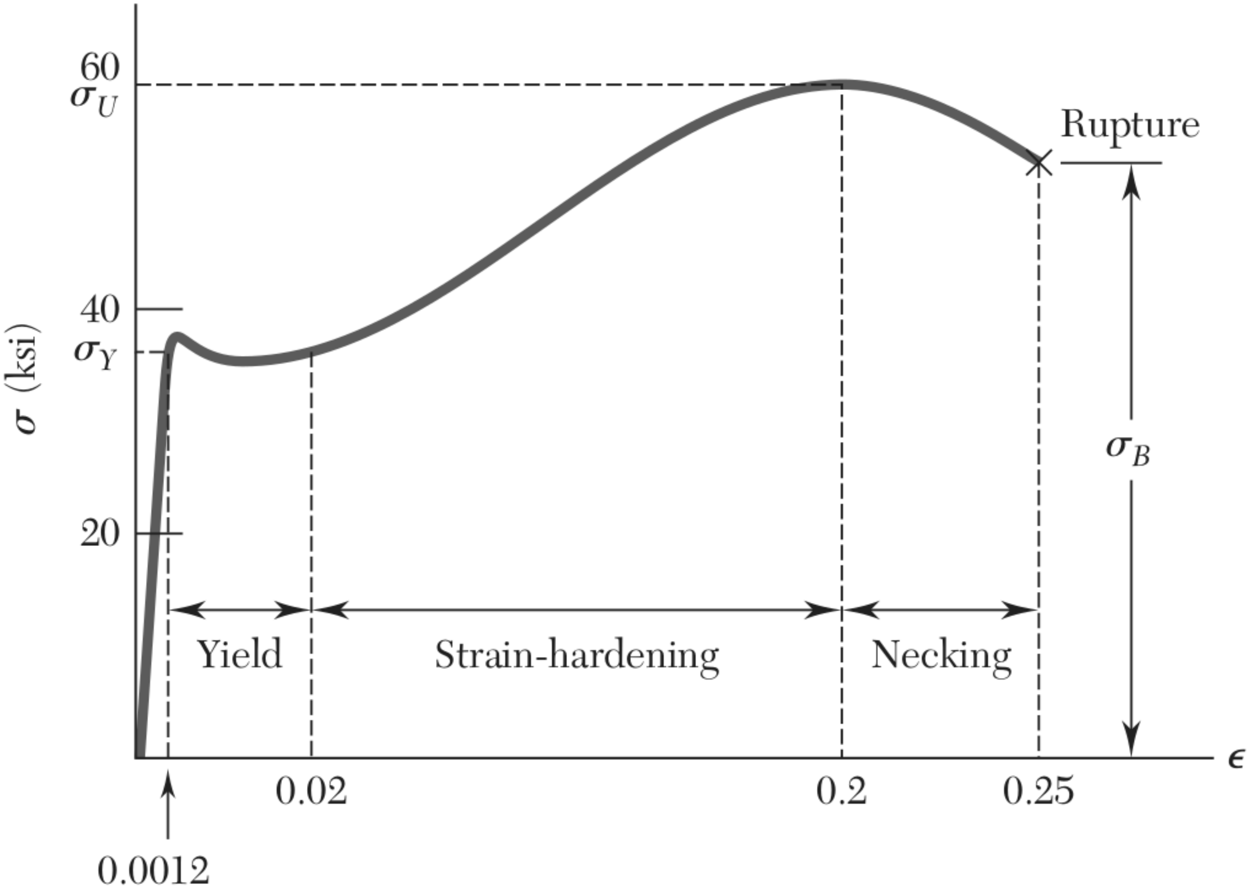
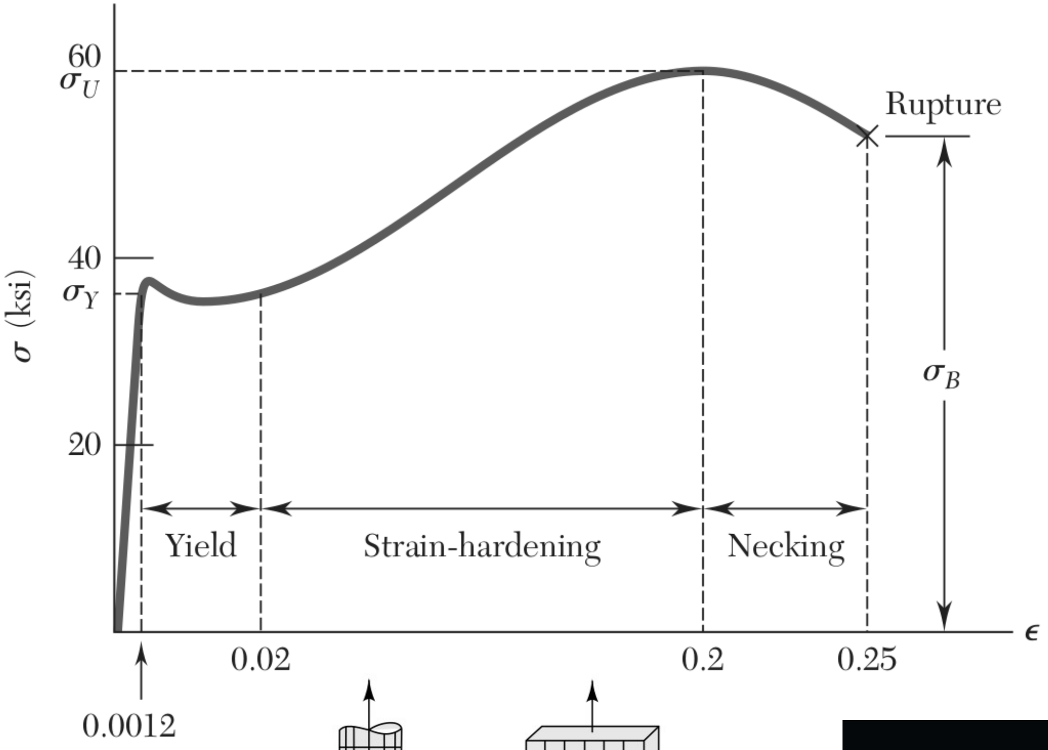
ME231: Solid Mechanics-I

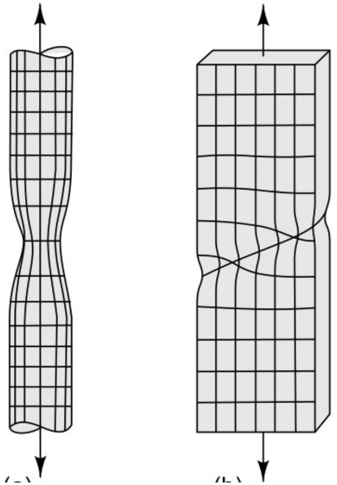
Stress, Strain and Temperature relationship

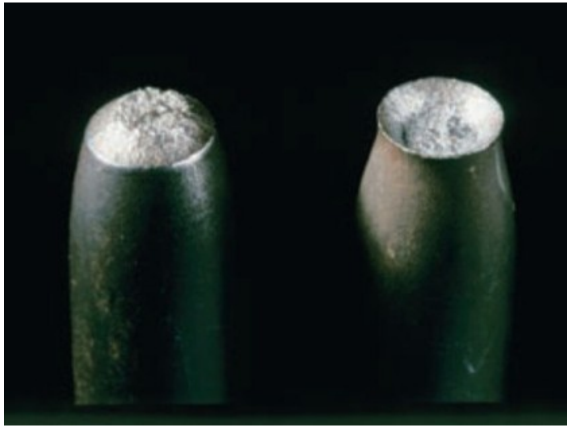


- As plastic deformation is continued, the load required for further plastic flow increases. This phenomenon is called **strain hardening**.
- Finally a point is reached where the load required to cause further elongation begins to decrease. At this point the load has passed a maximum and, consequently, so also has the engineering stress. This **maximum value of the engineering stress** is termed the **ultimate tensile stress (or tensile strength).**



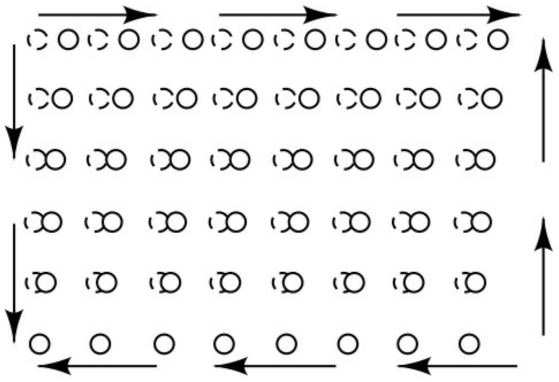
- After the ultimate tensile strength, it is observed that at a certain cross-section reduction in the cross-sectional area is higher than that in the other places. This non-uniform deformation is called necking,
- The tensile test reaches its conclusion when a small crack develops at the center of the neck and spreads outward to complete the fracture.
- The stress at which complete fracture occurs is called the **breaking stress.**



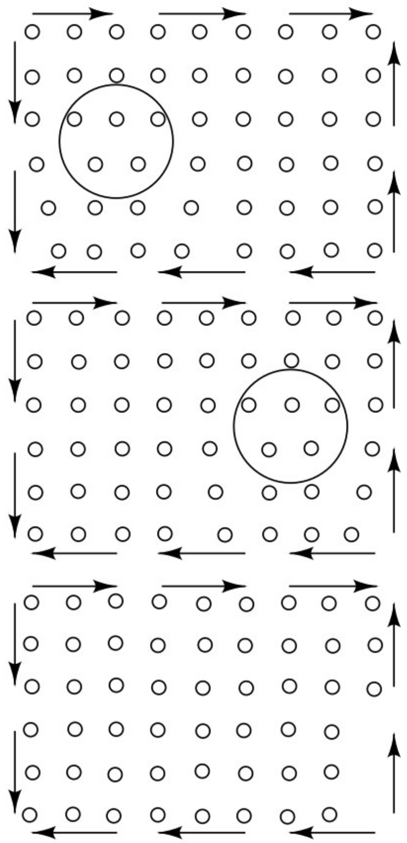


Deformation of a crystal lattice

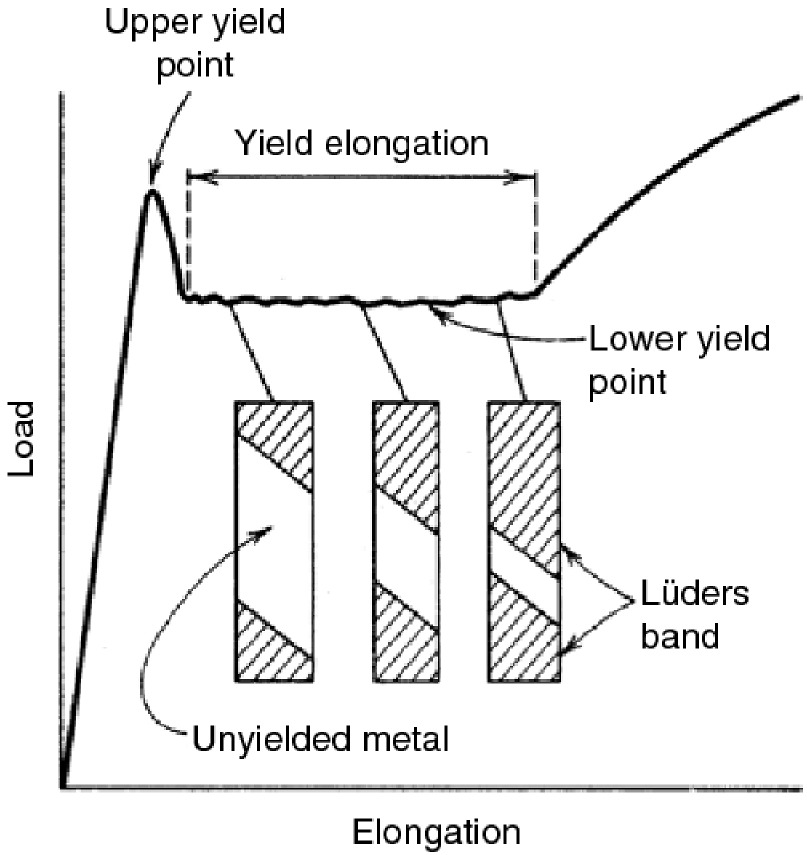
Elastic deformation



Plastic deformation



Lüders band


Upper yield point
Yield elongation
Lower yield point
Load
Lüders band
Unyielded metal
Elongation

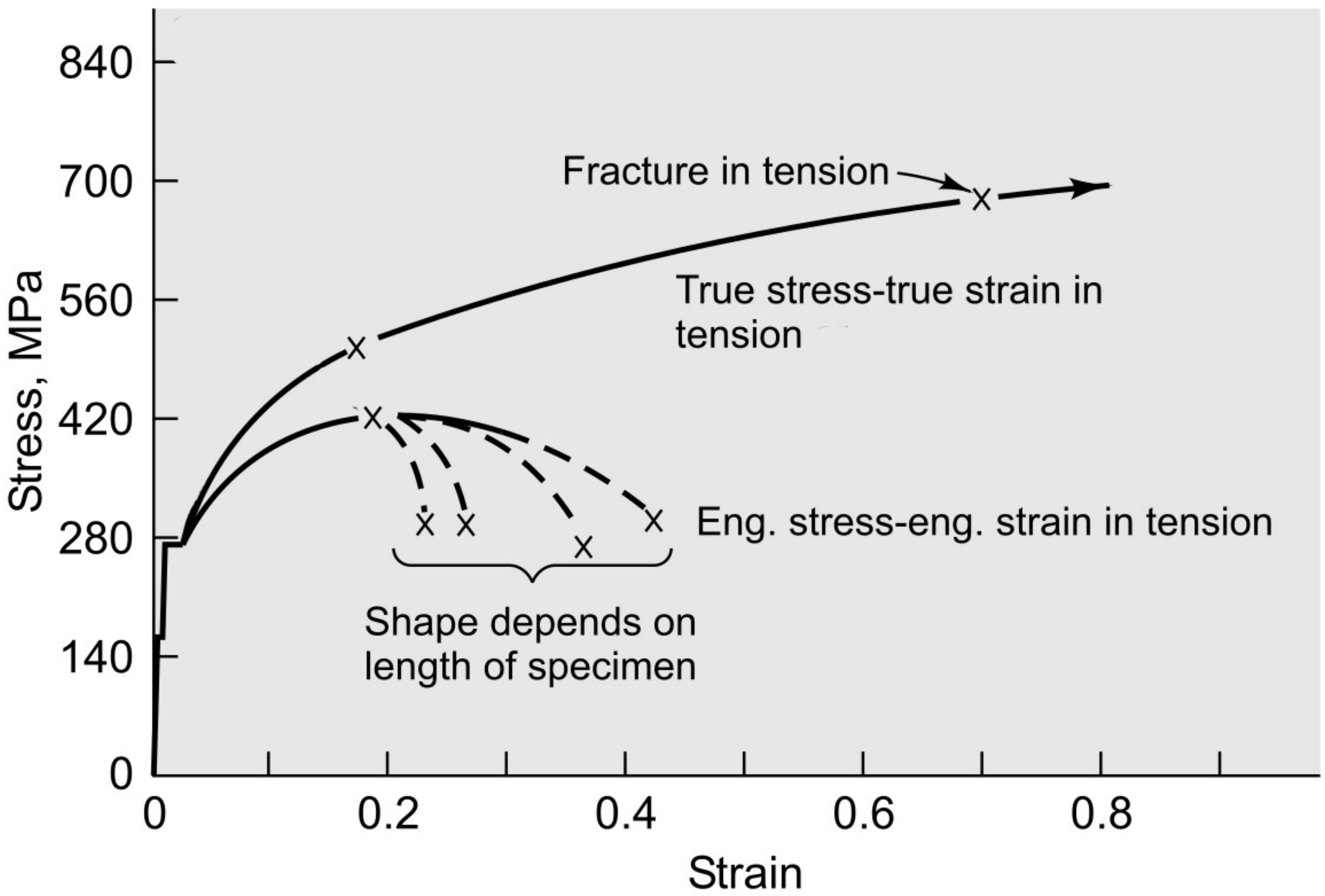
- It is to be noted that during the test cross-sectional area changes. Thus, it is necessary to distinguish between the stress based on the original cross-sectional area of the specimen and the stress based on the actual cross-sectional area at any stage of the elongation.
- Since the cross-sectional area decreases as the specimen is elongated, the stress based on the actual area is greater than that based on the original area.
- The intensity of load per unit of actual area is called the true stress; this stress describes the load intensity the material actually experiences. For small strains the fractional decrease in cross-sectional area is small, and the true stress and engineering stress are essentially equal.
- Similarly for small deformations, engineering strain and true strain is also equal. However, true strain describes the actual material behaviour.

$$\text{Engineering Stress: } \sigma = \frac{P}{A_0} \qquad \text{Engineering Strain: } \epsilon = \frac{\delta}{L_0}$$

$$\text{True Stress: } \sigma_t = \frac{P}{A} \qquad \text{True Strain: } \epsilon_t = \ln\frac{L}{L_0}$$

........................(1) ....(2)

Eng. stress – eng. strain curve and true stress – true strain curve for hot-rolled low-carbon steel



Standard measure of **ductility** of a material is its **percentage elongation** which is defined as,

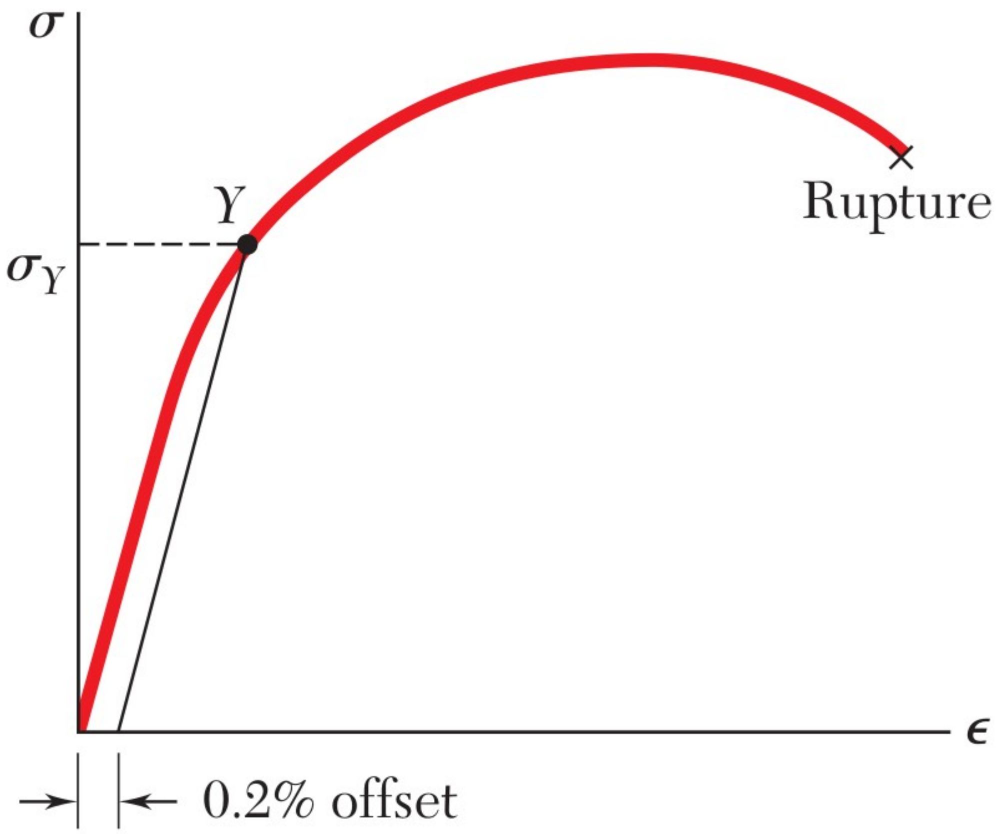
$$\% \text{ elongation} = \frac{L_B - L_0}{L_0} \times 100, \qquad \cdots\cdots\cdots\cdots(3)$$

where L_0 is the initial gage length and L_B is the final gage length at rupture.

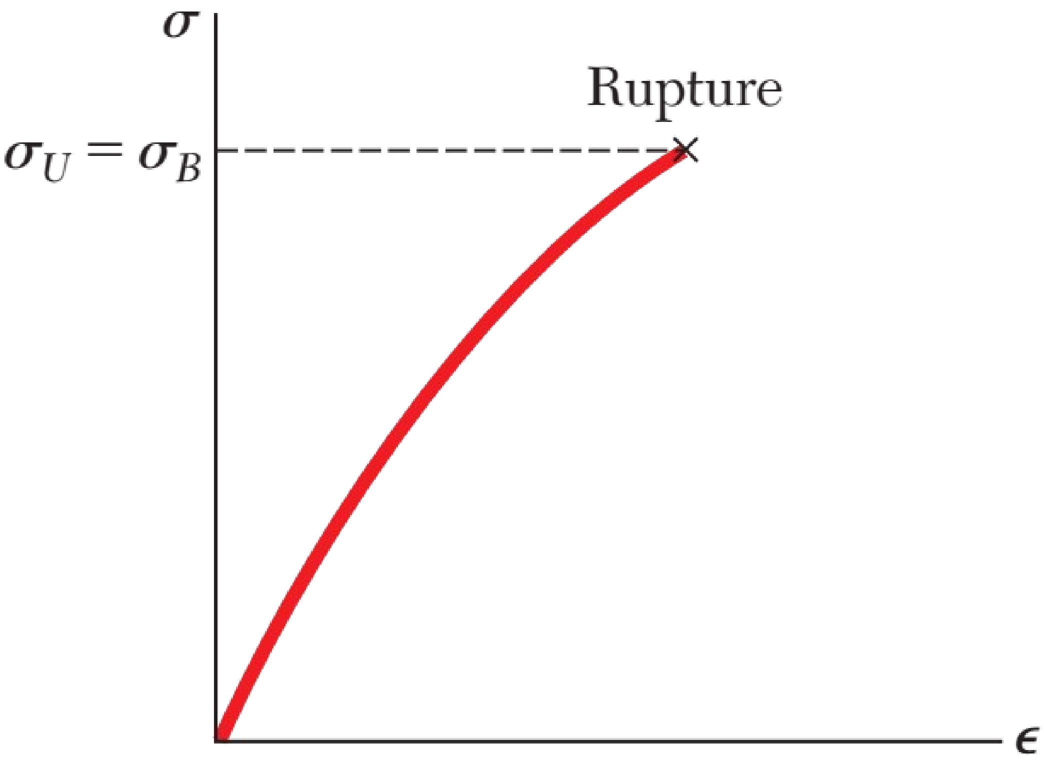
Another measure of ductility is the **percentage reduction is the cross-sectional area** which is defined as,

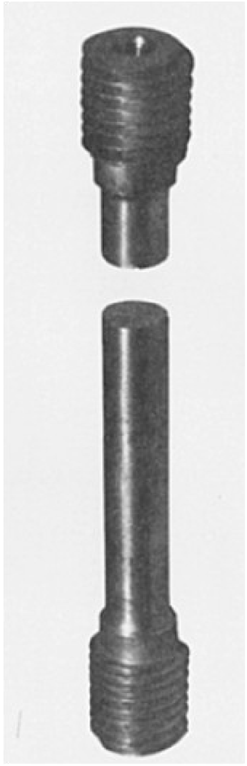
$$\% \text{ area reduction} = \frac{A_B - A_0}{A_0} \times 100, \qquad \cdots\cdots\cdots\cdots(4)$$

where A_0 is the initial cross-sectional area and A_B is the final cross-sectional area at the rupture.



- Most of the ductile materials (other than steels), yield point is not as clear as for steels, the yield strength is determined by drawing a line which is parallel to the initial tangent to the stress-strain curve; through the point corresponding to the arbitrary plastic strain, **usually 0.2% (0.002)**. The intersection of this line with the stress-strain curve defines the yield strength.
- Other features of stress-strain curve remain same as discussed for steels.
- Because of the method of determination, these yield strengths are more sharply defined than are the proportional limits.

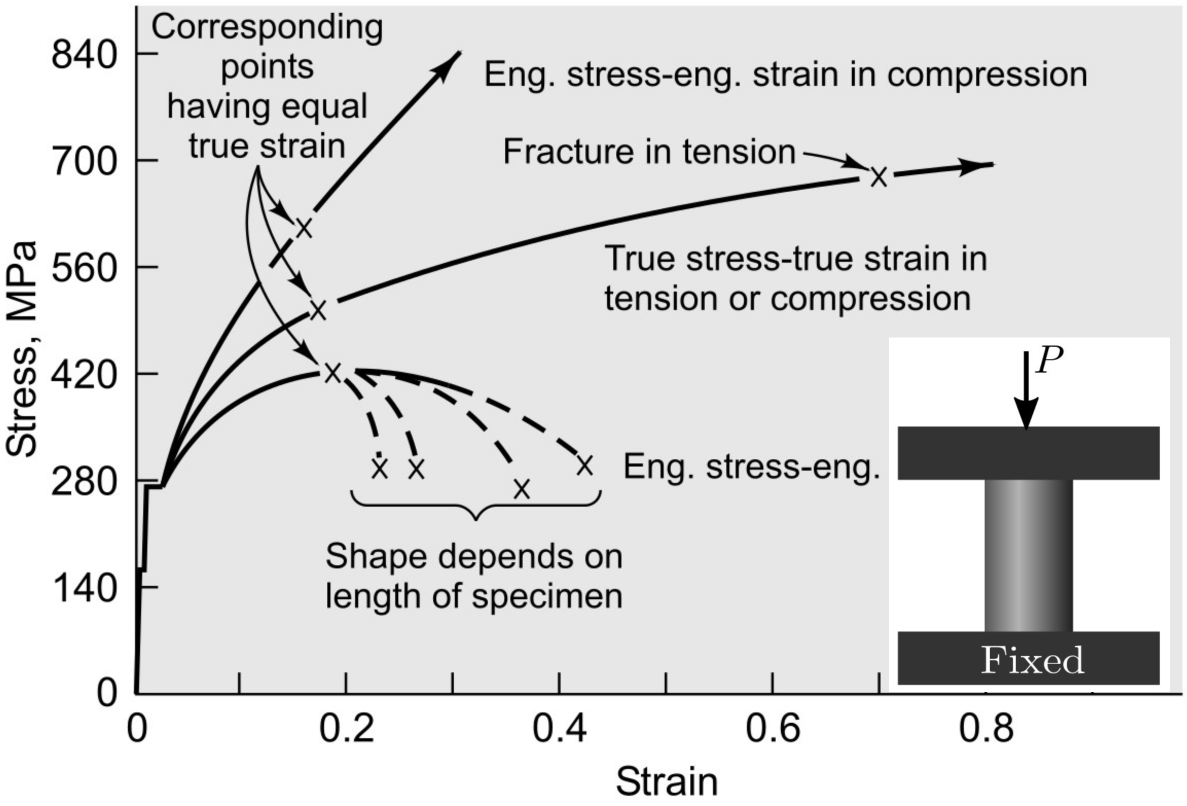




- For most of the engineering materials (such as glass and cast iron) rupture occurs at very low values of strains without appreciable plastic deformation. Rupture occurs without the specimen going under necking. In general, such materials are called **brittle material.**

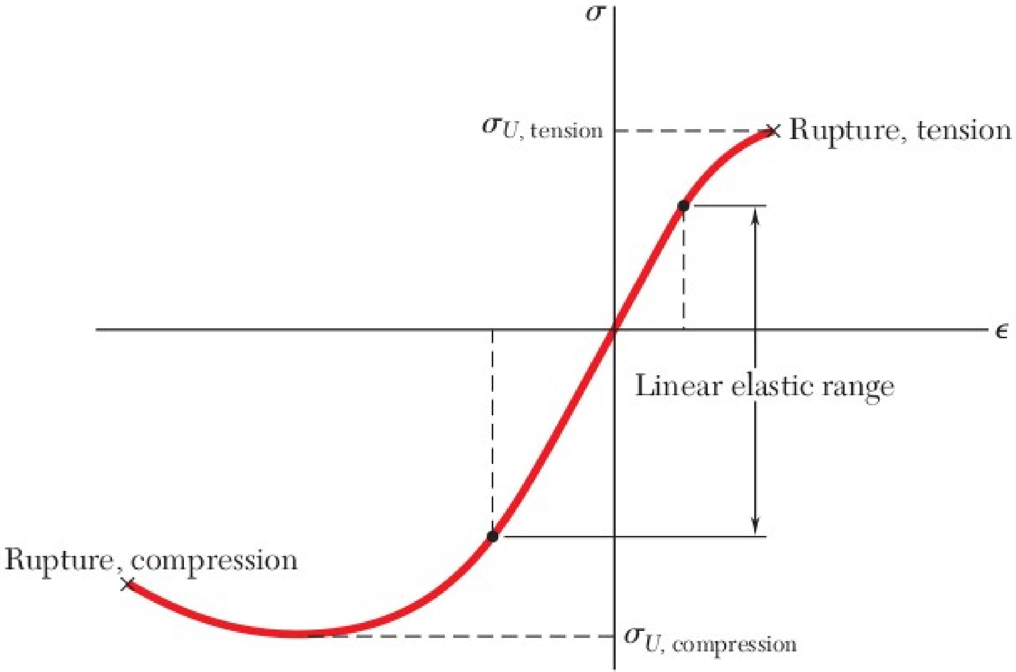
Compression test

Compression test is performed on a cylindrical specimen of given dimension, which is compressed between two platoons of the testing machine.



- For a ductile material the stress-strain curve under compression is essentially the same through its initial straight-line portion and through the beginning of the portion corresponding to yield and strain-hardening.
- Particularly for a given steel, the yield strength is the same in both tension and compression.
- For larger values of the strain, the tension and compression stress-strain curves diverge, and necking does not occur in compression.

Compression test



For most brittle materials, the ultimate strength in compression is much larger than in tension. This is due to the presence of flaws, such as microscopic cracks or cavities that tend to weaken the material in tension, while not appreciably affecting its resistance to compressive failure.

Hooke's Law; Modulus of Elasticity

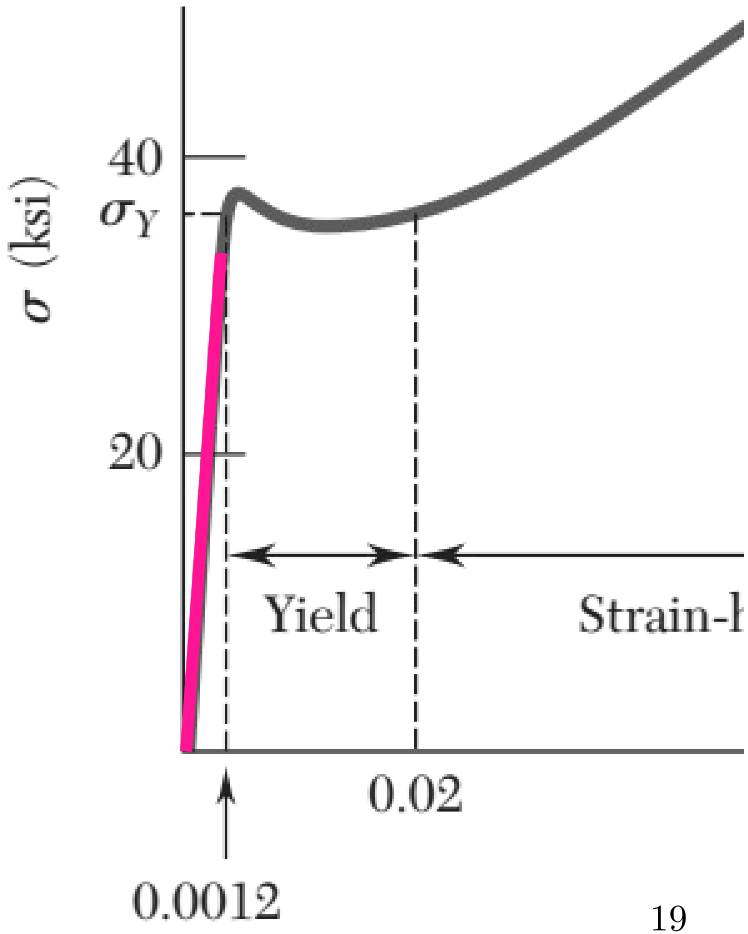
Most engineering structures are designed to undergo deformations within the proportionality limit of the stress-strain diagram. Within the proportionality limit we can write,

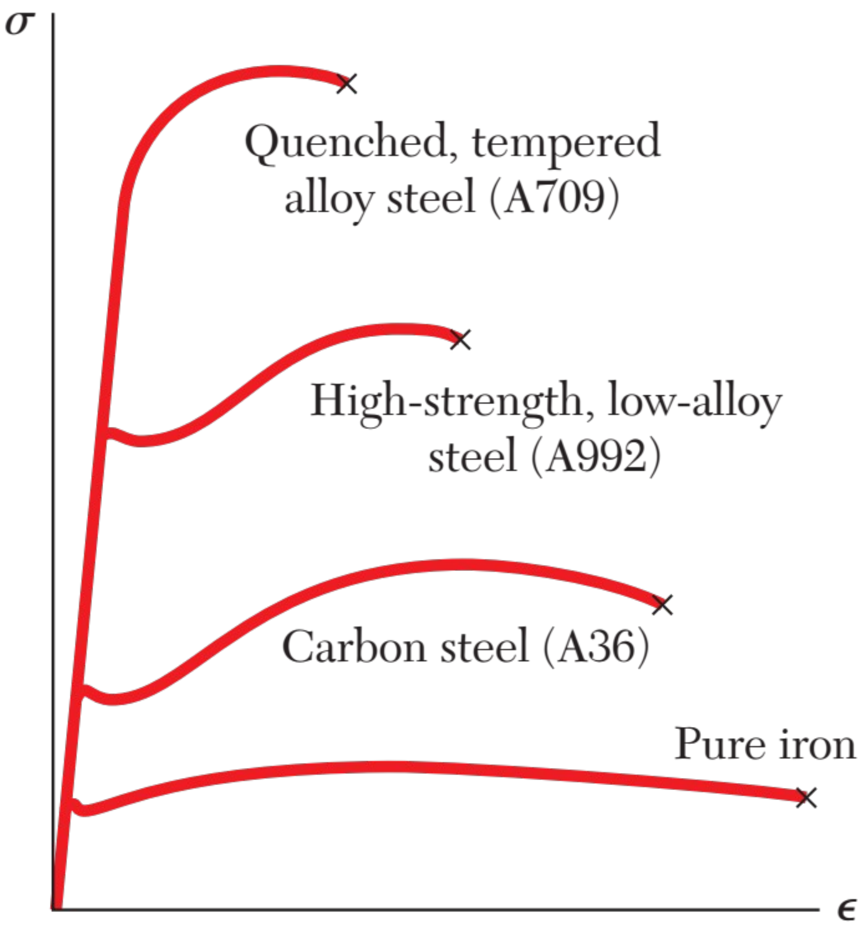
$$\sigma = E\epsilon, \qquad \cdots\cdots\cdots\cdots(5)$$

where E is the proportionality constant.

This is known as **Hooke's law,** after Robert Hooke (1635–1703), an English scientist and one of the early founders of applied mechanics.

The coefficient E of the material is the **modulus of elasticity or Young's modulus**, after the English scientist Thomas Young (1773–1829). Since the strain ϵ is a dimensionless quantity, E is expressed in the same units as stress σ i.e., in pascals or one of its multiples for SI units.





- Some physical properties of structural metals, such as strength, ductility, and corrosion resistance, can be varied by alloying, heat treatment, and the manufacturing process used.
- The stress-strain diagrams of pure iron and three different grades of steel show large variations in the yield strength, ultimate strength, and the ductility.
- However, all of these metals possess the same modulus of elasticity.
- Therefore, if a high-strength steel is substituted for a lower-strength steel and if all dimensions are kept the same, the structure will have an increased load-carrying capacity, but its stiffness will remain unchanged.