Petroleum and Mining Department

Second Grade- Spring Semester

Mechanics of Materials

(Lecture 4) Mechanical Properties of materials

Lecturer: Ms. Jwan Khaleel M.

Lecture content:

- Tension and compression test.
- The strain-stress diagram.
- The strain-stress behavior of brittle and ductile materials
- Hook’s law
- Strain Energy

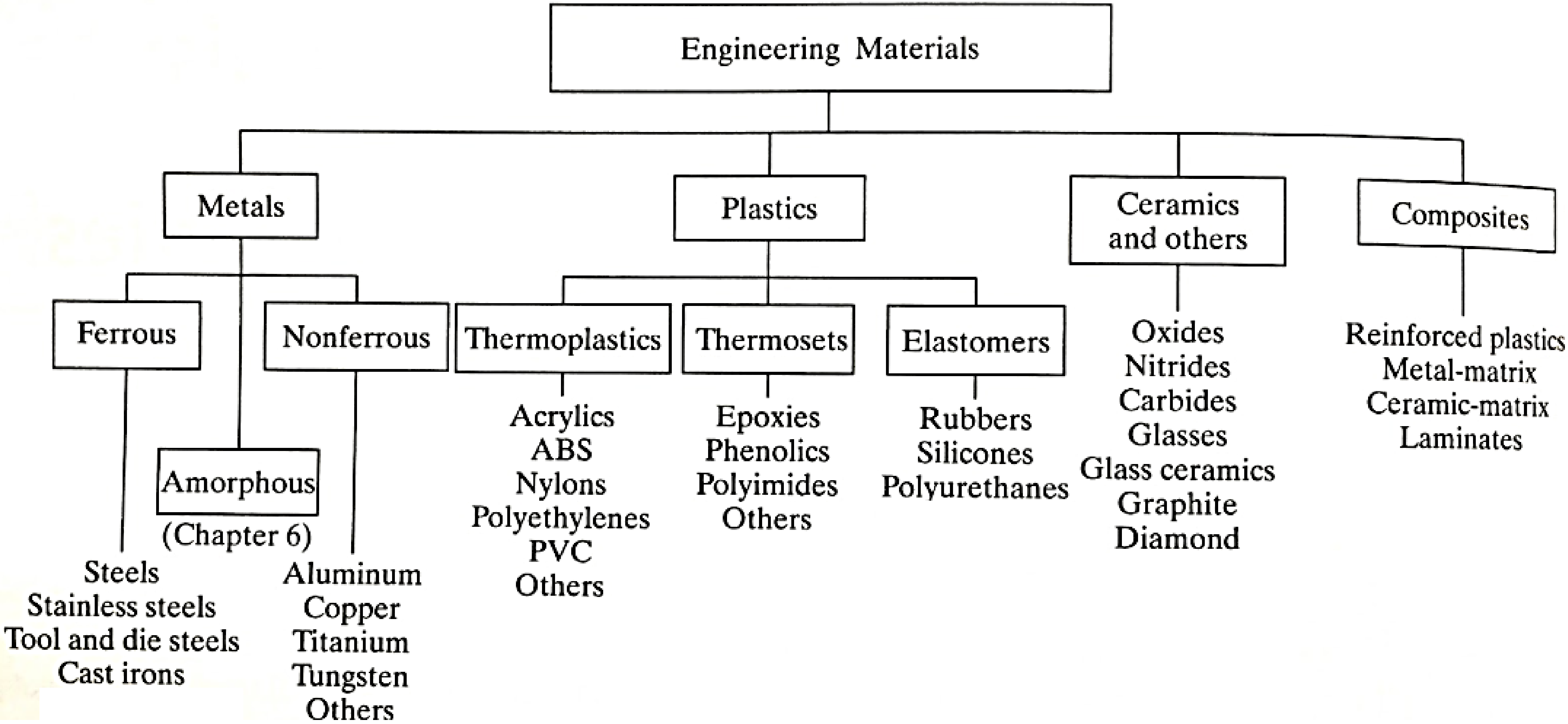
➢ ***Learning Outcomes:***

At the end of this lecture, you will be able to:

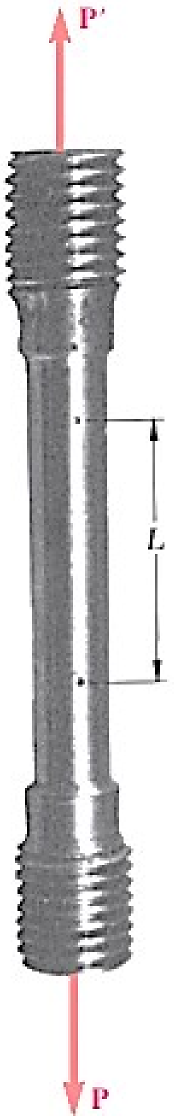
- Discuss the relationship between stress and strain by using experimental methods in different materials.
- Introduce Hooke's law and the modulus of elasticity.
- Define the difference between elastic and plastic behavior through a discussion of conditions such as elastic limit, plastic deformation, and residual stresses.
- Discuss the materials that are commonly used in engineering.

➢Tension and Compression Test

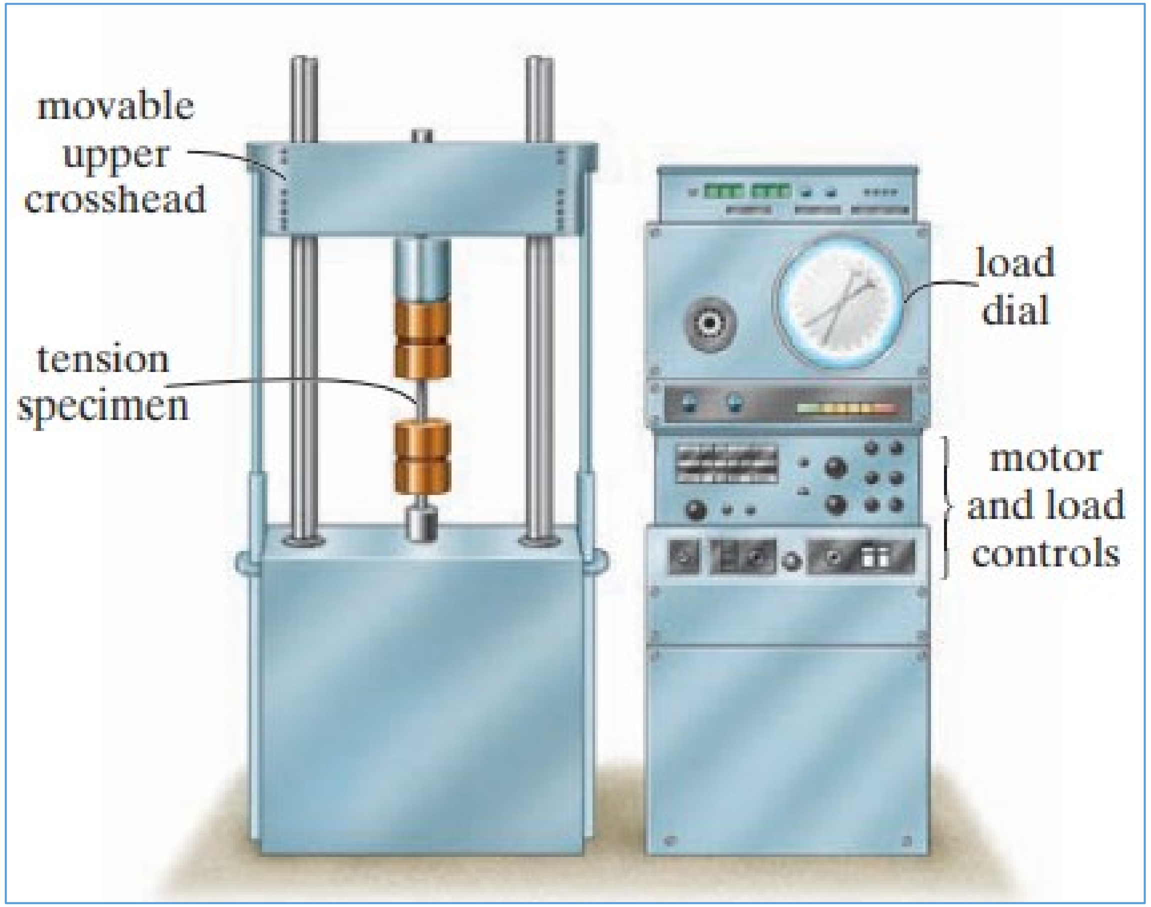
- The strength of a material depends on its ability to sustain a load without reaching deformation or failure.
- This property is inherent in the material itself and must be determined by experiment.
- One of the most important tests to perform in this regard is the tension or compression test.
- Although several important mechanical properties of a material can be determined from this test, it is used primarily to determine the relationship between the average normal stress and average normal strain in many engineering materials such as metals, ceramics, polymers, and composites.

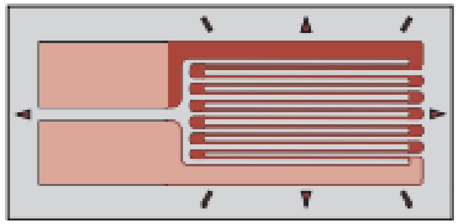

Engineering Materials
Metals
Plastics
Ceramics and others
Composites
Ferrous
Nonferrous
Amorphous
(Chapter 6)
Steels
Stainless steels
Tool and die steels
Cast irons
Aluminum
Copper
Titanium
Tungsten
Others
Thermoplastics
Thermosets
Elastomers
Acrylics
ABS
Nylons
Polyethylenes
PVC
Others
Epoxies
Phenolics
Polyimides
Others
Rubbers
Silicones
Polyurethanes
Oxides
Nitrides
Carbides
Glasses
Glass ceramics
Graphite
Diamond
Reinforced plastics
Metal-matrix
Ceramic-matrix
Laminates

➢Tension and Compression Test

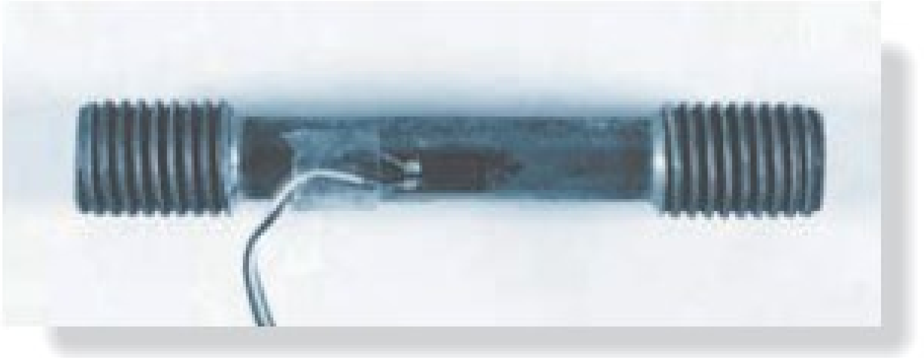


"standard" shape and size





Electrical–resistance strain gauge

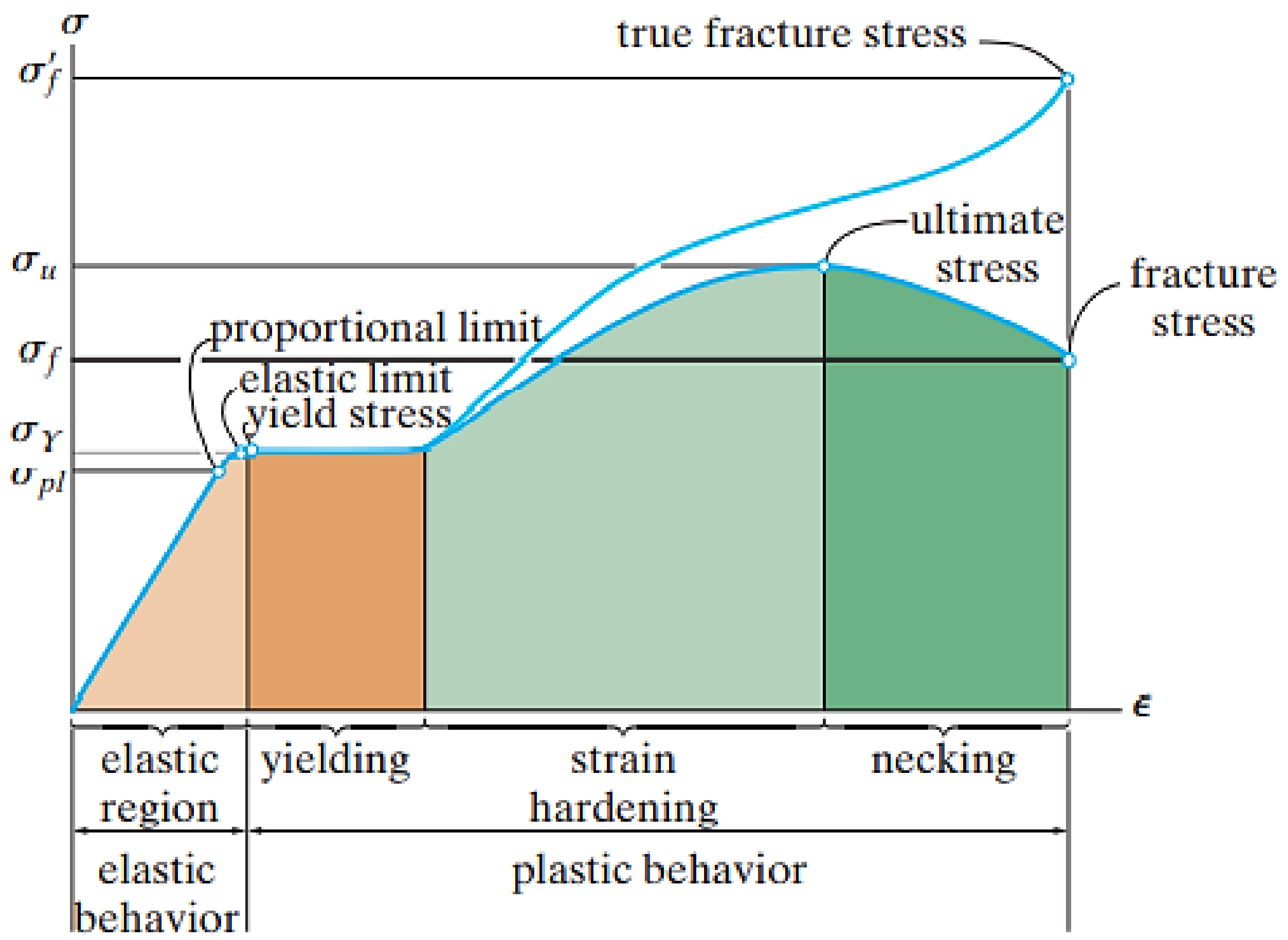


Typical steel specimen with attached strain gauge.

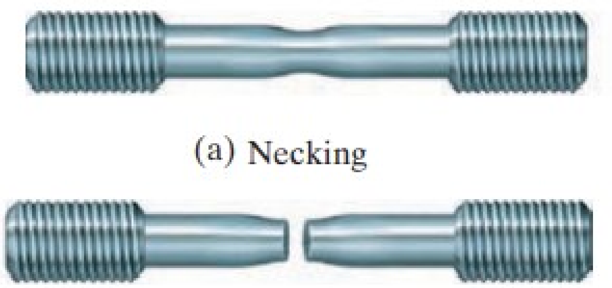
➢Stress-Strain Diagram

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

$$\epsilon = \frac{\delta}{L_0}$$



Conventional and true stress-strain diagrams for ductile material (steel) (not to scale)



(a) Necking

(b) Failure of a ductile material

Stress–Strain Behavior of Ductile and Brittle Materials

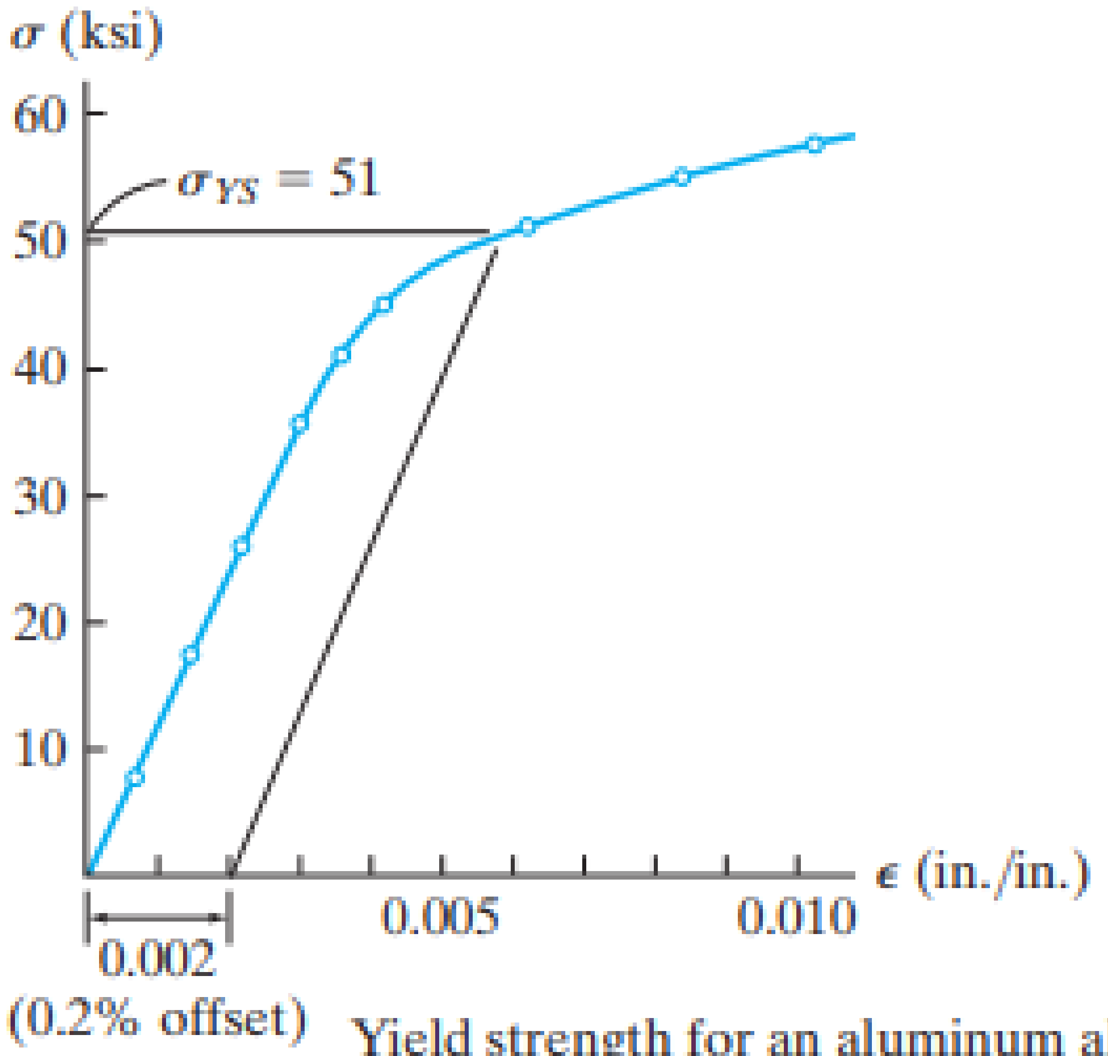
Ductile Materials. Any material that can be subjected to large strains before it fractures is called a ductile material. Mild steel, is a typical example. Engineers often choose ductile materials for design because these materials are capable of absorbing shock or energy, and if they become overloaded, they will usually exhibit large deformation before failing.

One way to specify the ductility of a material is to report its percent elongation or percent reduction in area at the time of fracture. ***The percent elongation / percentage area.***

$$\text{Percent elongation} = \frac{L_f - L_0}{L_0}(100\%)$$

$$\text{Percent reduction of area} = \frac{A_0 - A_f}{A_0}(100\%)$$

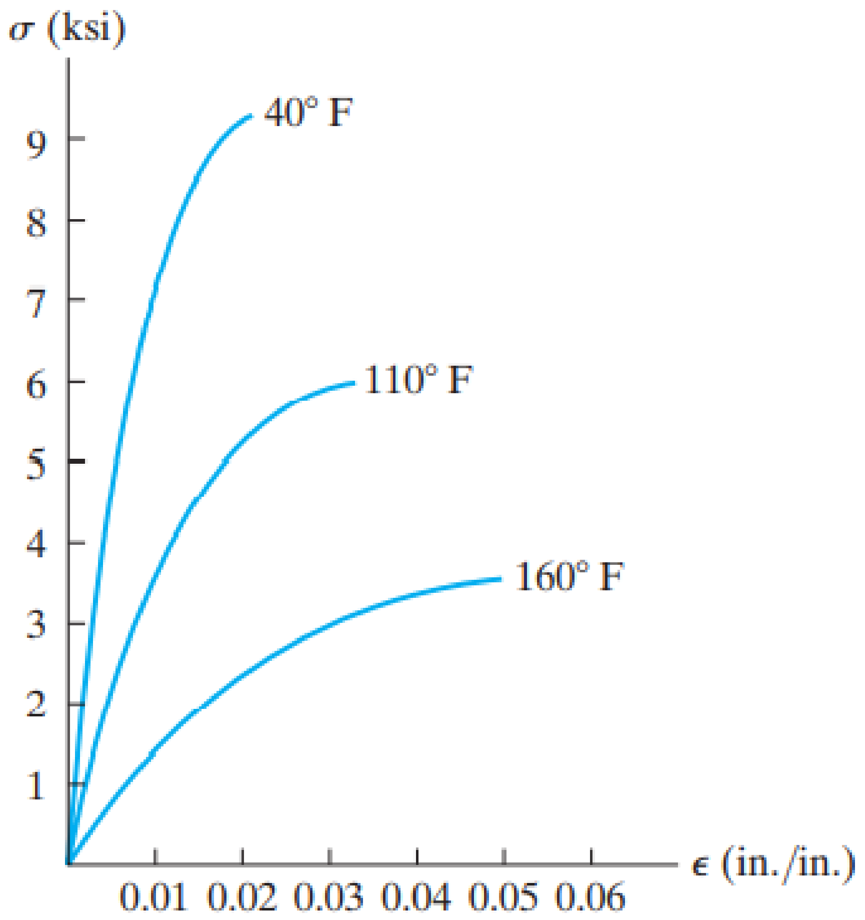
Actually, this metal often does not have a well-defined yield point, and consequently it is standard practice to define a yield strength using a graphical procedure called the ***offset method normally 0.2% = 0.002 in/in***



Yield strength for an aluminum alloy

➢Cartesian Strain Components

Brittle Materials. Materials that exhibit little or no yielding before failure are referred to as brittle materials. Gray cast iron is an example. change in the rate of elongation. Thus for brittle materials, there is no difference between the ultimate strength and the breaking strength. Also, the strain at the time of rupture is much smaller for brittle than for ductile materials. Note the absence of any necking of the specimen in the brittle material.

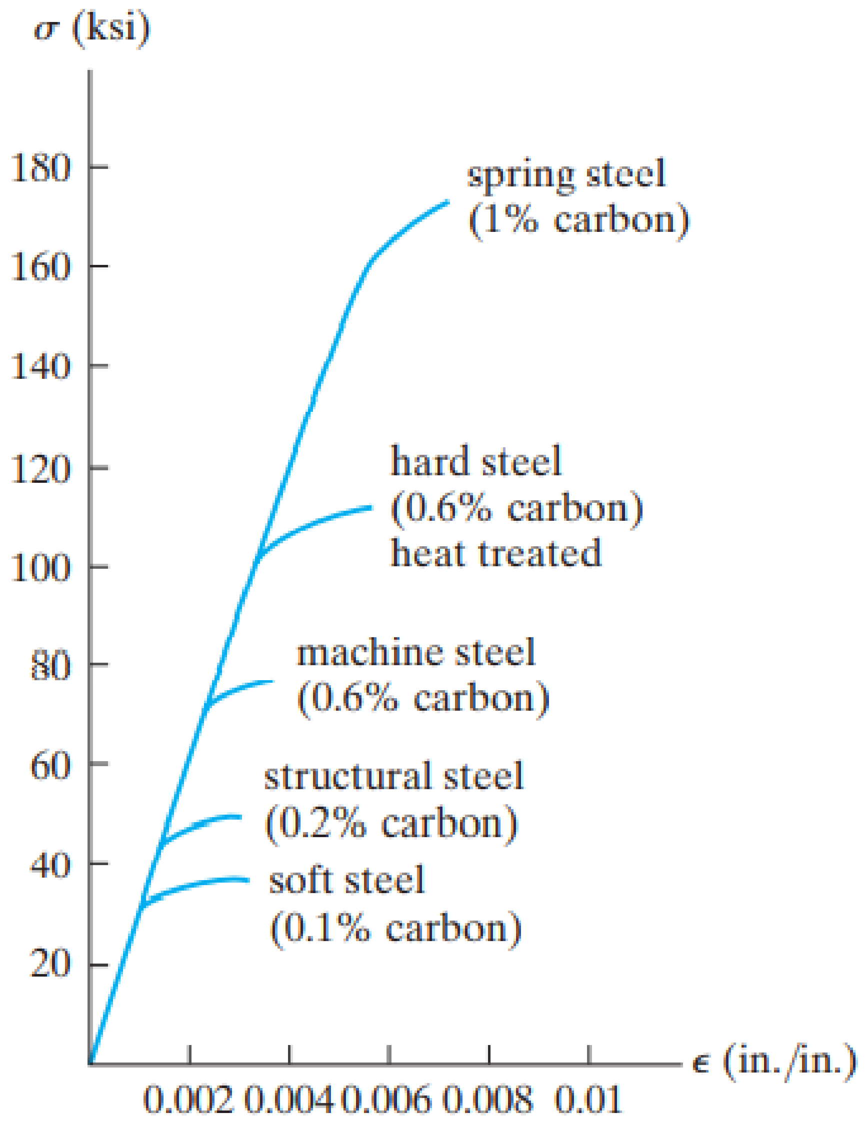


$\sigma - \epsilon$ diagrams for a methacrylate plastic

➢ Hooke’s Law; Modulus of Elasticity

Modulus of Elasticity. Most engineering structures are designed to undergo relatively small deformations, involving only the straight-line portion of the corresponding stress-strain diagram

$$E = \frac{\sigma}{\epsilon}$$

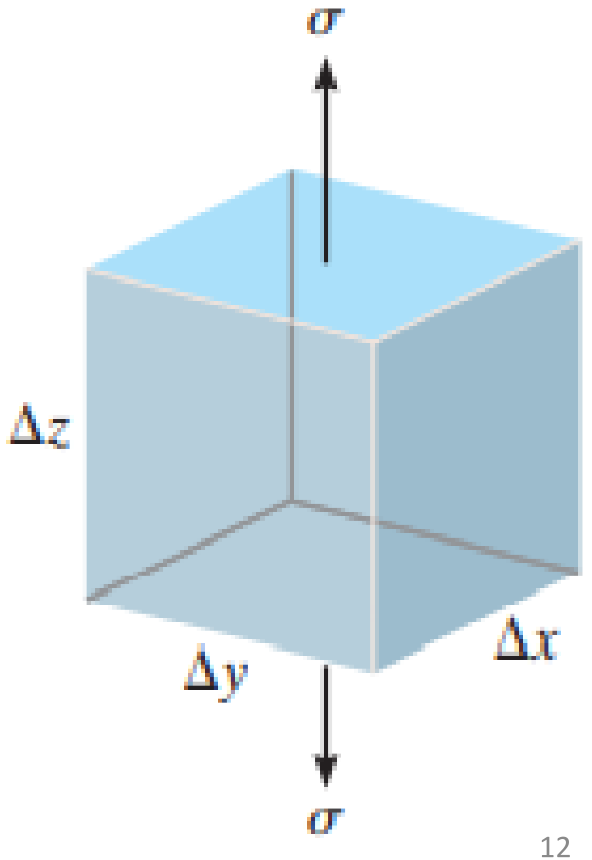


➢ Strain Energy:

As a material is deformed by an external loading, it tends to store energy internally throughout its volume. Since this energy is related to the strains in the material, it is referred to as **strain energy.**

$$u = \frac{\Delta U}{\Delta V} = \frac{1}{2}\sigma\epsilon$$

$$u = \frac{1}{2}\frac{\sigma^2}{E}$$

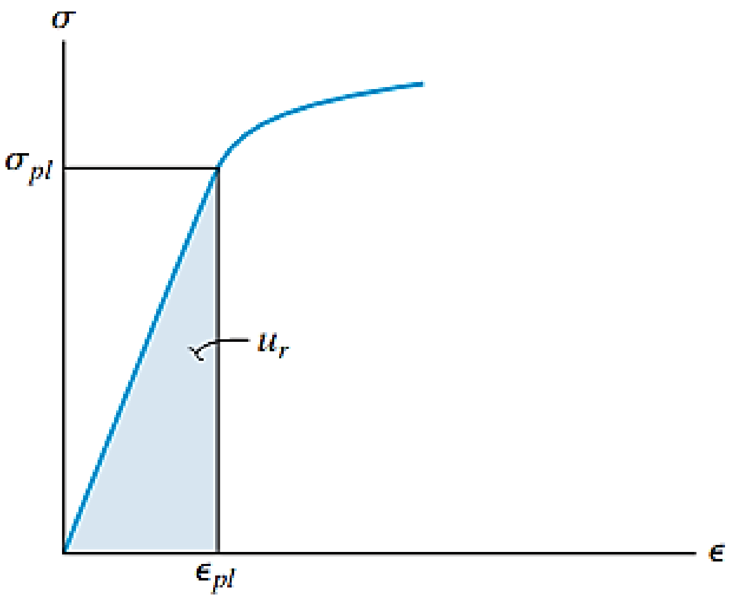


This is called the **strain-energy density**

• Modulus of Resilience.

In particular, when the stress reaches the proportional limit, the strain-energy density, is referred to as the modulus of resilience. The ability of material to absorb energy without permanent damage to the material.

$$u_r = \frac{1}{2}\sigma_{pl}\epsilon_{pl} = \frac{1}{2}\frac{\sigma_{pl}^2}{E}$$

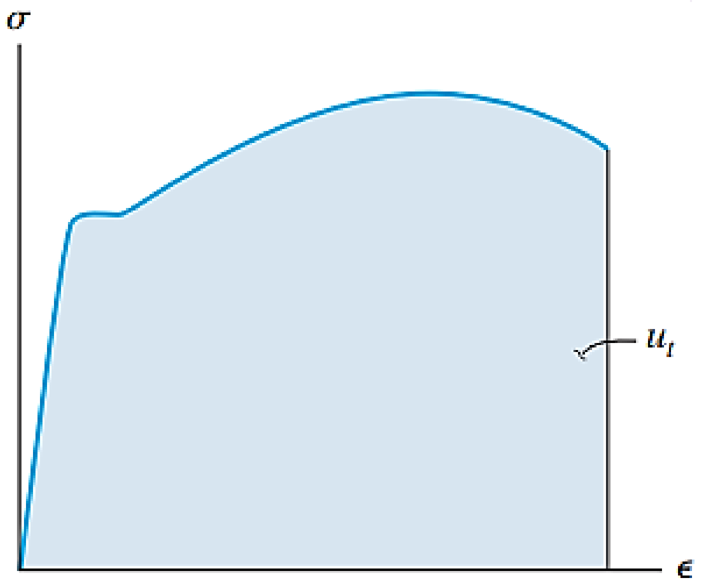


Modulus of resilience u_r

(a)

• Modulus of Toughness.

Another important property of a material is the modulus of toughness. This property is important in designing members that may accidentally overloaded



Modulus of toughness u_t

(b)

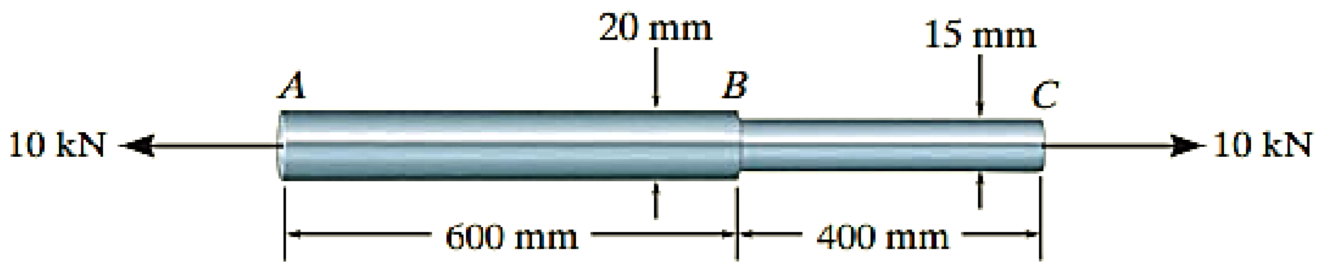
Example 1:

A tension test was performed on a steel specimen having an original diameter of 12.5 mm and gauge length of 50 mm. Using the data listed in the table, plot the stress–strain diagram, determine approximately the modulus of elasticity, the ultimate stress, and the fracture stress. Use a scale of 20mm=50 MPa and 20 mm = 0.05 mm/mm.

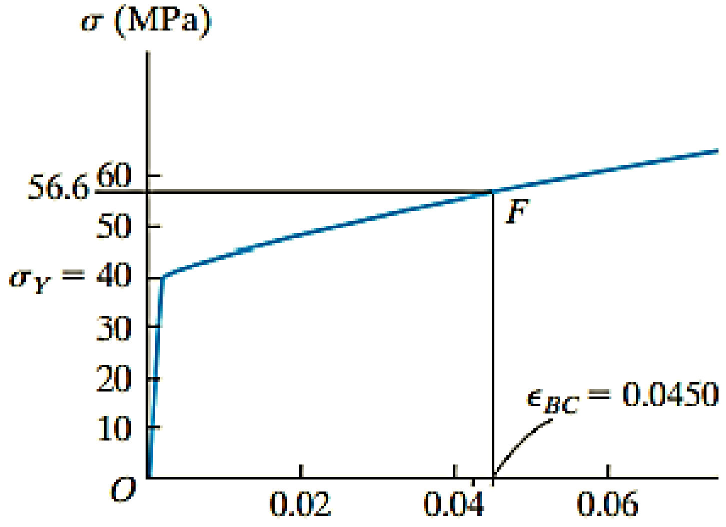
Load (kN)	Elongation (mm)
0	0
11.1	0.0175
31.9	0.0600
37.8	0.1020
40.9	0.1650
43.6	0.2490
53.4	1.0160
62.3	3.0480
64.5	6.3500
62.3	8.8900
58.8	11.9380

Example 2:

An aluminum rod shown in Fig.a has a circular cross section and is subjected to an axial load of 10 kN. If a portion of the stress–strain diagram is shown in Fig. b, determine the approximate elongation of the rod when the load is applied. Take $E = 70\ GPa$



(a)



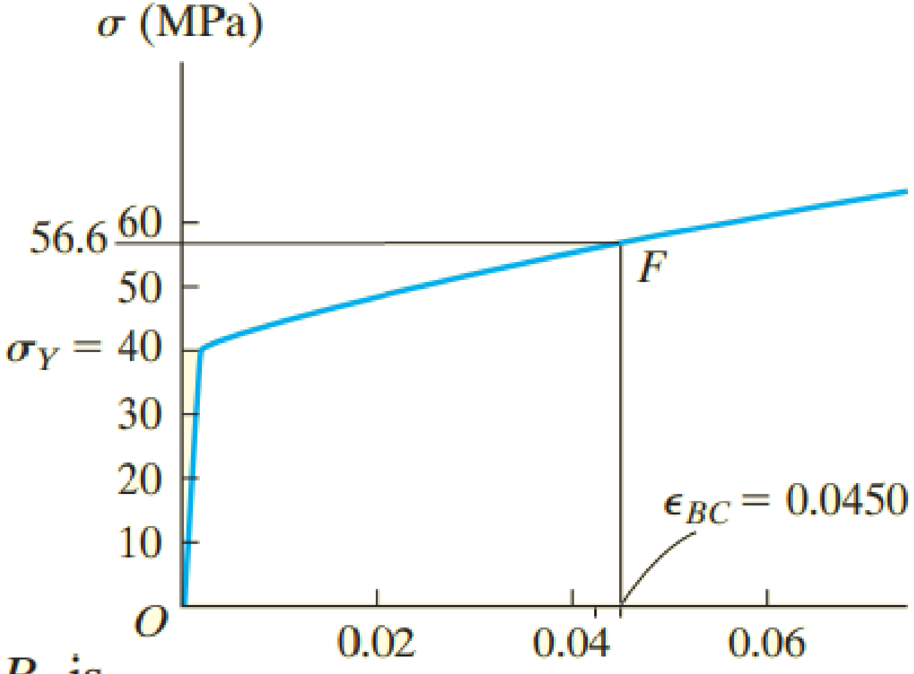
(b)

SOLUTION

The normal stress within each segment is

$$\sigma_{AB} = \frac{P}{A} = \frac{10(10^3)\text{ N}}{\pi(0.01\text{ m})^2} = 31.83\text{ MPa}$$

$$\sigma_{BC} = \frac{P}{A} = \frac{10(10^3)\text{ N}}{\pi(0.0075\text{ m})^2} = 56.59\text{ MPa}$$



From the stress–strain diagram, the material in segment AB is strained *elastically* since $\sigma_{AB} < \sigma_Y = 40$ MPa. Using Hooke's law,

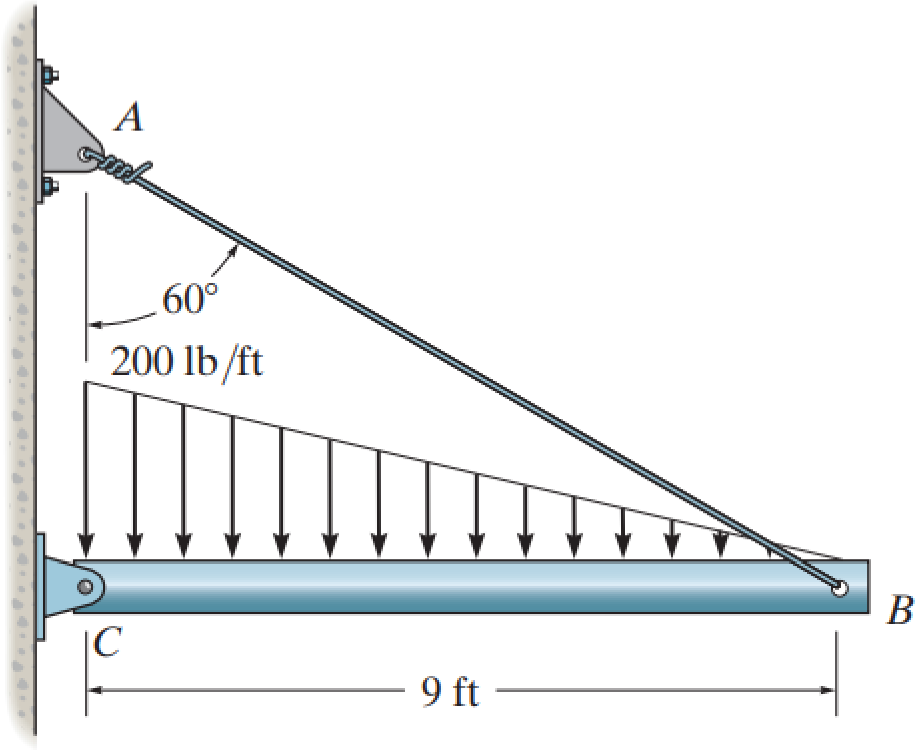
$$\epsilon_{AB} = \frac{\sigma_{AB}}{E_{al}} = \frac{31.83(10^6)\text{ Pa}}{70(10^9)\text{ Pa}} = 0.0004547\text{ mm/mm}$$

The material within segment BC is strained plastically, since $\sigma_{BC} > \sigma_Y = 40$ MPa. From the graph, for $\sigma_{BC} = 56.59$ MPa, $\epsilon_{BC} \approx 0.045$ mm/mm. The approximate elongation of the rod is therefore

$$\delta = \Sigma\epsilon L = 0.0004547(600\text{ mm}) + 0.0450(400\text{ mm})$$
$$= 18.3\text{ mm} \qquad \textit{Ans.}$$

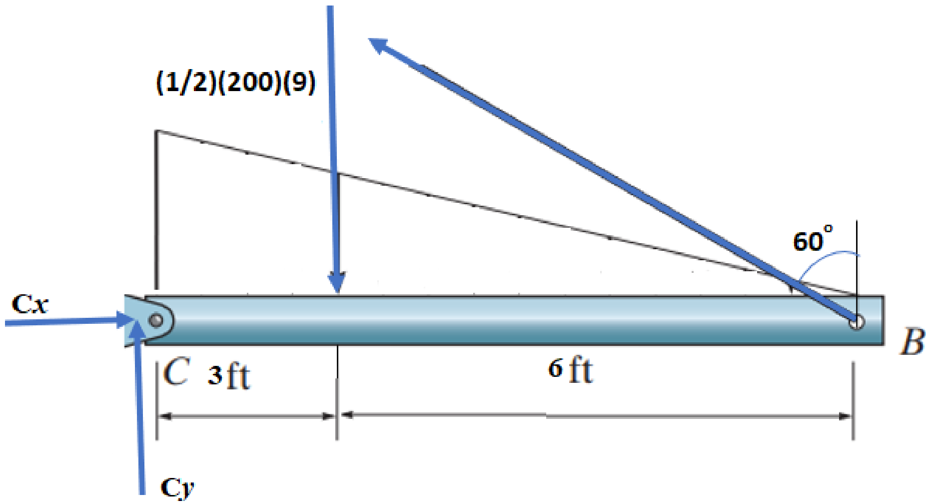
Example 3:

The strut is supported by a pin at C and an A-36 steel guy wire AB. If the wire has a diameter of 0.2 in., determine strain in AB. Take $E = 29\ kPa$



SOLUTION

Here, we are only interested in determining the force in wire AB.



$$\circlearrowleft + \Sigma M_C = 0; \qquad F_{AB}\cos 60°(9) - \frac{1}{2}(200)(9)(3) = 0 \qquad F_{AB} = 600 \text{ lb}$$

The normal stress the wire is

$$\sigma_{AB} = \frac{F_{AB}}{A_{AB}} = \frac{600}{\frac{\pi}{4}(0.2^2)} = 19.10(10^3) \text{ psi} = 19.10 \text{ ksi}$$

Since $\sigma_{AB} < \sigma_y = 36$ ksi, Hooke's Law can be applied to determine the strain in wire.

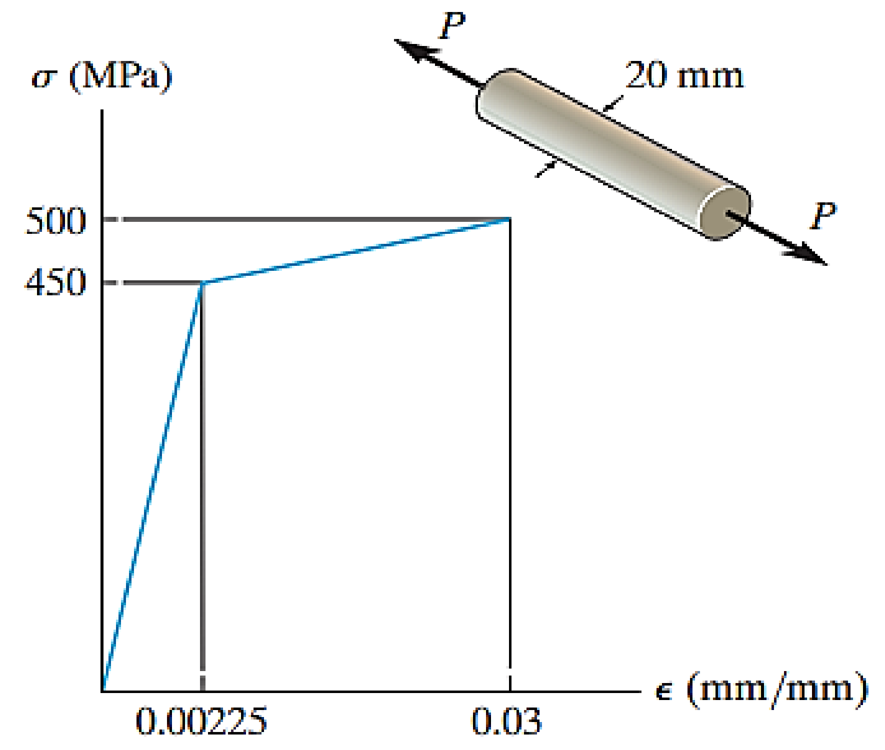
$$\sigma_{AB} = E\epsilon_{AB}; \qquad 19.10 = 29.0(10^3)\epsilon_{AB}$$

$$\epsilon_{AB} = 0.6586(10^{-3}) \text{ in/in}$$

Exercise Problems & Assignments

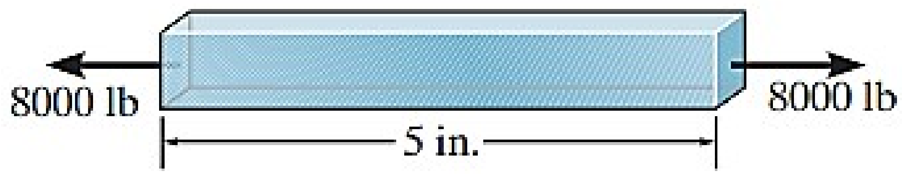
1. A 10-mm-diameter brass rod has a modulus of elasticity of $E = 100\ GPa$. If it is 4m long and subjected to an axial tensile load of 6 kN, determine its elongation.

2. The material for the 50-mm-long specimen has the stress–strain diagram shown. If $P = 150\ kN$ is applied and then released, determine the permanent elongation of the specimen.



3. A specimen is originally 1 ft long, has a diameter of 0.5 in., and is subjected to a force of 500 lb. When the force is increased from $500\, lb$ to $1800\, lb$, the specimen elongates 0.009 in. Determine the modulus of elasticity for the material if it remains linear elastic. If you know $1ksi = 1000\, Ib$ &1ft = 12in.

4. A bar having a length of 5 in. and cross-sectional area of 0.7 is subjected to an axial force of 8000 lb. If the bar stretches 0.002 in., determine the modulus of elasticity of the material. The material has linear-elastic behavior.

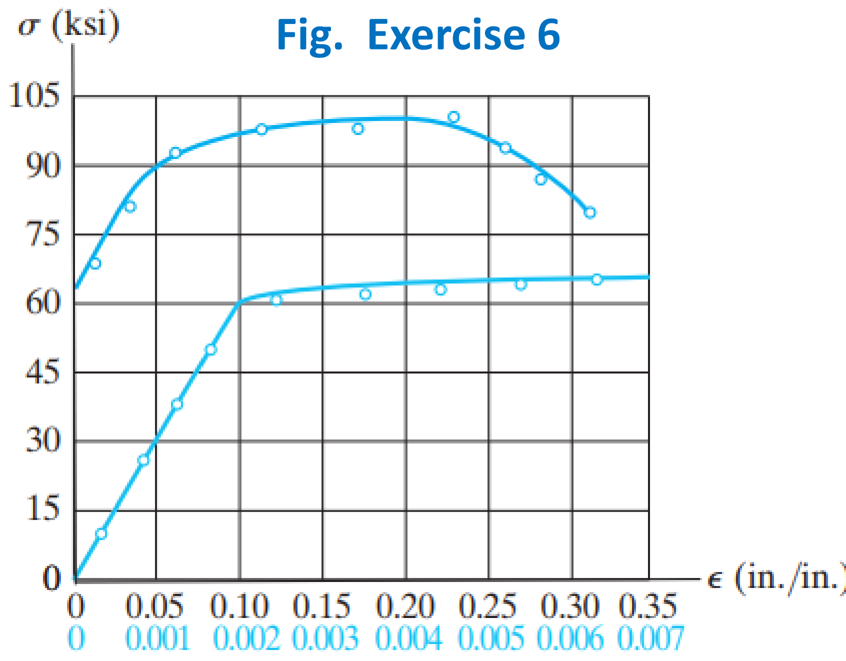


5. Data taken from a stress–strain test for a ceramic are given in the table. The curve is linear between the origin and the first point. Plot the diagram, and determine the modulus of elasticity and the modulus of resilience.

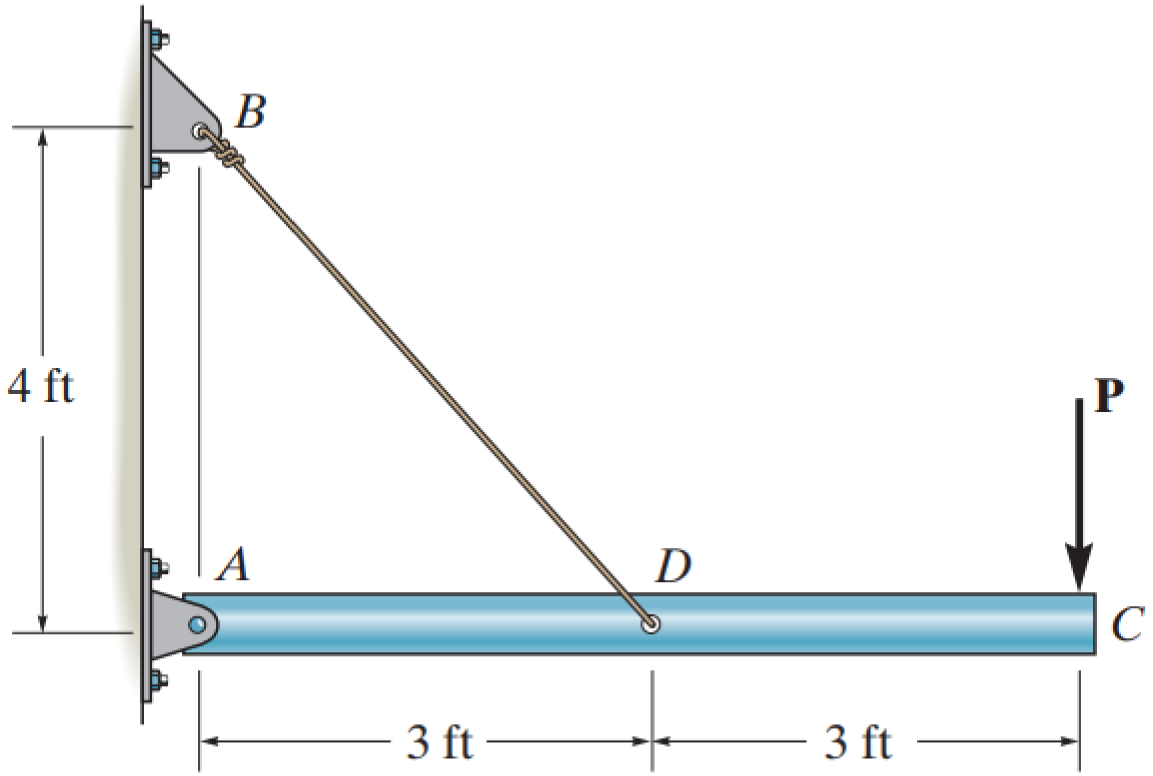
σ (ksi)	ϵ (in./in.)
0	0
33.2	0.0006
45.5	0.0010
49.4	0.0014
51.5	0.0018
53.4	0.0022

6. The stress–strain diagram for a metal alloy having an original diameter of 0.5 in. and a gauge length of 2 in. is given in the figure. Determine approximately the modulus of elasticity for the material, the load on the specimen that causes yielding, the ultimate load the specimen will support. Also find an approximately the modulus of resilience and the modulus of toughness for the material.

Fig. Exercise 6



7. The rigid pipe is supported by a pin at A and an A-36 guy wire BD. If the wire has a diameter of 0.25 in., determine the load P if the end C is displaced 0.075 in. downward.



Lecturer: Jwan Khaleel M.

Assignment:

Write A Report About Tensile and Compression Test and Find The Diagram Properties by Using The Following Data.

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62.3	8.8900
58.8	11.9380

References:

1. Mechanics of Materials, 8th Edition by R. C. Hibbeler.
2. Mechanics of Materials, 8th Edition by Ferdinand P. Beer, E. Russell Johnston Jr., John T. DeWolf, David F. Mazurek
3. Mechanics of materials, 3rd Edition by E.J. Hearn
4. Mechanics of Materials, 2nd Edition by Andrew Pytel, Jaan Kiusalaas (2011)

The End of the Lecture

Enjoy Your Time