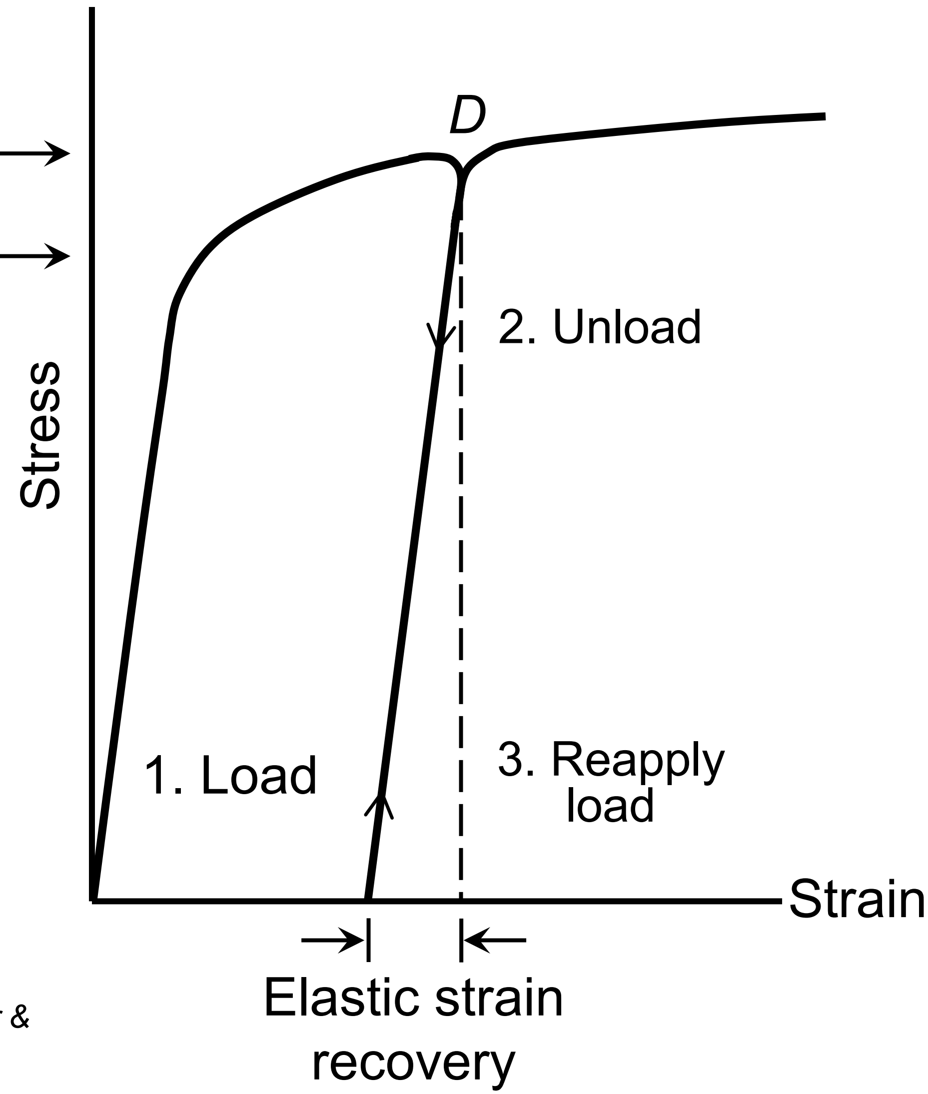
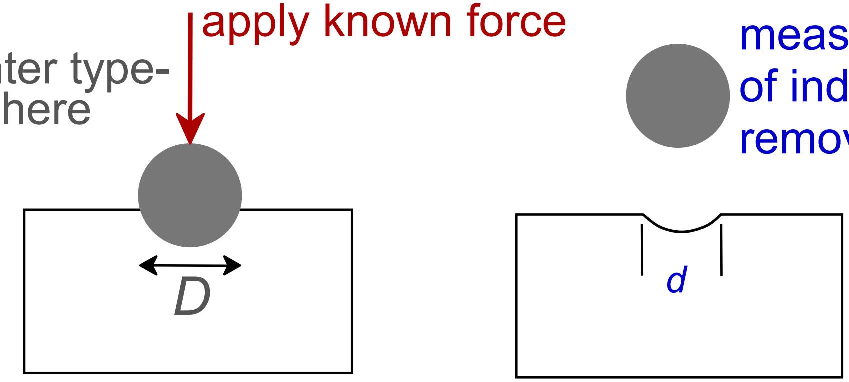


Fig. 6.17, *Callister & Rethwisch 10e.*

Hardness

- Measure of resistance to surface plastic deformation—dent or scratch.
- Large hardness means:
  - -- high resistance to deformation from compressive loads.
  - -- better wear properties.



Measurement of Hardness

Rockwell Hardness

- Several scales—combination of load magnitude, indenter size

	Indenters	Loads	
Rockwell and superficial Rockwell	Diamond cone: $\frac{1}{16}$-, $\frac{1}{8}$-, $\frac{1}{4}$-, $\frac{1}{2}$- in. diameter steel spheres	60 kg, 100 kg, 150 kg	Rockwell
		15 kg, 30 kg, 45 kg	Superficial Rockwell

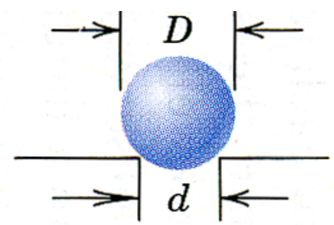
- Examples:
  - Rockwell A Scale – 60 kg load/diamond indenter
  - Superficial Rockwell 15T Scale – 15 kg load/ 1/16 in. indenter
- Rockwell hardness designation: (hardness reading) HR
- Examples: 57 HRA; 63 HR15T
- Hardness range for each scale: 0–130 HR; useful range: 20–100 HR

Measurement of Hardness (cont.)

Brinell Hardness

- Single scale
- Brinell hardness designation: (hardness reading) HB

10-mm sphere of steel or tungsten carbide



$$\mathrm{HB} = \frac{2P}{\pi D\left[D - \sqrt{D^2 - d^2}\right]}$$

  - P = load (kg)
  - 500 kg $\leq P \leq$ 3000 kg (500 kg increments)
- Relationships—Brinell hardness & tensile strength
  - TS (psia) = 500 x HB
  - TS (MPa) = 3.45 x HB

Variability of Material Properties

- Measured material properties—always scatter in values for same material
- Statistical treatments
- Typical value—take average value, $\bar{X}$ for some parameter *x:*

n = number of measurements

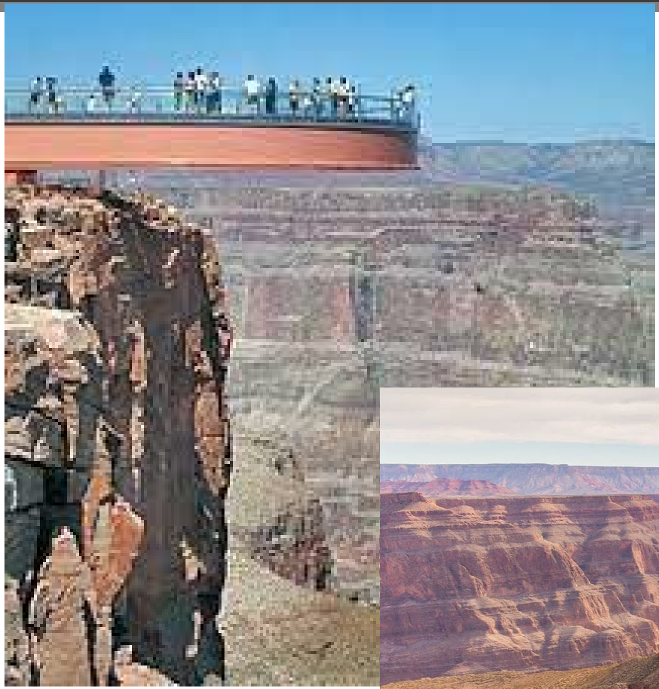
x_i = specific measured value

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$$

- Degree of scatter—use standard deviation, *s*

$$s = \left[\frac{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}{n-1}\right]^{\frac{1}{2}}$$

Grand Canyon



Design/Safety Factors

- Because of design uncertainties allowances must be made to protect against unanticipated failure
- For structural applications, to protect against possibility of failure—use working stress, σ_w, and a factor of safety, N

$$\sigma_w = \frac{\boxed{\sigma_y}}{N}$$

yield strength

Depending on application, N is between 1.2 and 4

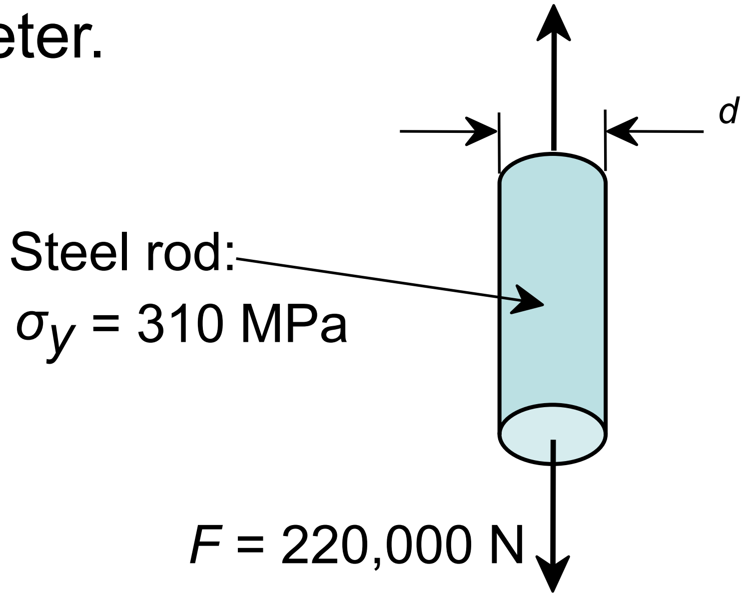
Design/Safety Factors (cont.)

Example Problem: A cylindrical rod, to be constructed from a steel that has a yield strength of 310 MPa, is to withstand a load of 220,000 N without yielding. Assuming a value of 4 for *N*, specify a suitable bar diameter.

$$\sigma_w = \frac{\sigma_y}{N}$$

$$\frac{220{,}000\ \text{N}}{\pi\left(\frac{d}{2}\right)^2}$$

4



Solving for the rod diameter *d* yields

$$\boxed{d = 0.060\ \text{m} = 60\ \text{mm}}$$