

# Chapter 6: Mechanical Properties

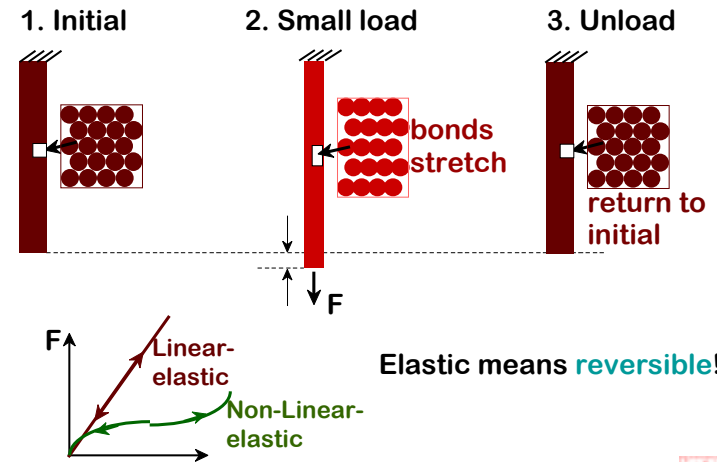
## ISSUES TO ADDRESS...

1. **Stress** and **strain**: What are they and why are they used instead of load and deformation?
2. **Elastic** behavior: when loads are small, how much deformation occurs? What materials deform least?
3. **Plastic** behavior: At what point do dislocations cause permanent deformation? What materials are most resistant to permanent deformation?
4. **Toughness** and **ductility**: What are they and how do we measure them?

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## ELASTIC DEFORMATION

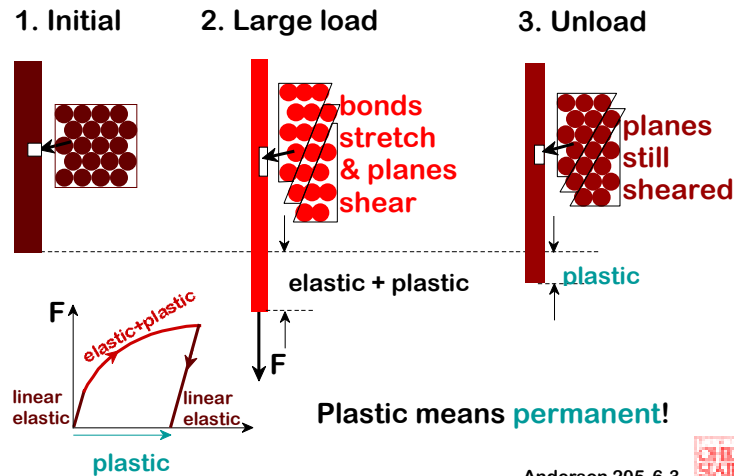


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## PLASTIC DEFORMATION (METALS)

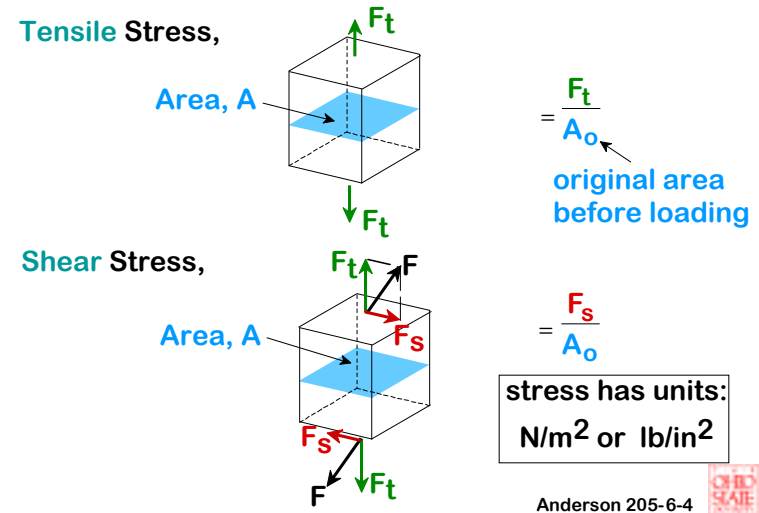
(at lower temperatures:  $T < T_{melt}/3$ )



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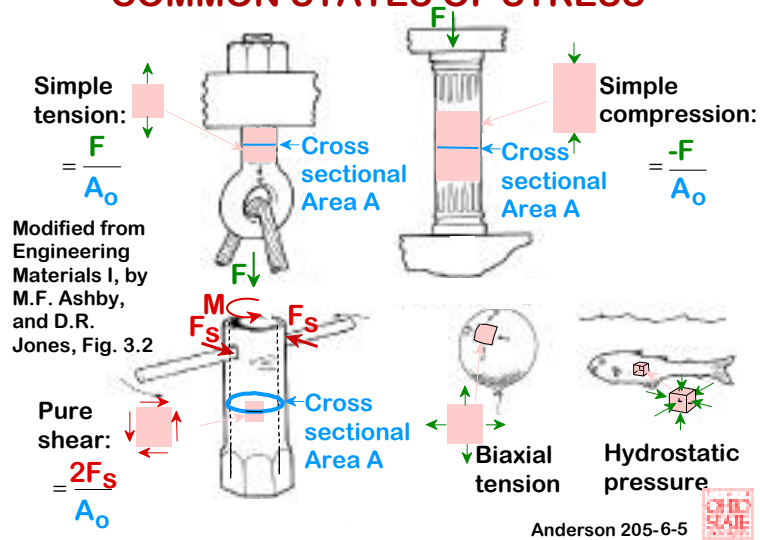
## ENGINEERING STRESS



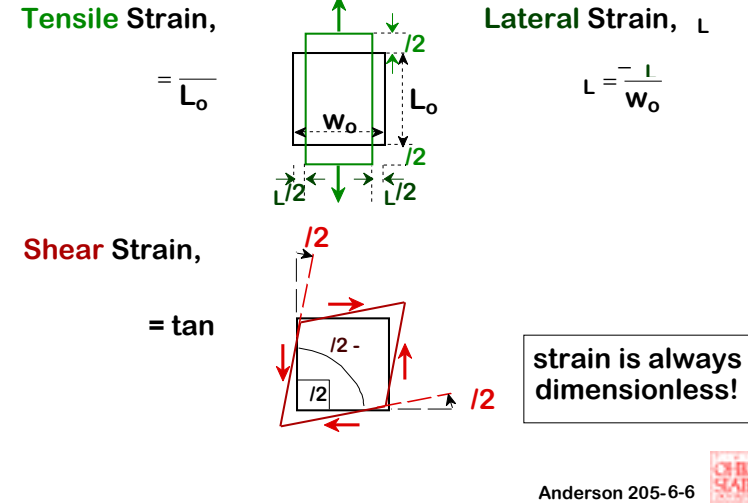
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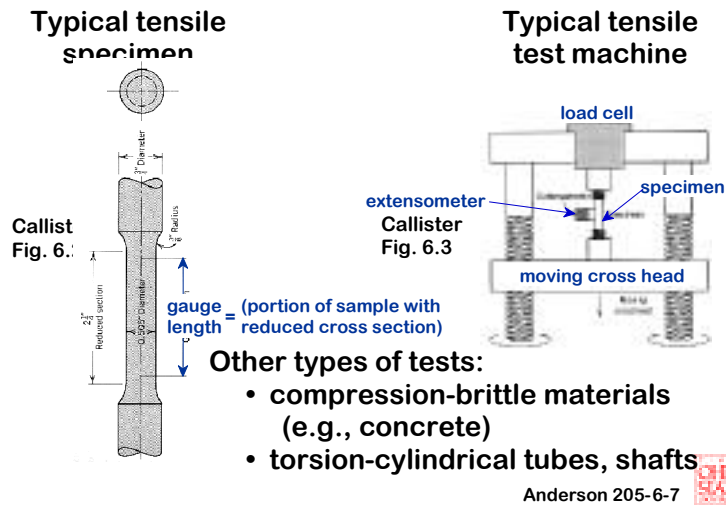
## COMMON STATES OF STRESS



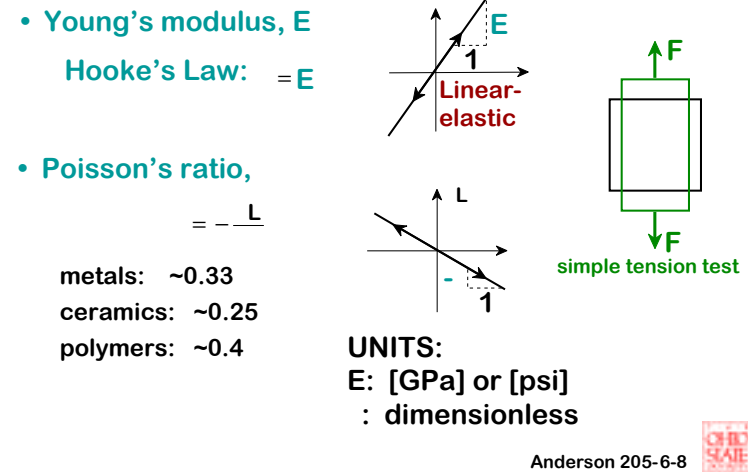
## ENGINEERING STRAIN



## STRESS-STRAIN TESTING



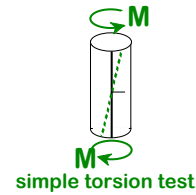
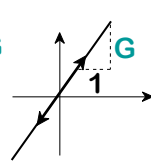
## LINEAR ELASTIC PROPERTIES



## OTHER ELASTIC PROPERTIES

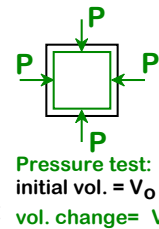
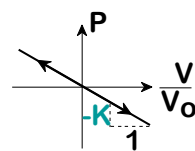
- Elastic shear modulus,  $G$

$$= G$$



- Elastic bulk modulus,  $K$

$$P = -K \frac{\Delta V}{V_0}$$



- Special relations for isotropic materials:

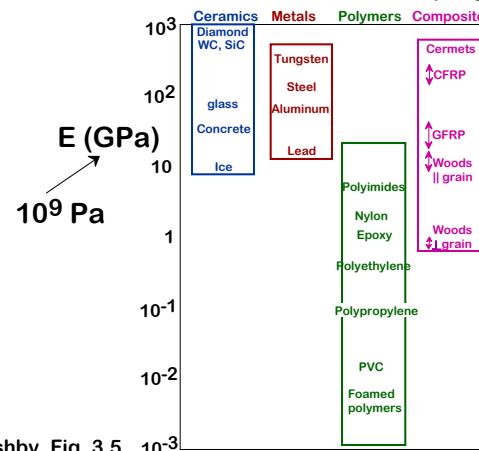
$$G = \frac{E}{2(1 + \nu)} \quad K = \frac{E}{3(1 - 2\nu)}$$

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## COMPARISON OF YOUNG'S MODULI

$E_{\text{ceramics}} > E_{\text{metals}} \gg E_{\text{polymers}}$



Ashby, Fig. 3.5

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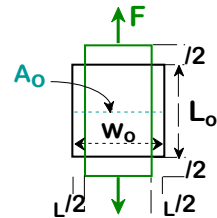


## USEFUL LINEAR ELASTIC RELATIONS

Simple tension:

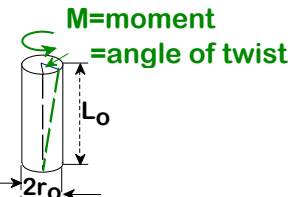
$$\Delta L = \frac{FL_0}{EA_0}$$

$$\Delta L = -\frac{Fw_0}{EA_0}$$



Simple torsion:

$$\Delta L = \frac{2ML_0}{r_0^4 G}$$



- Material, geometric, & loading parameters all contribute to deflection.
- Larger elastic moduli minimize elastic deflection.

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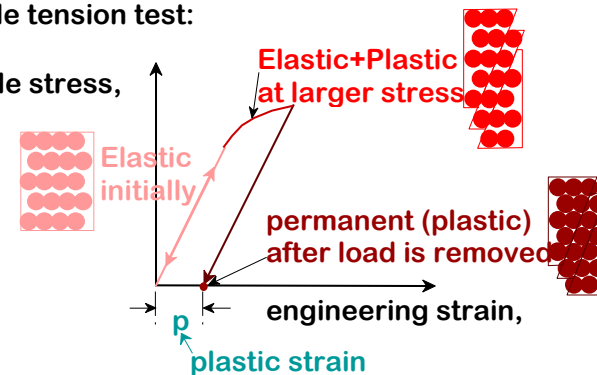


## PLASTIC (PERMANENT) DEFORMATION

(at lower temperatures:  $T < T_{\text{melt}}/3$ )

Simple tension test:

tensile stress,



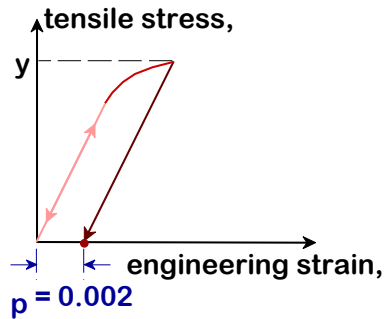
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## YIELD STRENGTH, $y$

Stress at which noticeable plastic deformation has occurred.

when  $p = 0.002$

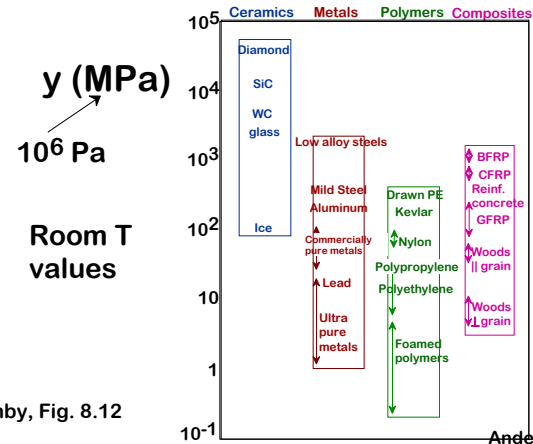


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## COMPARISON OF YIELD STRENGTH

$y(\text{ceramics}) \gg y(\text{metals}) \gg y(\text{polymers})$



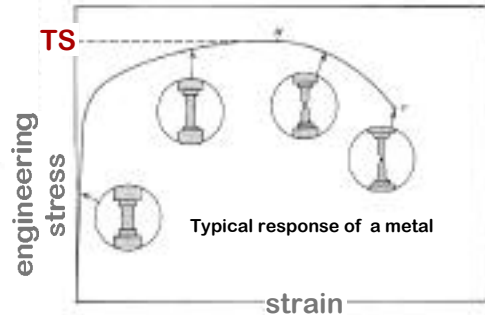
Ashby, Fig. 8.12

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## TENSILE STRENGTH, $T_S$

Maximum possible engineering stress in tension



Callister, Fig. 6.10

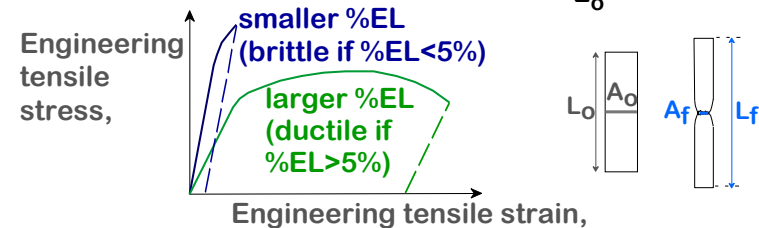
metals: occurs when noticeable "necking" starts  
 ceramics: occurs when crack propagation starts  
 polymers: occurs when polymer backbones are all aligned and about to break.

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## DUCTILITY, %EL

• Plastic tensile strain at failure:  $\%EL = \frac{L_f - L_o}{L_o} \times 100$



• Another ductility measure:  $\%AR = \frac{A_o - A_f}{A_o} \times 100$

• Note: crystal slip does not change material volume.  
 $\Rightarrow \%AR$  and  $\%EL$  are often comparable.  
 $\Rightarrow \%AR > \%EL$  may occur if internal voids form in the necked region.

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## COMPARISON: $\sigma_y$ , TS AND %EL

Material	$\sigma_y$ (MPa)	TS(MPa)	%EL
Diamond (ceramic)	50,000	50,000	0
Pure ductile metals	20 to 80	200 to 400	50 to 150
High density polyethylene	19 to 36	33 to 36	100 to 600

- Often, when  $\sigma_y$  and TS are high, %EL is low

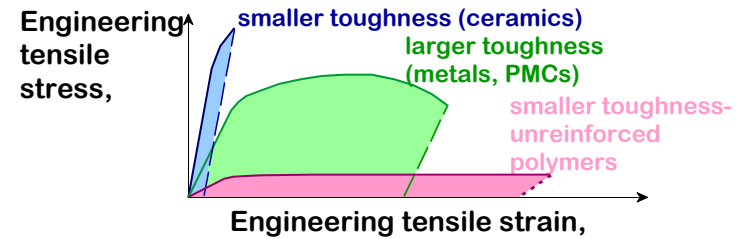
data from Ashby, Table 8.1 and Matthews, Table 5.3

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## TOUGHNESS

- Energy needed to break a unit volume of material
- Area under stress-strain curve

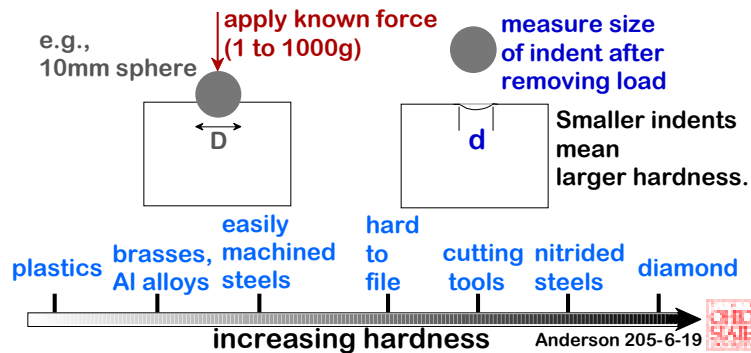


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## HARDNESS

- Resistance to permanently indenting the surface
- Large hardness means...
  - resistance to plastic deformation or cracking in compression
  - better wear properties

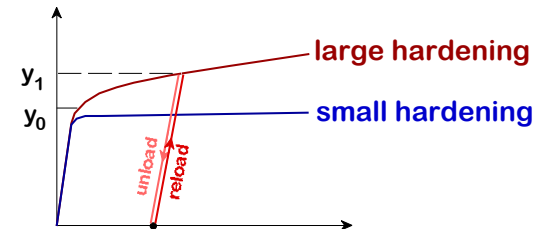


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## HARDENING

- An increase in  $\sigma_y$  due to plastic deformation.



- Curve fitting the stress-strain response

“true” stress:  $\sigma = \frac{F}{A}$

“true” strain:  $\epsilon = \ln \frac{L}{L_0}$

hardening exponent:  $n=0.15$  (some steels) to  $n=0.5$  (some copper)

Equation:  $\sigma = C \epsilon^n$

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## DESIGN OR SAFETY FACTORS

- Design uncertainties mean we don't push the limit.
- **Factor of safety, N**

$$\text{working} = \frac{y}{N}$$

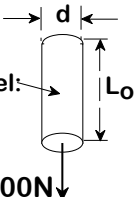
often N is between 1.2 and 4

- Ex: Calculate a diameter, d to ensure that yield does not occur in the 1045 carbon steel rod below. Use a factor of safety of 5.

$\text{working} = \frac{y}{N}$

1045 plain carbon steel:  
 $y=310\text{MPa}$   
 $\text{TS}=565\text{MPa}$

$F = 220,000\text{N}$



$\frac{220,000\text{N}}{(d^2/4)}$

$N = 5$

$d=67.2\text{mm}$

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