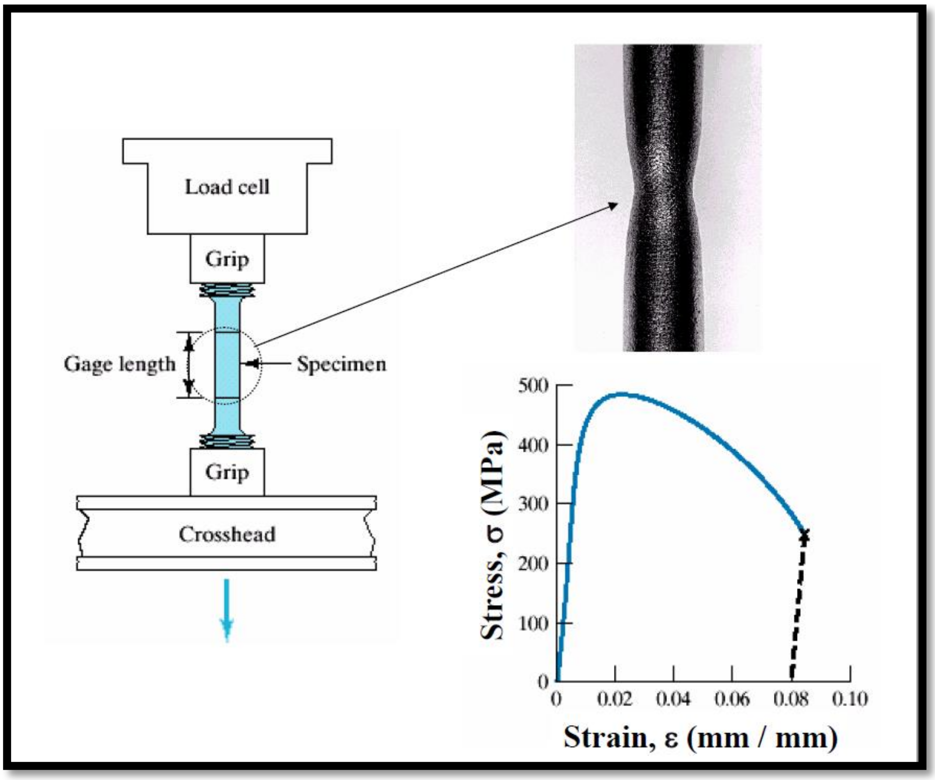
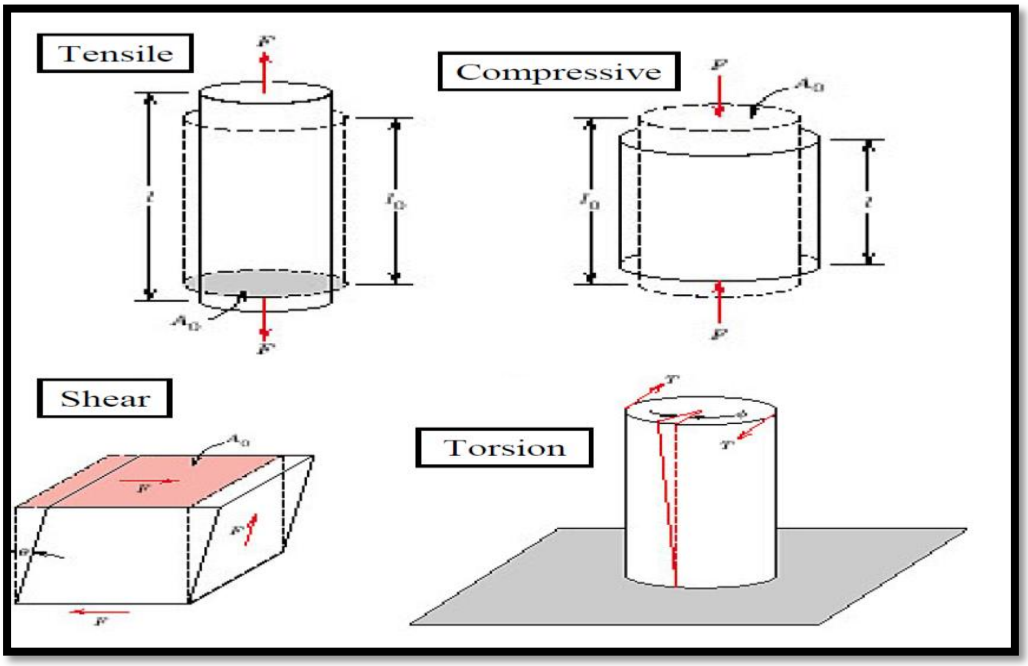
Mechanical Properties of Metals

To understand and describe how materials deform (elongate, compress, twist) or break as a function of applied load, time, temperature, and other conditions we need first to discuss standard test methods and standard language for mechanical properties of materials.



Types of loading:



Concepts of Stress and Strain

(Tension and compression)

To compare specimens of different sizes, the load is calculated per unit area.

Engineering stress: σ **= F / A_o**

F: is load applied perpendicular to specimen cross section;

A_0: is cross-sectional area (perpendicular to the force) **before** application of the load.

Engineering strain: ε **= Δ l / l_o ($\times$ 100 %)**

Δ l: is change in length, l_o is the original length.

These definitions of stress and strain allow one to compare test results for specimens of different cross sectional area A_0 and of different length l_0.

Stress and strain are positive for tensile loads, negative for compressive loads

<u>Shear and torsion</u>

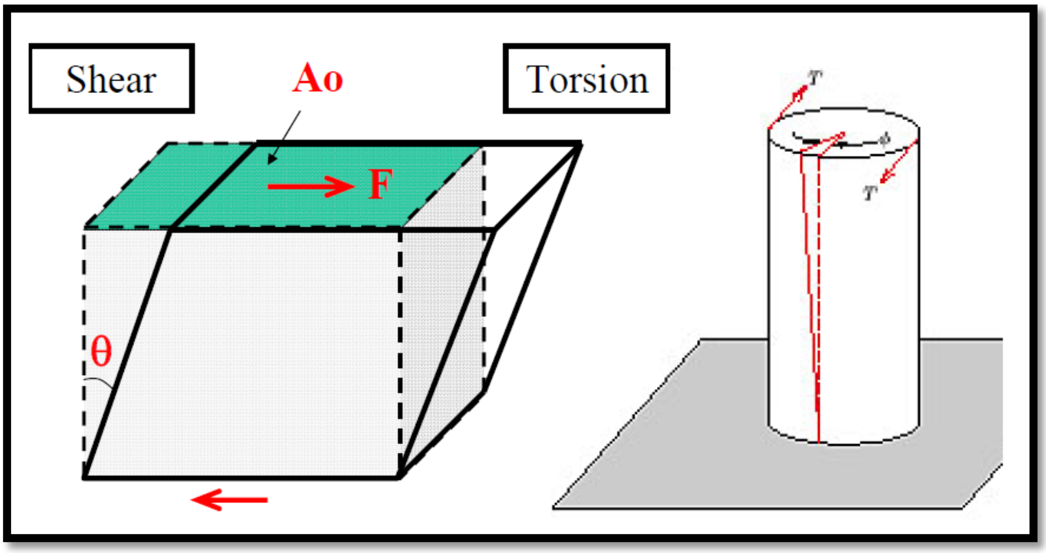
Shear stress: τ **= F / Ao**

F: is load applied parallel to the upper and lower faces each of which has an area A0.

Shear strain: γ **= tg** θ **($\times$ 100 %)**

θ is strain angle

Torsion is variation of pure shear. The shear stress in this case is a function of applied torque T, shear strain is related to the angle of twist, ϕ .

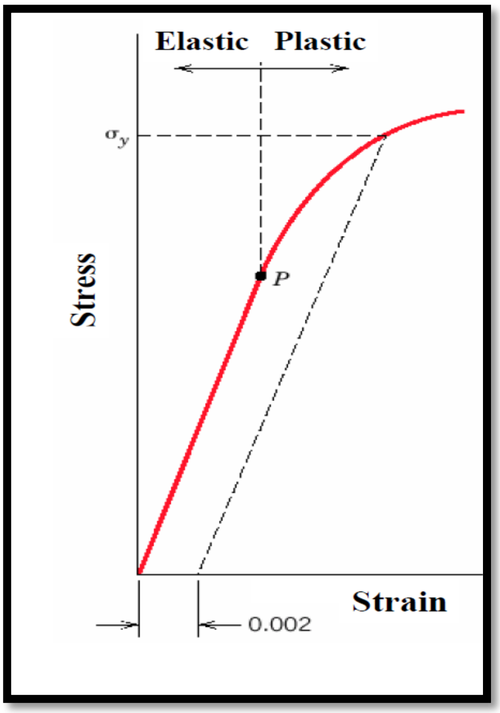


Stress-Strain Behavior

Elastic deformation

Reversible: when the stress is removed, the material returns to the dimensions it had before the loading.

Usually strains are small (except for the case of some plastics, e.g. rubber).



Plastic deformation

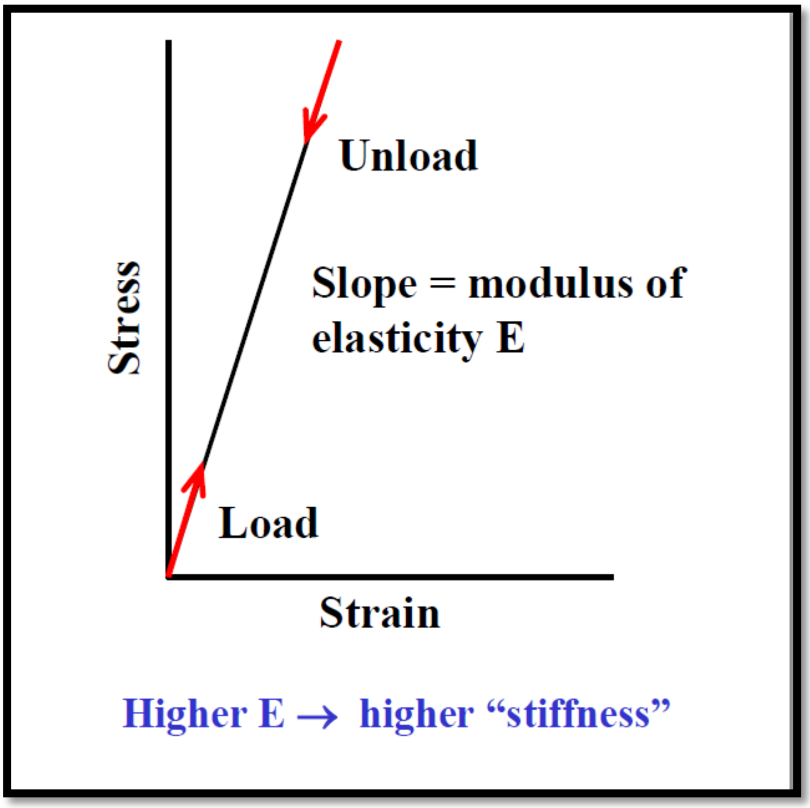
Irreversible: when the stress is removed, the material does not return to its original dimensions.

Stress-Strain Behavior: Elastic Deformation

In tensile tests, if the deformation is elastic, the stress strain relationship is called Hooke's law:

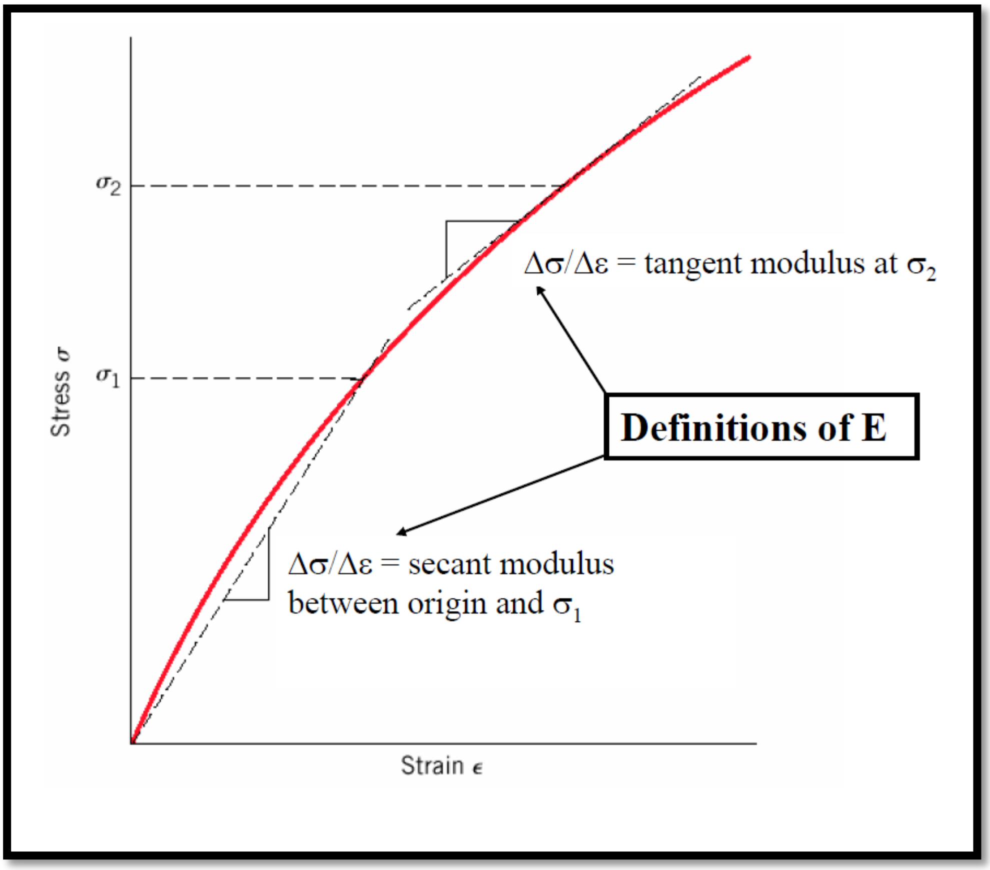
$$\sigma = E \varepsilon$$

E is Young's modulus or modulus of elasticity, has the same units as σ , N/m^2 or Pa.



Elastic Deformation: Nonlinear Elastic Behavior

In some materials (many polymers, concrete...), elastic deformation is not linear, but it is still reversible.

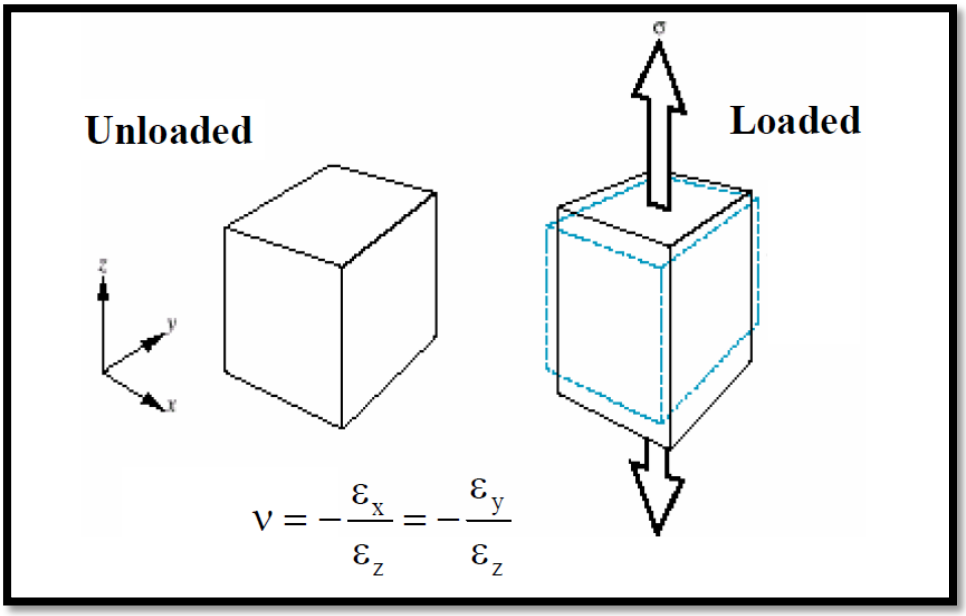


An elasticity (time dependence of elastic deformation)

- So far we have assumed that elastic deformation is time independent (i.e. applied stress produces instantaneous elastic strain)
- However, in reality elastic deformation takes time (finite rate of atomic/molecular deformation processes) - continues after initial loading, and after load release. This time dependent elastic behavior is known as **an elasticity**.

- The effect is normally small for metals but can be significant for polymers ("visco-elastic behavior").

Poisson's ratio



Materials subject to tension shrink laterally. Those subject to compression, bulge.

The ratio of lateral and axial strains is called the **Poisson's ratio** υ .

Sign in the above equations shows that lateral strain is in opposite sense to longitudinal strain υ *is dimensionless*

Theoretical value for isotropic material: 0.25

Maximum value: 0.50, Typical value: 0.24 - 0.30

Plastic deformation:

□ stress and strain are not proportional to each other

□ the deformation is not reversible

□ deformation occurs by breaking and re-arrangement of atomic bonds (in crystalline materials primarily by motion of dislocations.

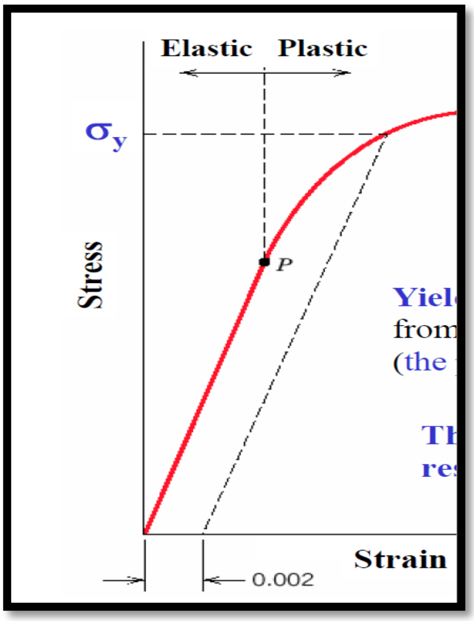
Tensile Properties: Yielding

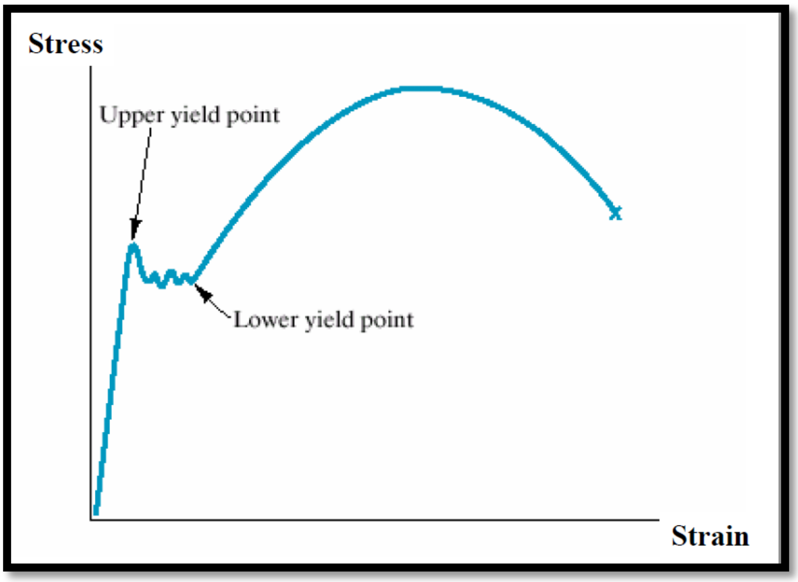
Yield strength σ_y - is chosen as that causing a permanent strain of 0.002

Yield point P - the strain deviates from being proportional to the stress

(the proportional limit)

The yield stress is a measure of resistance to plastic deformation





- In some materials (e.g. low-carbon steel), the stress vs. strain curve includes two yield points (upper and lower).
- The yield strength is defined in this case as the average stress at the lower yield point.
- For structural applications, the yield stress is usually a more important property than the tensile strength, since once the yield stress has passed, the structure has deformed beyond acceptable limits.

Tensile properties: Ductility

Ductility is a measure of the deformation at fracture.

Defined by percent elongation (plastic tensile strain at failure):

$$\%EL = \left(\frac{l_f - l_0}{l_0} \right) \times 100$$

or percent reduction in area:

$$\%RA = \left(\frac{A_0 - A_f}{A_0} \right) \times 100$$

Typical mechanical properties of metals

Metal Alloy	*Yield Strength MPa (ksi)*	*Tensile Strength MPa (ksi)*	*Ductility, %EL [in 50 mm (2 in.)]*
Aluminum	35 (5)	90 (13)	40
Copper	69 (10)	200 (29)	45
Brass (70Cu–30Zn)	75 (11)	300 (44)	68
Iron	130 (19)	262 (38)	45
Nickel	138 (20)	480 (70)	40
Steel (1020)	180 (26)	380 (55)	25
Titanium	450 (65)	520 (75)	25
Molybdenum	565 (82)	655 (95)	35

- ***The yield strength and tensile strength vary with prior thermal and mechanical treatment, impurity levels, etc.***
- ***The yield and tensile strengths and modulus of elasticity decrease with increasing temperature, ductility increases with temperature.***

What are the limits of "safe" deformation?

Design stress: $\sigma_d = N' \sigma_c$ where

σ_c = maximum anticipated stress,

N' is the "design factor" > 1. Want to make sure that $\sigma_d < \sigma_y$

Safe or working stress: $\sigma w = \sigma y/N$ where

N is "factor of safety" > 1.

True Stress and Strain

True stress = load divided by **actual area** in the necked-down region (Ai):

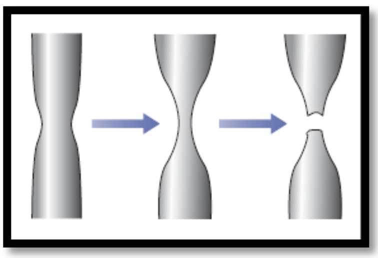
$$\sigma_T = F/A_i$$

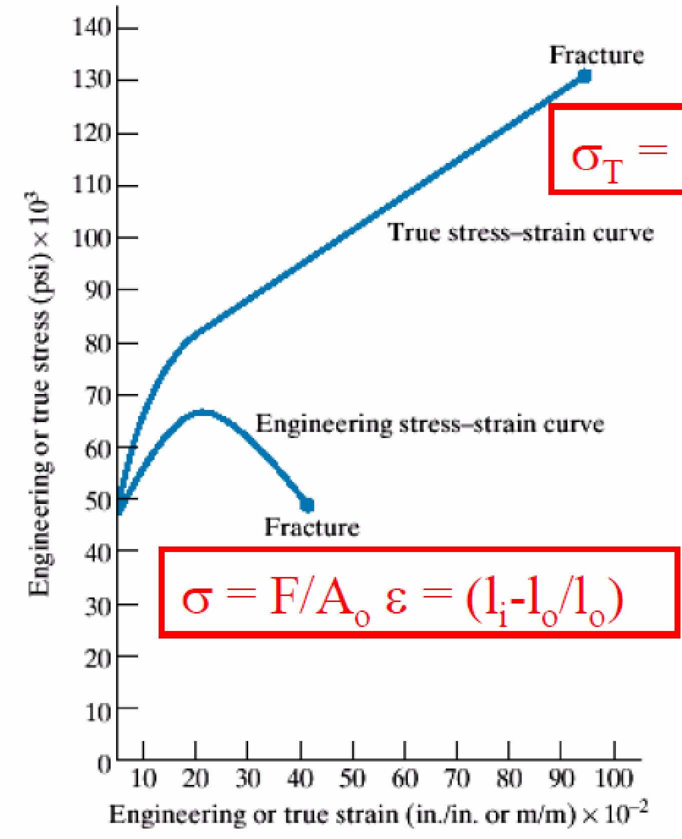
Sometimes it is convenient to use.

true strain defined as :

$\varepsilon_T = \ln(l_i/l_o)$

True stress continues to rise to the point of fracture, in contrast to the engineering stress.





$\sigma_T = F/A_i \quad \varepsilon_T = \ln(l_i/l_o)$

$\sigma = F/A_o \quad \varepsilon = (l_i - l_o/l_o)$

If no volume change occurs during deformation, $A_i l_i = A_0 l_0$ and the true and engineering stress and stress are related as

$$\sigma_T = \sigma(1 + \varepsilon)$$

$$\varepsilon_T = \ln(1 + \varepsilon)$$