

ME111
Instructor: Peter Pinsky
Class #3
October 2, 2000

Today's Topics

- Introduction to material properties beyond the linear elastic range
- Ductility and brittleness
- Definitions of material properties important for design
- Engineering materials selection and treatments for improved properties

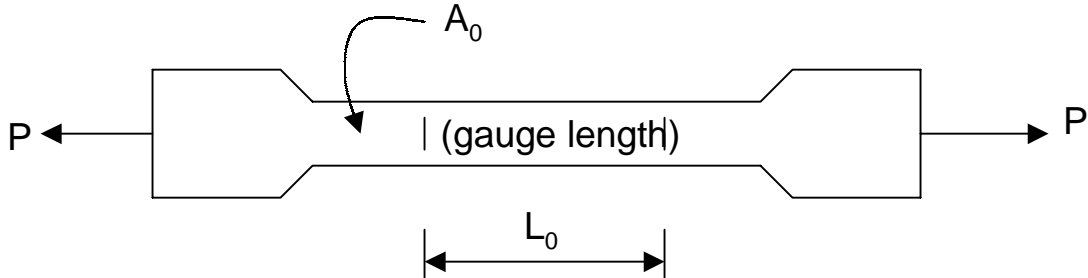
Reading Assignment Juvinall, Chapter 3.

Problem Set #1 Due in class 10/4/00

1. Juvinall 2.5
2. Juvinall 2.7
3. Juvinall 2.10
4. Juvinall 2.19

1. The Uniaxial Tension Test

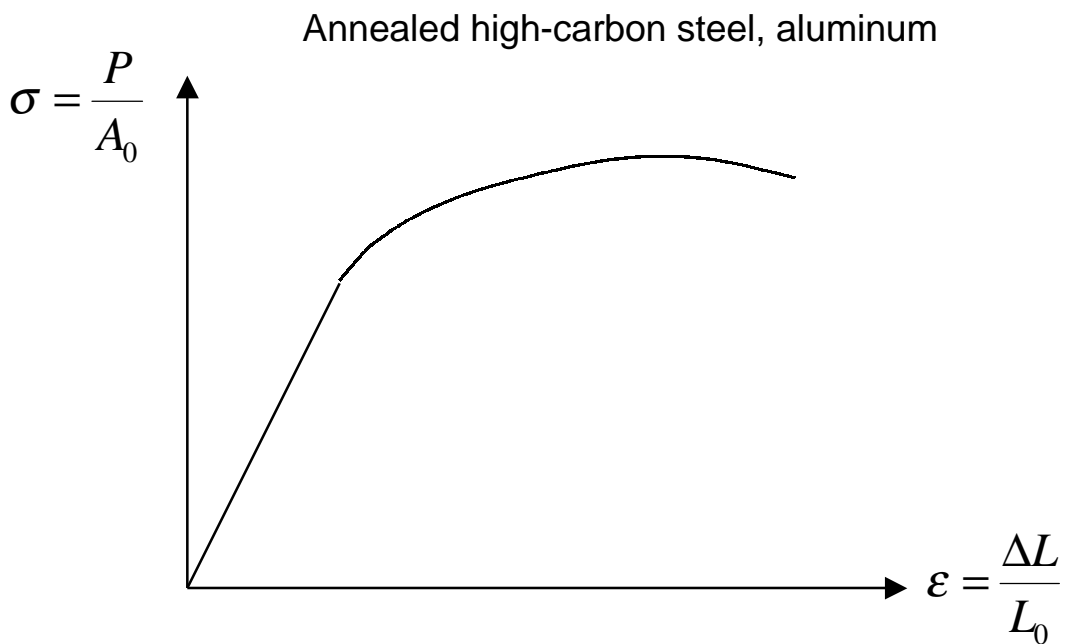
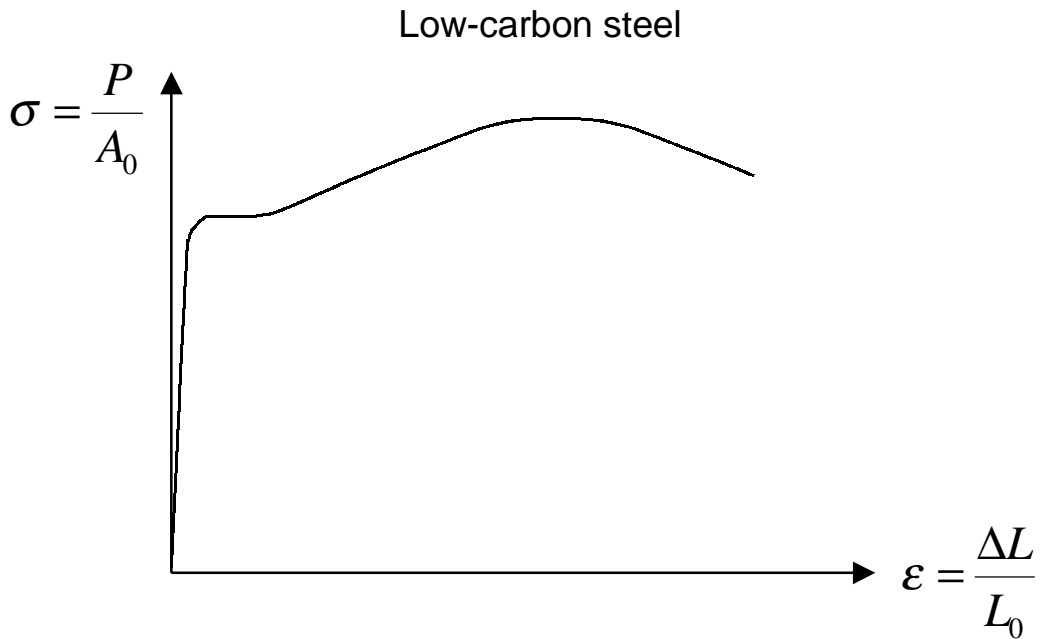
- Important for determining the stress-strain characteristics and strength of materials beyond the linear elastic range



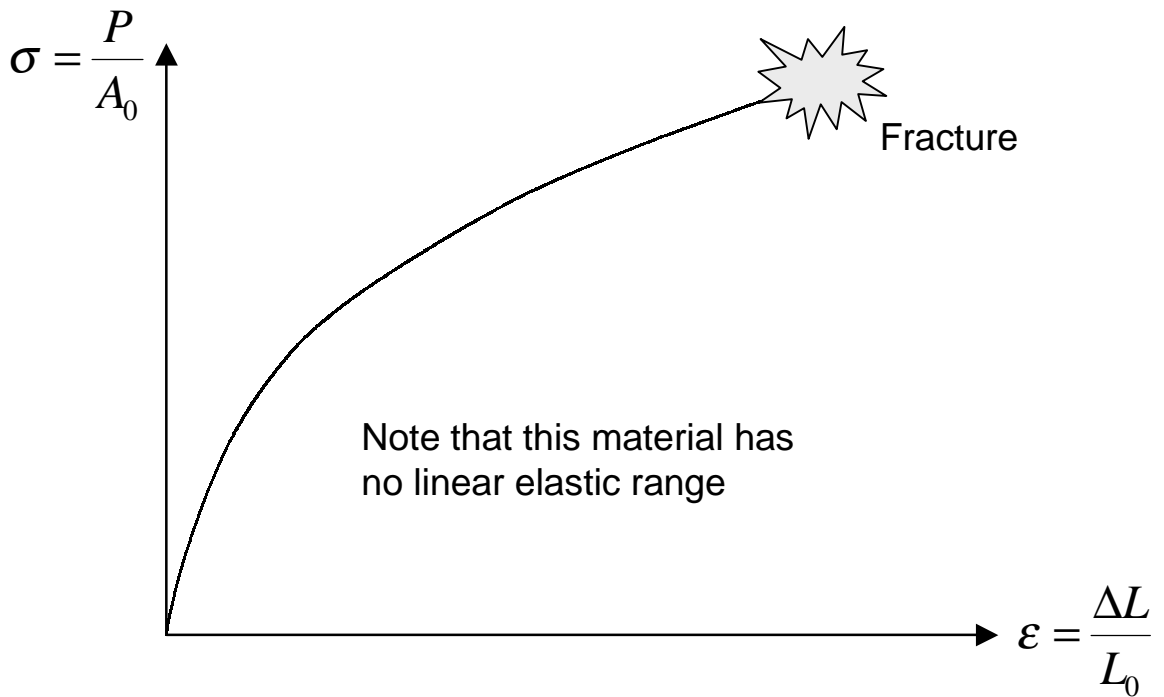
- Some important properties that can be determined from a static uniaxial tension test include:

• Elastic limit	S_e
• Yield stress/elastic limit	S_y
• Yield strain	ϵ_y
• Ultimate stress	S_u
• Ultimate strain	ϵ_u
• Ductility (strain at fracture)	ϵ_f
• Modulus of elasticity	E
• Fracture strength	S_f
• Modulus of toughness	R_m
• Modulus of resilience	T_m

- Let's look at some typical uniaxial test stress-strain curves:

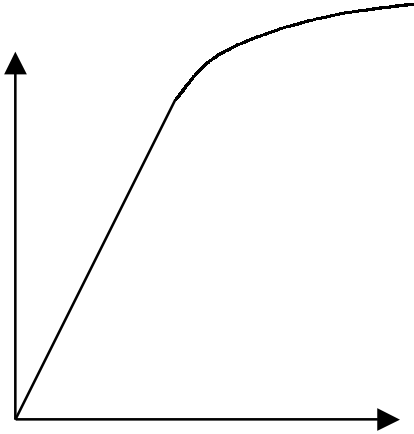


Brittle Material -- Cast Iron



Material property data that can be determined from a uniaxial test:

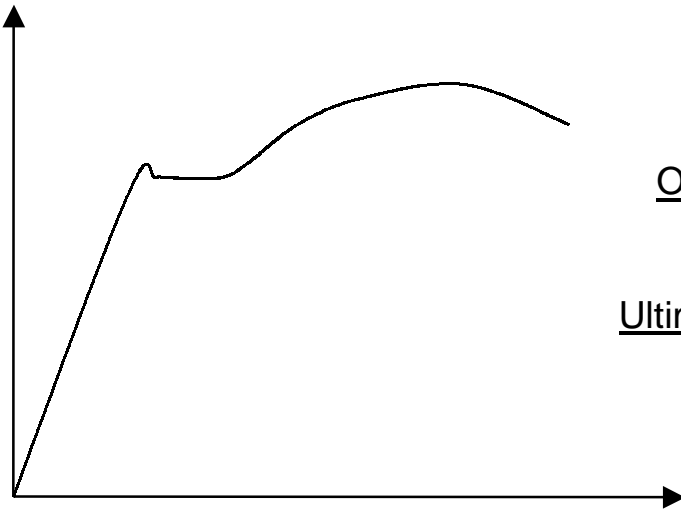
Measure of Elasticity



Young's modulus

$$E = \frac{\sigma_b - \sigma_a}{\epsilon_b - \epsilon_a}$$

Measures of Strength



Yield strength

$$S_y = \frac{P_y}{A_0}$$

Offset yield strength

$$S_y = \frac{P_y}{A_0}$$

Ultimate tensile strength

$$S_u = \frac{P_u}{A_0}$$

Fracture strength

$$S_f = \frac{P_f}{A_0}$$

2. Measures of Ductility

Measures ability of a material to accommodate inelastic deformation without fracturing

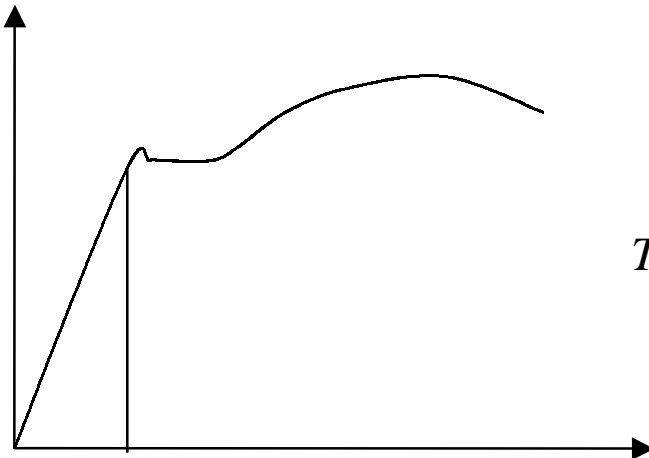
<p><i>Ductility</i> (fracture strain)</p> $\epsilon_f = \frac{L_f - L}{L}$ <p>$\epsilon_f > 5\%$ -> ductile material</p>	<p><i>Ductility ratio</i></p> $r_d = \frac{\epsilon_f}{\epsilon_y}$
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3. Measures of Toughness (or Impact Resistance)

Modulus of Resilience:

$$R_m = \frac{1}{AL} \int_0^{\Delta_{el}} P d\Delta = \int_0^{\Delta_{el}} \frac{P}{A} d\left(\frac{\Delta}{L}\right) = \int_0^{\epsilon_{el}} \sigma d\epsilon$$

$$= \frac{E\epsilon_{el}^2}{2} = \frac{\sigma_y^2}{2E}$$



Modulus of Toughness:

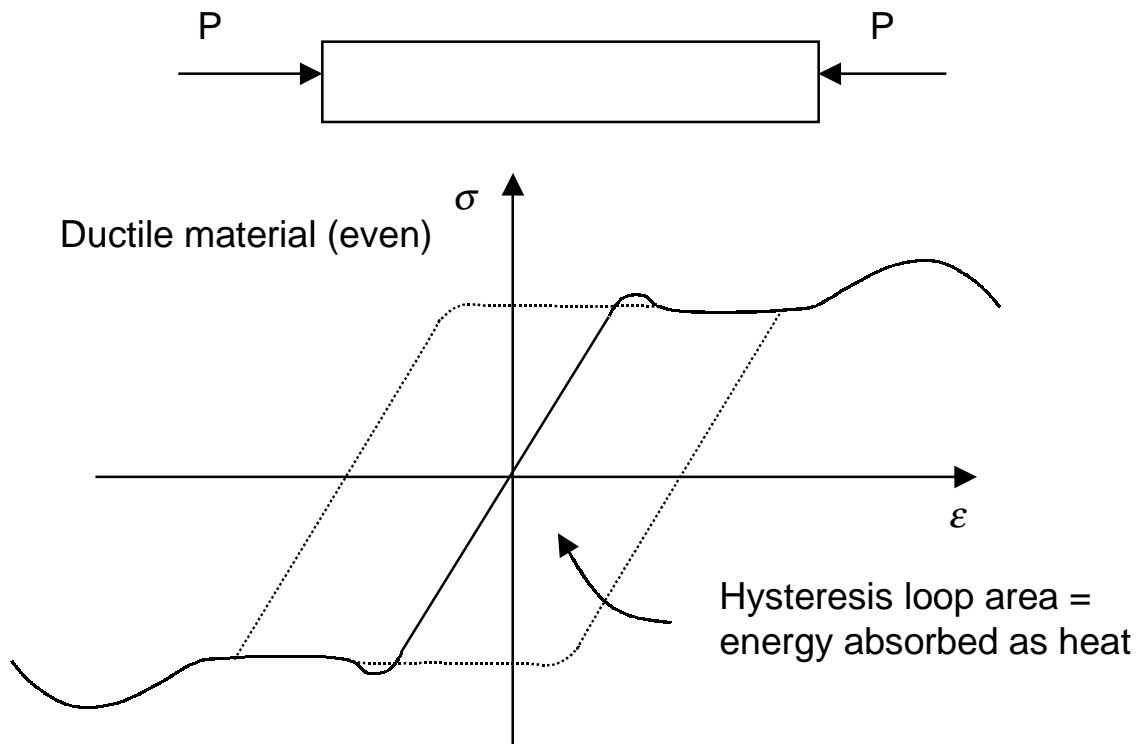
$$T_m = \int_0^{\sigma_u} \sigma d\epsilon \approx \left(\frac{S_y + S_u}{2} \right) \epsilon_f$$

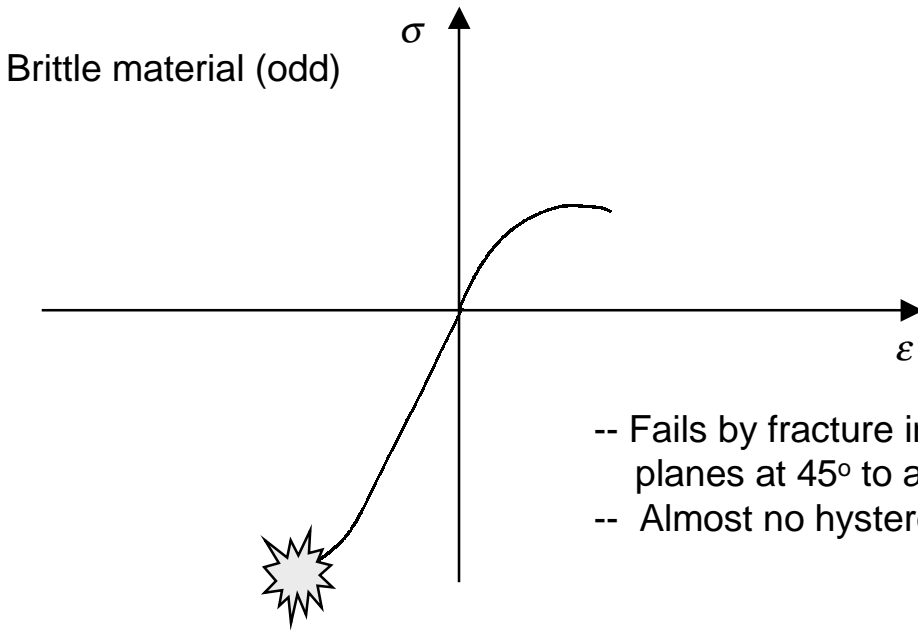
Summary

- Most important properties from the uniaxial tension test are:
 - E -- Young's modulus
 - S_y -- tensile yield strength
 - S_u -- ultimate tensile strength
- Note that for steels:
 - Young's modulus does not vary with heat treatment or alloying
 - Highest strength steel has the same modulus as lowest strength

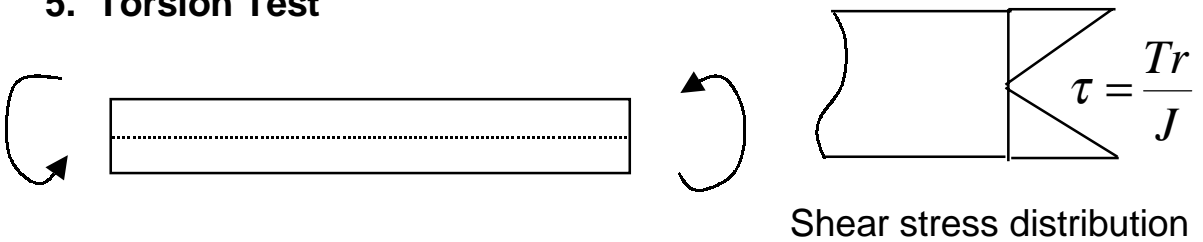
$$E \approx 30 \times 10^6 \text{ psi} \quad (207 \text{ GPa})$$

4. Uniaxial Compression Test





5. Torsion Test

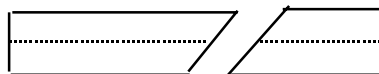


Ductile material



Shear failure with large plastic strain

Brittle material



Tensile failure with little or no plastic strain

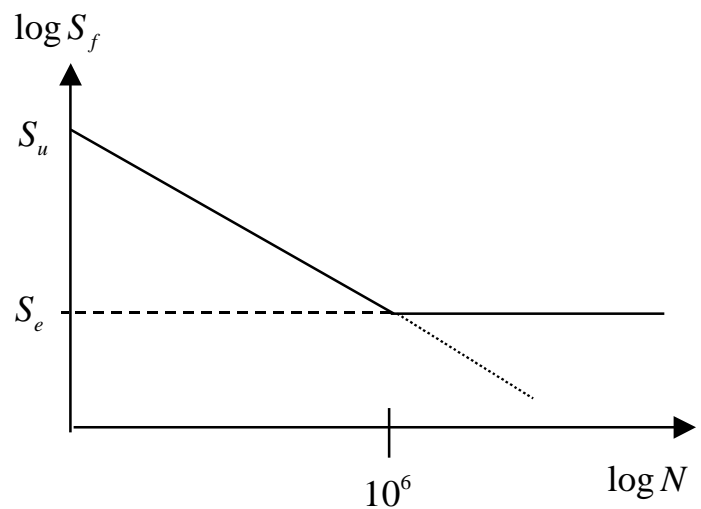
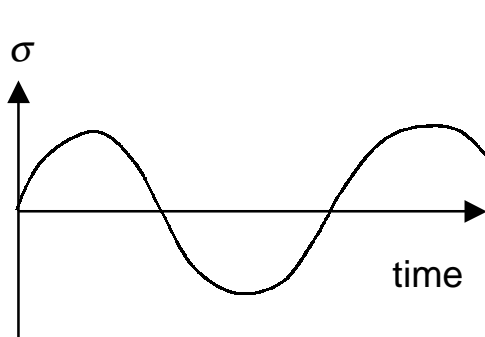
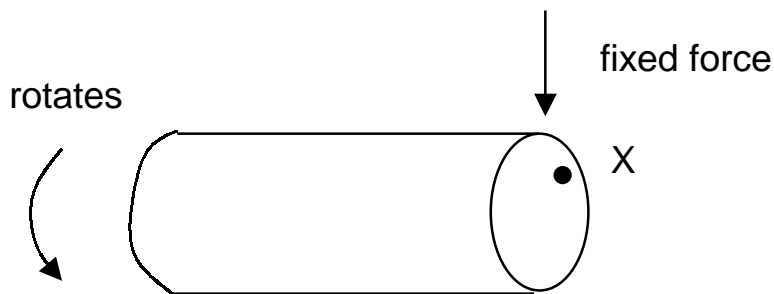
For steel:

$$S_{us} \approx 0.80 S_u$$

$$S_{ys} \approx 0.58 S_y$$

6. Fatigue Strength

- Most design situations involve loads that are not static but time-varying
- If the loading includes cycles of loading, the material will fail before the static strength S_u
- The strength under cyclic loads is called the *fatigue strength*



- S_e -- Called the endurance limit
- approximately 40-50% of S_u
 - depends on surface finish, type of loading, existence of notches (stress concentrations)

7 Creep and Temperature Effects

- All materials will creep (continuous growth in displacement under load) even below the yield strength.
- In ferrous metals the creep becomes significant at about 50% of the melting temperature.

8 Hardness

- Hardness is a measure of a material's resistance to penetration
- Strength properties of some materials (especially steels) can be related to hardness and this makes hardness tests good for field tests of strength
- Hardness tests involve indentation of a small probe into the surface
- There are three tests in common usage:

Rockwell -- quick, easy and reproducible

Brinell -- indentation is done through a small sphere

-- hardness is H_B = applied indenter load divided by the spherical indenter surface

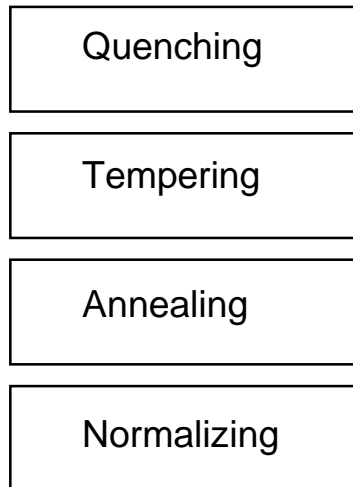
-- H_B is related to S_u for steels

$$\begin{aligned} S_u &= 500H_B \text{ psi} \\ &= 3.10H_B \text{ MPa} \end{aligned}$$

Vickers -- uses diamond pyramid indenter

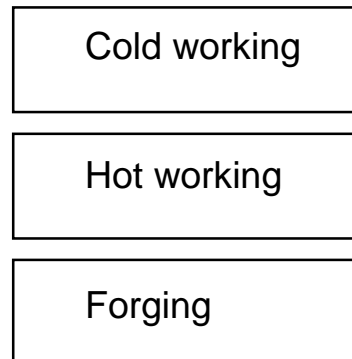
9. Heat Treatments

Goal is improve hardness and other characteristics by thermal processes:



10. Mechanical Working

Mechanical working will change strength and ductility:



11. Engineering Materials

• Metals

- Cast iron (white, gray, malleable, nodular)
- Cast steel
- Wrought steels (hot-rolled, cold-rolled)
 - plain carbon steel
 - alloy steels
 - tool steels
 - stainless steels
- Aluminum (wrought, cast alloys)
- Titanium
- Magnesium
- Copper alloys

• Non-Metals

- Polymers
- Ceramics
- Composites