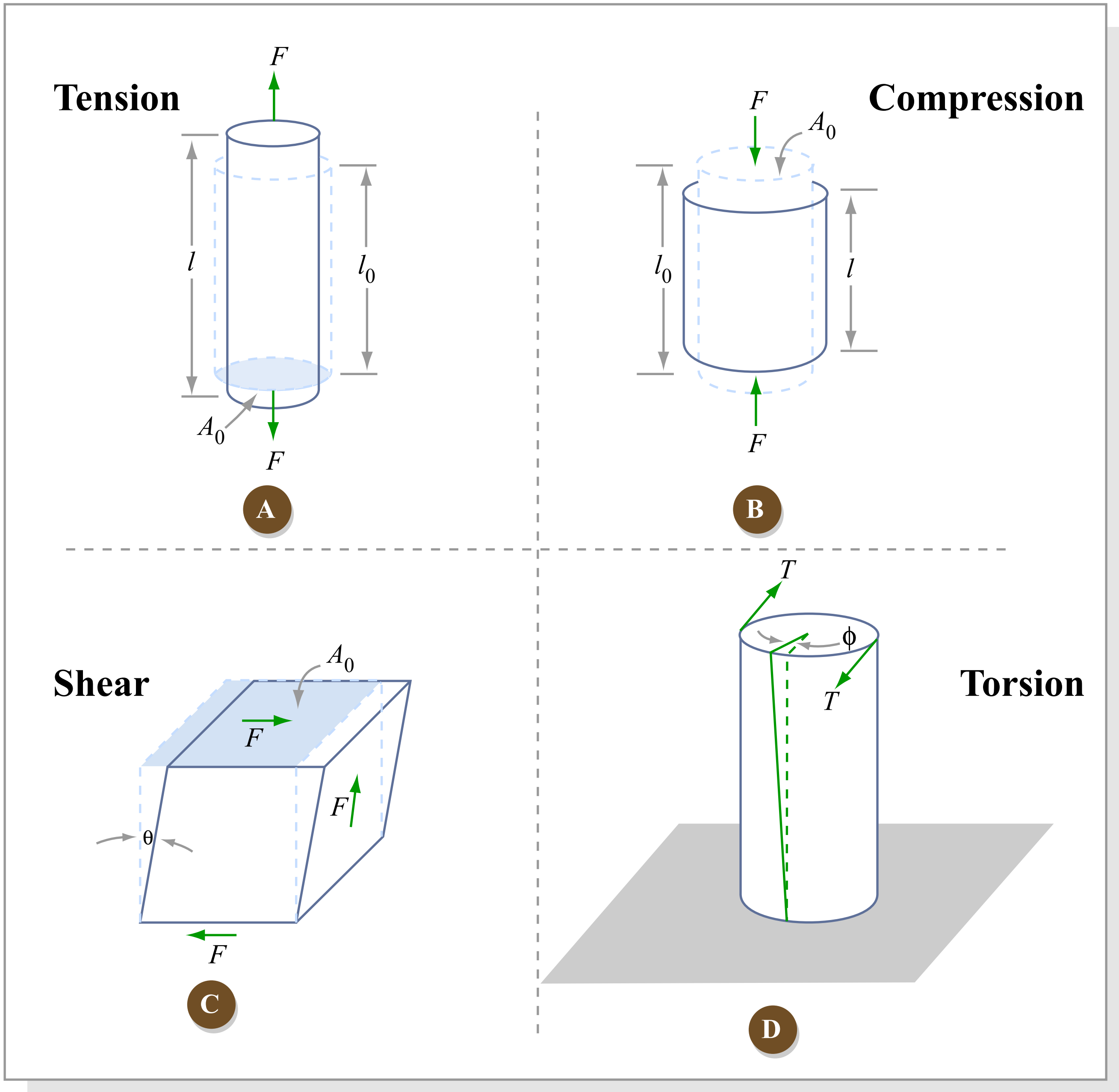
16.982 Bio-Inspired Structures
Spring 2009

Mechanical Properties of Metals

Strength of Materials

How strong is it?

Under what sort of deformation?



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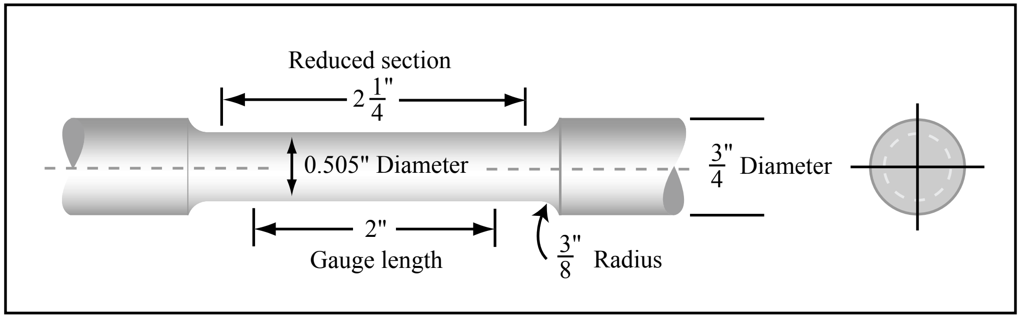
Tensile Test



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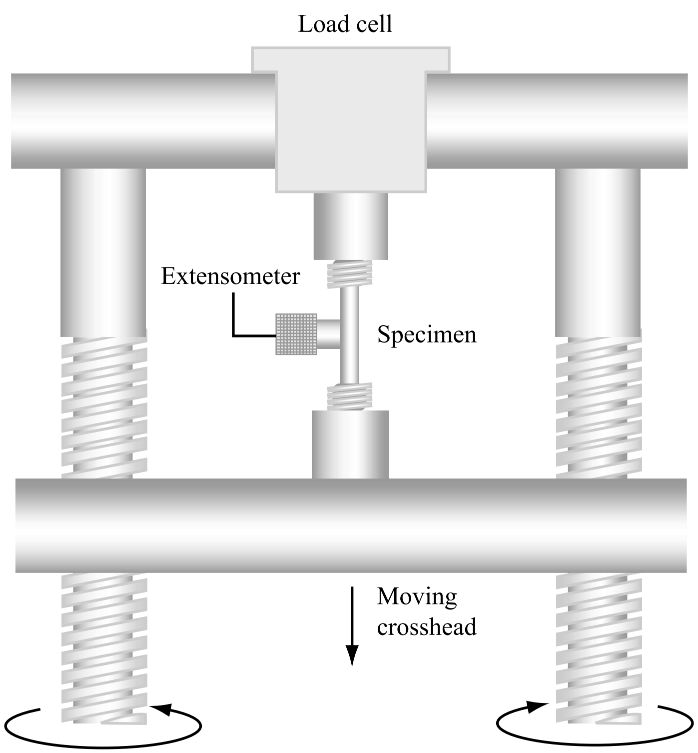

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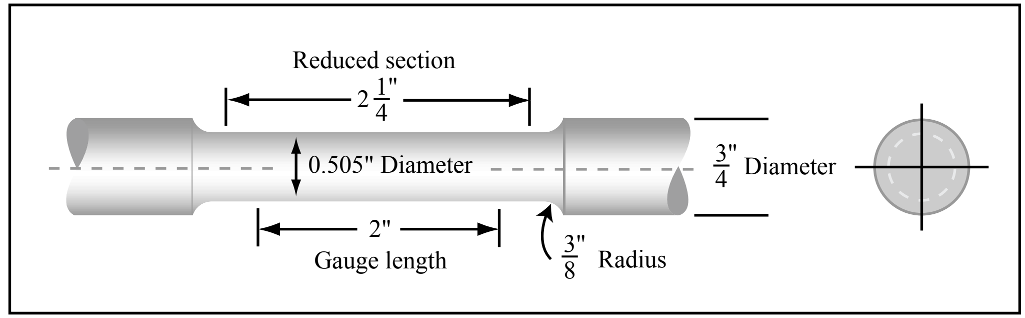
- Basic mechanical behavior of material
- Specimen is “pulled” in tension at a constant rate
- Load (F) necessary to produce a given elongation (ΔL) is monitored
- Load vs elongation curve
- Converted to stress-strain curve

Engineering Stress and Strain

Engineering Stress, σ

$$\sigma = \frac{F}{A_0}$$



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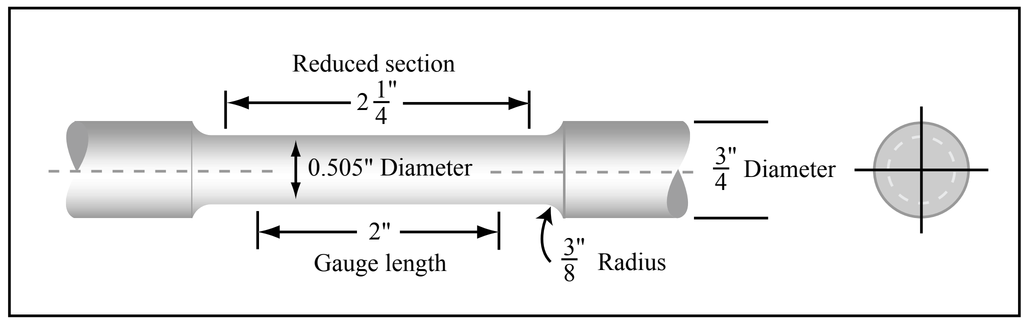
where *F* is the applied load and A_0 is the original cross-sectional area. Units: N/m^2 or lb/in^2

Engineering Strain, ε

$$\varepsilon = \frac{L_i - L_0}{L_0} = \frac{\Delta L}{L_0}$$



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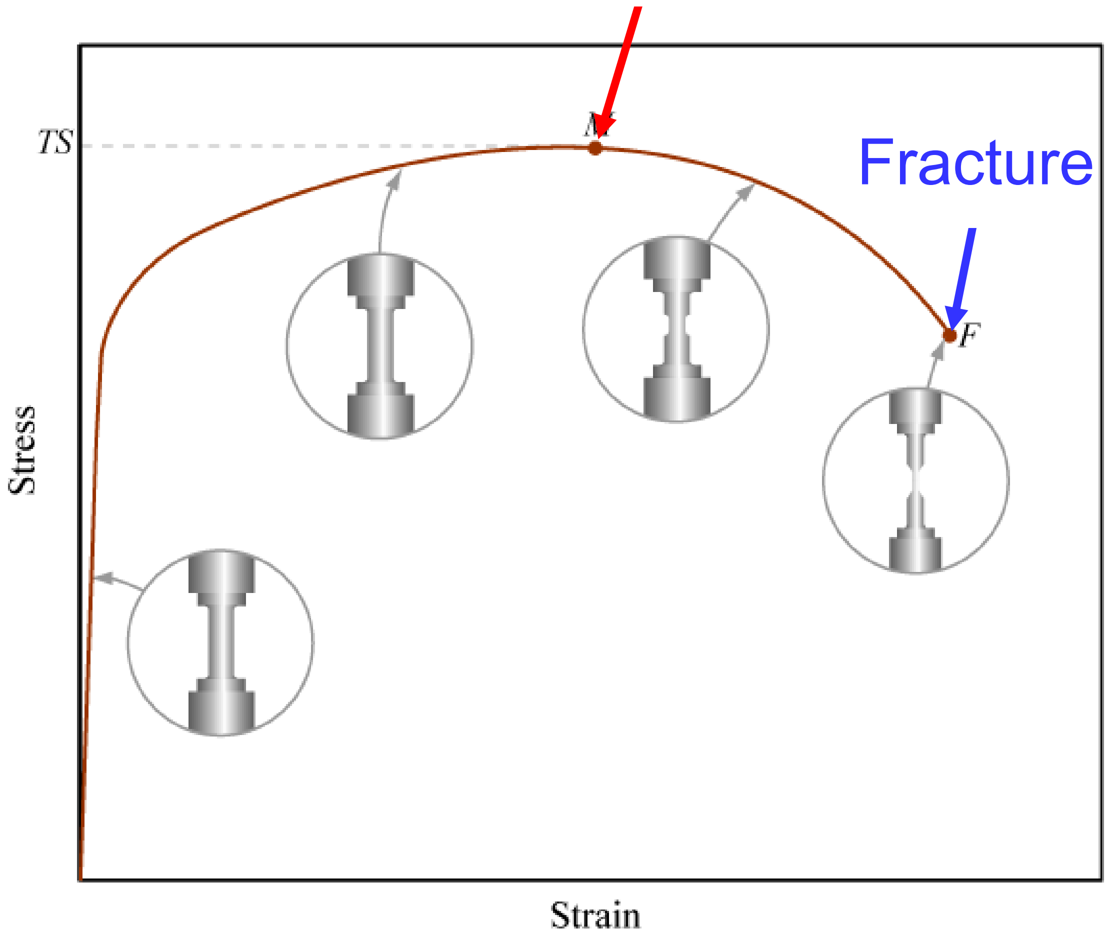
where L_0 is the original length and L_i is the instantaneous. Unitless.

Stress Strain Curve

(Maximum) Tensile Strength



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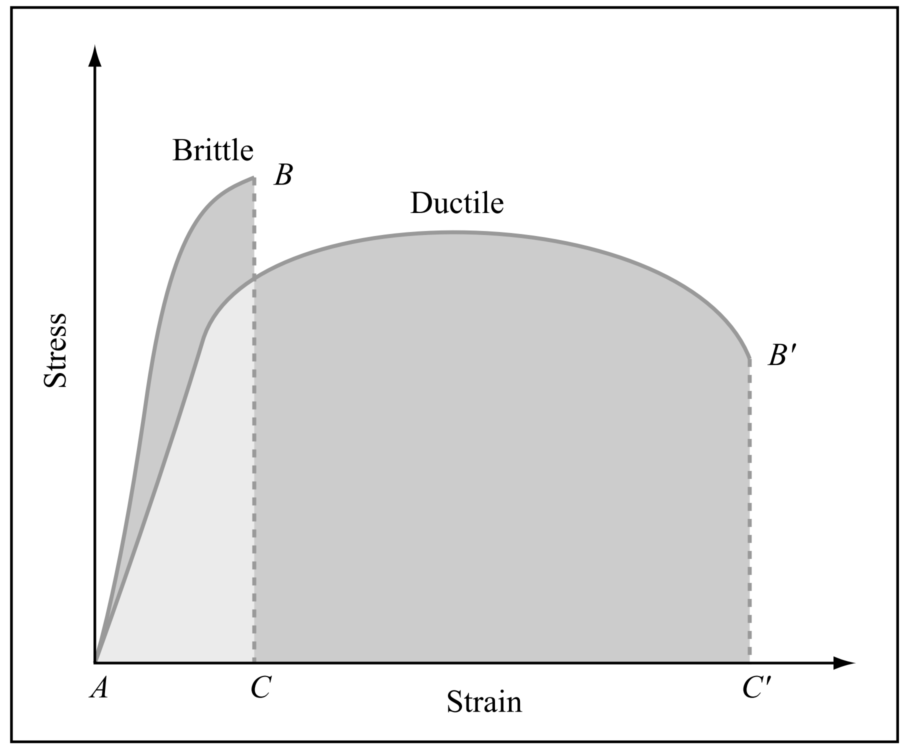
Classification of the material



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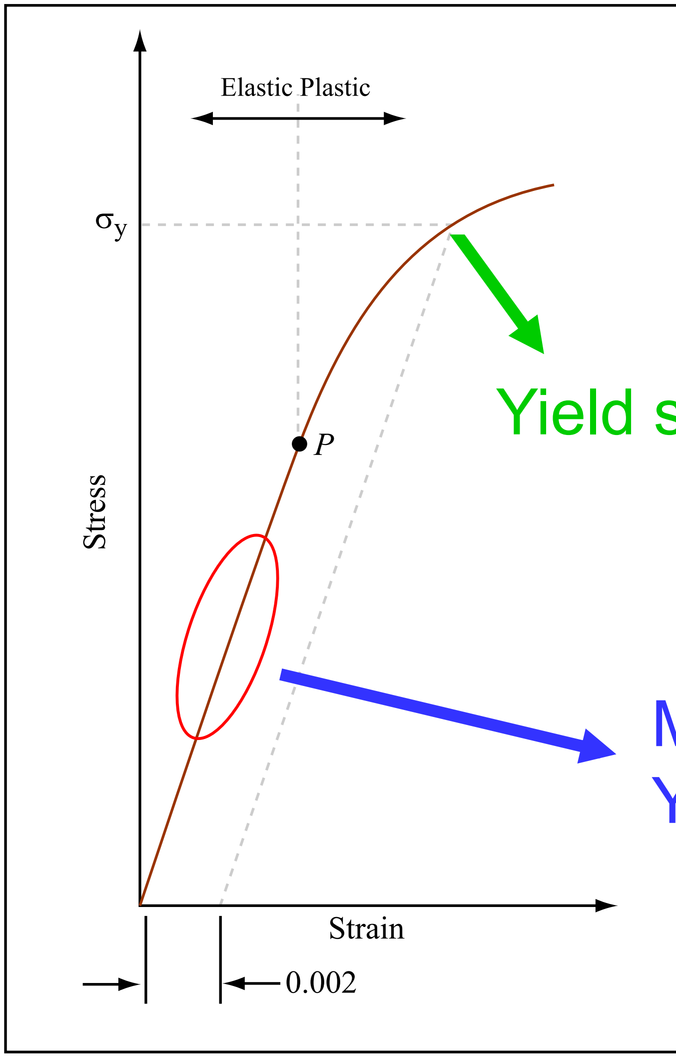
Tensile Properties

Yielding occurs



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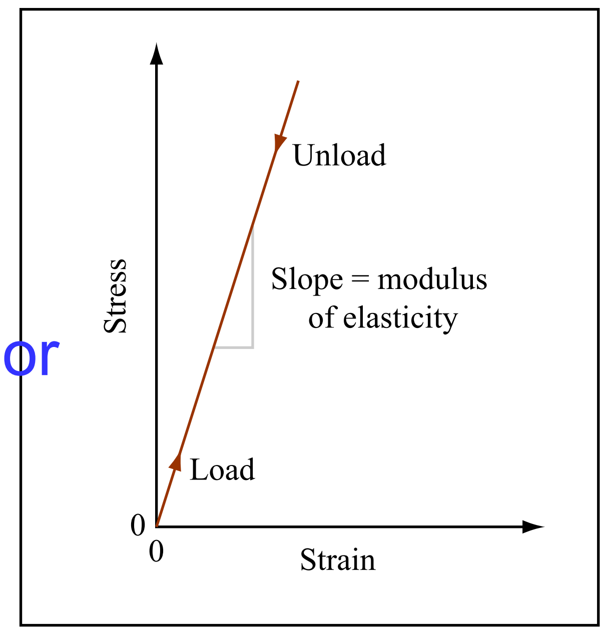
Yield strength

Modulus of Elasticity or Youngs Modulus, E

- Elastic means reversible
- Plastic means permanent



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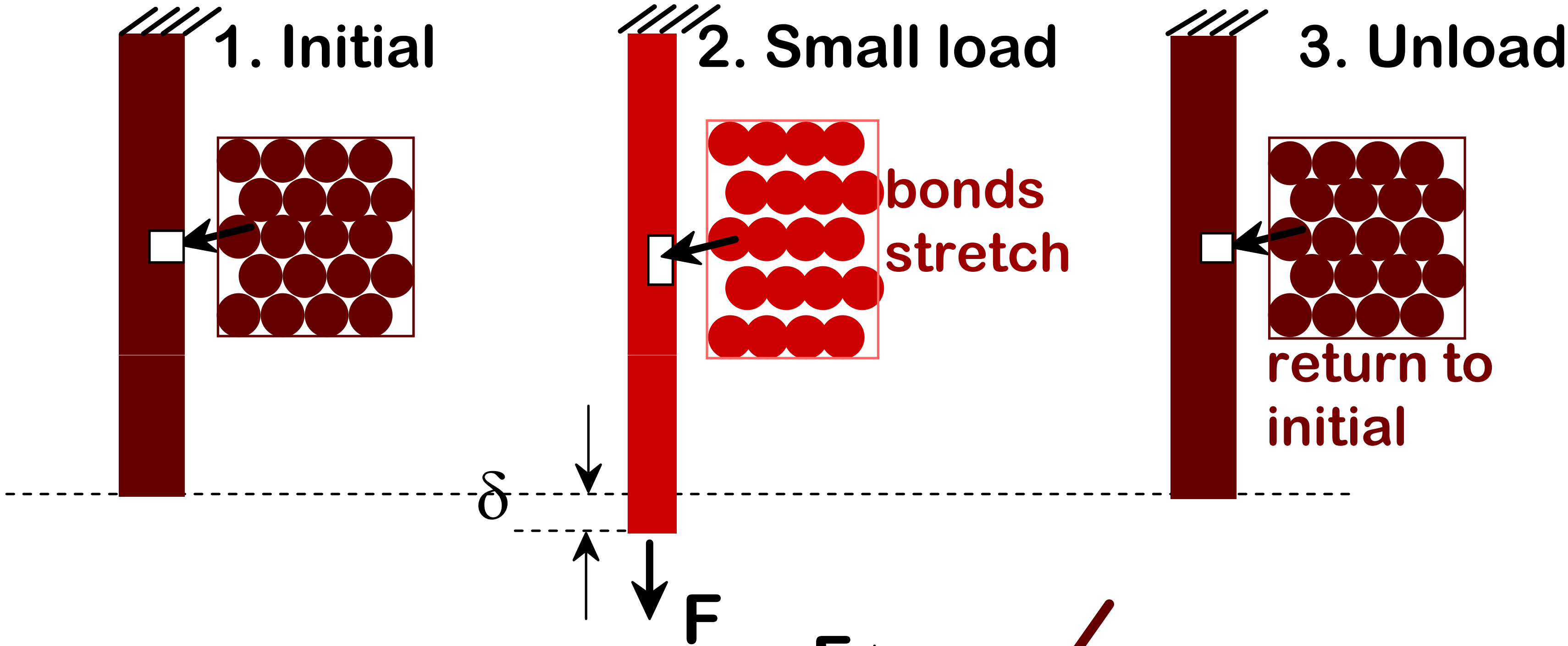
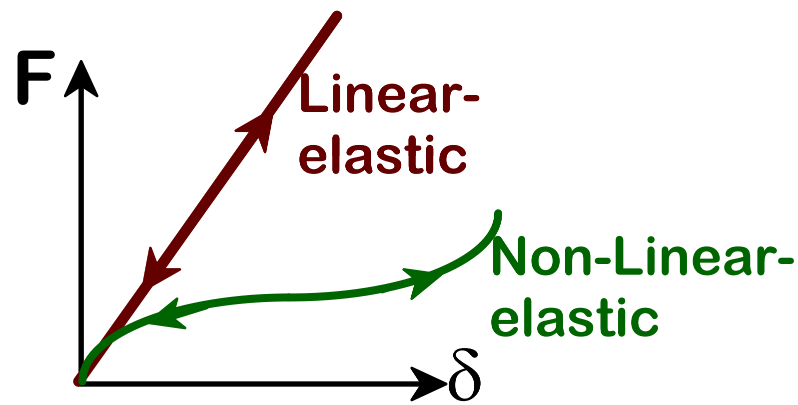
Elastic Deformation



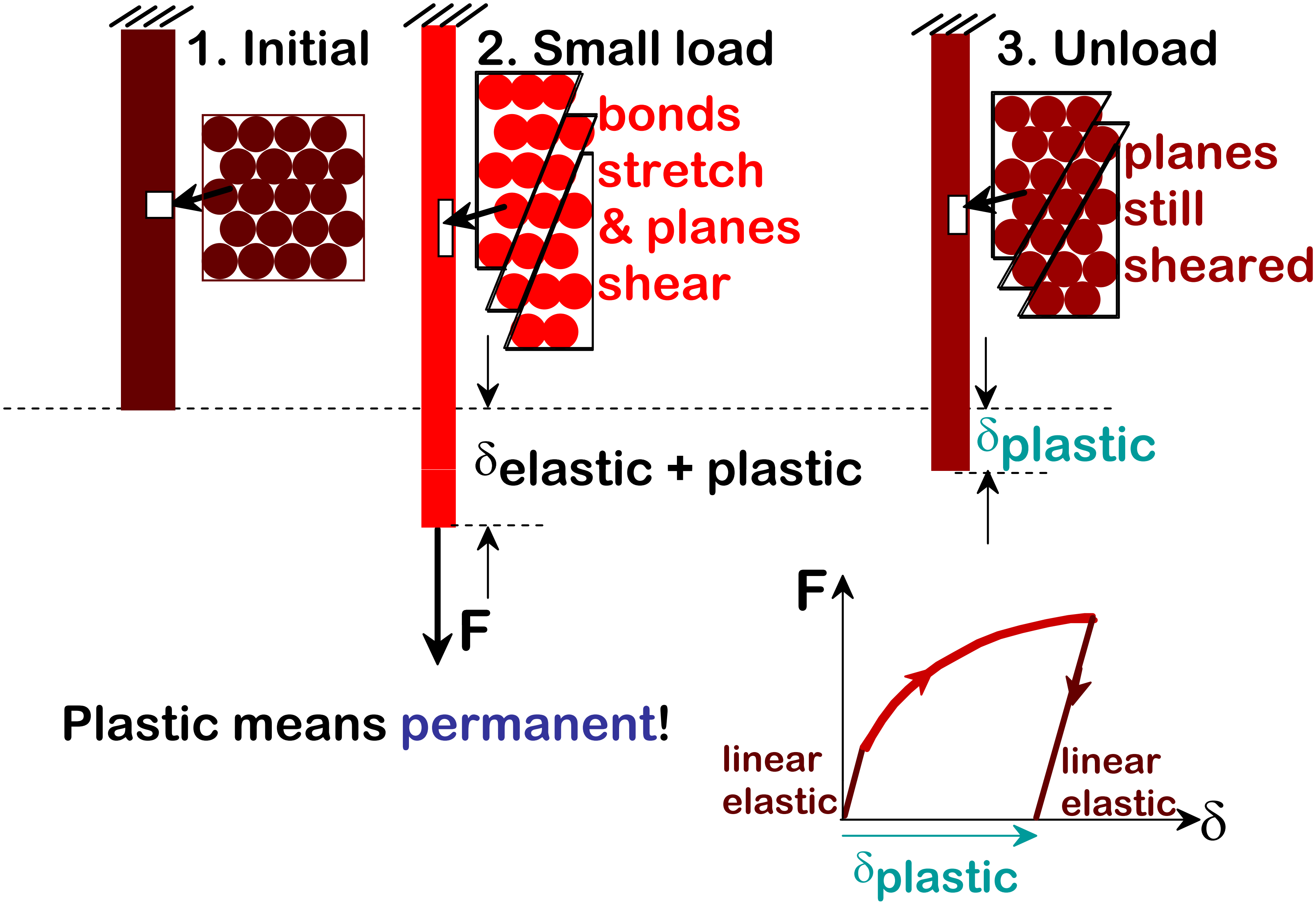
Elastic means reversible!



Hooke's Law

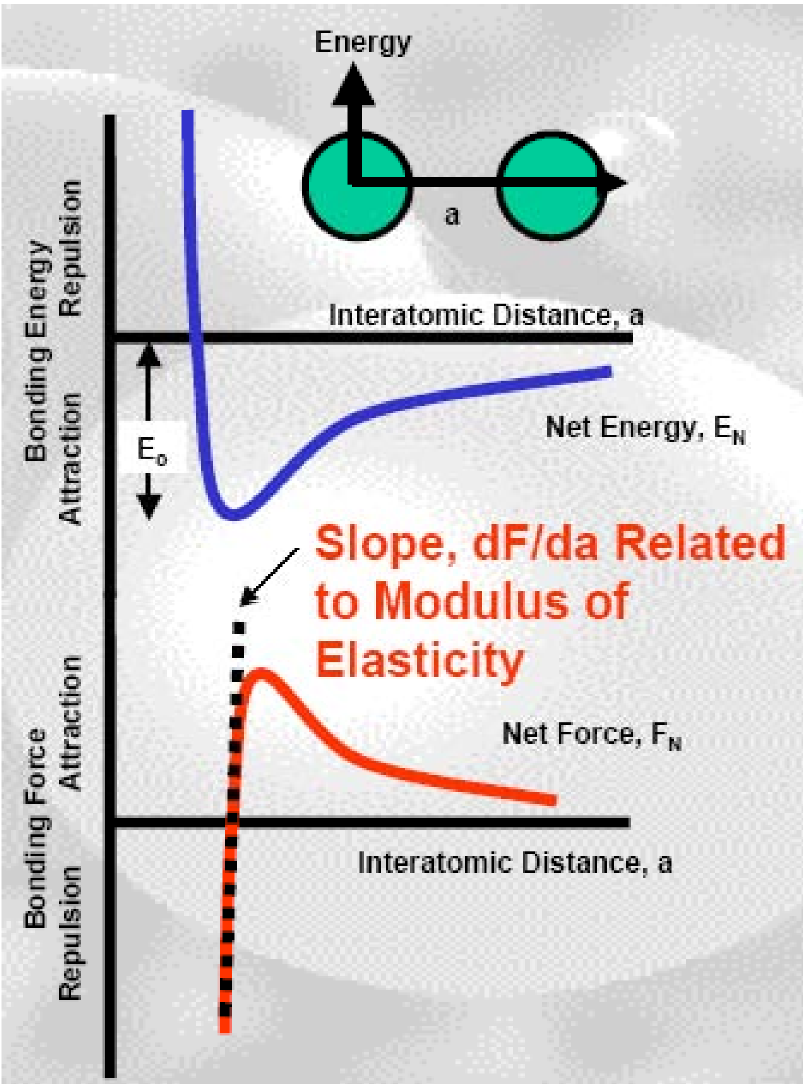
$$\sigma = E\varepsilon$$

Plastic Deformation

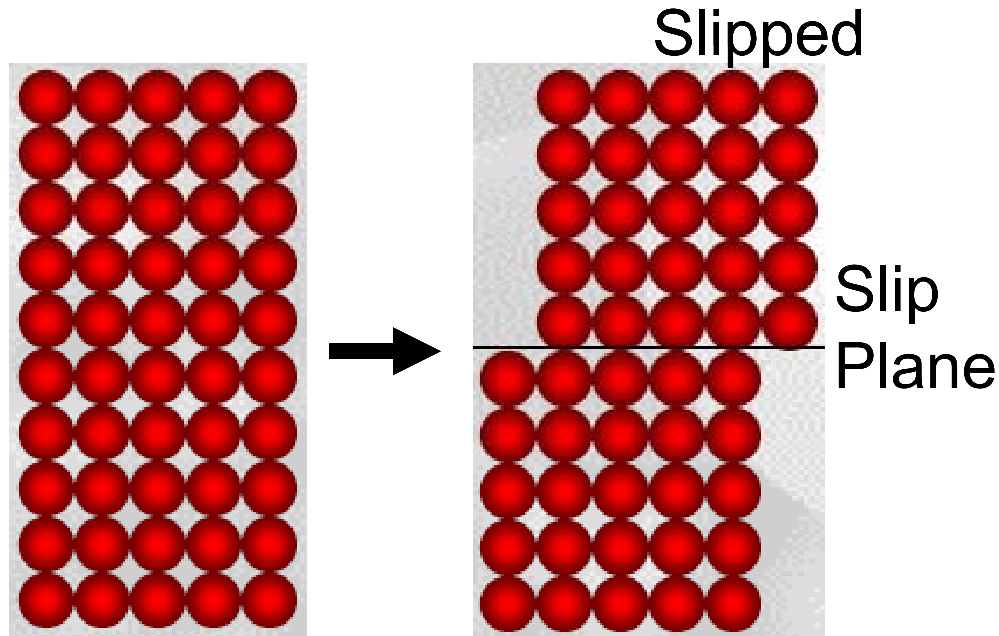


Plastic means permanent!

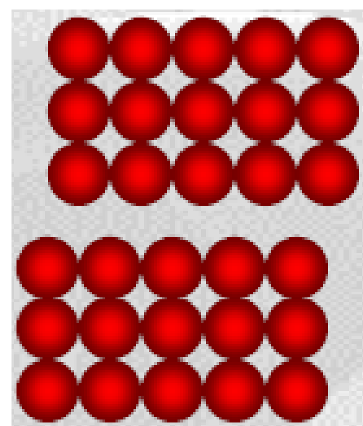
How does this occur?



Recall force is d(energy)/da



Do we break all bonds at once?



Likely Process for Slipping

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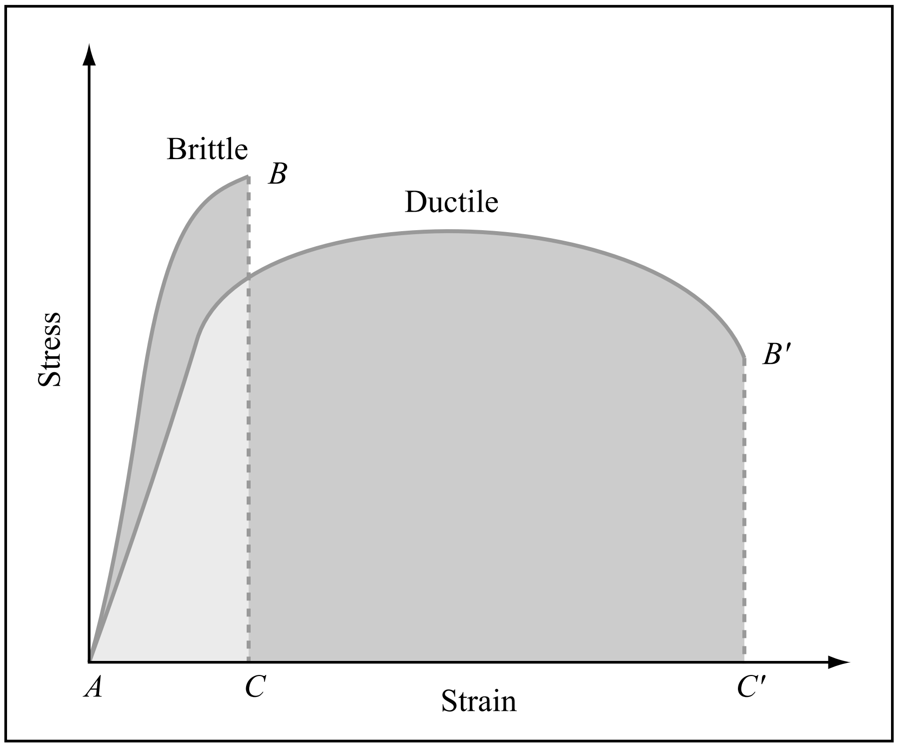
Dislocation Motion Along Slip Plane

- Requires only one broken bond at a given time
- Requires minimum energy
- Most plastic deformation occurs via dislocation motion along slip plane for metals and their alloys.

Ductility



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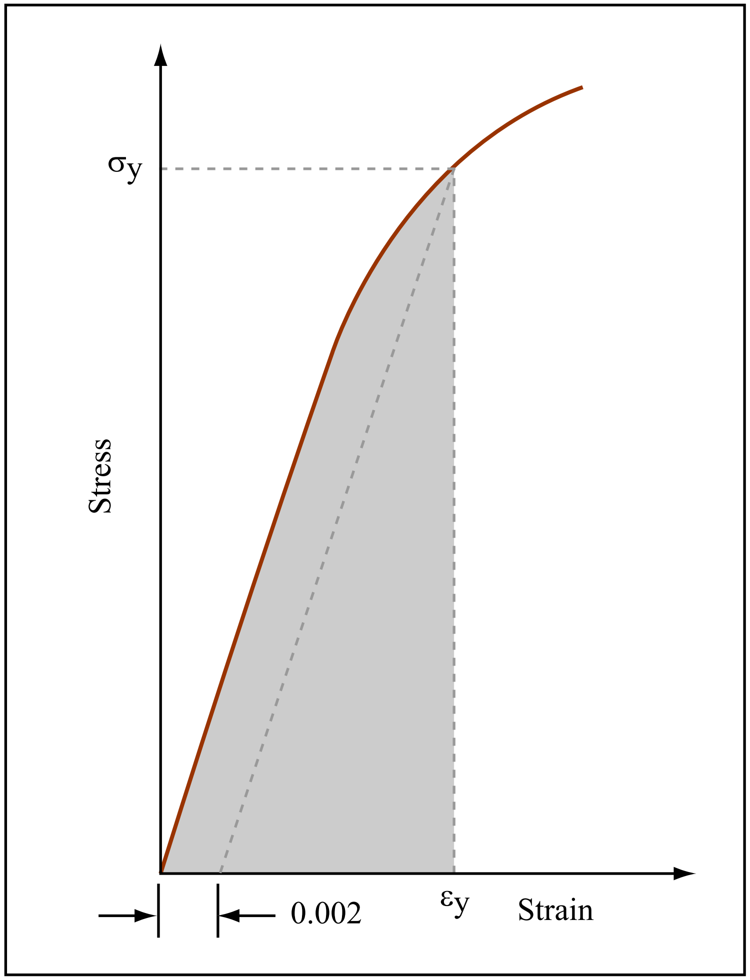
Ductility: degree of plastic deformation at fracture

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

$$\%EL = \left(\frac{L_f - L_0}{L_0} \right) \times 100$$

Brittle Materials have a fracture strain of less than approx. 5%

Resilience



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- Resilience is the capacity of material to absorb energy as elastic deformation and recover the energy
- Characterized by modulus of resilience, U_r

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

- If linear elastic region,

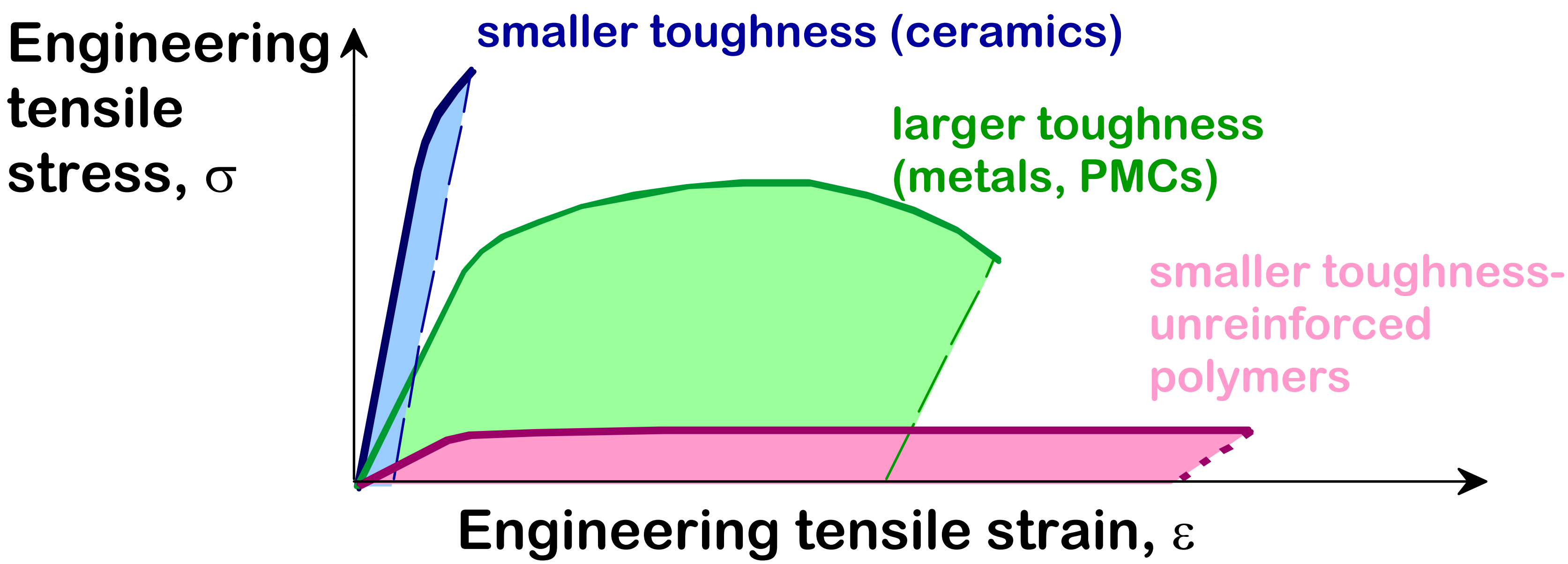
$$U_r = \frac{1}{2}\sigma_y \varepsilon_y$$

- These materials tend to have high yield strength and low modulus of elasticity

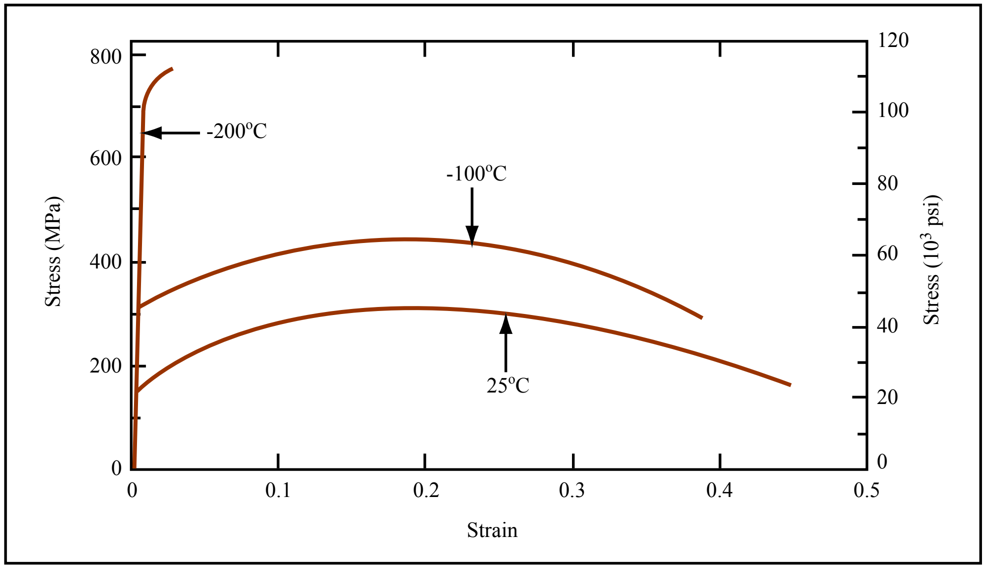
Fracture Toughness

Fracture Toughness

Energy required to fail → area under stress-strain curve. Material must be strong and ductile.



Temperature Effects on Engineering Stress and Strain



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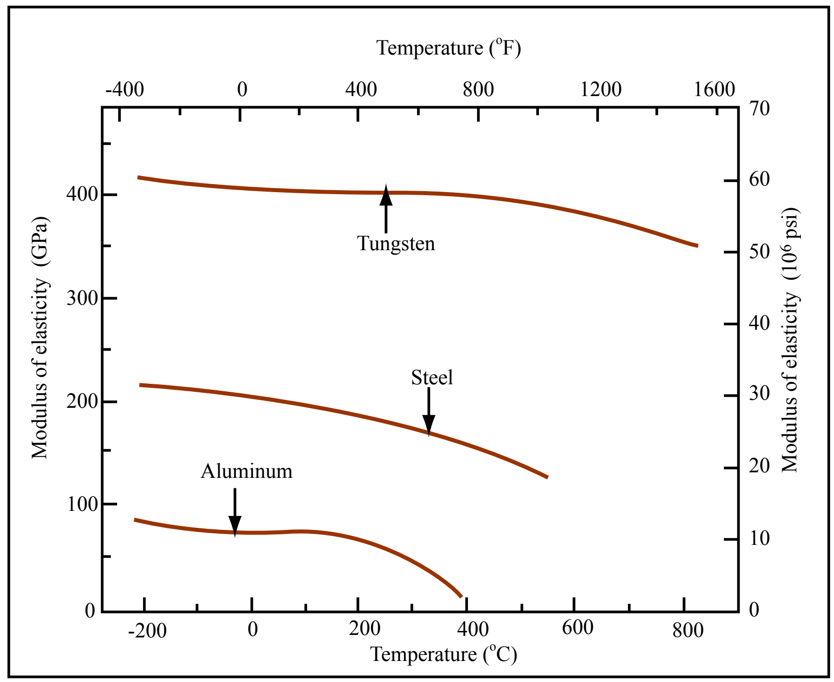
Think of a rose or banana dipped in liquid nitrogen

E, yield and tensile strength decrease with temperature

Ductility usually increases with temperature



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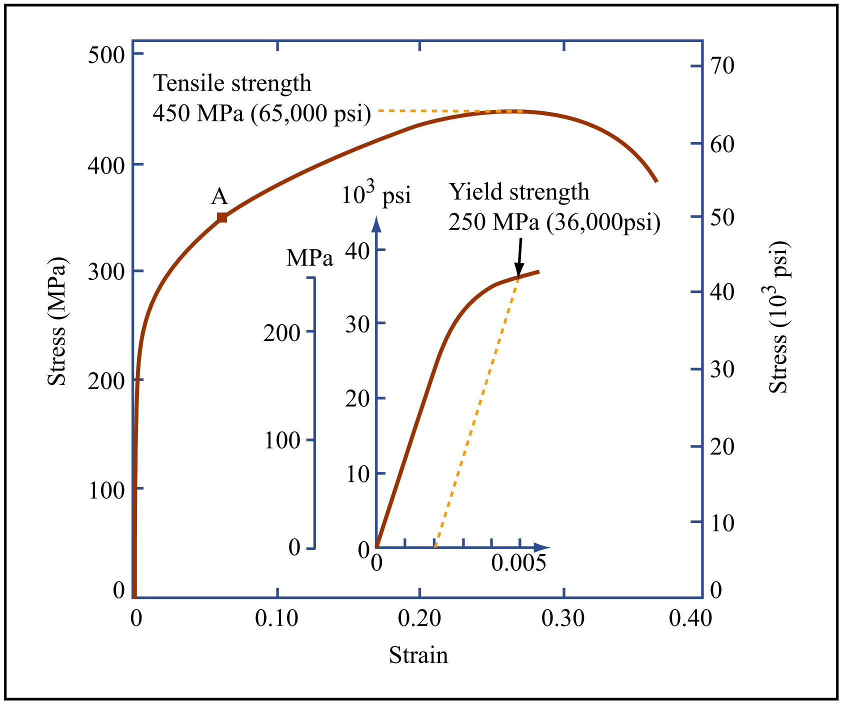
Engineering Stress and Strain vs True Stress and Strain



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Do you notice anything strange about the stress-strain curve after a material exceeds its Tensile Strength?

Engineering Stress and Strain vs True Stress and Strain

$\sigma = F/A_0$

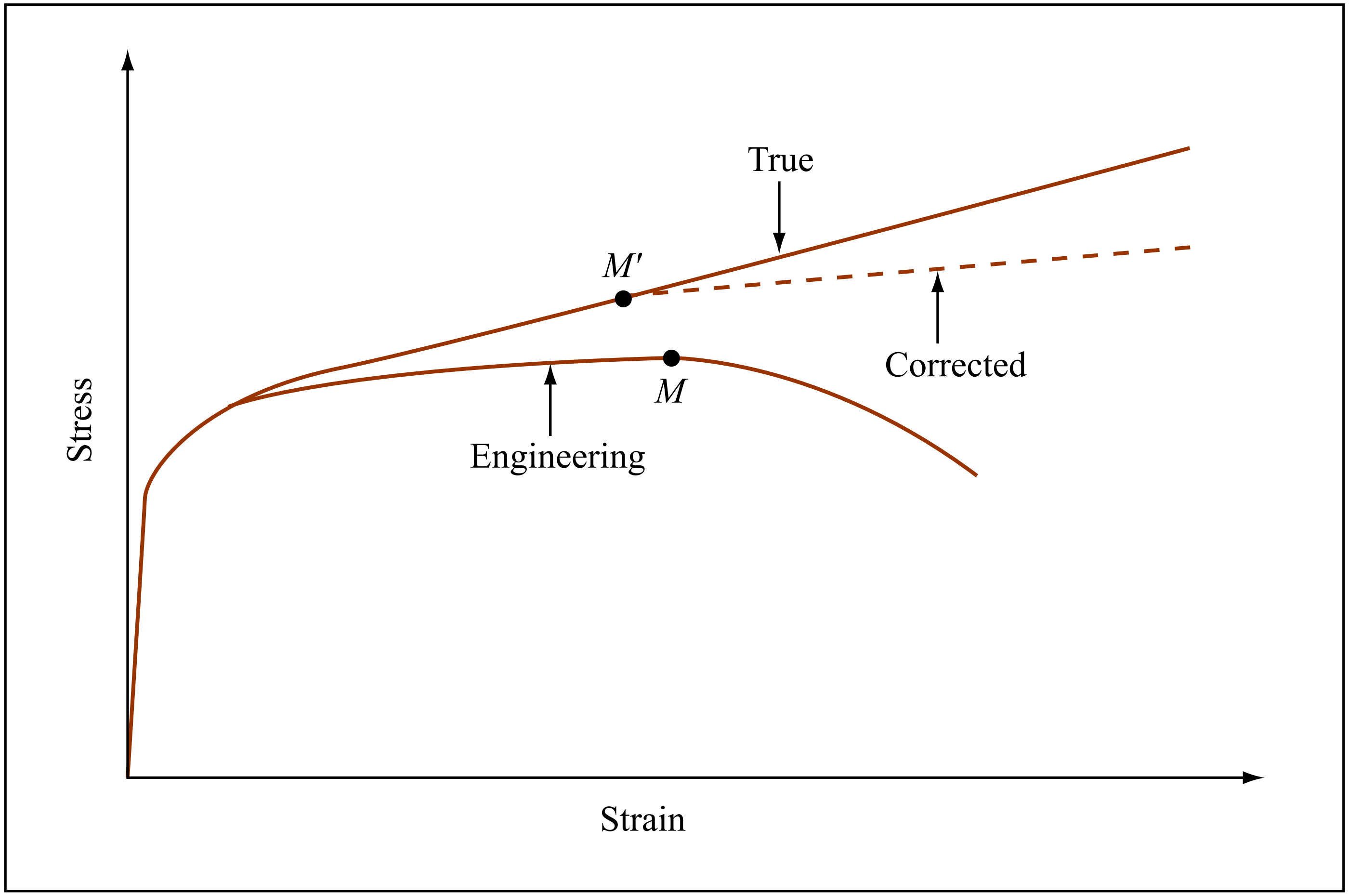
$\varepsilon = \Delta L / L_0$

$\sigma_T = F/A_i$

$\varepsilon_T = \ln(L_i / L_0)$

- In elastic region, change in cross-sectional area and length are negligible
- As material deforms plastically, the initial cross-sectional area and length changes instantaneously
- True stress and true strain are based on instantaneous cross-sectional area and instantaneous length

Engineering Stress and Strain vs True Stress and Strain



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If no volume occurs during deformation:

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

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

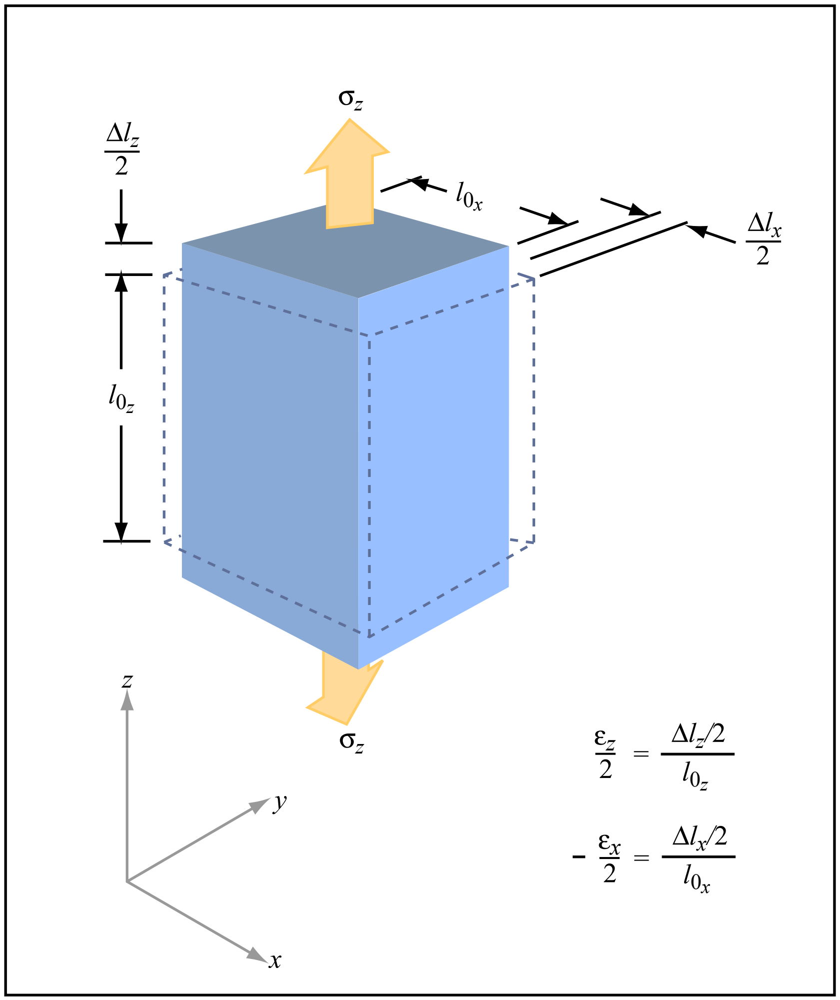
After plastic deformation until necking:

$\sigma_T = K\,\varepsilon^n_T$ where K and n (strain hardening) are constants

Poisson's Ratio, υ

isotropic material

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



- Elastic strain in compression perpendicular to extension caused by tensile stress
- Cannot be directly obtained from stress-strain curve
- υ = 0.26 to 0.35 for common metal alloys
- υ < 0.25 for ceramics
- υ has a maximum value of 0.50 (no volume change)

Figure by MIT OpenCourseWare.

Shear Stress

Shear Stress, τ

$$\tau = \frac{F_s}{A_0}$$

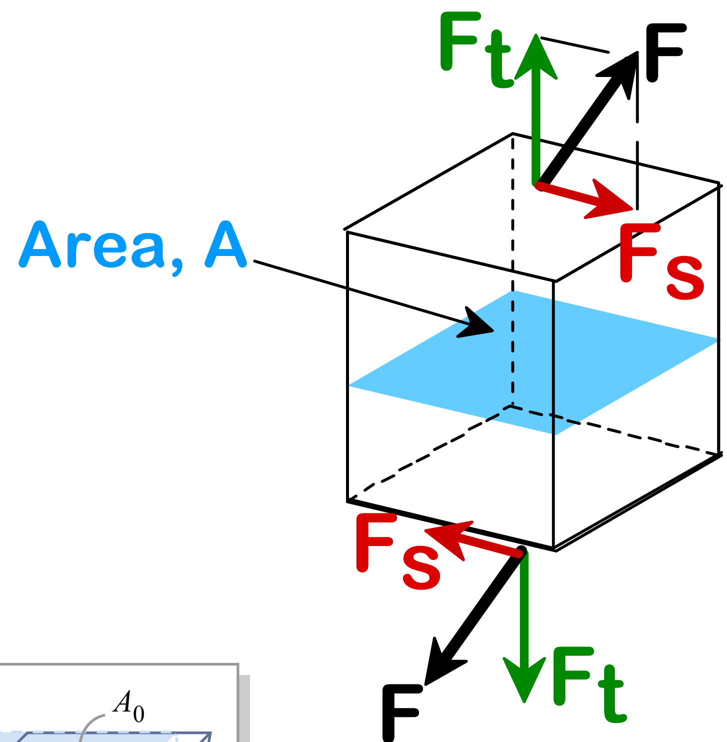
where F_s is the shear load and A_0 is the initial cross-sectional area parallel to the loading direction

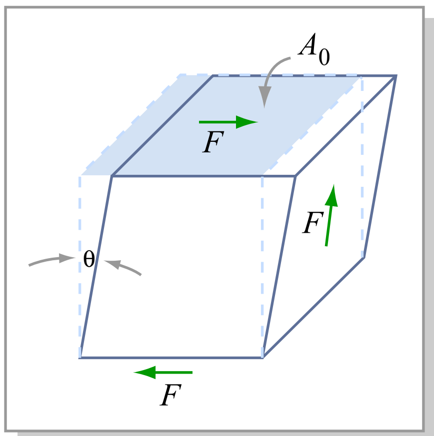
Shear Strain, γ

$$\gamma = \tan\theta$$

Shear Modulus, G

$$\tau = G\gamma$$





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Tensile and Shear Stress
Elastic and Shear Modulus

Tensile Stress and Strain

$$\sigma = \frac{F}{A_0}$$

$$\varepsilon = \frac{L_i - L_0}{L_0} = \frac{\Delta L}{L_0}$$

$$\sigma = E\varepsilon$$

Shear Stress and Strain

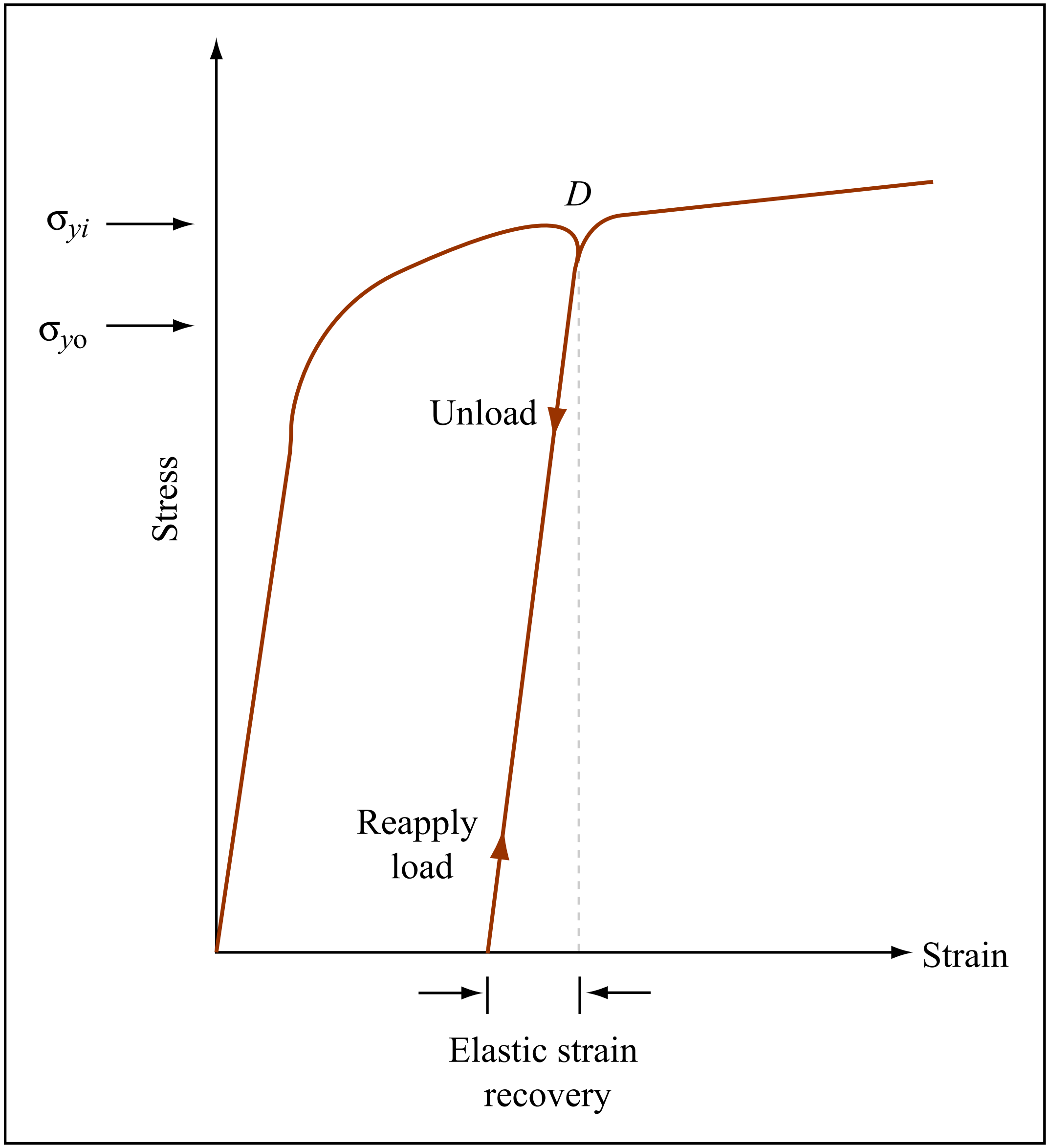
$$\tau = \frac{F_s}{A_0}$$

$$\gamma = \tan\theta$$

$$\tau = G\gamma$$

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

Strain (work) Hardening



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- Upon release of load during a stress-strain test, some fraction of the strain is recovered as elastic strain
- Reapplication of stress will traverse the same curve
- Note the increase in the yield stress – strain hardening
- Ductility decreases