Outline

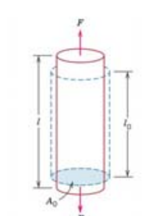
- Introduction
- Mechanical testing
- Tensile test
- Elastic deformation

Mechanical Properties

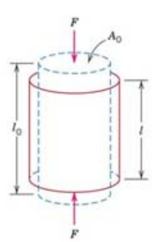
- From an applications standpoint, one of the most important topics within Materials Sc. & Eng. is the study of how materials respond to external loading or deformation.
- Most components, even if used primarily for other property (electronic substrate) have to fulfil certain *mechanical functions* as well.
- Important mechanical properties are strength, hardness, stiffness and ductility.
- Laboratory testing to measure mechanical properties attempts to replicate the service conditions.
- Consistency is accomplished by using standardised test, so people are measuring same thing in the same way
- **A**merican **S**ociety for **T**esting **M**aterials (ASTM) maintains and updates standards for mechanical properties.
- Several other standards organizations exist, e.g. SAE, ANSI, DIN….

Mechanical testing of metals

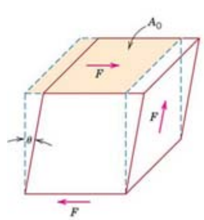
Loading can take any of the following forms:



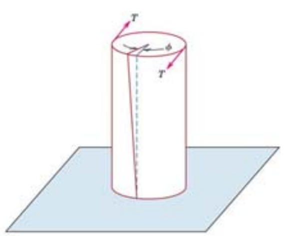
Pulling/ Stretching



squeezing/ squashing



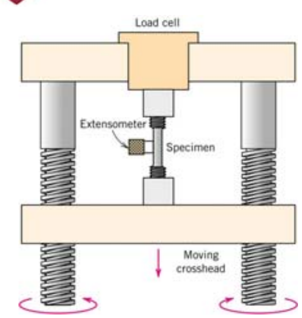
sliding



twisting

Different tests measure different types of loading conditions

Tensile Test

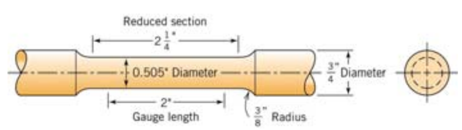


A typical tensile test machine

- The material's response to the applied tensile or compressive load is a change in length.
- We can monitor the change in length very precisely with an instrument called an *extensometer*.

$$\varepsilon = \frac{l_i - l_o}{l_o} = \frac{\Delta l}{l_o}$$

We call this quantity strain



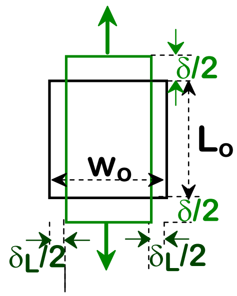
A typical standard tensile test specimen

Where:
l = instantaneous length
l_o = initial length

Strain is a dimensionless quantity (or, can be reported as m/m or in./in.)

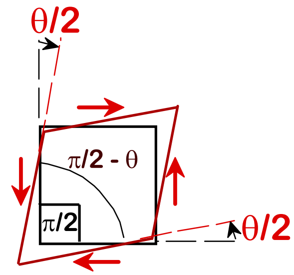
Engineering Strain

- Tensile strain: $\varepsilon = \frac{\delta}{L_o}$
- Lateral strain: $\varepsilon_L = \frac{-\delta_L}{w_o}$



- Shear strain:

$\gamma = \tan \theta$



Strain is always dimensionless.

Tensile Test

Typically, loading is normalized to cross sectional area:

$\sigma = \frac{F}{A_o}$

We refer to this ratio as the applied **stress**

when normalized to initial area, this is **engineering stress**.

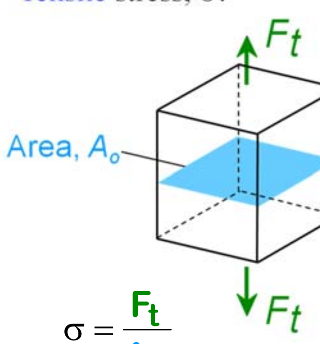
when normalized to actual area, this is **true stress**.

Tensile test

- Load - elongation testing
- But thin wire breaks at lower load than thicker one of the same material
- engineering stress (σ) - engineering strain (ε)

Engineering Stress

Tensile stress, σ:

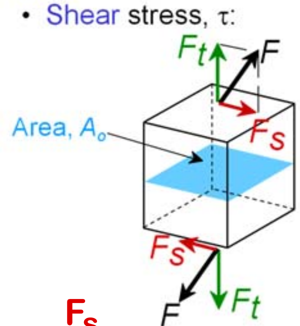


$\sigma = \frac{F_t}{A_o}$

original area before loading

Shear stress, τ:

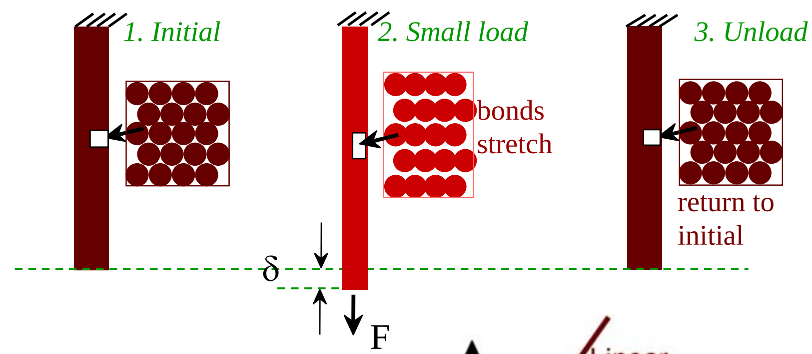
- Shear stress, τ:



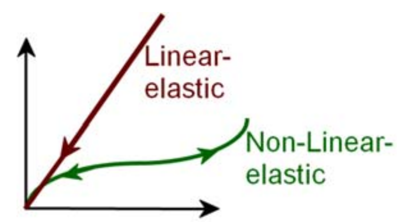
$\tau = \frac{F_s}{A_o}$

Stress has units: N/m^2 or lb/in^2

Elastic Deformation



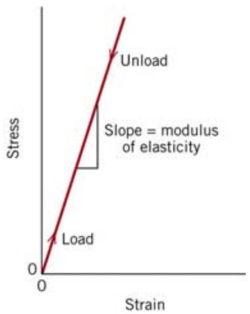
Elastic means reversible!



Stress-Strain Behaviour - *Elastic Response*

Initially, stress and strain are directly proportional to each other

• *Rationale: atoms can be thought of as masses connected to each other through a network of springs.*



According to Hooke's law, the extension of a spring, x, and the applied force, F, are related by the spring contant, k:

$$F = - kx$$

The constant of proportionality, *Young's modulus or modulus of elasticity*, is a measure of the material's stiffness.

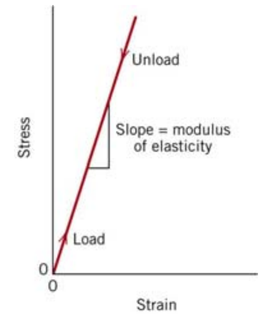
Materials possessing high stiffness: W, Ta, Mo → …….. slope

Materials possessing low stiffness: Al, Cu, Ag → ……… slope

Stress-Strain Behaviour - *Elastic Response*

In the elastic region a material returns to its original dimensions when load is released, and we can write

$$\sigma = E\,\varepsilon \quad \text{or} \quad \frac{F}{A_o} = E\frac{\Delta l}{l_o}$$



Example:

A steel wire with a cross sectional area of 0.55 mm^2 and length of 10 m is extended elastically 1.68 mm by a force of 17.24 N. What is the modulus of elasticity for this steel specimen?

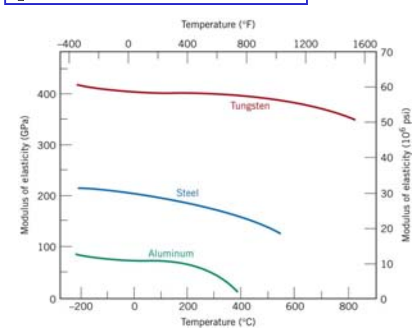
Young's modulus or modulus of elasticity

So E tells us how much something will stretch elastically when loaded, i.e. the **STIFFNESS** of that material

High E value - very stiff ←	Ceramics	300 GPa
	Steel	207 GPa
Medium E value ←	Copper	110 GPa
Low E value: - (not stiff) ←	plastics	3 GPa

In general, the a material's modulus (or stiffness) decreases with increasing temperature.

Can you think of why this happens?



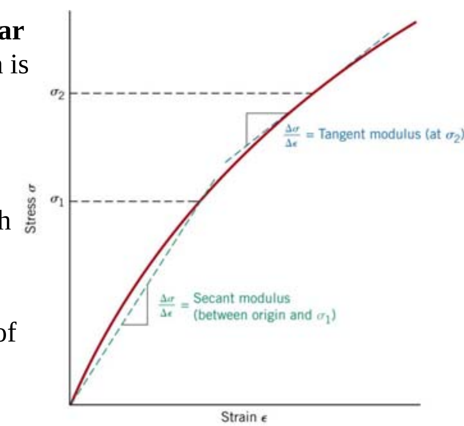
Temperature dependence of elastic moduli

Tangent and Secant Modulus

- Some materials do not show **linear** elastic region; their elastic region is non-linear. Cast iron, concrete, some polymers.

In this case E is harder to define:

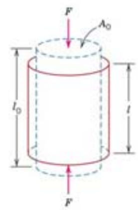
- Can use **Tangent modulus** which is slope of tangent at a particular stress level, or,
- **Secant modulus** which is slope of the line joining origin with some specified stress level.



Compression, Shear and Torsion Tests

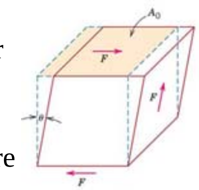
Compression

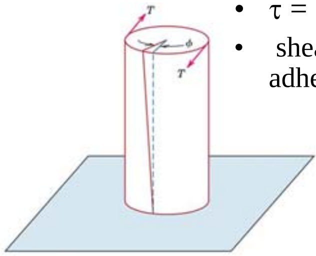
- by convention, stress and strain are negative
- used for measuring strength of brittle materials and for calculating forces required in manufacturing processing which involve compressive deformation



Shear

- shear stress is $\tau = F/A_o$ and γ (shear strain) is tangent of shear angle, θ
- $\tau = G\gamma$, G is shear modulus
- shear tests are often used to measure adhesive bonding, riveted joints etc



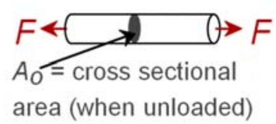


Torsion

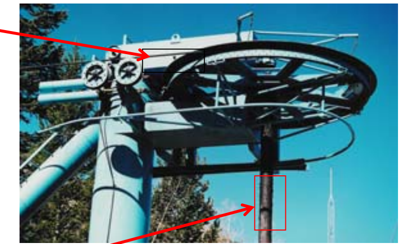
- *torsion* is a variation of shear occurring in *machine axles, drive shafts and twist drills*
- $T = f(\tau)$ and $\gamma = f(\phi)$

Common States of Stress

Simple tension: cable

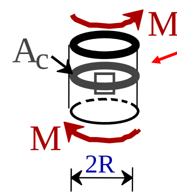


$$\sigma = \frac{F}{A_o}$$



Ski lift *(photo courtesy P.M. Anderson)*

Torsion: drive shaft



Simple compression:

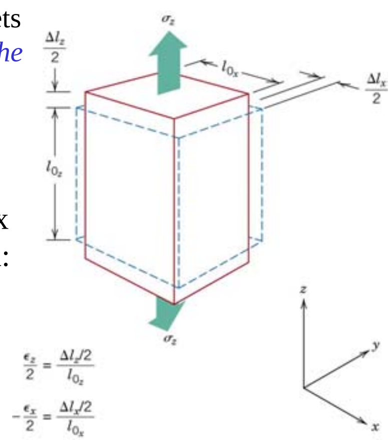
Canyon Bridge, Los Alamos, NM
(photo courtesy P.M. Anderson)

Poisson's Ratio

- When pulled in tension (Z), a sample gets longer and thinner, i.e., *a contraction in the width (X) and breadth (Y)*
  - *if compressed gets fatter*
- **Poisson's ratio** defines how much strain occurs in the lateral directions (x & y) when strained in the (z) direction:

$$\upsilon = -\frac{\text{lateral strain}}{\text{longitudinal strain}}$$

$$\nu = -\frac{\varepsilon_x}{\varepsilon_z} = -\frac{\varepsilon_y}{\varepsilon_z}$$



- Typical values = 0.2 to 0.5
- For isotropic materials

$$E = 2G(1+\nu)$$

Some materials are anisotropic so E & G vary with direction (e.g. composite materials and single crystals)

Elastic Deformation: *Anelasticity*

time dependence of elastic deformation

- So far we have assumed that elastic deformation is time …………….. (i.e. applied stress produces instantaneous elastic strain)
- However, in reality elastic deformation takes time and continues after initial loading, and after load release. This time dependent elastic behavior is known as **anelasticit**y.
- The effect is normally small for metals but can be significant for **polymers** ("visco-elastic behavior").

Next topic:
Plastic Deformation