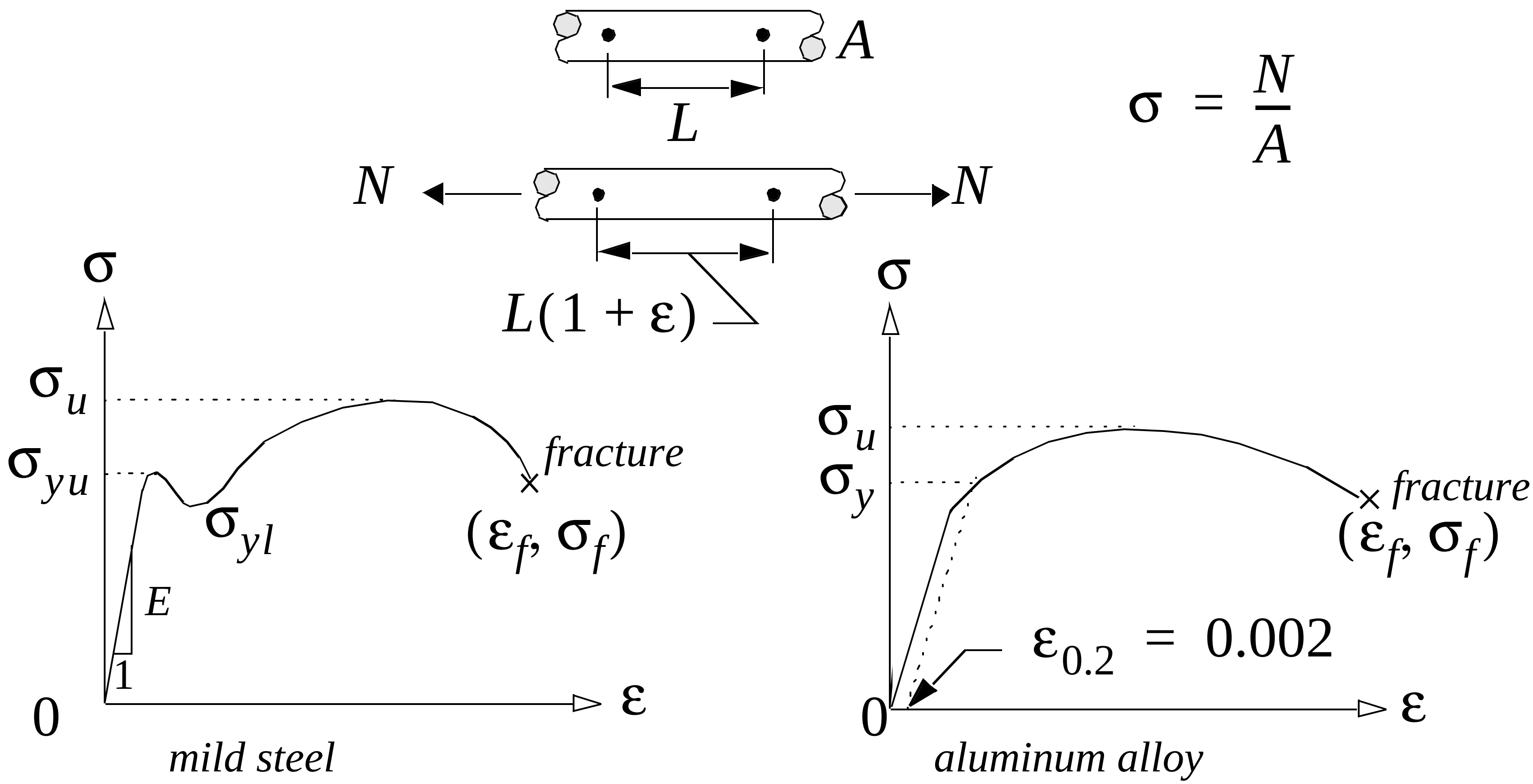
Typical stress-strain curves for mild steel and aluminum alloy from tensile tests

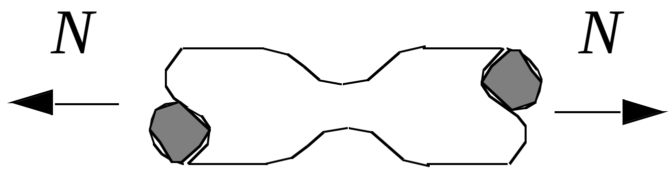


Data & definitions from the tensile test

Ultimate tensile strength σ_u

The maximum tensile load divided by the original cross-sectional area is called the ultimate tensile strength, or just the tensile strength, of the material.

At the maximum load the deformation of most metal specimens becomes localized in the form of an abrupt reduction in cross section along a small length in the gage section. Plastic deformation becomes concentrated in the reduced cross section after the maximum load. The non-uniform deformation is called necking



Lecture 4: Material Characteristics & Design

Plastic deformation

Deformation which is independent of time and remains on release of the load. The principal physical mechanism causing plastic deformation in metals is slippage between planes of atoms in the crystal grains of the material.

Yield Strength (stress) for mild steel

Stress at which the there is dramatic drop in load just after the initial linear portion of the stress-strain curve. Upper yield point σ_{yu} is followed by a lower yield point σ_{yl} .

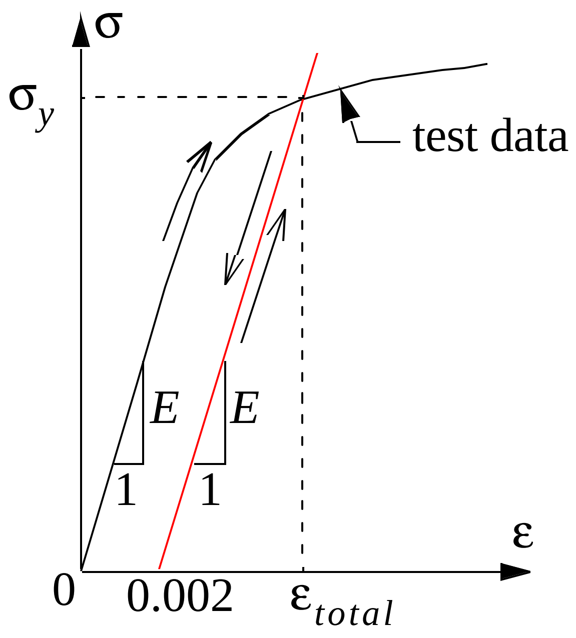
Material characteristics (continued)

0.2% Offset Yield Strength (stress) σ_y

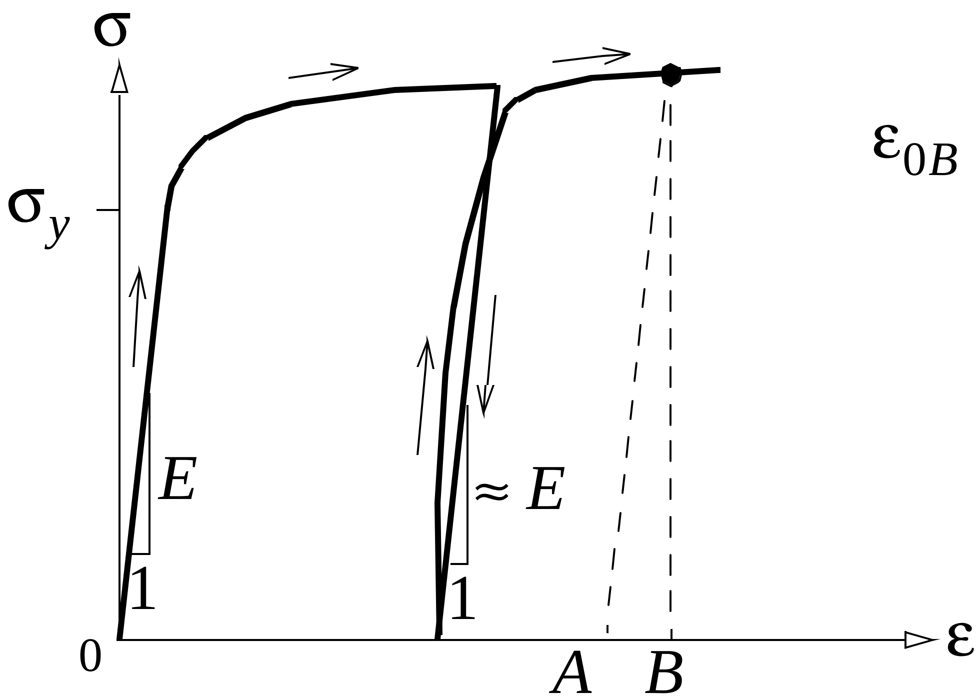
The stress at the intersection of the stress-strain curve and a straight line with slope of E and beginning at 0.002 (0.2%) on the strain axis.

The most satisfactory definition of yield strength for aluminum alloys and many other materials.

Note: At this definition of yield, the plastic portion of the strain is 0.002 and the elastic portion of the strain is σ_y / E .



Loading, unloading, and reloading of a metallic specimen beyond its yield stress



$$\varepsilon_{0B} = \varepsilon_{0A} + \varepsilon_{AB}$$

ε_{0B} = total strain

ε_{0A} = plastic strain

ε_{AB} = elastic strain

Loading, unloading, and reloading of a metallic specimen beyond its yield stress (concluded)

The unloading slope is nearly the same as the slope of the linear elastic portion, or E.

The total strain at load is the sum of the plastic strain (permanent portion upon removal of the load) and the elastic strain (recoverable portion).

Since plastic deformation of the material results in a change in size and shape of the structural component, it is undesirable in design. Hence, yielding of the material is an important phenomena to quantify.

Limit and ultimate loads

Limit loads

The maximum loads which an airplane maybe expected to encounter at any time in service.

Ultimate loads

Loads that result in structural failure.

With structures there are often several alternative possible modes of failure. For a tension bar, fracture occurs if the load is increased beyond ultimate load. So ultimate loads are associated with material ultimate tensile strength.

Factor of safety (F.S.)

The factor of safety is defined as the ultimate load divided by the maximum limit load.

F.S. > 1; Often S.F. = 1.5 in airplane design, but larger values may be specified depending on the component and material.

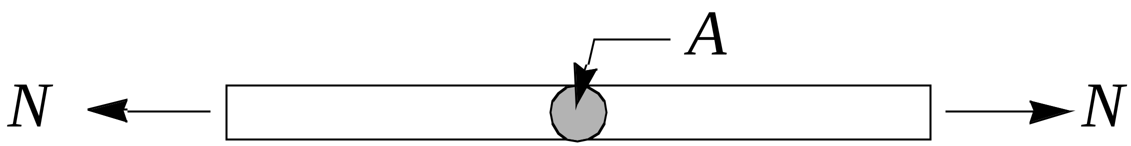
About 1850 engineers began to do calculations about the strength of important structures, such as bridges. They calculated the highest probable tensile stresses in the structure by methods of the day, and they saw to it that these stresses were less than the official “tensile strength” of the material. To make quite sure, they made the highest calculated working stress much less – three or four or even seven or eight times less – than the strength of the material as determined by breaking a simple, smooth parallel-stemmed test-piece. This was called “applying a factor of safety”. Any attempt to save weight and cost by reducing the factor of safety was only too likely to lead to disaster. (J.E. Gordon,1978, p.64.)

Airplane structural design requirements

1. All parts of the airplane are designed so that they are not stressed beyond the yield strength at the limit load.

2. Airplane structural members must carry the ultimate loads without failure, even though the members may acquire permanent deformation under these loads.

Design of a tension bar or tie



The limit load is 10,000 lb and the factor of safety is 1.5. Determine the cross-sectional area for the two cases described below:

1. The material is 2024-T4 aluminum with $\sigma_y = 42\ \text{ksi}$ and $\sigma_u = 57\ \text{ksi}$ (Table 7.2 in text).

2. The material has $\sigma_y = 42\ \text{ksi}$ and $\sigma_u = 66\ \text{ksi}$.

The ultimate load is equal to the factor of safety times the limit load, or 15,000 lb. Either the limit load or ultimate load will design the member depending on the values of σ_y and σ_u .

Design of a tension bar or tie in the 1st case

Here, $\frac{\sigma_u}{\sigma_y} = \frac{57\text{ksi}}{42\text{ksi}} = 1.36 < \text{F.S.}$ The ultimate load determines the area. If the limit were used, then the ultimate load requirement would be violated. So

$$A = \frac{15000\text{lb}}{57000\text{lb/in}^2} = 0.263\text{in}^2$$

At limit load $\sigma = \frac{10000\text{lb}}{0.263\text{in}^2} = 38\text{ksi} < \sigma_y = 42\text{ksi}$

which satisfies the requirement that the tie does not yield at the limit load.

Design of a tension bar or tie in the 2nd case

Here $\frac{\sigma_u}{\sigma_y} = \frac{66\text{ksi}}{42\text{ksi}} = 1.57 > \text{F.S.}$. The limit load determines the area. If the ultimate load were used, then the limit load requirement would be violated. So

$$A = \frac{10000\text{lb}}{42000\text{lb/in}^2} = 0.238\text{in}^2$$

At the ultimate load $\sigma = \frac{15000\text{lb}}{0.238\text{in}^2} = 63\text{ksi} < \sigma_u = 66\text{ksi}$

which satisfies the requirement that the bar does not fail at ultimate load.