Chapter 11 - Mechanical Properties of Materials
Reading: Chapter 11 — Pages 385 - 397

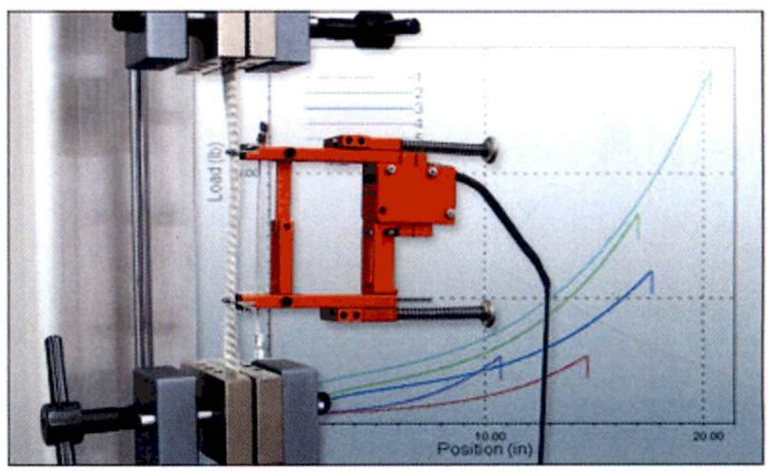
11-1
Introduction

Stress-Strain Diagrams
Tension and/or compression tests are conducted on materials to produce stress-strain diagrams that reveal important properties of materials, such as:

- Modulus of elasticity
- Yield
- Ultimate Strength
- Stiffness
- Elastic and Plastic behavior
- Ductility

11-2
The Tension Test

- Tensile tests are used to determine how materials will behave under tension load.
- In a simple tensile test, a sample is typically pulled to its breaking point to determine the ultimate tensile strength of the material.
- The amount of force (P) applied to the sample and the elongation (δ) of the sample are measured throughout the test.



Material Properties
To obtain stress, the force measurements are divided by the sample's cross sectional area:

Stress

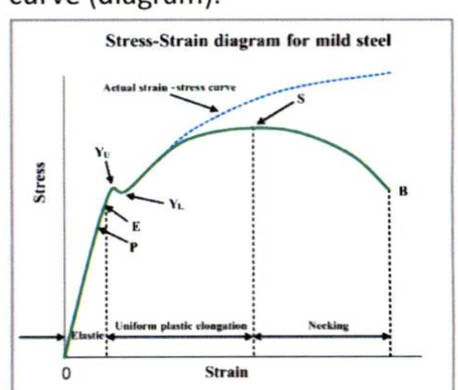
$$\sigma = \frac{P}{A}$$

Strain measurements are obtained by dividing the change in length by the initial length of the sample:

Strain

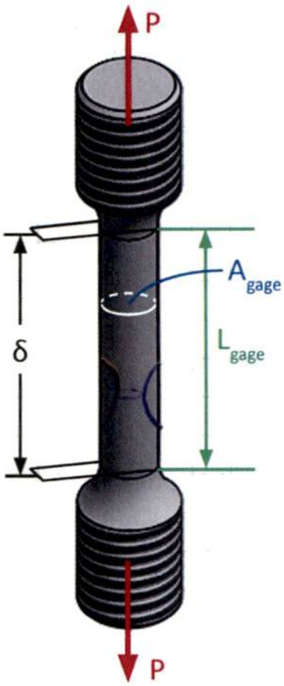
$$\varepsilon = \frac{\delta}{L}$$

These values are then presented on an XY plot called a stress-strain curve (diagram).



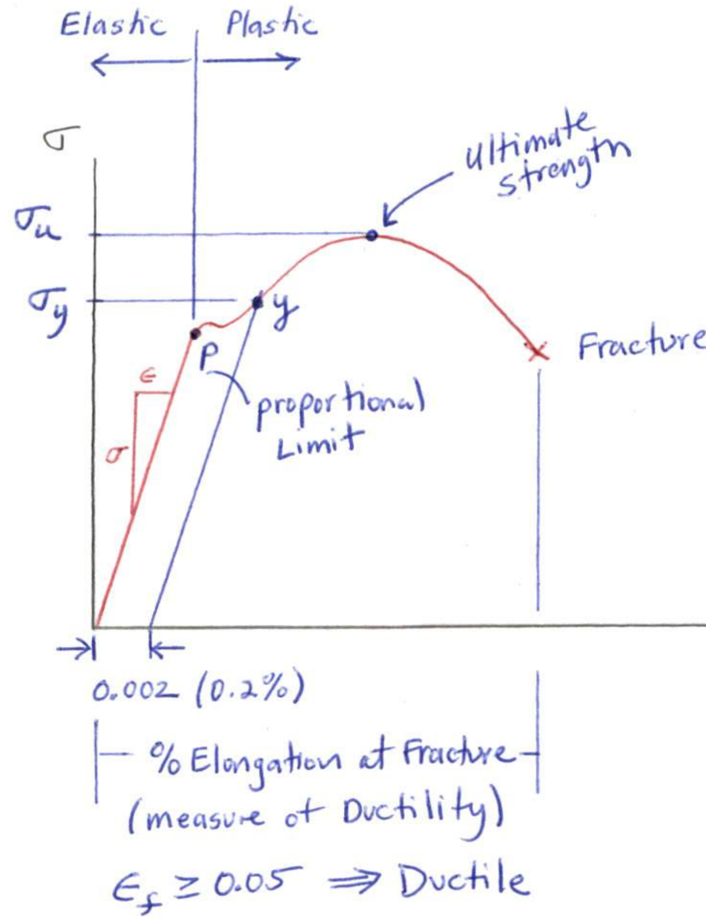
11-3
The Stress-Strain Diagram

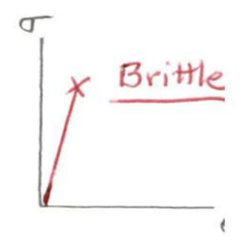
Material Testing and Characterization
Specimen:



$$\frac{P}{A_{gage}} : \frac{\delta}{L_{gage}}$$

$$\sigma : \epsilon$$





Elastic Modulus (E)

$$\text{Young's Modulus} = \text{Modulus of Elasticity} = E = \frac{\sigma}{\epsilon} \quad (\text{in the elastic Region})$$

Yield (or Yielding) Strength (σ_y)

The yield strength is an indicator of how much stress a material can withstand before permanently deforming.

Ultimate Strength (σ_u)

The maximum stress the material can withstand (based on the original area). Sometimes called the tensile strength.

} Important for Calculations

11-4
Mechanical Properties of Materials

Mechanical Properties of Materials. The stress-strain diagram obtained from tension characterizes many important properties of a material. These properties are:

Strength. The strength of a material is the greatest stress that the material can withstand without excessive deformation or failure.

Stiffness. The stiffness of a material is the ability of a material to resist deformation. A material with a high value for the modulus of elasticity E is stiffer than materials with a lower value of E.

Elasticity. Elasticity is the property of a material that enables it to regain its original undeformed length once the load is removed.

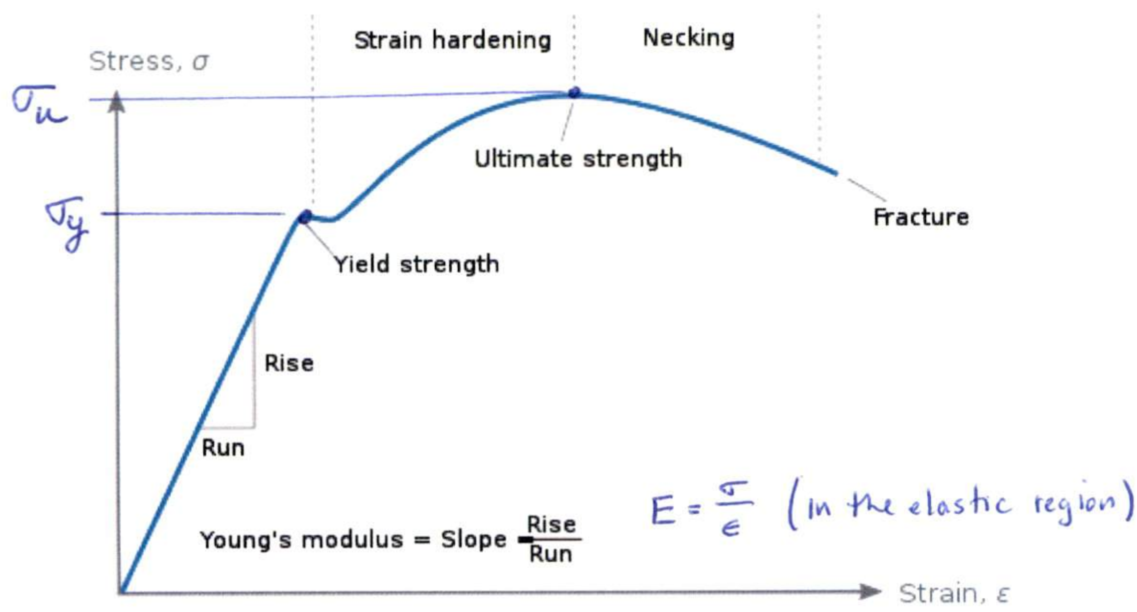
Ductility. Ductility is the ability of a material to undergo a lot of plastic deformation before rupture. Ductility is indicated by the percent elongation of the gage length as well as by the percent reduction in cross-sectional area at the fractured section. Materials with a percent of elongation greater than 5 percent are called ductile materials.

Brittleness. A material that undergoes very little plastic deformation before rupture is said to be brittle. A brittle material ruptures suddenly and without warning at the ultimate strength.
Hardness. Hardness is a measure of the resistance of a material to penetration. Hardness is very useful for quality control purposes.

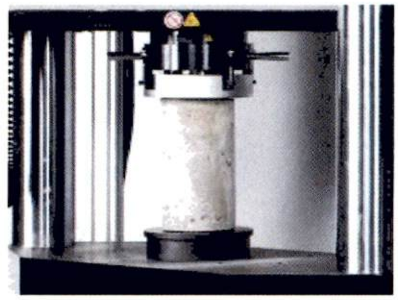
Machinability. Machinability is the ease with which a material can be machined. It is frequently a critical factor for the selection of metals for parts made by automatic machine tools.

Resilience. The capacity of a material to absorb energy within the elastic range is called resilience. Resilience is measured by the triangular area under the elastic portion of the stress-strain curve.

Toughness. The capacity of a material to absorb energy without fracture is called toughness. Toughness is measured by the total area under the entire stress-strain curve up to the point of fracture.



11-5
The Compression Test



Brittle materials, such as concrete, are tested in compression due to the low tensile strength and brittleness.

In a *compression test*, the specimen used is generally a cylinder with a height 1 ½ to 3 times the diameter, so that the specimen will not buckle under the compressive load.

Compression tests are rarely performed for ductile materials.

Examples of brittle materials: concrete, brick and ceramics.
The ultimate strength of these materials are usually much higher in compression than in tension.
A compression test is much more applicable than a tension test.

11-6
Allowable Stresses and Factor of Safety

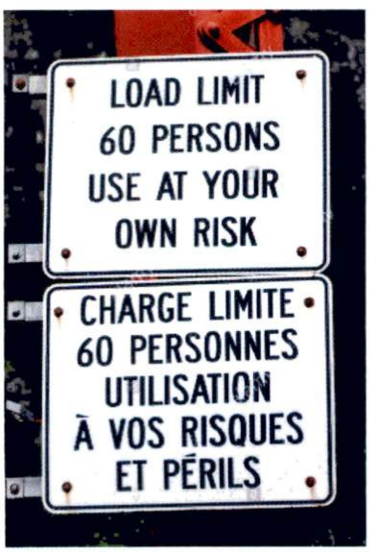
$$\text{Factor of Safety (F.S.)} = \frac{\text{Failure Stress}}{\text{Allowable Stress}}$$

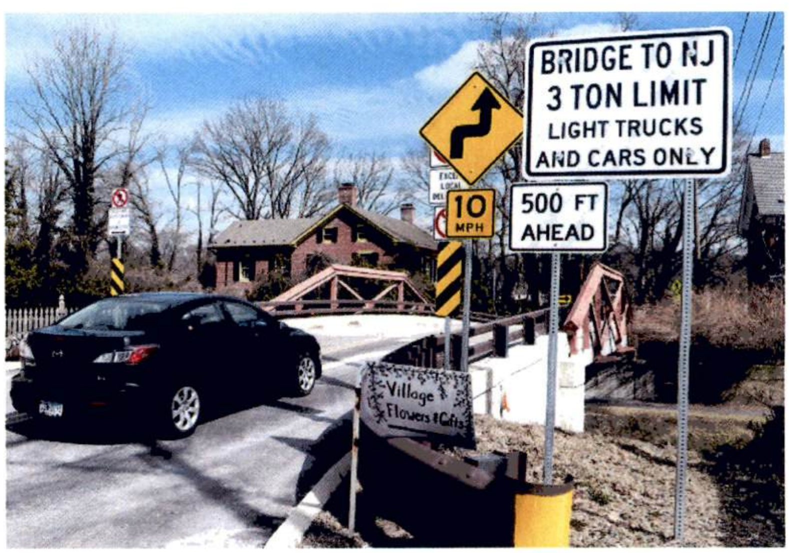
$$\text{F.S.} = \frac{\text{yield strength}}{\text{allowable Stress}} = \frac{\sigma_y}{\sigma_{allow}} \qquad \text{(for ductile materials)}$$

$$\text{F.S.} = \frac{\text{ultimate strength}}{\text{allowable Stress}} = \frac{\sigma_u}{\sigma_{allow}} \qquad \text{(for brittle materials)}$$

60 @ 200 lb?
6T

60 @ 100 lb?
3T



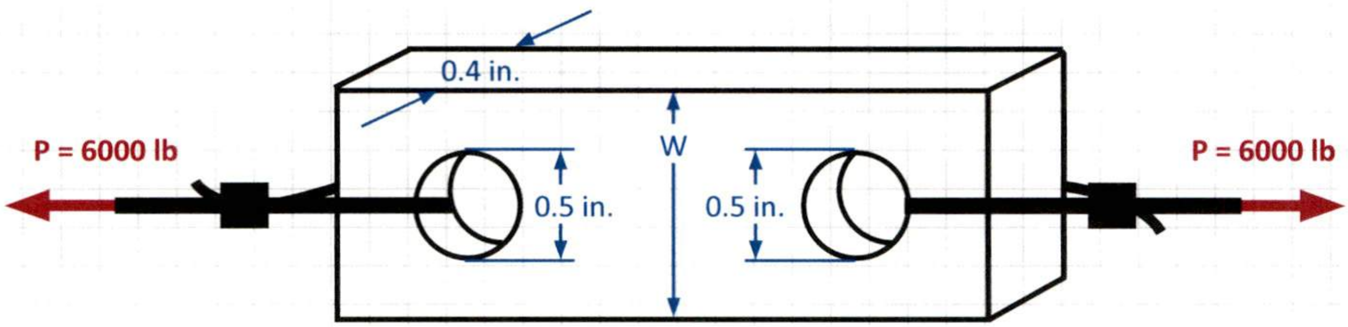


Engineers typically design for an allowable stress and apply a factor of safety.

$$\text{Allowable Stress } (\sigma_{allow}) = \frac{\text{Yield Strength}}{\text{Factor of Safety}} = \frac{\sigma_y}{\text{F.S.}} \quad \text{(for ductile materials)}$$

$$\text{Allowable Stress } (\sigma_{allow}) = \frac{\text{Ultimate Strength}}{\text{Factor of Safety}} = \frac{\sigma_u}{\text{F.S.}} \quad \text{(for brittle materials)}$$

Example



To achieve a factor of safety of 2.5 against fracture find the minimum width (W) of the structural steel plate shown. What is the resulting strain at a cross-section at the middle of the plate?

A36 (Table A-7(a))

Solution.

$$\text{Factor of Safety} = \frac{\text{Failure Stress}}{\text{Allowable Stress}} = \frac{\sigma_u}{\sigma_{allow}}$$

$$2.5 = \frac{58 \text{ ksi}\left(\frac{1000 \text{ psi}}{\text{ksi}}\right)}{\dfrac{6000 \text{ lb}}{(0.4 \text{ in})(W - 0.5 \text{ in})}}$$

$$W = 1.147 \text{ in.}$$

$$\frac{58 \text{ ksi}}{2.5} = 23.2 \text{ ksi} < \sigma_y = 36 \text{ ksi} \Rightarrow \text{Elastic Region, } E = \frac{\sigma}{\epsilon}$$

$$30\,000 \text{ ksi}\left(\frac{1000 \text{ psi}}{\text{ksi}}\right) = \frac{\dfrac{6000 \text{ lb}}{(0.4 \text{ in})(1.147 \text{ in})}}{\epsilon}$$

$$\epsilon = 4.359 \times 10^{-4}$$

TABLE A–7(a) Typical Mechanical Properties of Common Materials: U.S. Customary Units

Material	Specific Weight	Modulus of Elasticity	Modulus of Rigidity	Yield Strength		Ultimate Strength			Coefficient of Thermal Expansion
				Tension	Shear	Tension	Compression	Shear	
	γ (lb/ft^3)	E ($\times 10^3$ ksi)	G ($\times 10^3$ ksi)	σ_y (ksi)	τ_y (ksi)	$(\sigma_u)_t$ (ksi)	$(\sigma_u)_c$ (ksi)	τ_u (ksi)	α ($\times 10^{-6}$/°F)
Steel:									
ASTM-A36 (carbon)	490	30	12	36	21	58			6.5
ASTM-A441 (alloy)	490	30	12	46		67			6.5
AISI 1020 (hot rolled)	490	30	11.5	30		55			6.5
AISI 1040 (hot rolled)	490	30	11.5	42		76			6.5
Stainless steel (annealed)	490	30	11.6	38	22	85			9.6
Cast Iron:									
Gray cast iron	450	13	6			25	90	32	5.8
Malleable cast iron	460	25	12	33		50	90	48	6.7
Aluminum:									
Alloy 2014-T6	173	10.9	3.9	58	33	66		40	12.8
Alloy 2024-T4	173	10.6		47		68		41	12.9
Alloy 6061-T6	169	10.1	3.7	35	20	38		24	13.1
Copper:									
Annealed	556	17	6.4	10		32		22	9.4
Hard-drawn	556	17	6.4	53		57		29	9.4
Alloys:									
Magnesium alloy	110	6.5	2.4	22		40		21	14.0
Titanium alloy	275	16.5	6.5	120		130		100	5.3
Timber:									
Douglas fir	30	1.9				15	7.2	1.1	
Westen white pine	31	1.7					5.0	1.4	
Southern pine	36	1.8					8.4	1.5	
White oak	43	1.8					7.4	2.0	
Red oak	41	1.8					6.8	1.8	
Western hemlock	28	1.6				13	7.2	1.3	
California redwood	26	1.3				9.6	6.1	0.9	
Concrete:									
Medium strength	150	3.6					4.0		5.5
High strength	150	4.5					6.0		5.5

11-13 A tie rod of A36 steel with σ_y = 36 ksi is used to support a tensile load of 2.50 kips. Select the diameter of the tie rod using a factor of safety of 2 to guard against yielding.

Solution.

F.S. = 2

σ_y = 36 ksi (yield strength)

P = 2.5 kips

$$F.S. = \frac{\sigma_y}{\sigma_{allow}}$$

$$2 = \frac{36 \text{ ksi}}{\dfrac{2.5 \text{ kips}}{\dfrac{\pi d^2}{4}}}$$

d = 0.421 in

0.421 × 16 = 6.7 = 7

use $d = \frac{7}{16}$ in. (0.4375 in.)