Chapter 3: Mechanical Properties of Materials

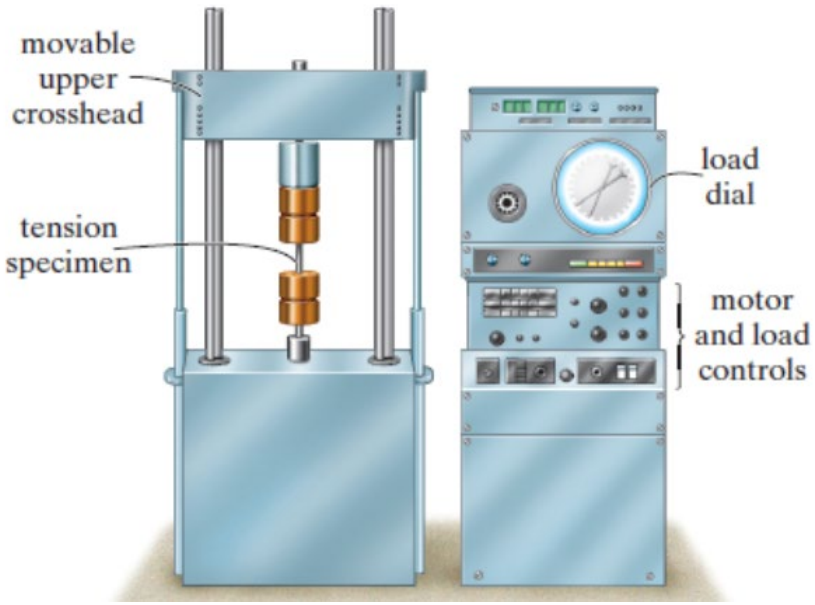
Chapter Objectives

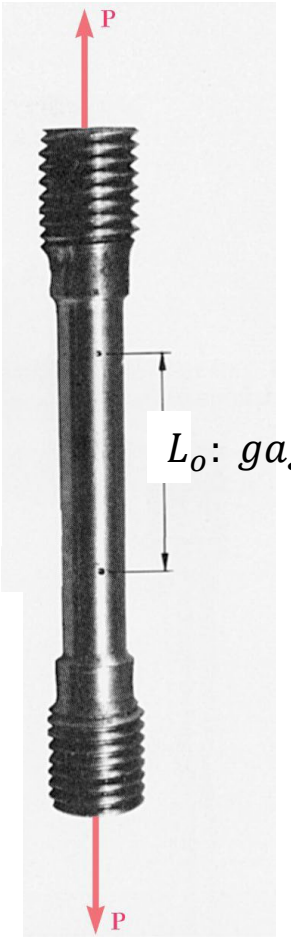
- ✓ Understand how to measure the stress and strain through experiments
- ✓ Correlate the behavior of some engineering materials to the stress-strain diagram

Tension and compression test

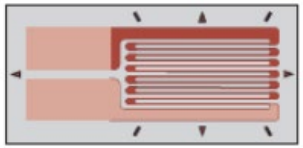
https://www.youtube.com/watch?v=AFCA81ocFgo

https://www.youtube.com/watch?v=jbslR-6GVCs

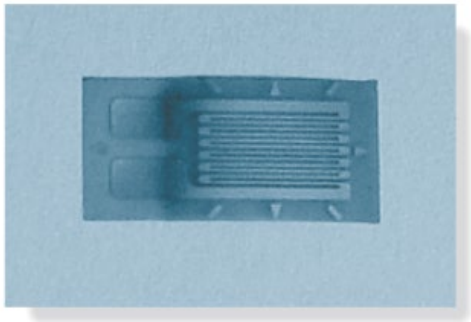


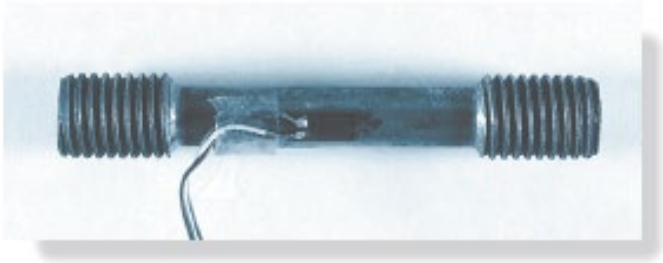


L_o: *gage length*



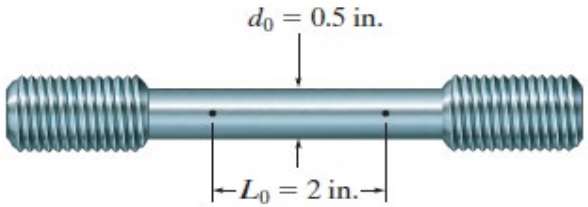
Electrical–resistance strain gauge





Typical steel specimen with attached strain gauge.

Stress-strain diagram

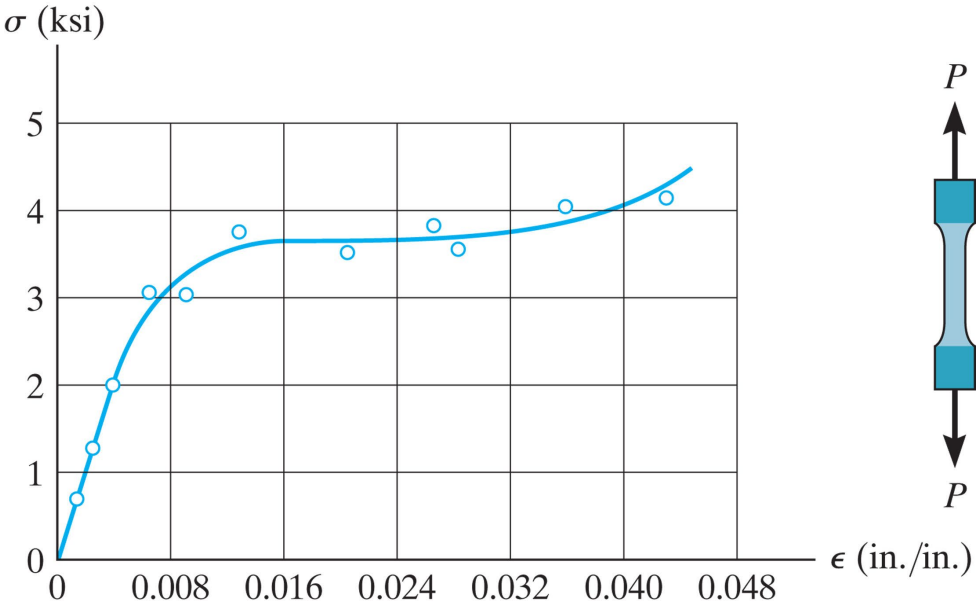


Uniaxial tension test:

- Specimen is stretched at a very slow, constant rate
- Measure distance L and load P at frequent intervals
- Convert L and P to engineering stress-strain data

Note that two stress-strain diagrams for a particular material will be similar, but not identical, due to variability in:

- Material composition
- Specimen imperfections
- Rate of loading
- Ambient temperature



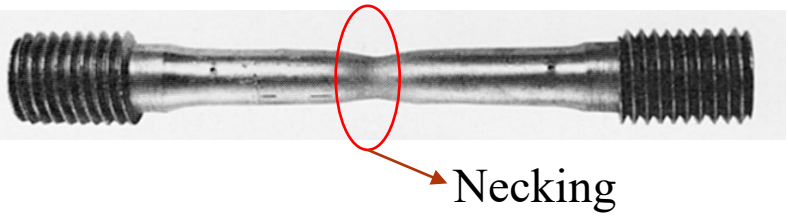
Characteristics of stress-strain diagram

Elastic behavior (recoverable deformation):

- Materials loaded in this region regain its original shape if load is removed
- The curve is a straight line throughout most of this region (stress is proportional to strain).
- Linear region is limited by the *proportional limit* σ_{pl}
- Region formally ends after yielding (σ_Y)

Plastic behavior (permanent deformation):

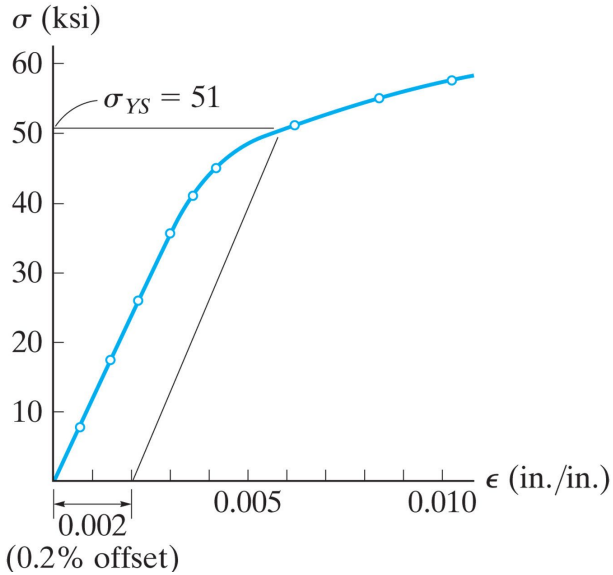
- Stresses above the *elastic limit* will cause the material to deform permanently
- *Yield strength* σ_Y: highest stress that the material can withstand without undergoing significant yielding
- *Ultimate strength* (σ_u) is the maximum value of engineering stress that the material can withstand
- *Necking* occurs after the ultimate strength is exceeded
- *Fracture (or rupture) stress* (σ_f) the value of stress at fracture



Ductile materials

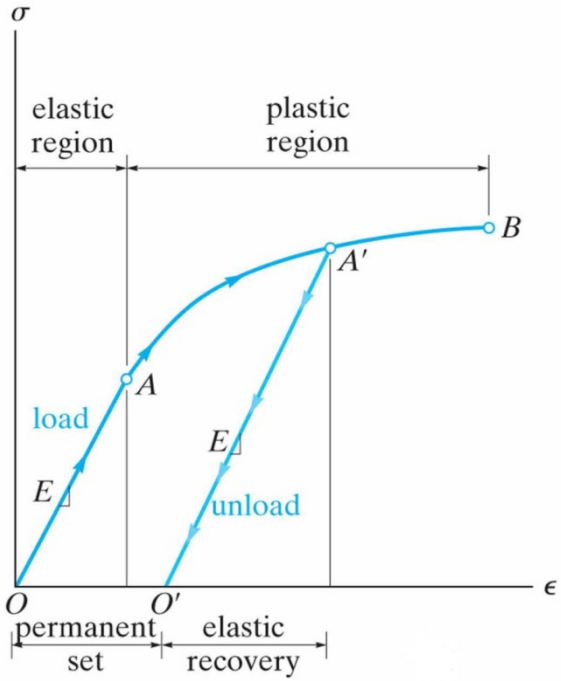
- Rupture occurs along a cone-shaped surface that forms an angle of approximately 45° with the original surface of the specimen
- Shear is primarily responsible for failure in ductile materials
- Axial loading: maximum shear stress occurs at 45°

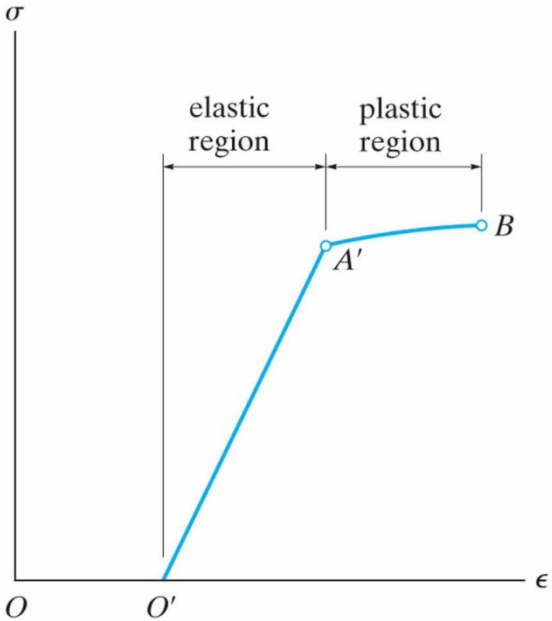
- Ways to specify ductility:
  - % elongation $= 100 \times \frac{(L_f - L_0)}{L_0}$
  - % area reduction $= 100 \times \frac{(A_0 - A_f)}{A_0}$
- The *yield strength* σ_Y is often defined as the stress at which unloading would produce a plastic or permanent strain of *0.002* (***offset method***)



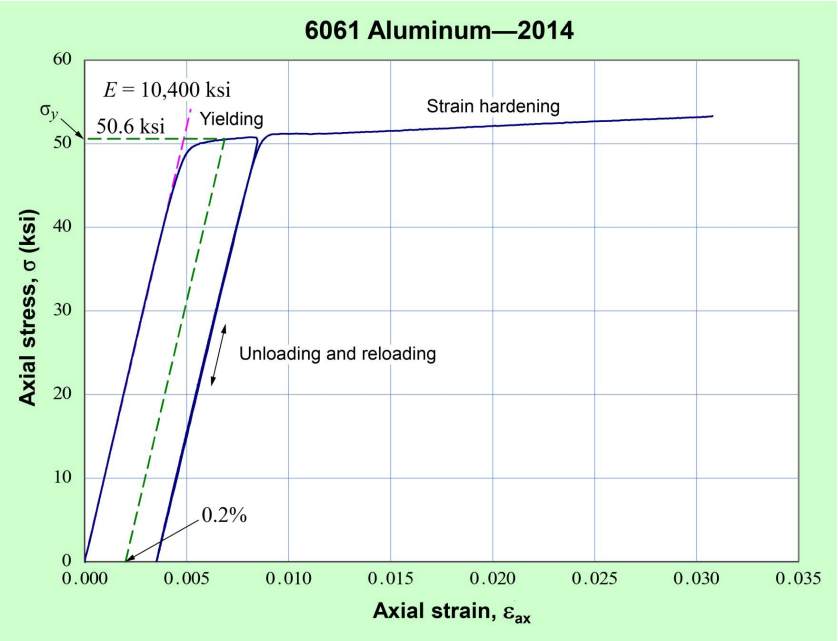
Strain-Hardening:

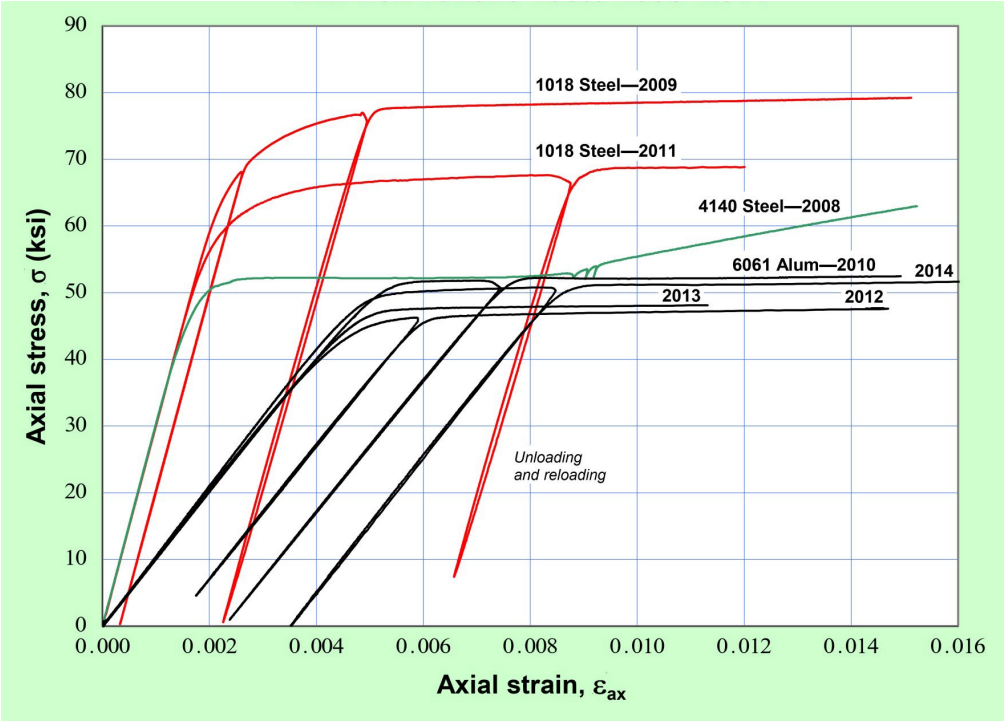
- If a specimen of a ductile material is loaded into the plastic region and then unloaded, *elastic strain* is recovered as the material return to its equilibrium state
- The *plastic strain* remains, resulting in *permanent deformation*
- If material is reloaded, it will have a higher yielding point – *strain hardening*. The material has a **greater elastic region**, however is has **reduced ductility**





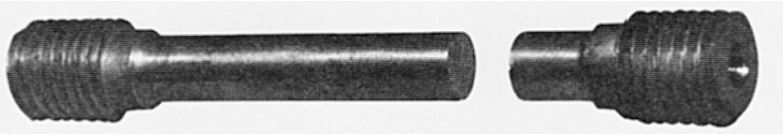
Some Example Data: Loading and unloading of some structural metals

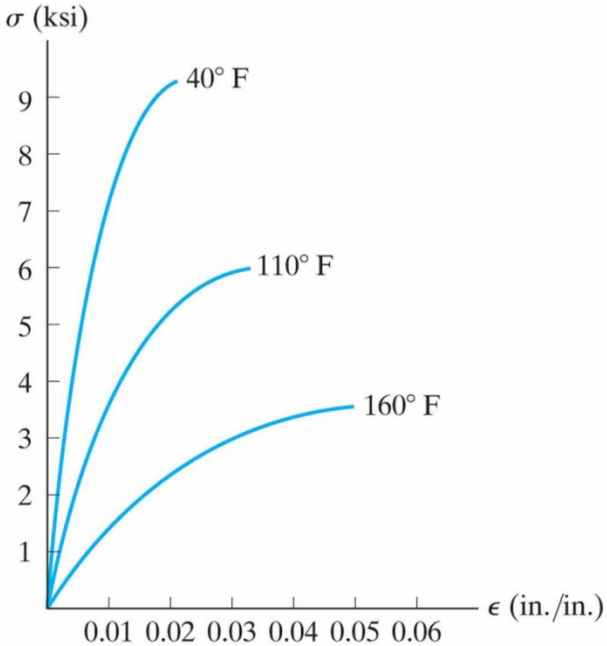




Brittle materials

- Material that exhibit little or no yielding before failure
- Absence of necking
- Rupture occurs along a surface perpendicular to the load
- Normal stress is primarily responsible for failure of brittle materials

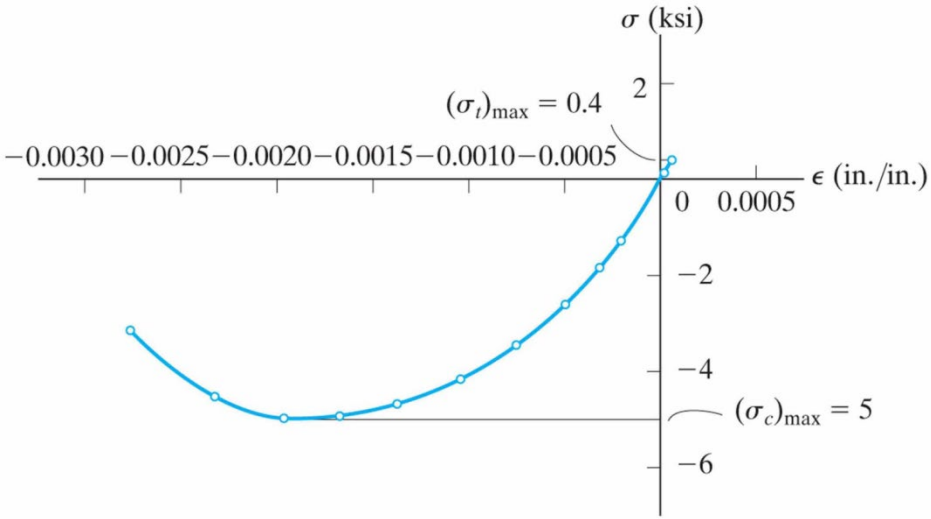




Concrete (brittle material)

- Maximum compressive strength is substantially larger than the maximum tensile strength
- For this reason, concrete is almost always reinforced with steel bars or rods whenever it is designed to support tensile loads

Compression causes material to bulge out

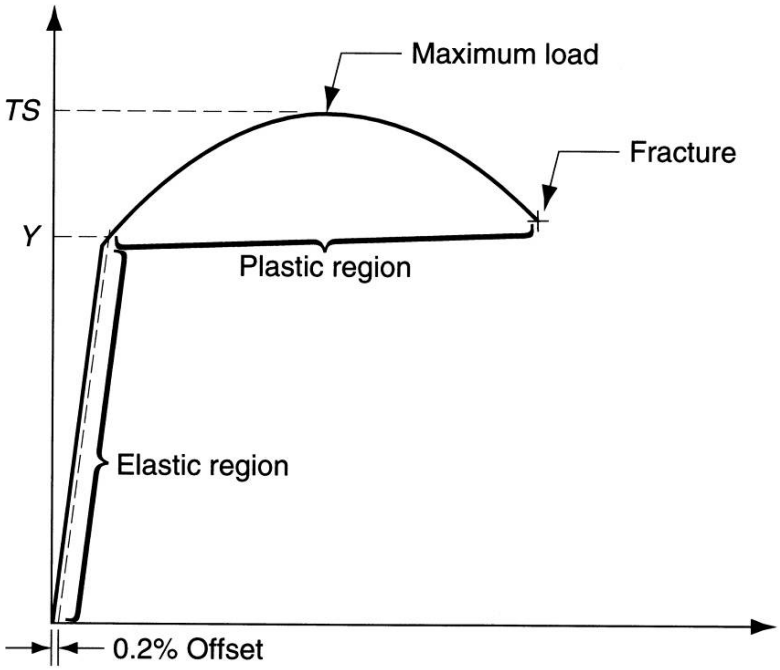


$\sigma - \epsilon$ diagram for typical concrete mix

Hooke's law

For small deformations (elastic region up to yield strength)

$$\sigma = E\,\epsilon$$



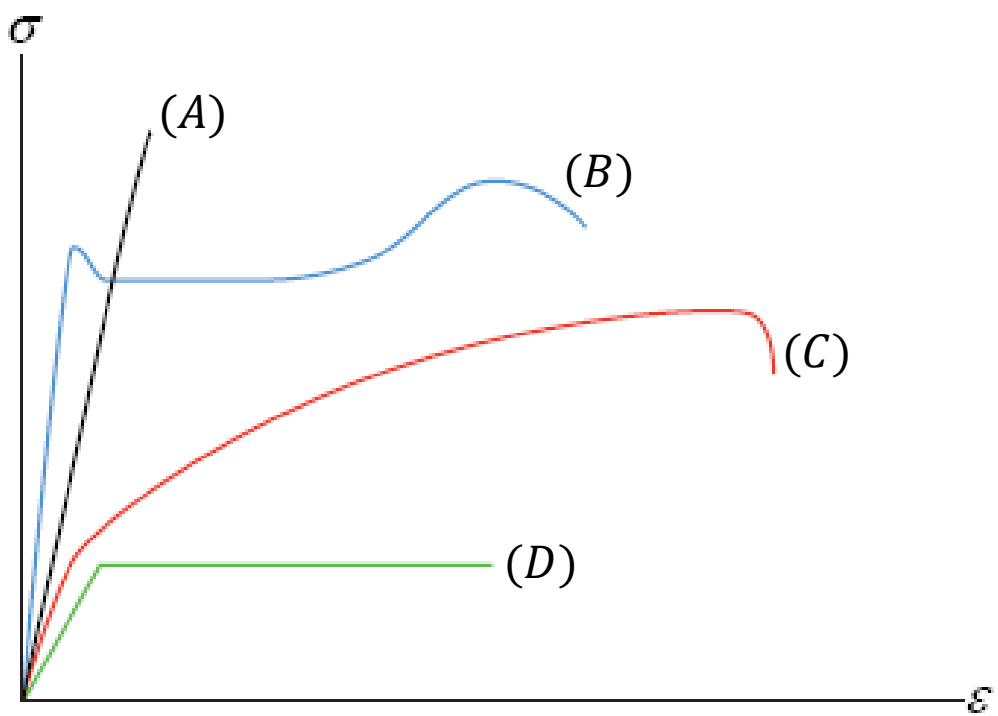
For plastic deformation:

For the plastic region: $\sigma = K\,\epsilon^n$

K = strength coefficient

n = strain hardening exponent

	σ_u	σ_Y	E
Steel	400 MPa	250 MPa	200 GPa
Al	110 MPa	95 MPa	70 GPa
Concrete (compression)	28 MPa	-	25 GPa



Which material has highest stiffness (Young's modulus, E)?

Which material is most ductile?

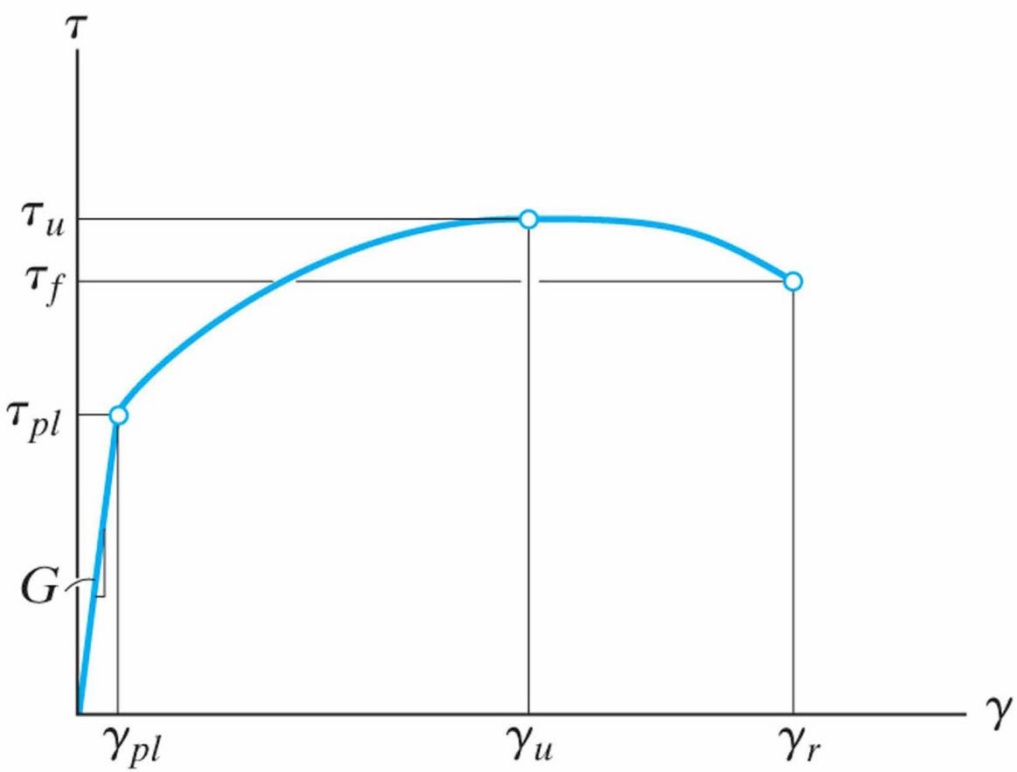
Which material is most brittle?

Which material has the lowest yield strength σ_Y?

Hooke's law for shear stress and strain

$$\tau_{xy} = \boxed{G}\gamma_{xy}$$

Modulus of rigidity or shear modulus

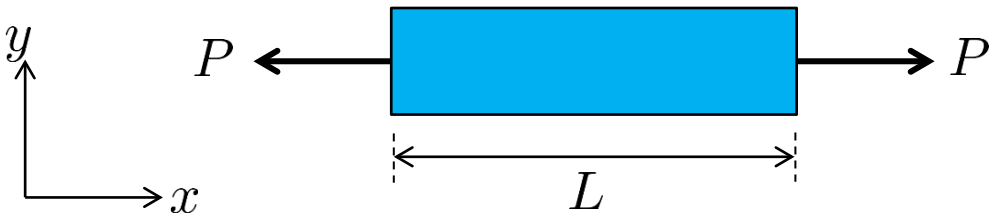


ONLY TWO OF THE THREE MATERIAL CONSTANTS ARE INDEPENDENT IN ISOTROPIC MATERIALS!

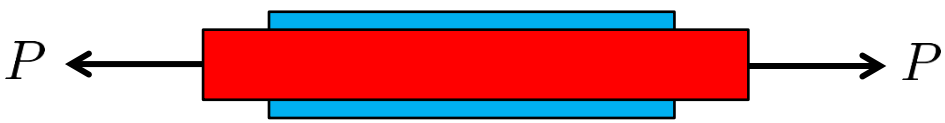
$$G = \frac{E}{2(1+\nu)}$$

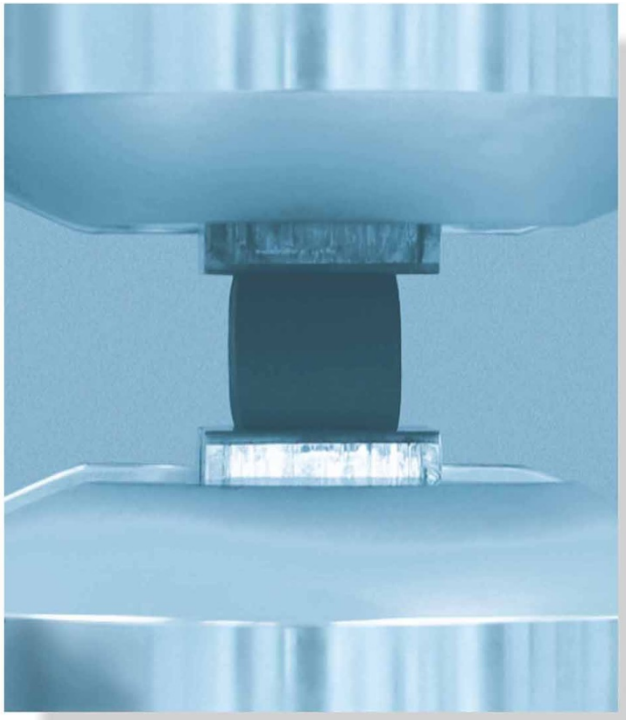
Poisson's ratio

Undeformed configuration



Deformed configuration





Axial (normal) strain $\epsilon_x = \dfrac{\delta}{L}$

Poisson's ratio: $\nu = -\dfrac{\text{lateral strain}}{\text{axial strain}}$

$$0 < \nu < 0.5$$

Lateral strain

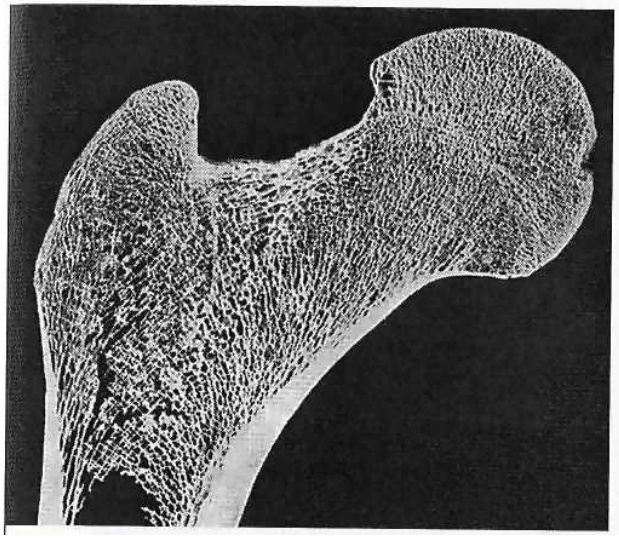
$$\epsilon_z = \epsilon_y = -\boxed{\nu}\,\epsilon_x$$

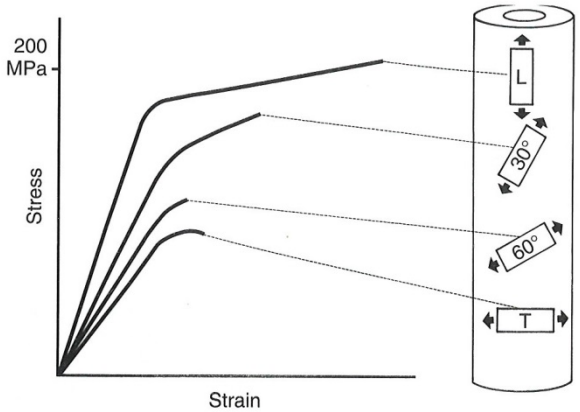
Poisson's ratio

Axial extension → Lateral contraction

Isotropic vs. anisotropic materials:

- Isotropic: material properties are independent of the direction
- Anisotropic: material properties depend on the direction





Repeated Loadings – Fatigue

- If stress does not exceed the *elastic limit,* the specimen returns to its original configuration
- However, this is not the case if the loading is repeated thousands or millions of times
- In such cases, rupture will happen at a stress lower than the *fracture stress* - this phenomenon is known as fatigue