Stress–Strain Diagrams

- The mechanical properties of materials are determined by tests performed on small specimens of the material
- In order that test results may be compared easily, the dimensions of test specimens and the methods of applying loads have been standardized

Standards organizations: ***American Society for Testing and Materials*** (ASTM), ***American Standards Association*** (ASA) and the ***National Bureau of Standards*** (NBS)

Tension Test

- The axial stress σ in the test specimen is calculated by dividing the load P by the cross–sectional area A
- Strain in the bar is found from the measured elongation δ between the gage marks by dividing δ by the gage length L

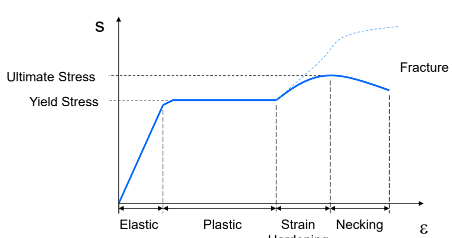
Developing a Stress–Strain Diagram

- After performing a tension or compression test and determining the stress and strain at various magnitudes of the load, we can plot a diagram of stress versus strain
- Stress–strain diagrams were originated by: *Jacob Bernoulli (1654–1705) and J. V. Poncelet (1788–1867)*

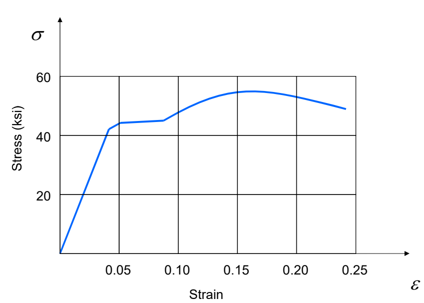
Developing a Stress–Strain Diagram

Stress–Strain for Steel

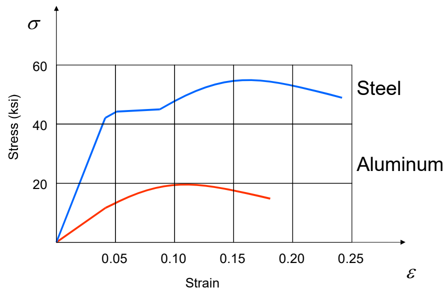
- The first material we will discuss is: ***structural steel***
- A stress–strain diagram for a typical structural steel in tension is shown:



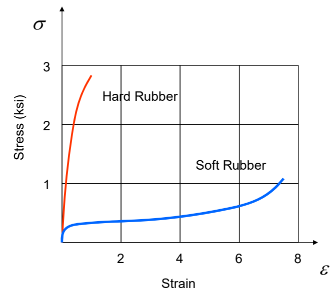
Stress–Strain for Steel



Stress–Strain for Aluminum



Stress–Strain for Rubber



Linear Elasticity

- When a material returns to its original dimensions after unloading, it is called ***elastic***
- When a material behaves elastically and also exhibits a linear relationship between stress and strain, it is said to be ***linearly elastic***.

Linear Elasticity

The linear relationship between stress and strain for a bar in simple tension or compression can be expressed by the equation:

$$\sigma = E\varepsilon$$

where ***E*** is a constant known as the

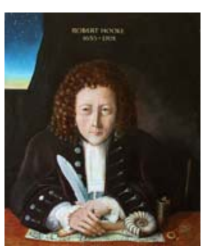
modulus of elasticity

(units are either *psi* or Pa)

Hooke's Law

The equation $\sigma = E\,\varepsilon$ commonly known as ***Hooke's law***

- For the famous English scientist Robert Hooke (1635–1703).
- Hooke was the first person to investigate the elastic properties of materials, and he tested such diverse materials as metal, wood, stone, bones, and sinews.
- He measured the stretching of long wires supporting weights and observed that the elongations "always bear the same proportions one to the other that the weights do that make them"



Hooke's Law

- The modulus of elasticity ***E*** has relatively large values for materials that are very stiff, such as structural metals
  - Steel has a modulus of 30,000 ksi or 200 GPa
  - Aluminum is approximately 10,600ksi or 70 GPa
  - Wood is 1,600 ksi or 11 Gpa
- The modulus of elasticity is often called ***Youug's modulus***, after another English scientist, Thomas Young (1773–1829)

Linear Elasticity

If the material in the bar is considered linear-elastic and the tensile stress is 25,000 psi and the tensile strain is 0.005, what is the modulus of elasticity of the material?

$$\sigma = E\varepsilon \quad \Rightarrow \quad E = \frac{\sigma}{\varepsilon}$$

$$E = \frac{25{,}000\ psi}{0.00\bar{5}} = \bar{5}{,}000{,}000\ psi = \bar{5} \times 10^{6}\ psi$$

Linear Elasticity

If you substitute the formulas for stress and strain into Hooke's Law you get:

$$\sigma = E\varepsilon \qquad \Rightarrow \sigma = \frac{P}{A} \qquad \Rightarrow \varepsilon = \frac{\delta}{L}$$

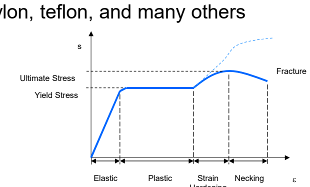
$$\frac{P}{A} = E\frac{\delta}{L}$$

Group Problem 6

- Determine the cross-sectional area of a 100-ft. steel cable supporting a 20,000 lb. tensile force while not exceed the an allowable tensile stress of 50,000 psi or a maximum elongation of 0.050 ft. Assume the modulus of elasticity of steel is *E* = 29,000,000 psi (assume all value are "exact" measurements).

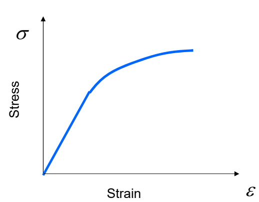
Stress–Strain Diagram

- Materials that undergo large strains before failure are classified as ***ductile***
- Ductile materials include mild steel, aluminum and some of its alloys, copper, magnesium, lead, molybdenum, nickel, brass, bronze, nylon, teflon, and many others



Stress–Strain Diagram

- Materials that fail in tension at relatively low values of strain are classified as ***brittle*** materials.
- Examples are *concrete*, stone, cast iron, glass, ceramic materials, and many common metallic alloys.
- Ordinary ***glass*** is a nearly ideal brittle material



Compression Test

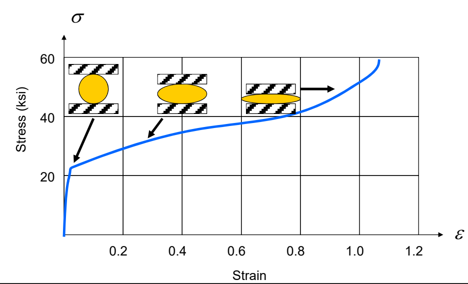
- Compression tests of metals are customarily made on small specimens in the shape of cubes or circular cylinders.
- Concrete is tested in compression on every important construction project to ensure that the required strengths have been obtained.
- The standard ASTM concrete test specimen is 6 in. in diameter, 12 in. long, and 28 days old (the age of concrete is important because concrete gains strength as it cures)

Compression Test

- Stress–strain diagrams for ***compression*** have different shapes from those for tension.
- Ductile metals such as steel, aluminum, and copper have proportional limits in compression very close to those in tension.

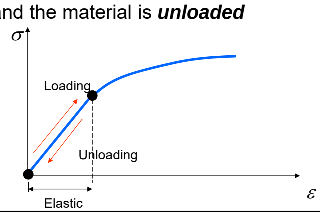
Compression Test

- However, when yielding begins, the behavior is quite different. Consider compression of copper:



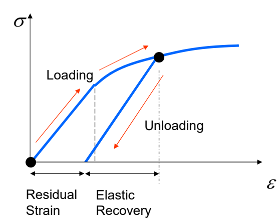
Elasticity

- The stress–strain diagrams described in the preceding section illustrate the behavior of various materials as they are ***loaded*** statically in tension or compression.
- Now let us consider what happens when the load is slowly removed, and the material is ***unloaded***



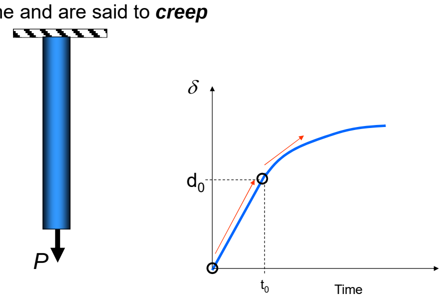
Plasticity

- Now let us suppose that we load this same material to a much higher level
   - If the loading is too great a ***residual strain***, or ***permanent strain***, remains in the material
   - The corresponding residual elongation of the bar is called the ***permanent set***. The material is said to be ***partially elastic***

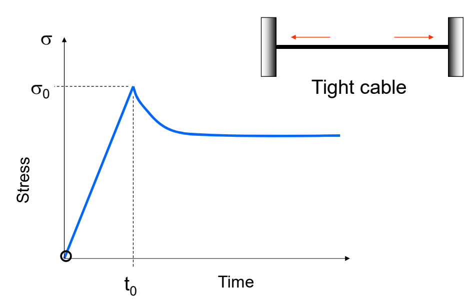


Creep

- Development of additional strains over long periods of time and are said to ***creep***



Relaxation



Mechanics of Materials

End of Part 2

Any Questions?