TAM251_Chapter3 _MechanicalPropertiesofMaterials_prelecture_Johnson

Friday, June 18, 2021 9:40 AM

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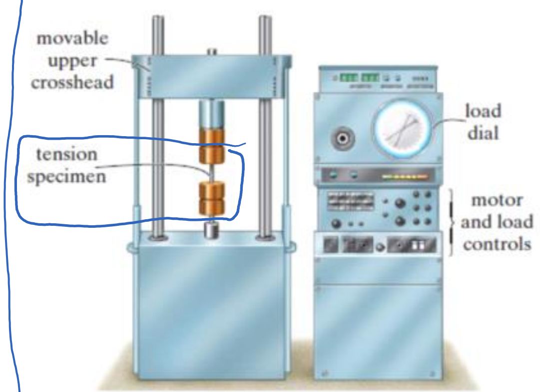
Chapter 3: Mechanical Properties of Materials

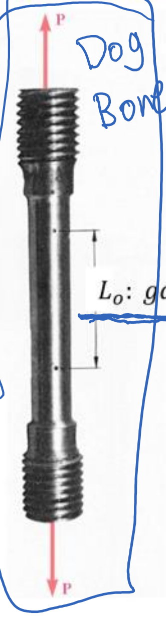
Chapter Objectives

- ✓ 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

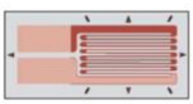




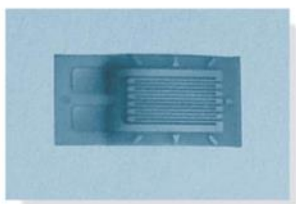
L_o: *gage length*

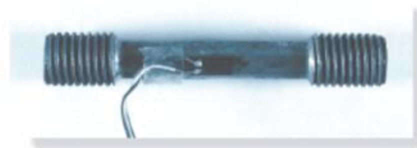
Dog Bone

universal testing machine
~ Instron
~ CEE 300, TAM 324, ME 330



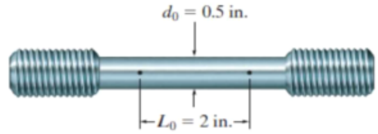
Electrical-resistance strain gauge





Typical steel specimen with attached strain gauge.

Stress-strain diagram



Uniaxial tension test:

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

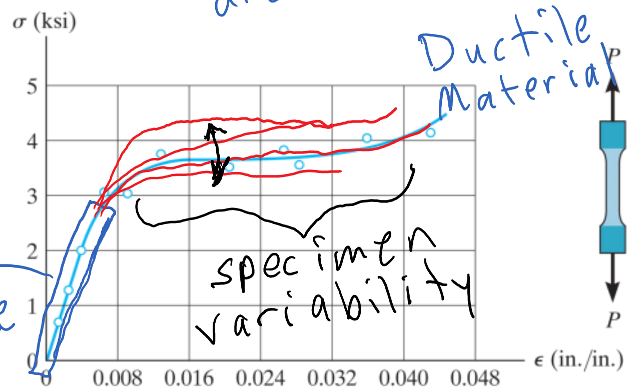
$$\varepsilon = \frac{L - L_0}{L_0} \qquad \sigma = \frac{P}{A_0}$$

axis of the specimen

initial cross-section area of the specimen

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



can find many material properties

Characteristics of stress-strain diagram

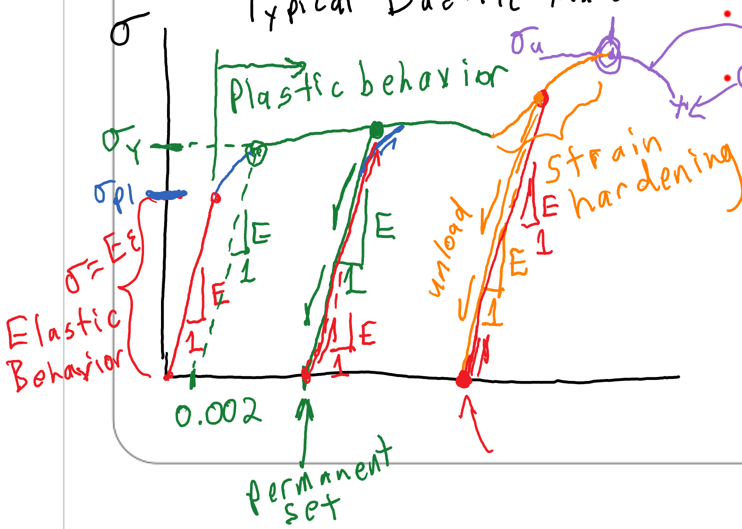
Elastic behavior (recoverable deformation):

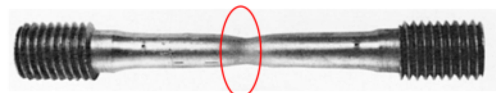
- Reversible deformation
- Materials loaded in this region regain its original shape if load is removed
- The curve is a straight line throughout most of this region (stress is proportional to strain).
- Linear region is limited by the ***proportional limit*** (σ_{pl})
- Region formally ends after yielding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

Plastic behavior (permanent deformation): only in ductile materials

- 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

Typical Ductile Material





Necking

$[E] = [\sigma] = \frac{\text{force}}{\text{area}}$

Linearly elastic regime
slope $= E$: $\sigma = E \cdot \varepsilon$ $\quad [\varepsilon] = 1$

σ_Y = yield stress – found by 0.2% offset method
– unloadings after yielding also have slope $= E$

"flat" region after we reach σ_Y is known as "yielding"

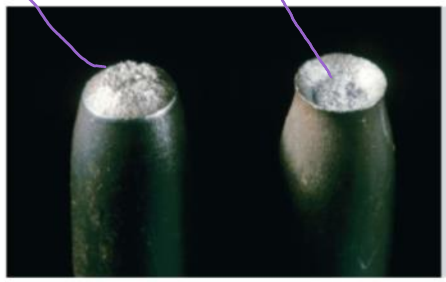
Upon reloading, we observe slope of E

In strain hardening, σ_Y increases!

Necking
– rapid, localized reduction of cross-section
  – locally, σ increases rapidly
– Final behavior we observe in a ductile material prior to rupture (fracture)

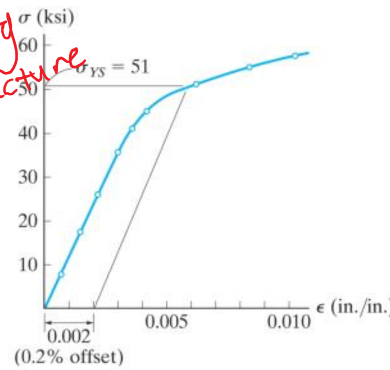
Ductile materials

cone cup



- Rupture occurs along a cone-shaped surface that forms an angle of approximately 45° with the original surface of the specimen
- <u>Shear is primarily responsible for failure in ductile materials</u>
- Axial loading: maximum shear stress occurs at 45° ← "shear lips" ⇒ happen where τ is maximized

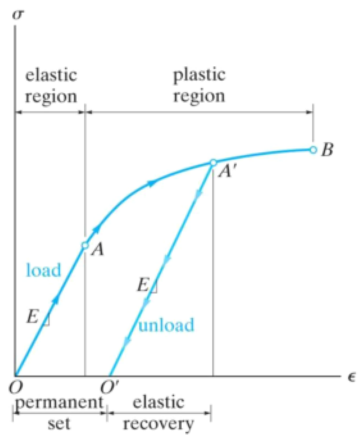
- Ways to specify ductility:
  - $\boxed{\% \text{ elongation} = 100 \times \frac{(L_f - L_0)}{L_0}}$ } after testing to fracture
  - $\% \text{ area reduction} = 100 \times \frac{(A_0 - A_f)}{A_0}$ ← at the neck
- The <u>*yield strength*</u> σ_Y is often defined as the stress at which unloading would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

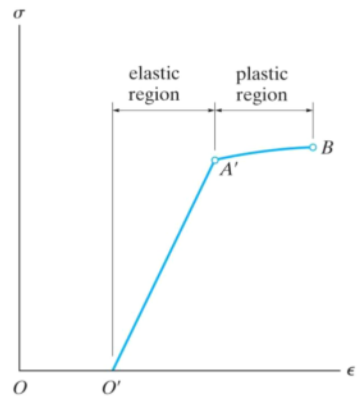


Strain-Hardening:

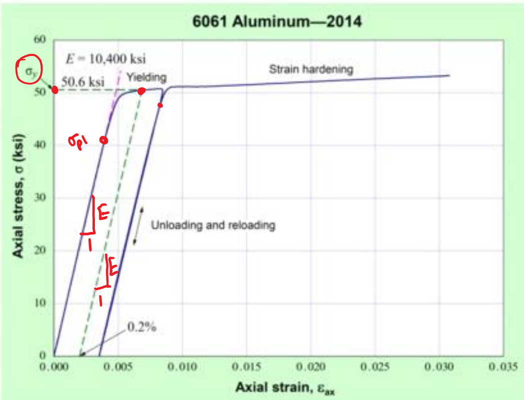
Plastic deformation example

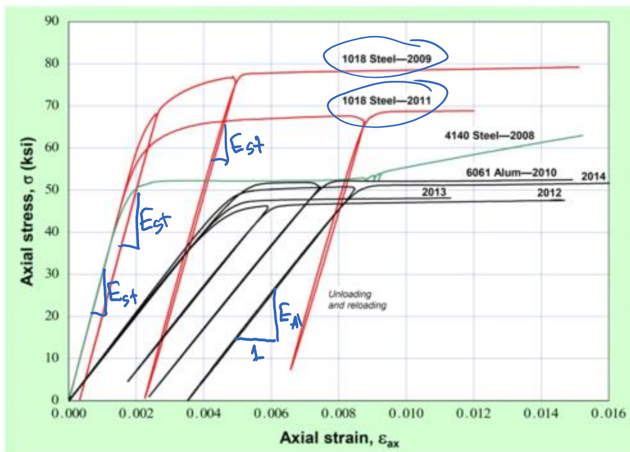
- If a specimen of a ductile material is loaded into the plastic region and then unloaded, *elastic strain* is recovered as the material return to its equilibrium state
- The *plastic strain* remains, resulting in *permanent deformation*
- If material is reloaded, it will have a higher yielding point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





Some Example Data: Loading and unloading of some structural metals





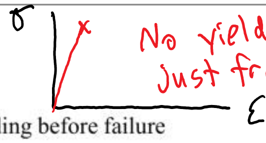
E is determined by the primary element of the alloy

Steels have one E value

Aluminums have one different E value

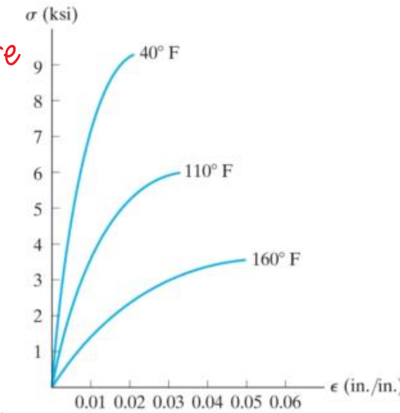
Etc.

Brittle materials



No yielding, just fracture

- 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

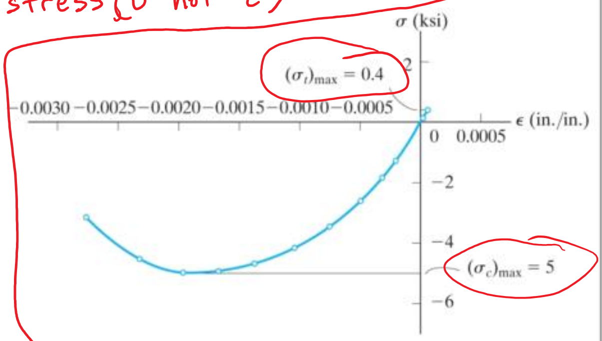


brittle materials fail due to max normal stress (σ not τ)

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



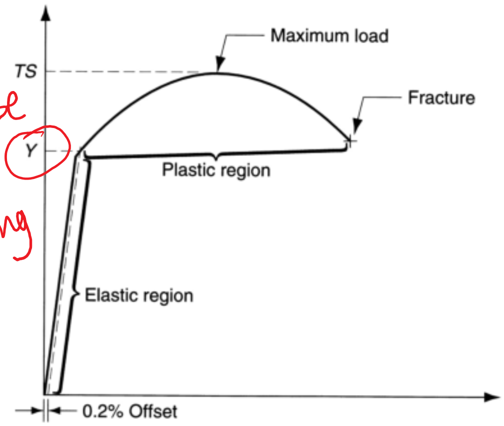
σ − ϵ diagram for typical concrete mix

Hooke's law

For small deformations (elastic region up to yield strength)

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

We will use this all semester long



For plastic deformation:

For the plastic region: $\sigma = K\,\epsilon^n$ power law curve fit

K = strength coefficient

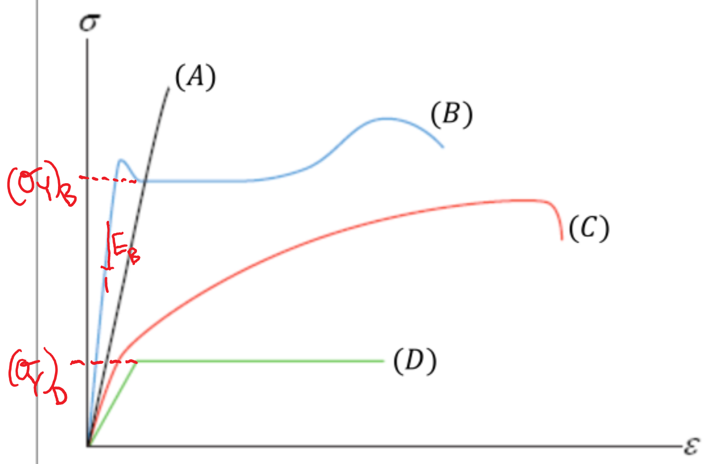
n = strain hardening exponent

depends on alloy and pre-working of the material

very reliable

	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

determined by the 0.2% offset method



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

B, steepest linear region

Which material is most ductile?

C, highest ε before rupture

Which material is most brittle?

A, least yielding region (none)

Which material has the lowest yield strength σ_Y? D

Hooke's law for shear stress and strain

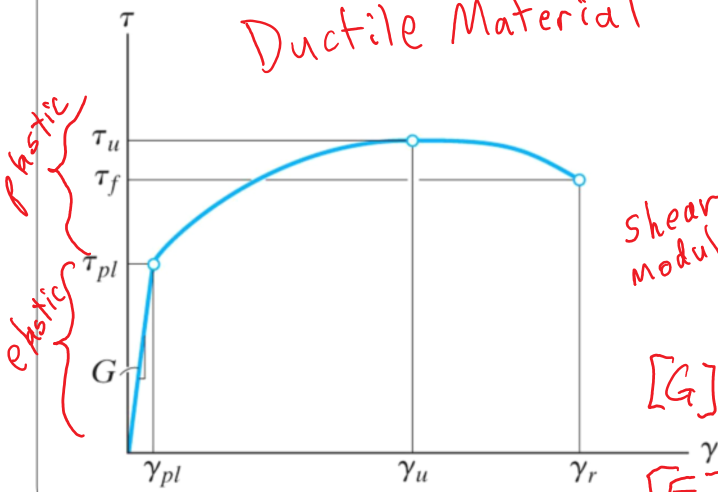
$$\tau_{xy} = \boxed{G}\,\gamma_{xy}$$

Hookes Law
- linear relation between τ and γ

usually determined using torsion experiments

G → Modulus of rigidity or shear modulus

Ductile Material



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

shear modulus

Young's Modulus

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

Poisson's Ratio

$[G] = \frac{\text{force}}{\text{area}}$

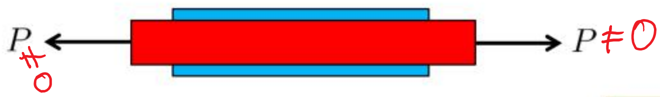
$[E] = \frac{\text{force}}{\text{area}}$

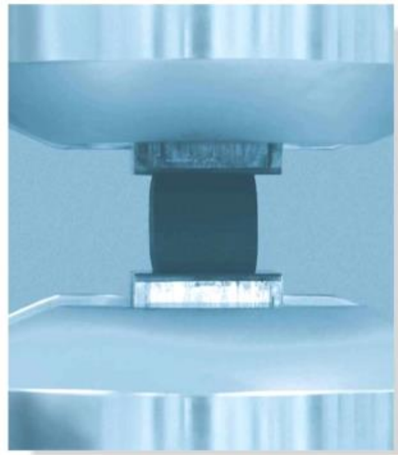
$[\nu] = 1$

Poisson's ratio

Undeformed configuration

Deformed configuration





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

"nu"

$$\overbrace{\epsilon_z = \epsilon_y}^{\text{Lateral strain}} = -\boxed{\nu}\,\epsilon_x$$

axial strain

Poisson's ratio

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

$-1\,\cancel{0} < \nu < 0.5$

some materials do have $\nu < 0$

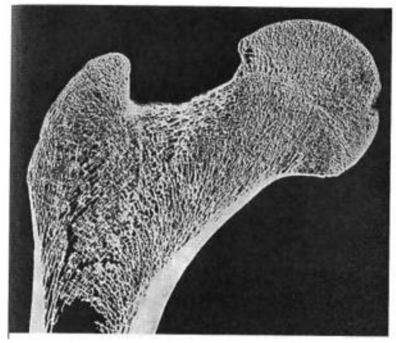
$\nu \approx 0.3$ for metals

Axial extension ➡ Lateral contraction

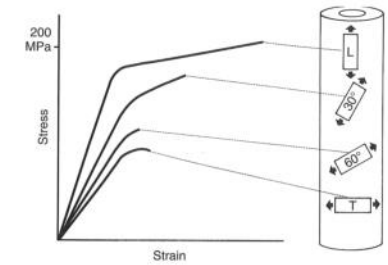
$\nu = 0.5 \Rightarrow$ isochoric material $\Rightarrow$ "volume-preserving"

Isotropic vs. anisotropic materials:

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



metals tend to be isotropic



Repeated Loadings – Fatigue

σ_{pl} or σ_Y

- 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