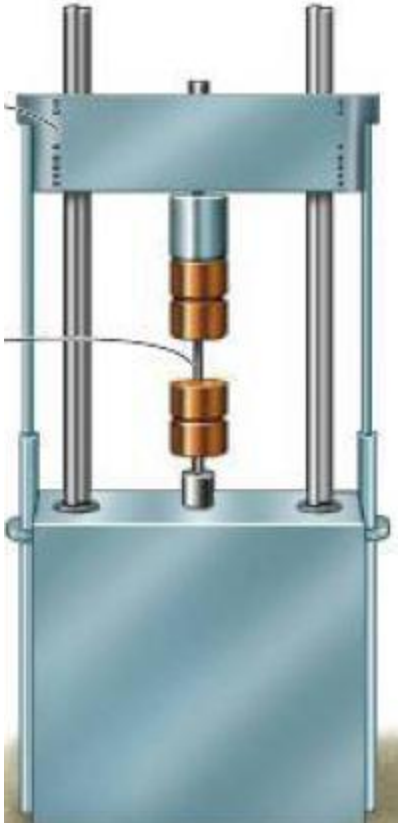
Strength of Materials: Second Class

3 Mechanical Properties of Materials 83

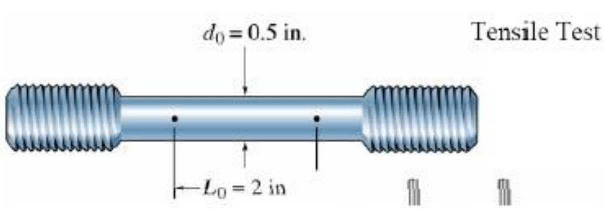


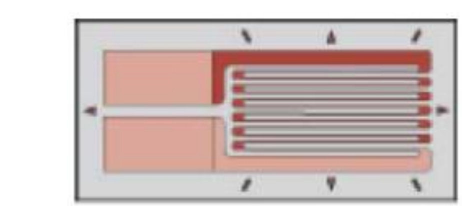
3.1 The Tension and Compression Test

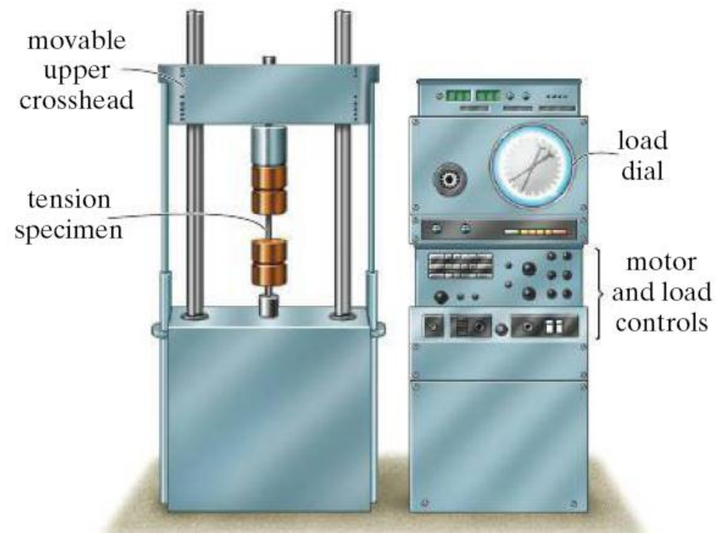
- One of the most important tests to perform in this regard is the ***tension or compression test*** .
- Although several important mechanical properties of a material can be determined from this test
- It is used primarily to determine the relationship between the average normal stress and average normal strain in many engineering materials such as metals, ceramics, polymers, and composites.

The elongation $\delta = L - L_0$ between the punch marks on the specimen measured using either a caliper or a mechanical or optical device called an ***extensometer*** .

This value of (δ) is then used to calculate the average normal strain, also possible to read the strain *directly* by using an ***electrical-resistance strain gauge***







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3.2 The Stress–Strain Diagram

- The test results must be reported so they apply to a member of *any size.*
- To achieve this, the load and corresponding deformation data are used to calculate various values of the stress and corresponding strain in the specimen.
- A plot of the results produces a curve called the ***stress–strain diagram*** . There are two ways in which it is normally described.

1) Conventional Stress–Strain Diagram.

2) True Stress–Strain Diagram.

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1) Conventional Stress–Strain Diagram

- We can determine the ***nominal*** or ***engineering stress*** by dividing the applied load ***P*** by the specimen's *original* cross-sectional area ***A0*** .

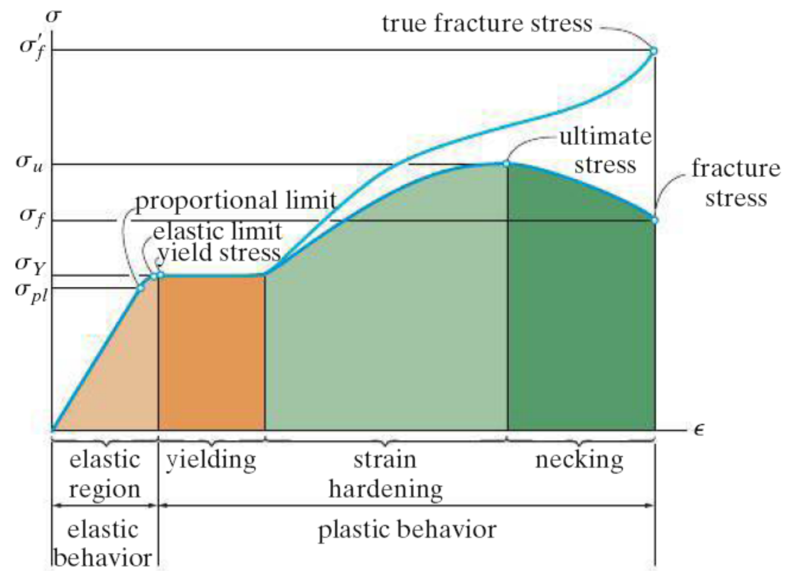
$$\sigma = \frac{P}{A_0}$$

- Likewise, the ***nominal*** or ***engineering strain*** is by dividing the change in the specimen's gauge length **(*δ*)** by the specimen's original gauge length ***L0***

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

2) True Stress–Strain Diagram.

- the *actual* cross-sectional area and specimen length used at the *instant* the load is measured.
- The values of stress and strain found from these measurements are called *true stress* and *true strain* , and a plot of their values is called the ***true stress–strain diagram*** .
- the conventional and true diagrams are practically coincident when the **strain is small.**



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

3.3 Stress-Strain Relationship of Ductile and Brittle Materials

Materials can be classified as either being ***ductile*** or ***brittle***, depending on their stress–strain characteristics.

- **Ductile Materials**. Any material that can be subjected to large strains before it fractures is called a ***ductile material*** .

- 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.

- The ***percent elongation*** is the specimen's fracture strain expressed as a percent.

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

- L_0 is the specimen's original gauge length
- L_f is the length at fracture.

- The ***percent reduction in area*** is another way to specify ductility. It is defined within the region of necking as follows:

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

Here $\boldsymbol{A_0}$ is the specimen's original cross sectional area and $\boldsymbol{Af}$ is the area of the neck at fracture.

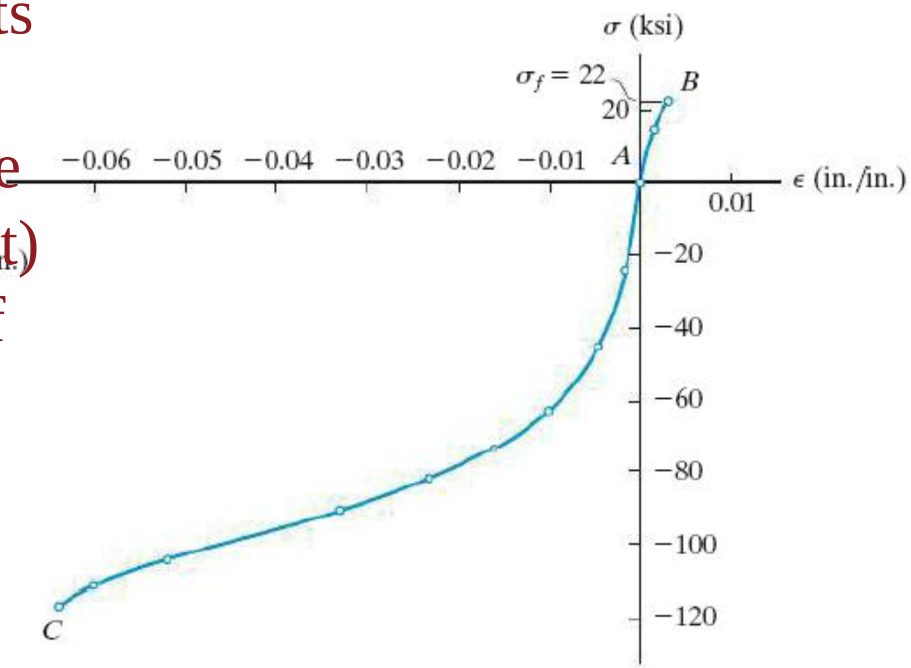
Offset method to determine yield strength

In most metals, however, constant yielding will *not occur* beyond the elastic range.

One metal for which this is the case is aluminum. 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*** .

- **Brittle Materials**. Materials that exhibit little or no yielding before failure are referred to as ***brittle materials.*** Example Gray cast iron

Like gray cast iron, **concrete** is classified as a brittle material, and it also has a low strength capacity in tension. The characteristics of its stress–strain diagram depend primarily on the mix of concrete (water, sand, gravel, and cement) and the time and temperature of curing.



σ–ϵ diagram for gray cast iron

3.4 Hook's Laws

- Most engineering materials exhibit a **linear** relationship between stress and strain with **the elastic region**

- Discovered by Robert Hooke in 1676 using springs known as Hooke's law

$$\sigma = E\varepsilon$$

- E represents the constant of proportionality, also called the modulus of elasticity or Young's modulus

- E has units of stress, i.e., pascals, MPa or GPa.

As shown above, most grades of steel have same modulus of elasticity, E_{st}= 200 Gpa

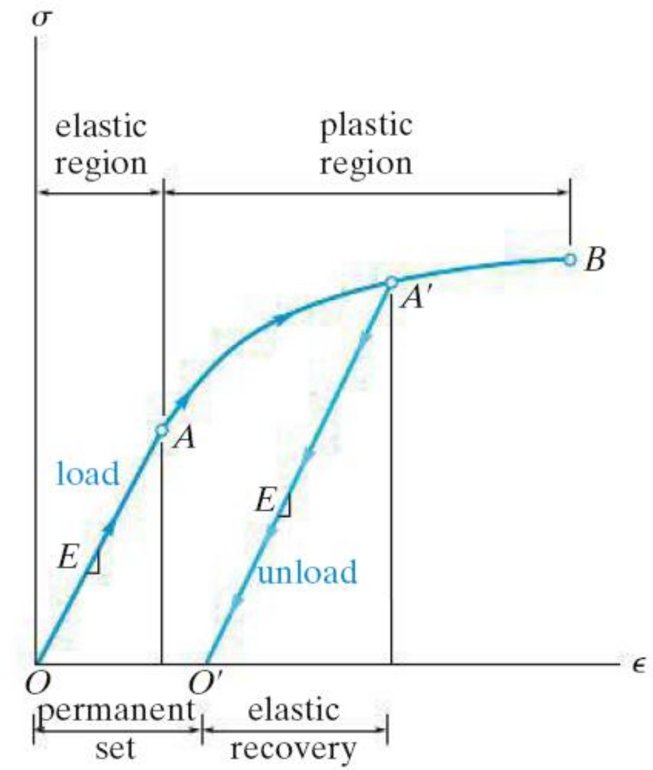
•Modulus of elasticity is a mechanical property that indicates **the stiffness** of a material

•Materials that are still have large E values, while spongy materials (vulcanized rubber) have low values

Strain Hardening

If a specimen of ductile material, such as steel, is loaded into the *plastic region* and then unloaded, *elastic strain is recovered* as the material returns to its equilibrium state.

- Interatomic forces have to be overcome elongate specimen to elastically, these same forces pull atoms back together when load is removed
- Since E is the same, slope of line ’is the same as line OA & O’A’



(a)

3.5 Strain Energy

- As a material is deformed by an external load, the load will do external work, which in turn will be stored in the material as internal energy.
- This energy is related to the strains in the material, and so it is referred to as ***strain energy*** .

•Stress develops a force

$$\boxed{\Delta F = \sigma \, \Delta A = \sigma(\Delta x \, \Delta y)}$$

• **Strain-energy density** is strain energy per unit volume of materials

$$u = \frac{\Delta U}{\Delta V} = \frac{1}{2}\sigma\epsilon \qquad (3\text{–}6)$$

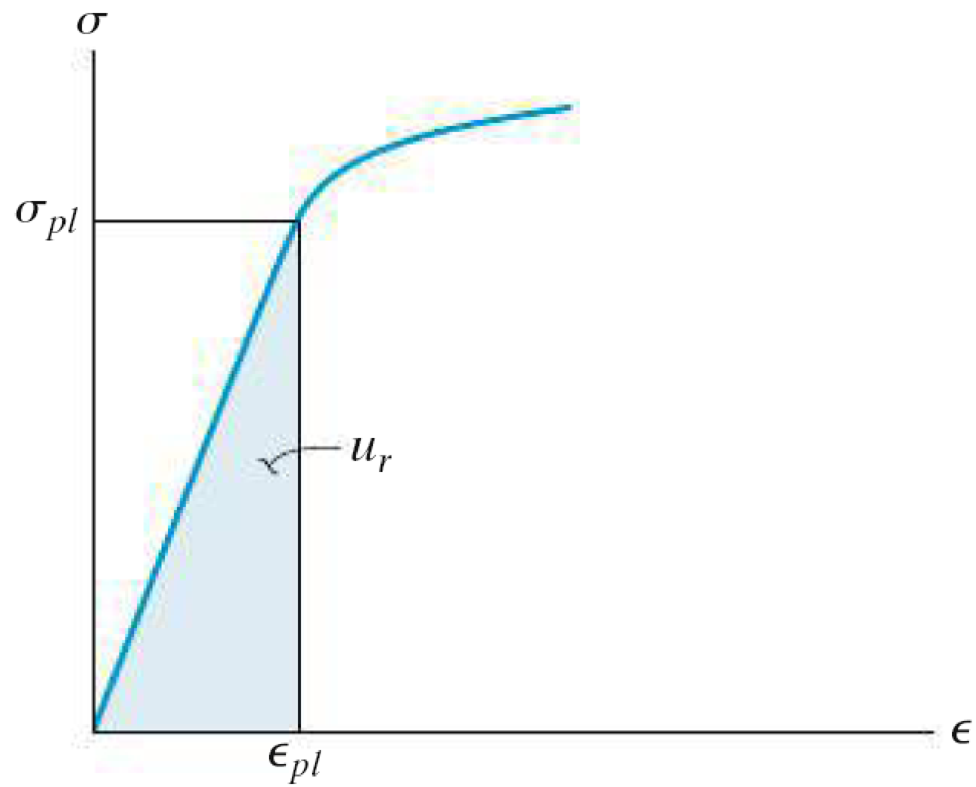
If material behavior is linear elastic, Hooke's law applies,

$$u = \frac{1}{2}\frac{\sigma^2}{E} \qquad (3\text{–}7)$$

Modulus of Resilience (u_r).

In particular, when the stress σ reaches the proportional limit, the strain-energy density, as calculated by Eq. 3–6 or 3–7, is referred to as the ***modulus of resilience***, i.e.

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



Modulus of resilience u_r

Ex1:- A tension test for a steel alloy results in the stress–strain diagram shown in Fig. 3–18 . Calculate the modulus of elasticity and the yield strength based on a **0.2%** offset. Identify on the graph the ultimate stress and the fracture stress.

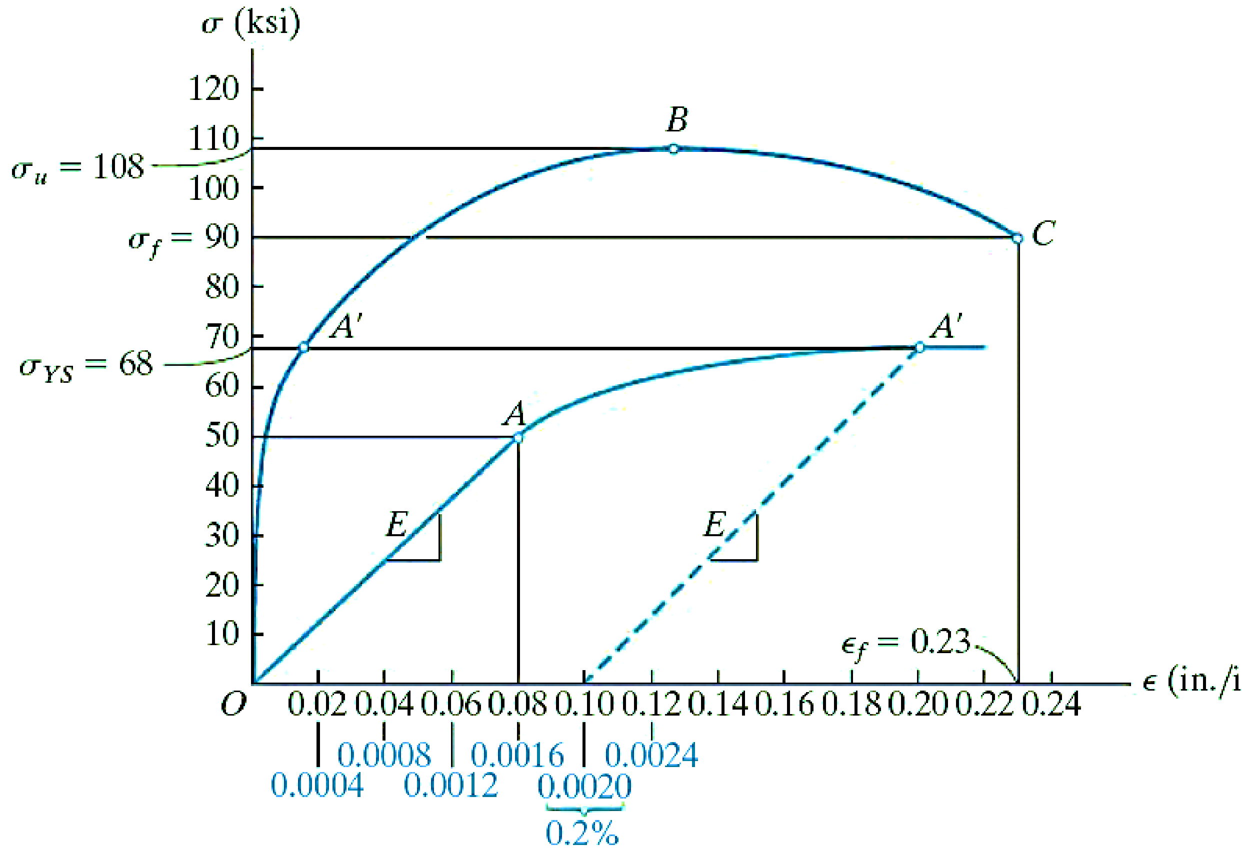


Fig. 3–18

SOLUTION

Modulus of Elasticity. We must calculate the *slope* of the initial straight-line portion of the graph. Using the magnified curve and scale shown in blue, this line extends from point O to an estimated point A, which has coordinates of approximately (0.0016 in./in., 50 ksi). Therefore,

$$E = \frac{50\text{ ksi}}{0.0016\text{ in./in.}} = 31.2(10^3)\text{ ksi} \qquad \textit{Ans.}$$

Note that the equation of line OA is thus $\sigma = 31.2(10^3)\epsilon$.

Yield Strength. For a 0.2% offset, we begin at a strain of 0.2% or 0.0020 in./in. and graphically extend a (dashed) line parallel to OA until it intersects the σ–ϵ curve at A'. The yield strength is approximately

$$\sigma_{YS} = 68 \text{ ksi} \qquad \textit{Ans.}$$

Ultimate Stress. This is defined by the peak of the σ–ϵ graph, point B in Fig. 3–18.

$$\sigma_u = 108 \text{ ksi} \qquad \textit{Ans.}$$

Fracture Stress. When the specimen is strained to its maximum of $\epsilon_f = 0.23$ in./in., it fractures at point C. Thus,

$$\sigma_f = 90 \text{ ksi} \qquad \textit{Ans.}$$

Homework

1. 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

2:-A bar having a length of **5 in**. and cross-sectional area of **0.7 in.2 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.