Mechanical Properties of Materials - I

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- Mechanical Properties
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  - ✓ Impact strength

The Elastic Moduli

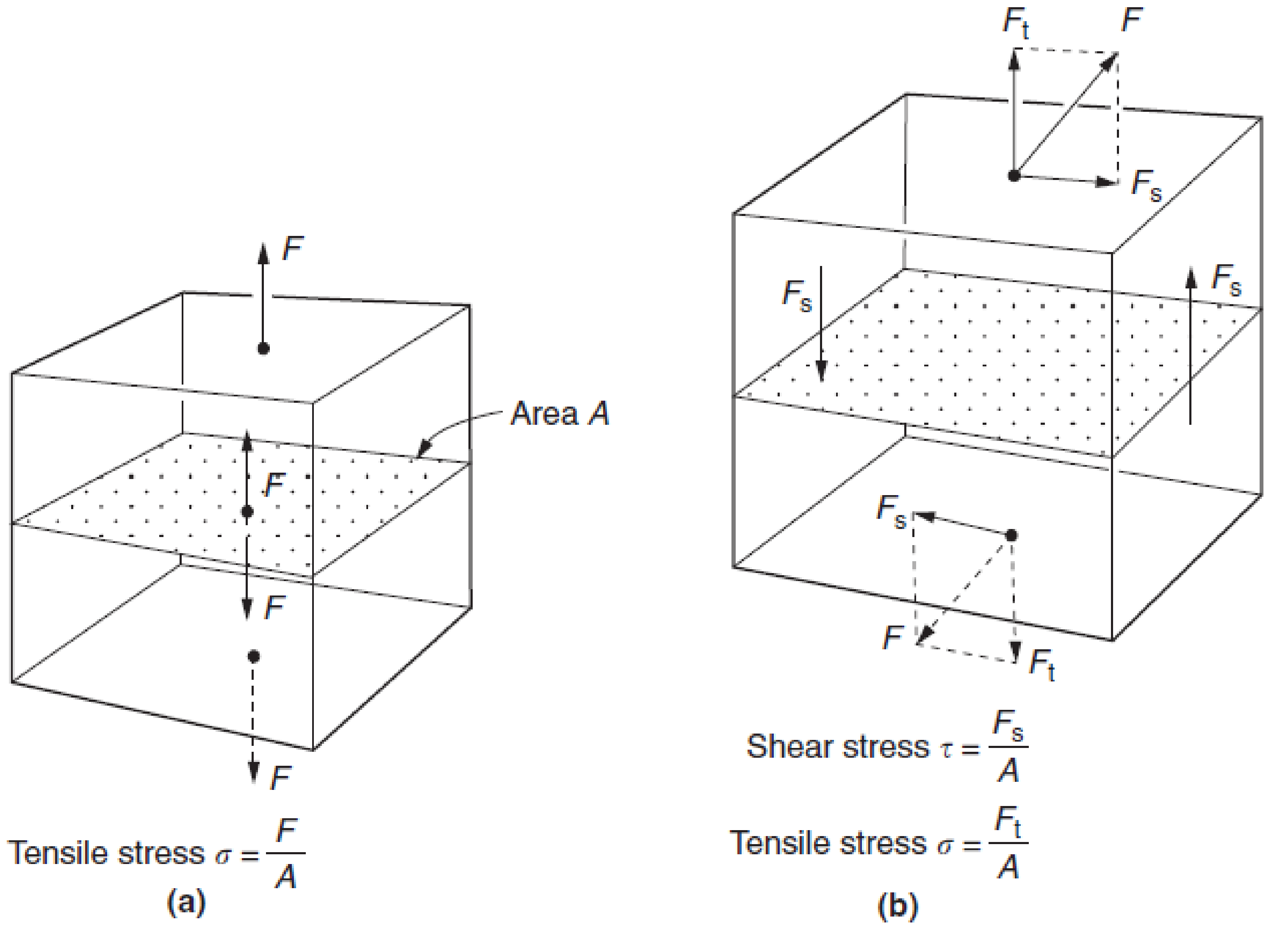
3.2 DEFINITION OF STRESS

Imagine a block of material to which we apply a force F, as in Figure 3.3(a). The force is transmitted through the block and is balanced by the equal, opposite force which the base exerts on the block (if this were not so, the block would move). We can replace the base by the equal and opposite force, F, which acts on all sections through the block parallel to the original surface; the whole of the block is said to be in a state of stress. The intensity of the stress, σ, is measured by the force F divided by the area, A, of the block face, giving

$$\sigma = \frac{F}{A} \tag{3.1}$$

This particular stress is caused by a force pulling at right angles to the face; we call it the *tensile* stress.

Suppose now that the force acted not normal to the face but at an angle to it, as shown in Figure 3.3(b). We can resolve the force into two components—one,



Tensile stress $\sigma = \frac{F}{A}$

Shear stress $\tau = \frac{F_s}{A}$

Tensile stress $\sigma = \frac{F_t}{A}$

FIGURE 3.3

Definitions of (a) tensile stress σ and (b) shear stress τ; balancing shear required for equilibrium, as shown.

F_s, normal to the face and the other, F_s, parallel to it. The normal component creates a tensile stress in the block. Its magnitude, as before, is F_t/A.

The other component, F_s, also loads the block, but it does so in *shear*. The shear stress, τ, in the block parallel to the direction of F_s, is given by

$$\tau = \frac{F_s}{A} \tag{3.2}$$

The important point is that the magnitude of a stress is always equal to the magnitude of a *force* divided by the *area* of the face on which it acts.

Ways of writing stress

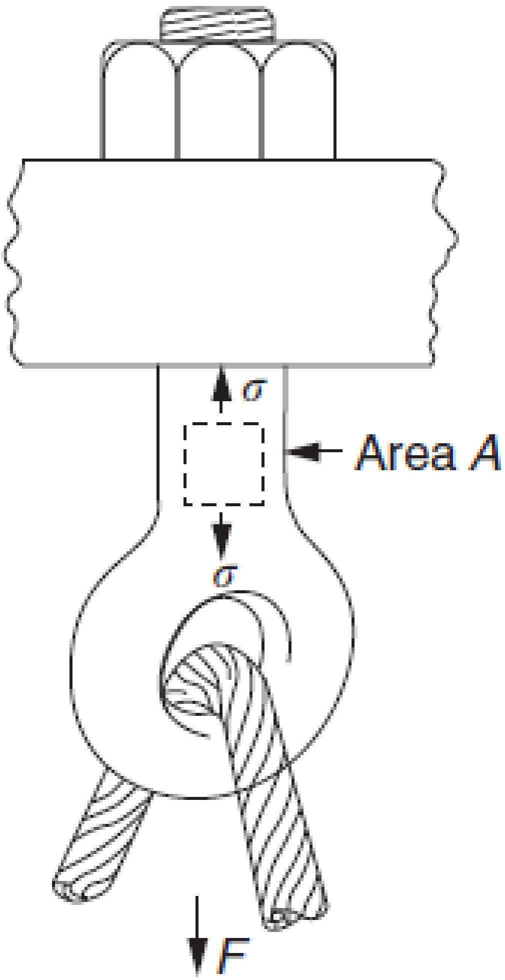
Forces are measured in newtons, so stresses are measured in units of newtons per meter squared ($N\ m^{-2}$). This has also been turned into a relatively new SI unit—the pascal—written as Pa. So a stress might be written as $10\ N\ m^{-2}$ (ten newtons per square meter) or 10 Pa (ten pascals). Stresses in materials are usually sufficiently large that these basic SI units are too small, so the multiple of mega (10^6) usually goes in front—for example $10\ MN\ m^{-2}$

(ten mega-newtons per square meter) or 10 MPa (ten mega-pascals). Values of the elastic modulus are usually larger again, so a multiple of giga (10^9) is used for them—for example 200 GN m^{-2} (200 giga-newtons per square meter) or 200 GPa (200 giga-pascals).

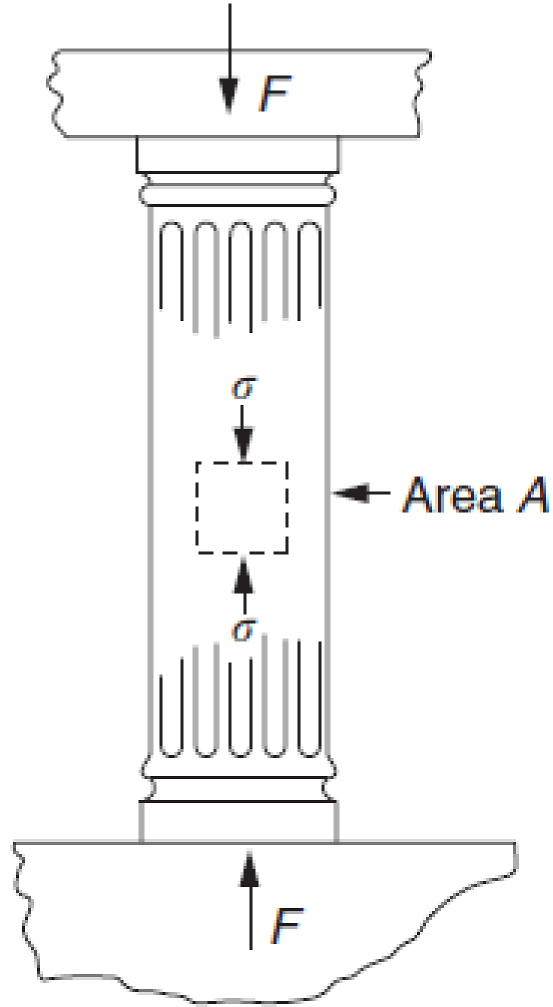
Finally, a *mega*-newton per square meter is the same as a newton per square *millimeter*—for example 10 N mm^{-2} is the same as 10 MN m^{-2}. You can do this in your head—a square meter has an area that is larger than that of a square millimeter by $(10^3)^2 = 10^6$. But a note of warning—if you are using stresses in connection with calculating things such as vibration frequencies, which involve Newton's law of acceleration ($F = ma$)—you must use the basic SI stress unit of N m^{-2} (and the basic mass/density units of kg/kg m^{-3}).

Common states of stress

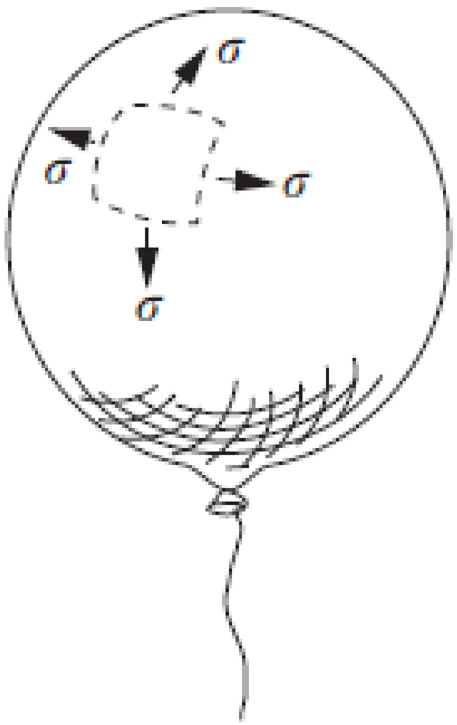
There are four commonly occurring states of stress, shown in Figure 3.4. The simplest is that of *simple tension* or *compression* (as in a tension member loaded by pin joints at its ends or in a pillar supporting a structure in compression). The stress is, of course, the force divided by the section area of the member or pillar. The second common state of stress is that of *biaxial tension*. If a spherical shell (e.g., a balloon) contains an internal pressure, then the skin of the shell is loaded in two directions, not one, as shown in Figure 3.4. This state



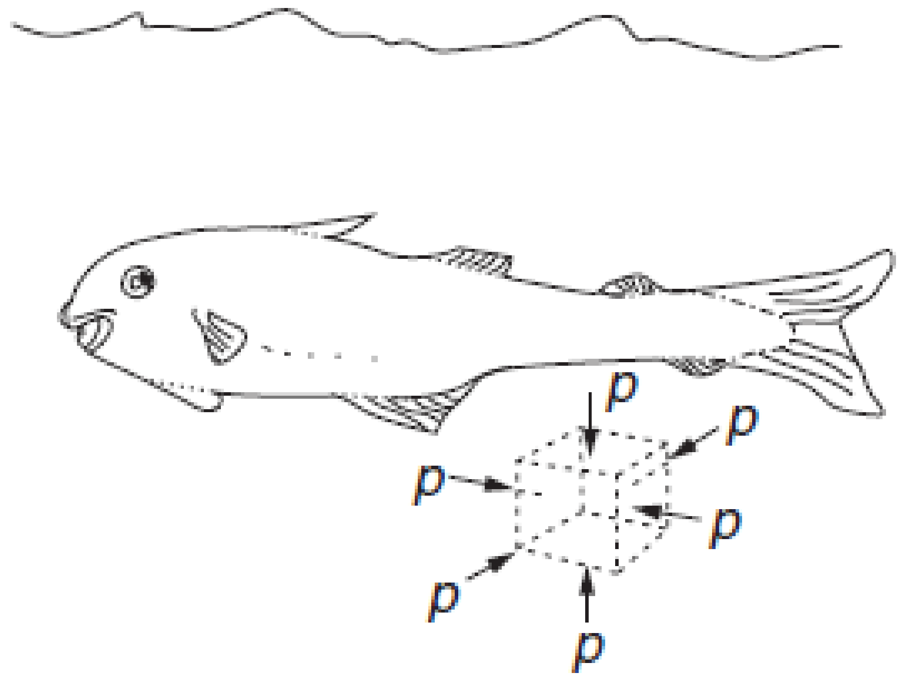
Simple tension, $\sigma = \dfrac{F}{A}$



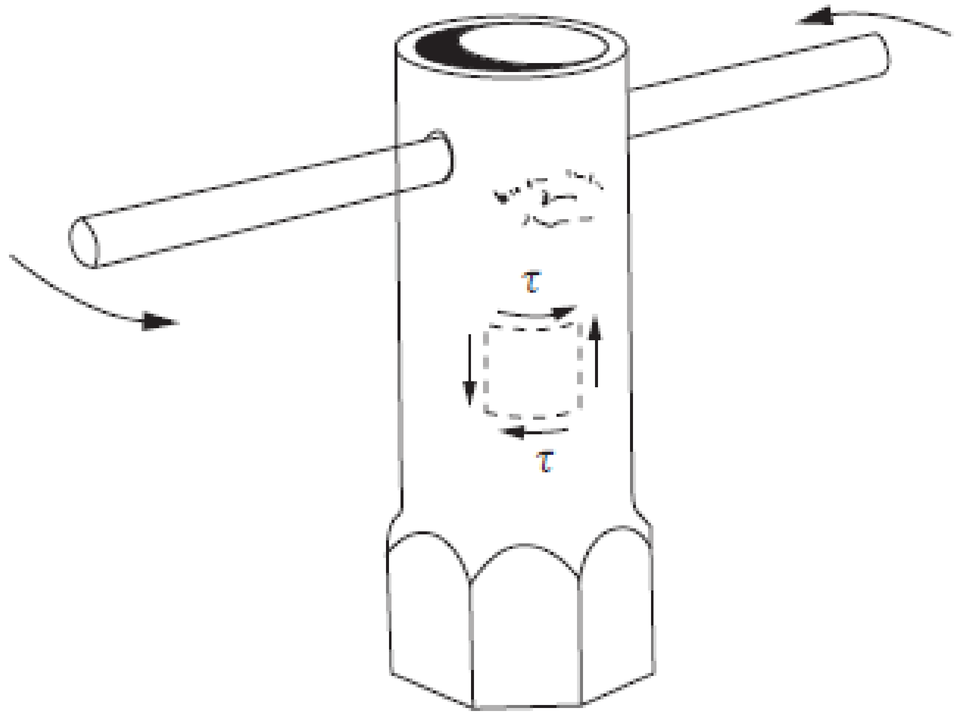
Simple compression, $\sigma = \dfrac{F}{A}$



Biaxial tension, $\sigma = \dfrac{F}{A}$



Hydrostatic pressure, $p = -\dfrac{F}{A}$



Pure shear, $\tau = \dfrac{F_s}{A}$

FIGURE 3.4

Common states of stress: tension, compression, hydrostatic pressure, and shear.

of stress is called biaxial tension (unequal biaxial tension is obviously the state in which the two tensile stresses are unequal). The third common state of stress is that of *hydrostatic pressure*. This occurs deep in the Earth's crust, or deep in the ocean, when a solid is subjected to equal compression on all sides.

There is a convention that stresses are *positive* when they *pull*, as we have drawn them in earlier figures. Pressure, however, is positive when it *pushes*, so that the magnitude of the pressure differs from the magnitude of the other stresses in its sign. Otherwise it is defined in exactly the same way as before: the force divided by the area on which it acts. The final common state of stress is that of *pure shear*. If you try to twist a tube, then elements of it are subjected to pure shear, as shown. This shear stress is simply the shearing force divided by the area of the face on which it acts.

3.3 DEFINITION OF STRAIN

Materials respond to stress by *straining*. Under a given stress, a stiff material (e.g., aluminum) strains only slightly; a floppy or compliant material (e.g., polyethylene) strains much more. The modulus of the material describes this property, but before we can measure it, or even define it, we must define strain properly.

The kind of stress that we called a tensile stress induces a tensile strain. If the stressed cube of side l, shown in Figure 3.5(a) extends by an amount u parallel to the tensile stress, the *nominal tensile strain* is

$$\varepsilon_n = \frac{u}{l} \tag{3.3}$$

When it strains in this way, the cube usually gets thinner. The amount by which it shrinks inwards is described by Poisson's ratio, υ, which is the negative of the ratio of the inward strain to the original tensile strain:

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

A shear stress induces a shear strain. If a cube shears sideways by an amount ω then the *shear strain* is defined by

$$\gamma = \frac{\omega}{l} = \tan\theta \qquad (3.4)$$

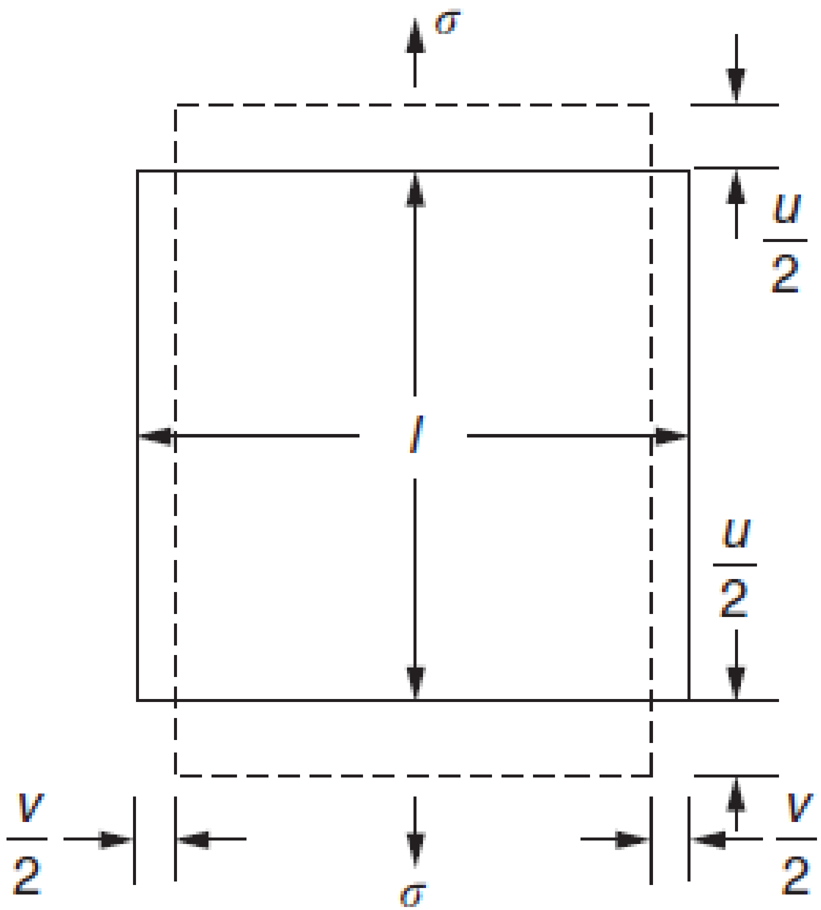
where θ is the angle of shear and l is the edge-length of the cube (Figure 3.5(b)). Since the elastic strains are almost always very small, we may write, to a good approximation,

$$\gamma = \theta$$

Finally, hydrostatic pressure induces a volume change called *dilatation*, as shown in Figure 3.5(c). If the volume change is ΔV and the cube volume is V, we define the dilatation by

$$\Delta = \frac{\Delta V}{V} \tag{3.5}$$

Since strains are the ratios of two lengths or of two volumes, they are dimensionless.



(a)

Nominal tensile strain, $\epsilon_n = \dfrac{u}{l}$

Nominal lateral strain, $\epsilon_n = \dfrac{v}{l}$

Poisson's ratio, $\nu = -\dfrac{\text{lateral strain}}{\text{tensile strain}}$

Concept of Stress and Strain

Stress

- The internal resistance force per unit area acting on a material.
- It uses **original cross section area** of the specimen and also known as **Engineering Stress or Conventional Stress.**

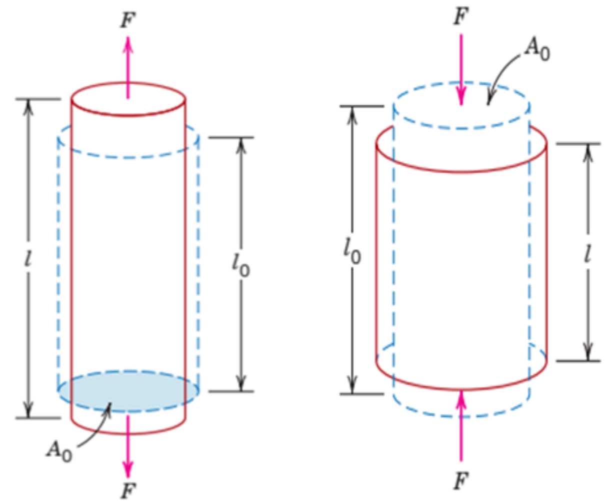
$$\boldsymbol{\sigma} = \frac{\boldsymbol{F}}{\boldsymbol{A_o}}$$

Unit : Pascal (Pa) or N/m^2

1 kPa = 10^3 Pa (kPa = Kilo Pascal)

1 MPa = 10^6 Pa = 1 N/mm^2 (MPa = Mega Pascal)

1 GPa = 10^9 Pa (GPa = Giga Pascal)



Tensile force **Compressive force**

Reference: W.D Callister, 7Ed.

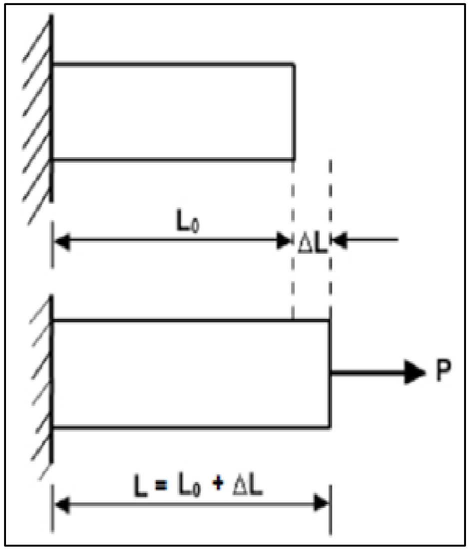
Concept of Stress and Strain

Strain

- Defined as change in length per original length.
- It is unit-less and also known as **Engineering Strain or Conventional Strain/Normal strain.**

$$\in_n = \frac{\Delta L}{L_o}$$

- Sometimes strain is expressed in micro strain. (1 µstrain = 10^{-6})



Strain

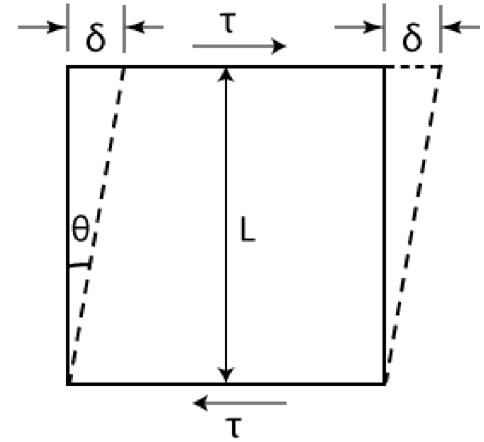
Shear Stress

- Shear stress is tangential to the area over which it acts.

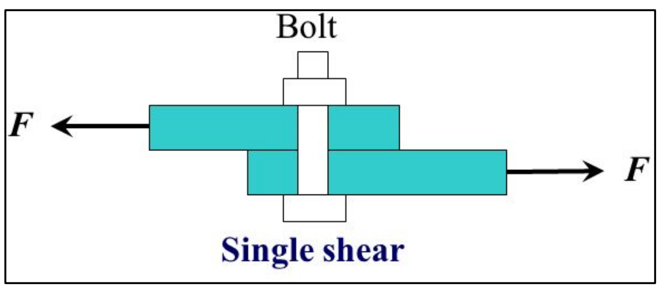
$$Shear\ stress, \tau = \frac{Shear\ force}{Shear\ area}$$

$$Shear\ strain, \gamma = \frac{Lateral\ displacement\ (\delta)}{Distance\ between\ faces\ (L)} = \tan\theta$$

$\approx \theta$ for small strain



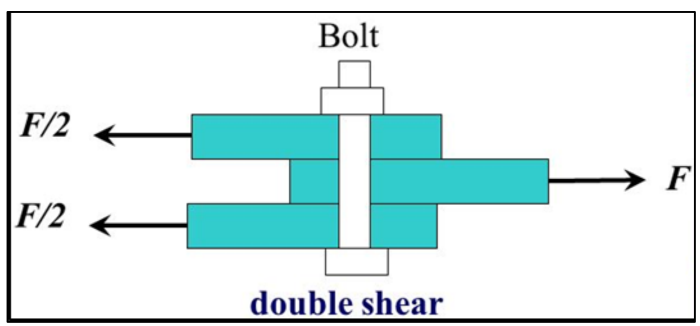
Shear deformation



Single shear

$$\tau = \frac{F}{\frac{\pi}{4} d^2}$$

Reference: Engineering Materials 1: Ashby & Jones, 4th Ed.



double shear

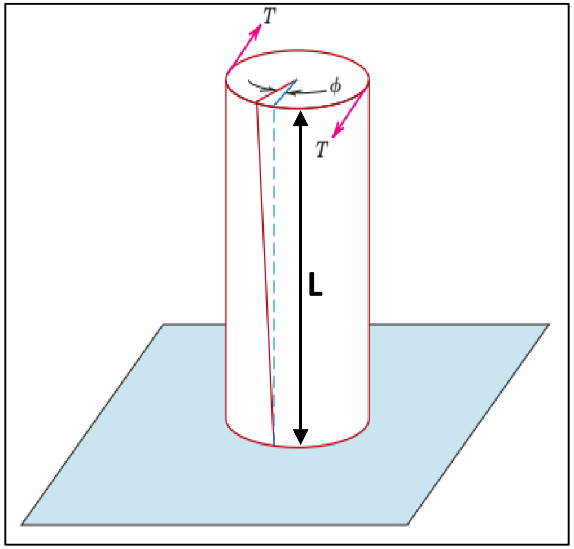
$$\tau = \frac{F/2}{\frac{\pi}{4} d^2}$$

Torsion

- Torsion is a variation of pure shear.
- A structural member is twisted in a manner that torsional forces produce a rotational motion about the longitudinal axis of one end of the member relative to the other end.
- Examples : Machine axles, drive shafts, and drills, etc.
- The Torsion equation is given by:

$$\frac{T}{J} = \frac{\tau}{R} = \frac{G\emptyset}{L}$$

where T is applied torque, J is polar M.I (circular section = $\pi/32\ d^4$) , G is shear modulus, R is the radial position of the element, ϕ is the twist angle, and L is the specimen length.



Torsional deformation

Reference: W.D Callister, 7Ed

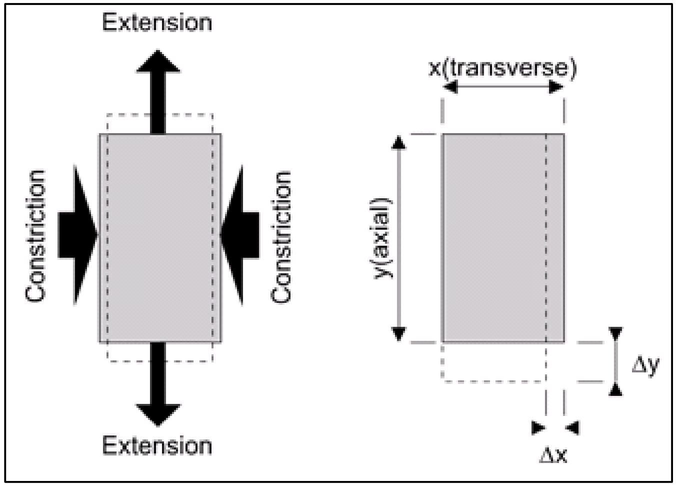
Poisson's Ratio

- A tensile force produces an extension along that axis while it produces contraction along the transverse direction.

$$\text{Poisson's ratio, } \upsilon = \frac{Lateral\ strain}{Tensile\ strain}$$

- If a piece of material neither expands nor contracts in volume when subjected to stress, then the Poisson's ratio must be zero.

- Cork is used in a bottle as it is easily inserted and removed, also withstand the pressure. It can compress to half its size, without bulging out the other side or increasing its length from within the bottle.



S. No.	Material	Poisson's ratio
1.	Steel	0.25-0.33
2.	Cast iron	0.23-0.27
3.	Concrete	0.2
4.	Rubber	0.48-0.5
5.	**Cork**	**Nearly zero**
6.	Novel Foam	Negative

Champagne bottle

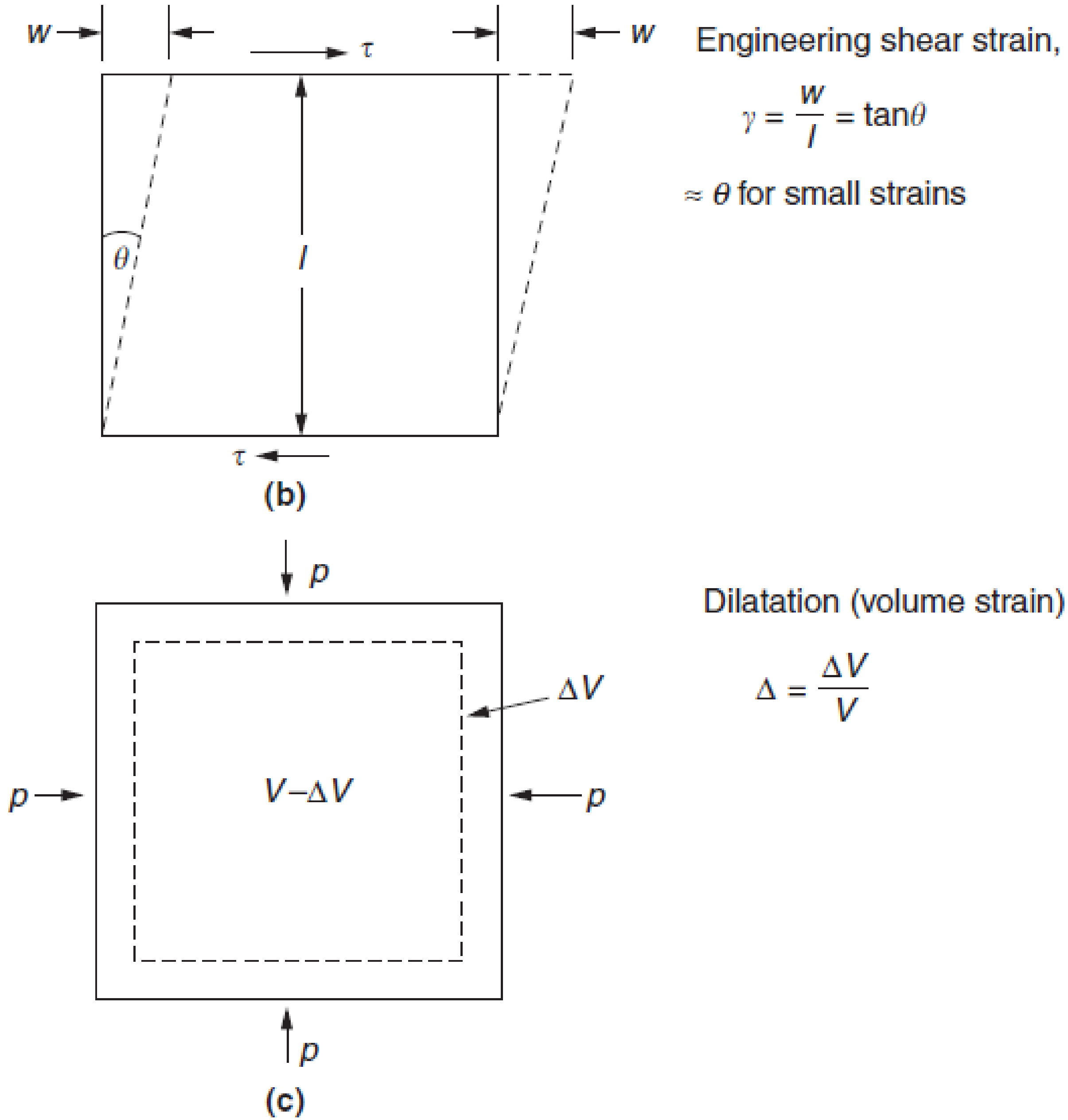
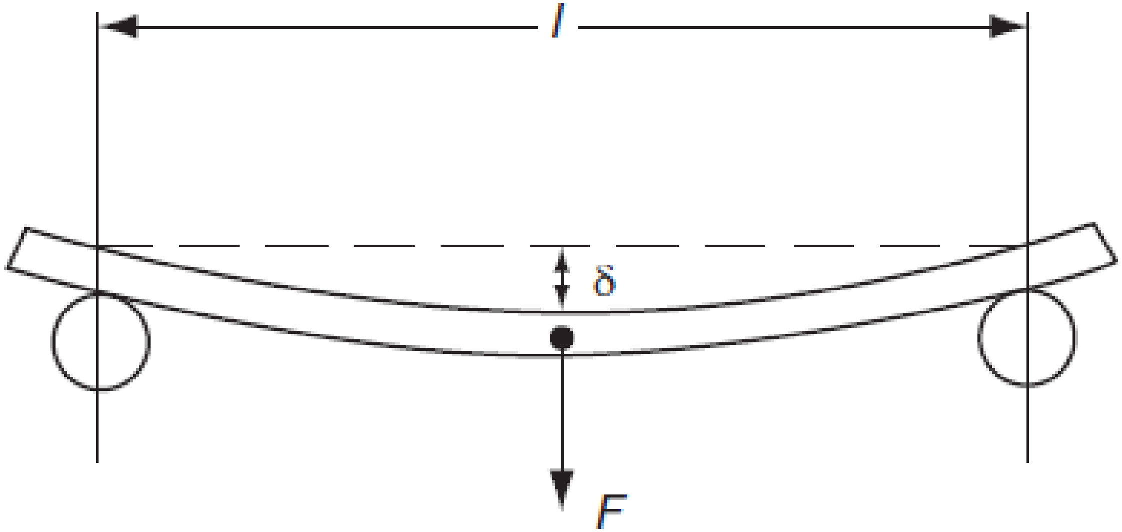


FIGURE 3.5

Definitions of tensile strain, ε_n, shear strain, γ, and dilatation, Δ.



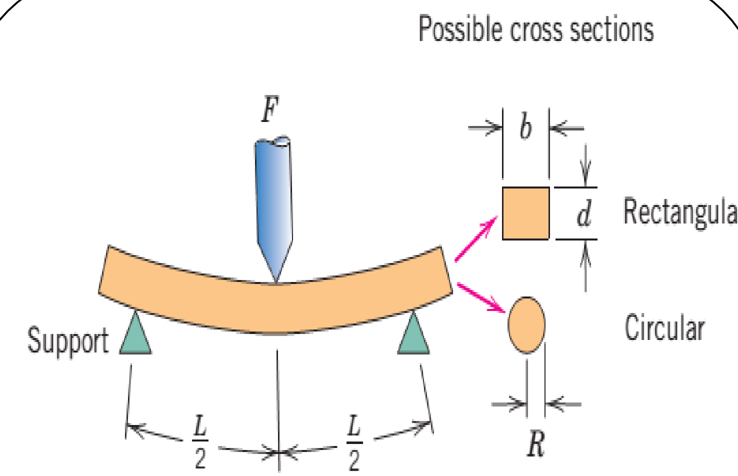
$$\delta = \frac{1}{48}\left(\frac{Fl^3}{EI}\right)$$

FIGURE 3.6

Three-point bend test.

Three-point bending test

- At the point of loading
  - ✓ Specimen top surface in compression
  - ✓ Bottom surface in tension
- Stress is computed from the specimen thickness, B.M, and the M.I of the cross section.
- Maximum tensile stress at the bottom surface directly below the loading point.
- Fracture occurs on the tensile specimen face.
- Tensile strengths of ceramics are about one-tenth of their compressive strengths.



$$\sigma = \text{stress} = \frac{Mc}{I}$$

where M = maximum bending moment

c = distance from center of specimen to outer fibers

I = moment of inertia of cross section

F = applied load

	M	c	I	σ
Rectangular	$\frac{FL}{4}$	$\frac{d}{2}$	$\frac{bd^3}{12}$	$\frac{3FL}{2bd^2}$
Circular	$\frac{FL}{4}$	R	$\frac{\pi R^4}{4}$	$\frac{FL}{\pi R^3}$

Reference: W.D Callister, 7 Ed.

3.4 HOOKE'S LAW

We can now define the elastic moduli. They are defined through Hooke's law, which is a description of the experimental observation that—when strains are small—the strain is very nearly proportional to the stress; the behavior of the solid is *linear elastic*. The nominal tensile strain, for example, is proportional to the tensile stress; for simple tension

$$\sigma = E\varepsilon_{\mathrm{n}} \tag{3.6}$$

where E is called *Young's modulus*. The same relationship also holds for stresses and strains in simple compression.

In the same way, the shear strain is proportional to the shear stress, with

$$\tau = G\gamma \tag{3.7}$$

where G is the *shear modulus*. Finally, the negative of the dilatation is proportional to the pressure (because positive pressure causes a shrinkage of volume) so that

$$p = -K\Delta \tag{3.8}$$

where K is called the *bulk modulus*. Because strain is dimensionless, the moduli have the same dimensions as those of stress.

This linear relationship between stress and strain is a very useful one when calculating the response of a solid to stress, but it must be remembered that many solids are elastic only to *very small* strains: up to about 0.002. Beyond that some break and some become plastic—and this we will discuss in later chapters. A few solids, such as rubber, are elastic up to very much larger strains of order 4 or 5, but they cease to be *linearly* elastic (that is the stress is no longer proportional to the strain) after a strain of about 0.01.

We defined Poisson's ratio as the ratio of the lateral shrinkage strain to the tensile strain. This quantity is also an elastic constant, so altogether we have four elastic constants: E, G, K and ν. In a moment when we give data for the elastic constants we list data only for E. But for many materials it is useful to know that

$$K \approx E, \qquad G \approx \frac{3}{8}E \qquad \text{and} \qquad \nu \approx 0.33 \tag{3.9}$$

(although for some the relationship can be more complicated).

3.5 MEASUREMENT OF YOUNG'S MODULUS

How is Young's modulus measured? This requires both stress and strain to be measured with enough accuracy. In the case of metals, because they are stiff, either the strain needs to be measured very accurately, or there needs to be some way of magnifying it. So we could load a bar of material in tension, having first glued strain gauges to its surface, and use the amplified electrical signal from them to measure the strain. Or we could load a bar in bending—equations for the relationships between applied load and deflection for elastic beams having various loading geometries are given at the end of this chapter.

The three-point bend test is an especially easy geometry to adopt (Figure 3.6). The three-point bend test is also good for brittle materials (brittle metals, ceramics, polymers, composites), because if loaded in tension they may break where they are gripped by the testing machine. It is also good for natural composites, like wood or bamboo.

Floppy materials, like the lower modulus thermoplastics, rubbers and foamed polymers can be tested in compression, reading the strain directly from the movement of the testing machine. However, care needs to be taken that any deflection of the machine itself is allowed for, and also that there is no other source of non-elastic strain like creep. For such materials, the *rate* at which the specimen is strained will often have a significant effect on the modulus values calculated from the test.

Finally, we can measure the velocity of sound in the material. The velocity of longitudinal waves is given by

$$V_L = \left(\frac{E(1-\nu)}{\rho(1+\nu)(1-2\nu)}\right)^{1/2}$$

where ρ is the material density. The velocity of shear (transverse) waves is given by

$$V_T = \left(\frac{G}{\rho}\right)^{1/2}$$

The equation

$$\nu = \frac{1-2(V_T/V_L)^2}{2-2(V_T/V_L)^2}$$

gives the value of Poisson's ratio. An electronic pulser-receiver is placed in contact with one end face of a short solid cylinder of the material. The times of travel of longitudinal and shear waves over the known distance are measured electronically, and used to determine V_L and V_T.

Table 3.1 Data for Young's Modulus, E

Material	E (GN m^{-2})
Diamond	1000
Tungsten carbide, WC	450–650
Osmium	551
Cobalt/tungsten carbide cermets	400–530
Borides of Ti, Zr, Hf	450–500
Silicon carbide, SiC	430–445
Boron	441
Tungsten and alloys	380–411
Alumina, Al_2O_3	385–392

Beryllia, BeO	375–385
Titanium carbide, TiC	370–380
Tantalum carbide, TaC	360–375
Molybdenum and alloys	320–365
Niobium carbide, NbC	320–340
Silicon nitride, Si_3N_4	280–310
Beryllium and alloys	290–318
Chromium	285–290
Magnesia, MgO	240–275
Cobalt and alloys	200–248
Zirconia, ZrO_2	160–241
Nickel	214

Nickel alloys	130–234
CFRP	70–200
Iron	196
Iron-based super-alloys	193–214
Ferritic steels, low-alloy steels	196–207
Stainless austenitic steels	190–200
Mild steel	200
Cast irons	170–190
Tantalum and alloys	150–186
Platinum	172
Uranium	172

Boron/epoxy composites	80–160
Copper	124
Copper alloys	120–150
Mullite	145
Vanadium	130
Titanium	116
Titanium alloys	80–130
Palladium	124
Brasses and bronzes	103–124

Table 3.1 Data for Young's Modulus, E—Cont'd

Material	E (GN m^{-2})
Niobium and alloys	80–110
Silicon	107
Zirconium and alloys	96
Silica glass, SiO_2 (quartz)	94
Zinc and alloys	43–96
Gold	82
Calcite (marble, limestone)	70–82
Aluminum	69
Aluminum and alloys	69–79
Silver	76

Soda glass	69
Alkali halides (NaCl, LiF, etc.)	15–68
Granite (Westerly granite)	62
Tin and alloys	41–53
Concrete, cement	30–50
Fiberglass (glass-fiber/epoxy)	35–45
Magnesium and alloys	41–45
GFRP	7–45
Calcite (marble, limestone)	31
Graphite	27
Shale (oil shale)	18

Common woods, ∥ to grain	9–16
Lead and alloys	16–18
Alkyds	14–17
Ice, H_2O	9.1
Melamines	6–7
Polyimides	3–5
Polyesters	1.8–3.5
Acrylics	1.6–3.4
Nylon	2–4
PMMA	3.4
Polystyrene	3–3.4

Epoxies	2.6–3
Polycarbonate	2.6
Common woods, ⊥ to grain	0.6–1.0
Polypropylene	0.9
PVC	0.2–0.8
Polyethylene, high density	0.7
Polyethylene, low density	0.2
Rubbers	0.01–0.1
Cork	0.01–0.03
Foamed polymers	0.001–0.01

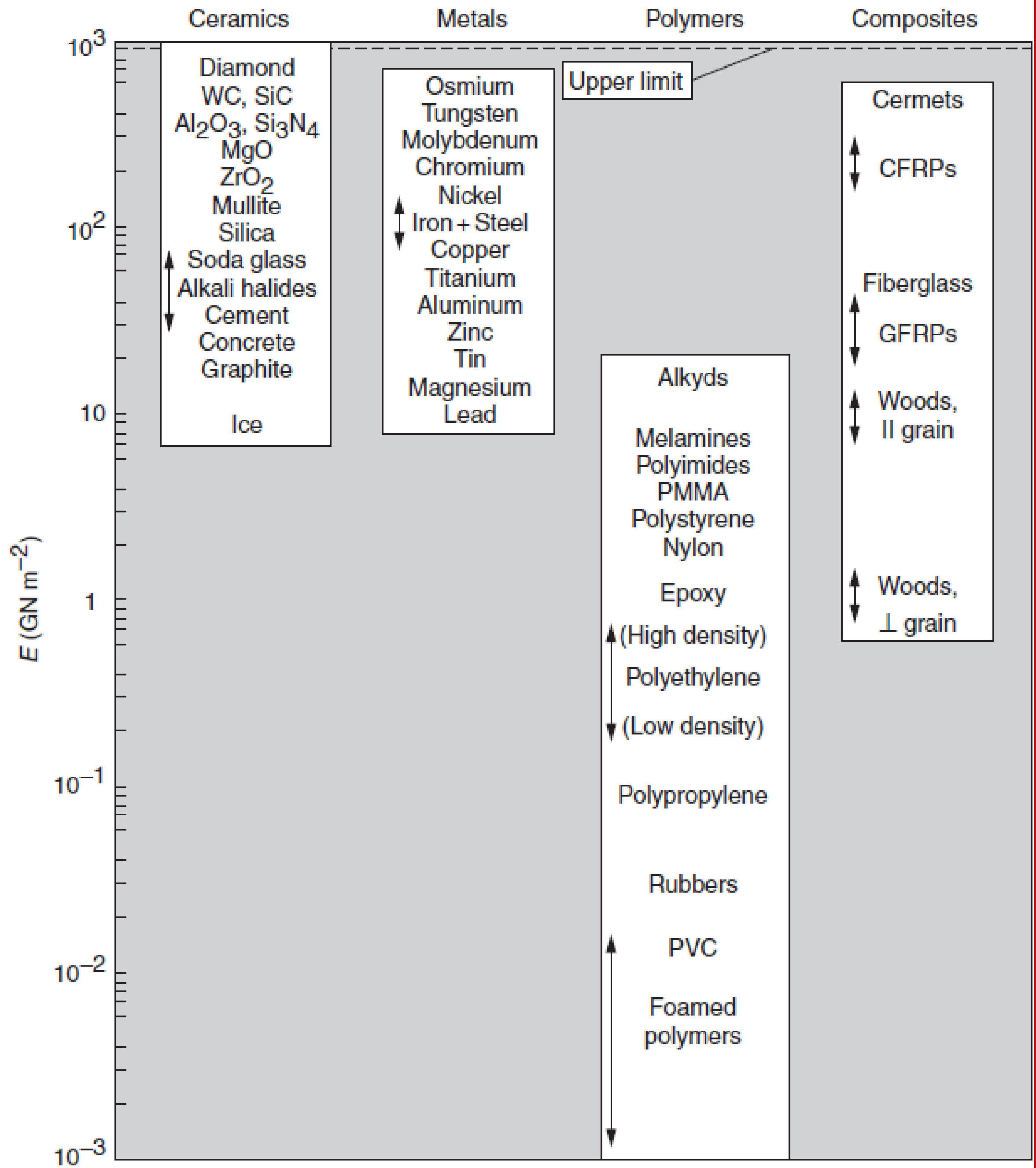
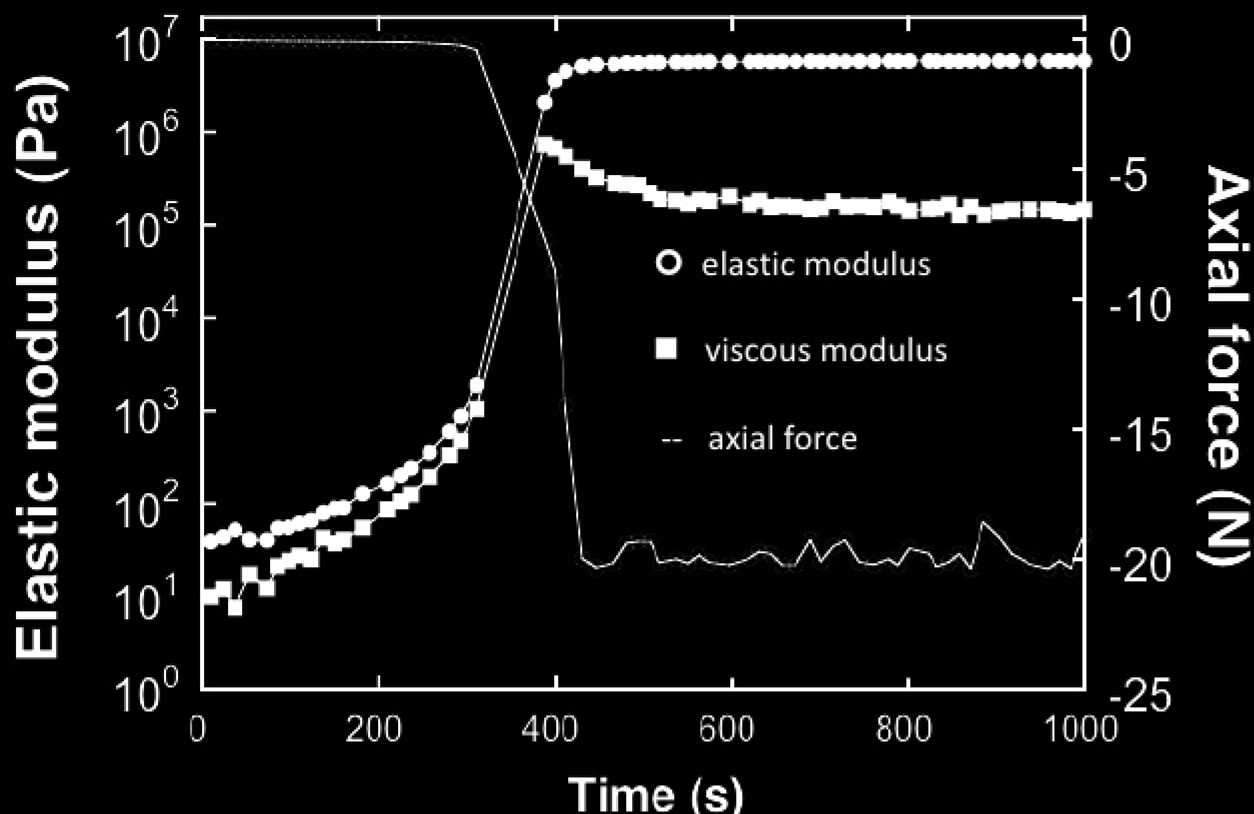


FIGURE 3.7

Bar chart of data for Young's modulus, E.

What is the Modulus of Elasticity of Chocolate?

The rheometer can help quantify the liquid to solid phase transition in cocoa butter.



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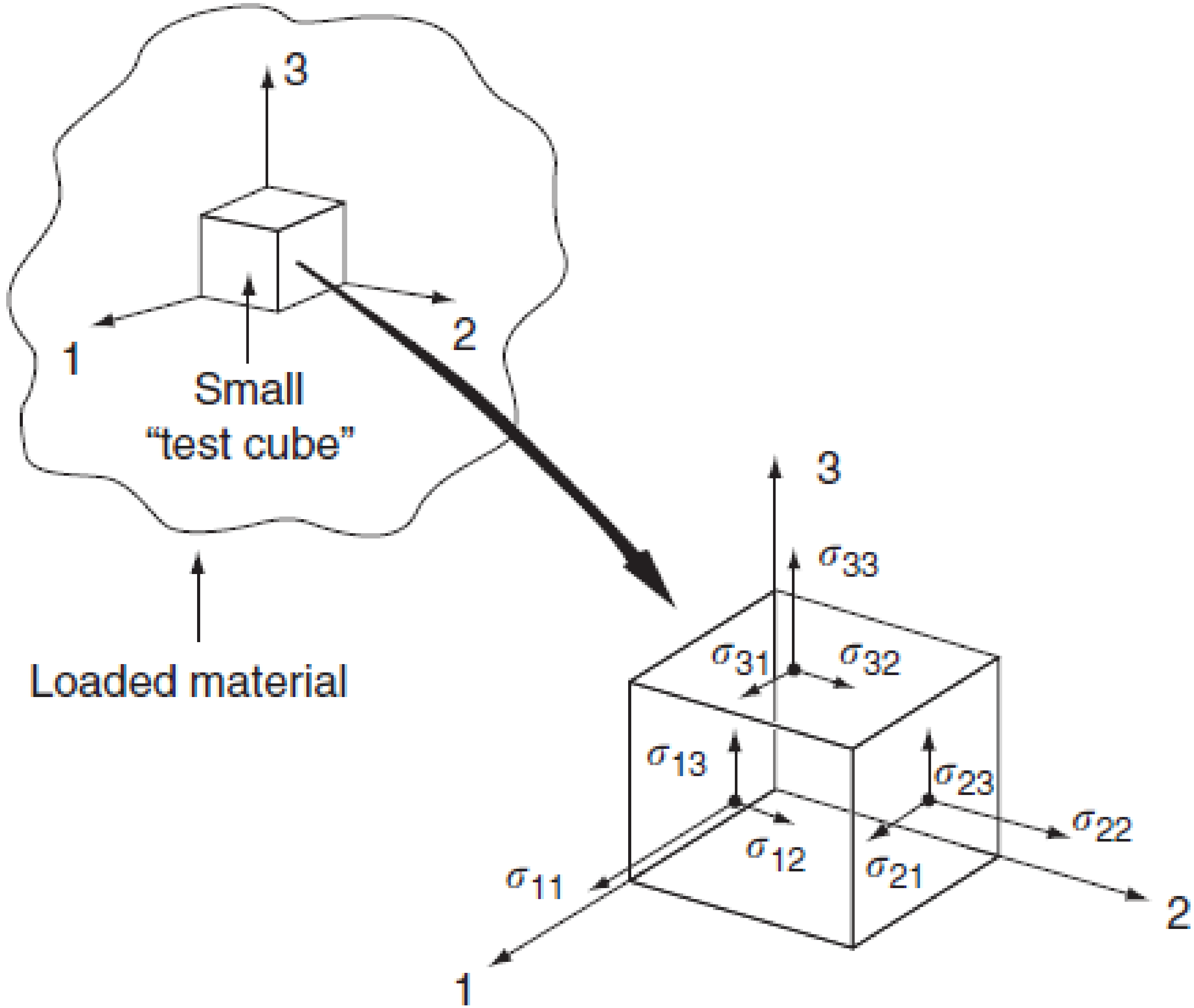
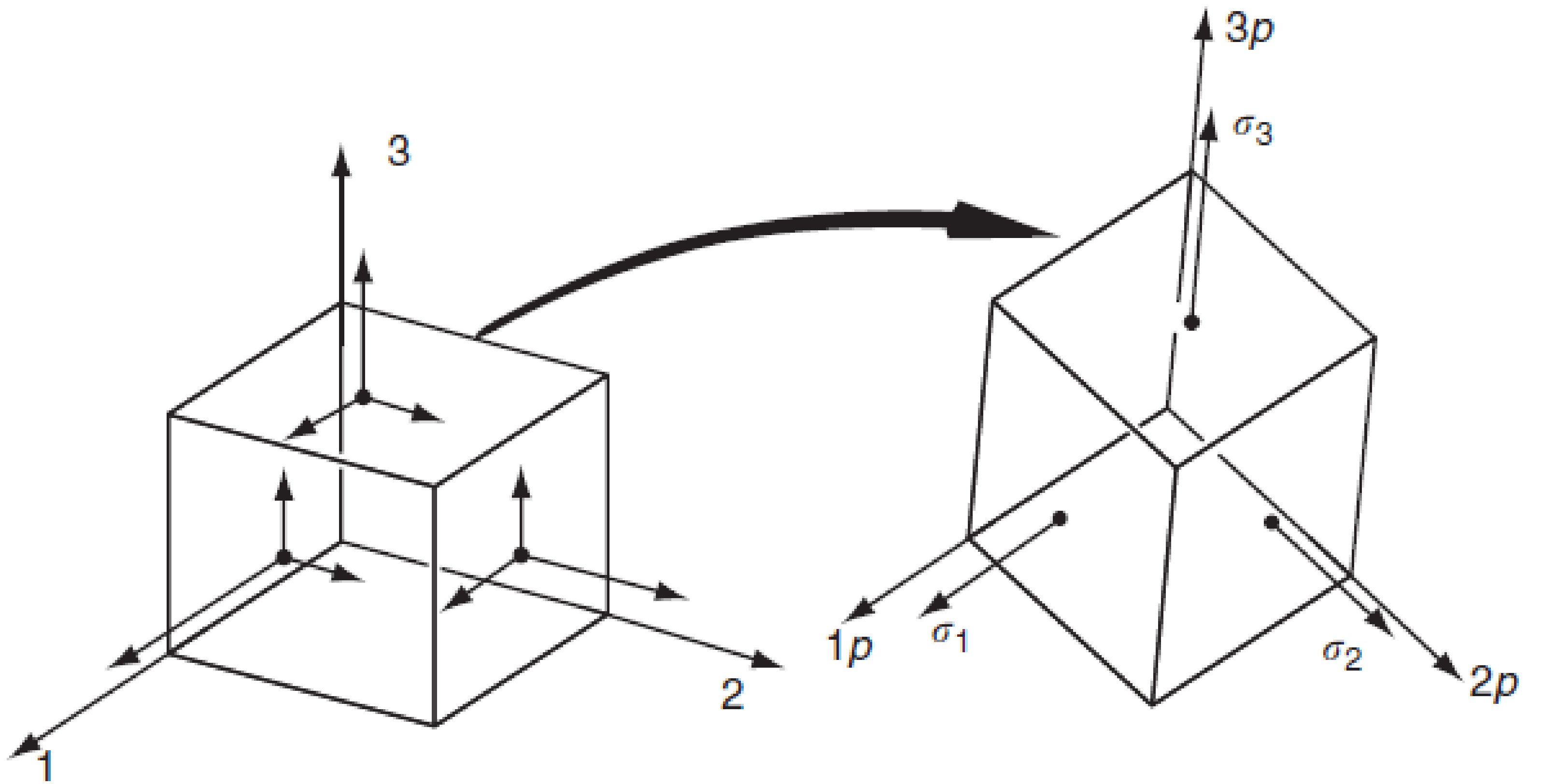
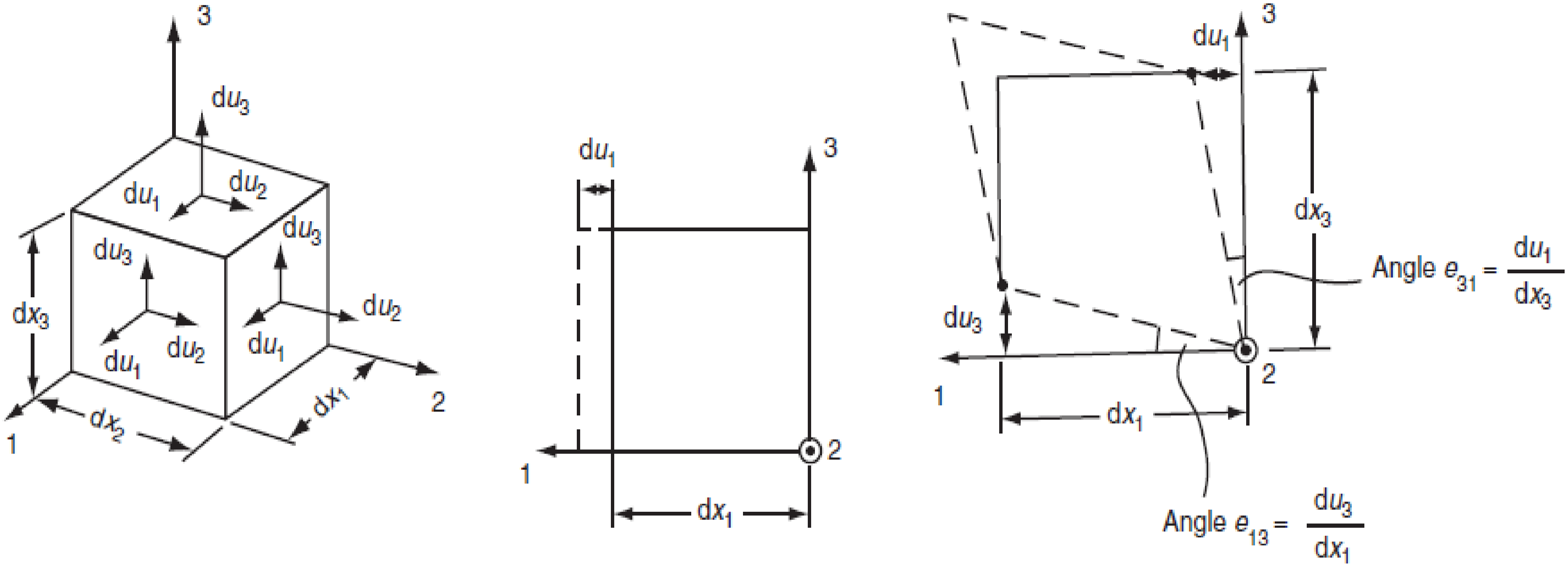

3
2
1
Small
"test cube"
Loaded material
3
σ_{33}
σ_{31}
σ_{32}
σ_{13}
σ_{23}
σ_{22}
σ_{12}
σ_{21}
σ_{11}
2
1



The test cube can always be rotated into one particular orientation where all the shear components vanish.



3
du3
du1
du2
du3
du3
dx3
du2
du1
du2
du1
dx2
dx1
1
2
du1
3
1
2
dx1
3
du1
dx3
Angle e31 = du1 / dx3
du3
1
2
dx1
Angle e13 = du3 / dx1

Hooke's Law

- Within **elastic limit** (low strain value), the stress (σ) is directly proportional to strain (ϵ), i.e., the behavior of solid is ***linear elastic***. The constant of proportion is called the **Elastic Modulus**.

$$\boxed{\sigma = E\epsilon}$$

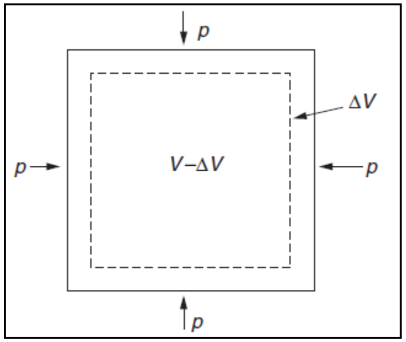
It also holds good for stresses and strain in simple compression.

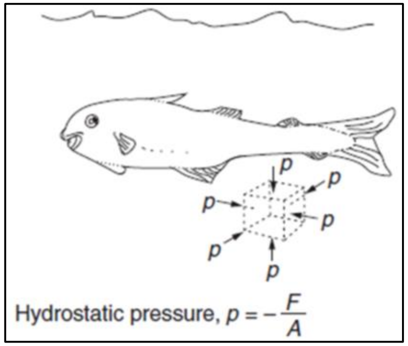
- In the same way shear stress (τ) is proportional to shear strain (γ) as:-

$$\boxed{\tau = G\gamma \text{ , where G is shear modulus}}$$

- The pressure is proportional to the negative of the dilatation (volumetric strain), because positive pressure causes a shrinkage of volume. Hence,

$$\boxed{P = -K\,\frac{\nabla V}{V}\text{, where K is Bulk modulus}}$$

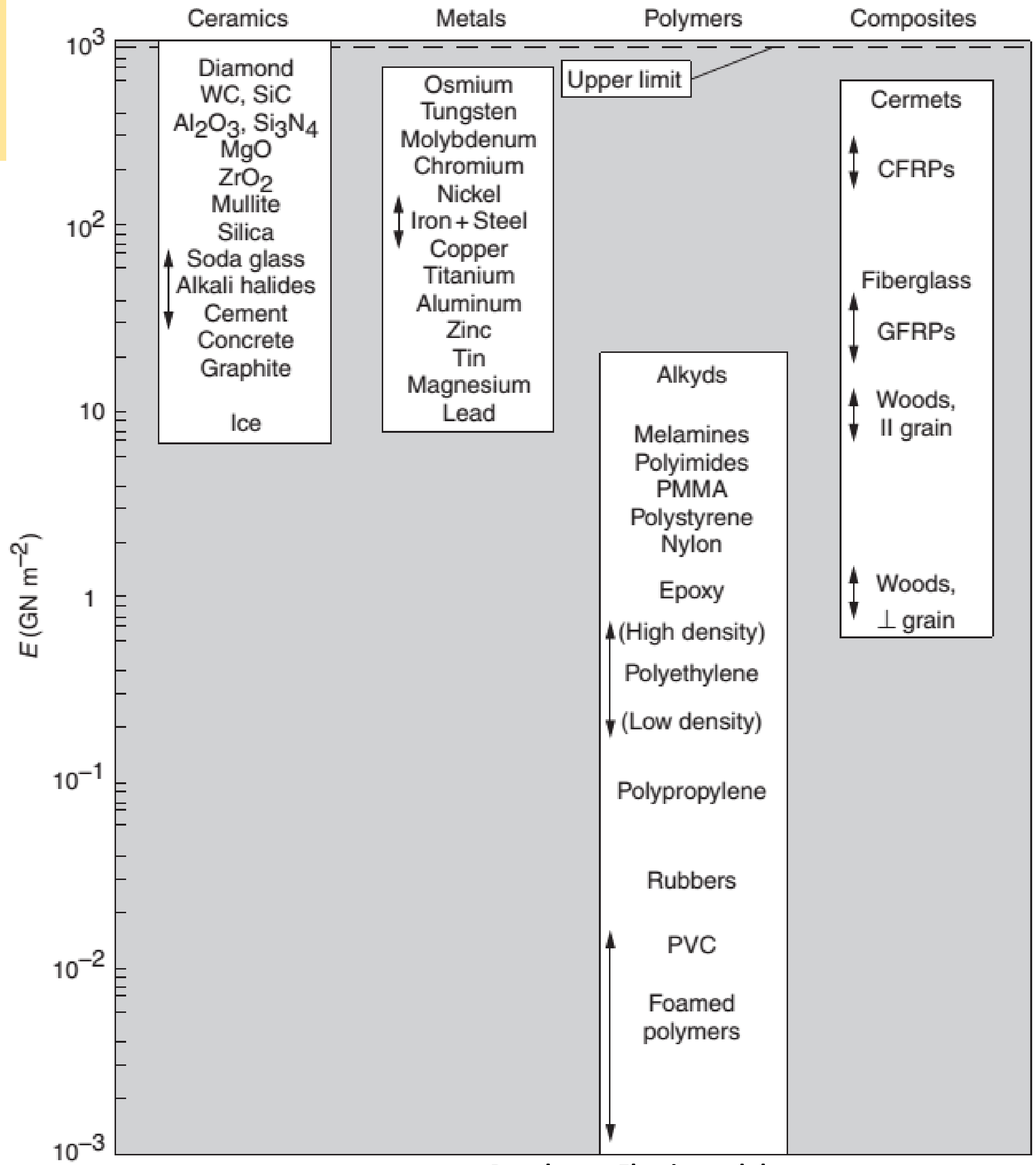




- All three moduli have the same dimension as that of stress.

Reference: Engineering Materials 1: Ashby & Jones, 4th Ed.

Elastic/Young's modulus bar chart data



Bar chart – Elastic modulus

Reference: Engineering Materials 1: Ashby & Jones, 4th Ed.

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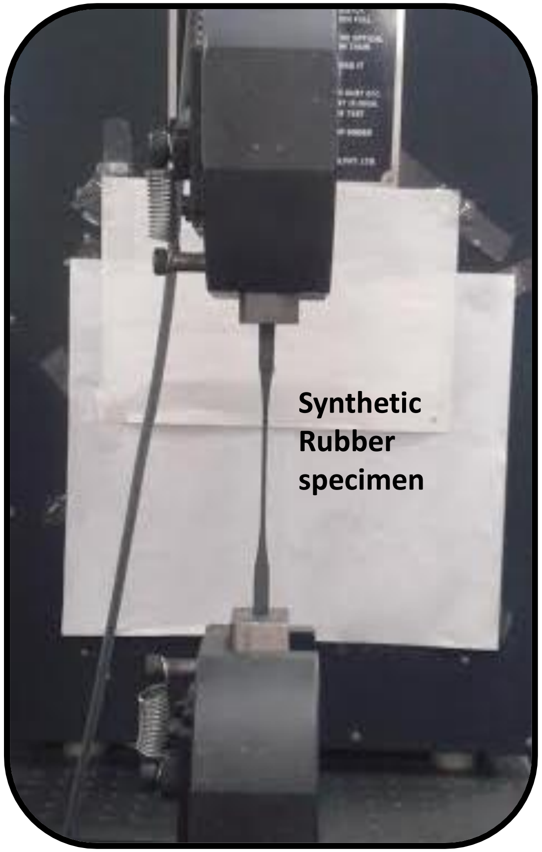
Room-Temperature Elastic and Shear Moduli, and Poisson's Ratio for Various Metal Alloys

Metal Alloy	Modulus of Elasticity GPa	Modulus of Elasticity 10^6 psi	Shear Modulus GPa	Shear Modulus 10^6 psi	Poisson's Ratio
Aluminum	69	10	25	3.6	0.33
Brass	97	14	37	5.4	0.34
Copper	110	16	46	6.7	0.34
Magnesium	45	6.5	17	2.5	0.29
Nickel	207	30	76	11.0	0.31
Steel	207	30	83	12.0	0.30
Titanium	107	15.5	45	6.5	0.34
Tungsten	407	59	160	23.2	0.28

Reference: W.D Callister, 7Ed.

Tensile Testing

- Used for determining Ultimate Tensile Strength (UTS), yield strength, % age elongation, and Young's Modulus of Elasticity.
- The ends of a test piece are fixed into grips, one of which is attached to the load measuring device on the tensile machine and the other to the straining device (load cell).

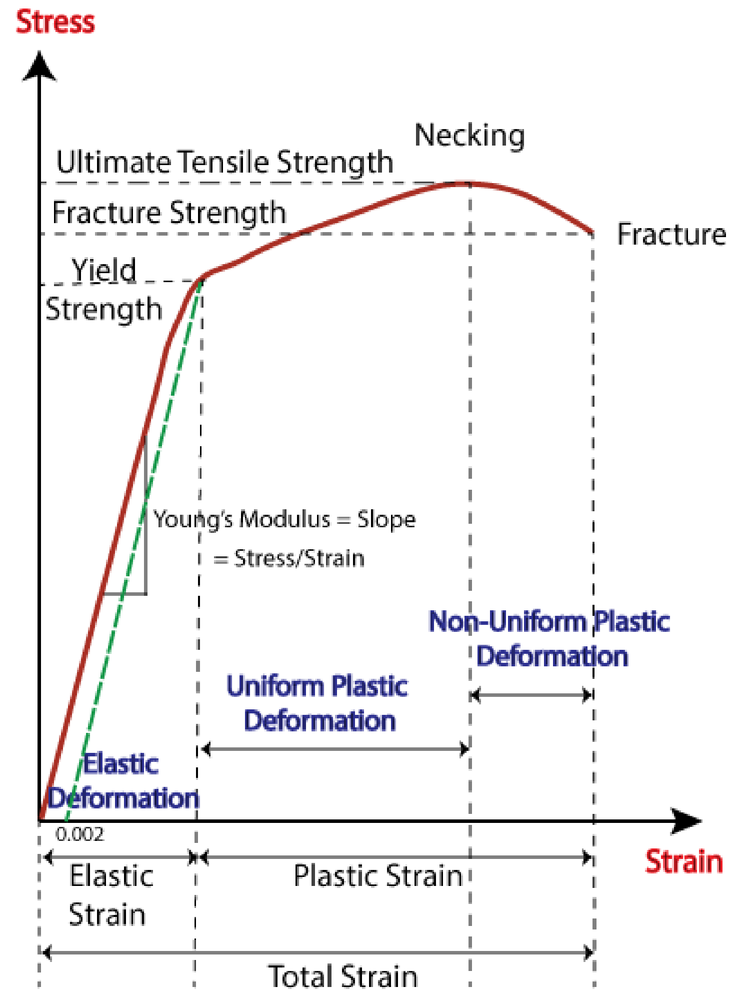


Tensile Testing(UTM), IIT Kanpur

- **Elastic limit**: The greatest stress that material can withstand without any measurable permanent strain after unloading.
- **Yield strength :** Stress at which a material begins to deform plastically.

  Determined by the stress corresponding to the intersection of the stress-strain curve and a line parallel to the elastic line offset by a strain of 0.2 % ($\varepsilon = 0.002$).

- **Tensile strength or Ultimate tensile strength** (UTS): It is the maximum load P_{max} divided by the original cross-sectional area A_o of the specimen.
- % Elongation = $\frac{L_{final} - L_{initial}}{L_{initial}}$ x 100
- % Reduction in Area = $\frac{A_{initial} - A_{final}}{A_{initial}}$ x 100



Typical stress-strain curve

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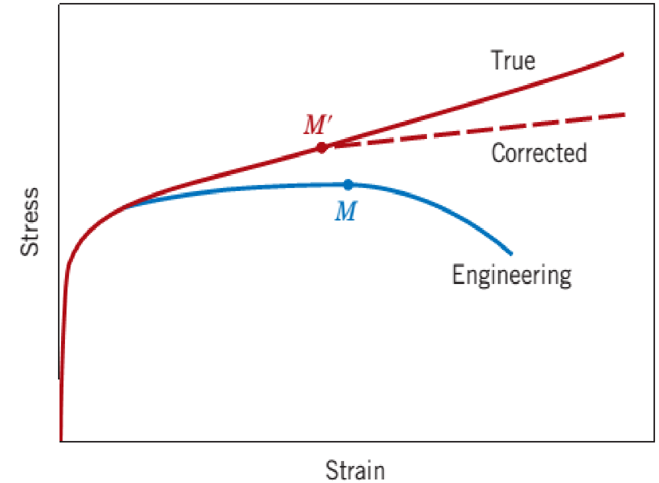
True Stress - Strain curve or Flow Curve

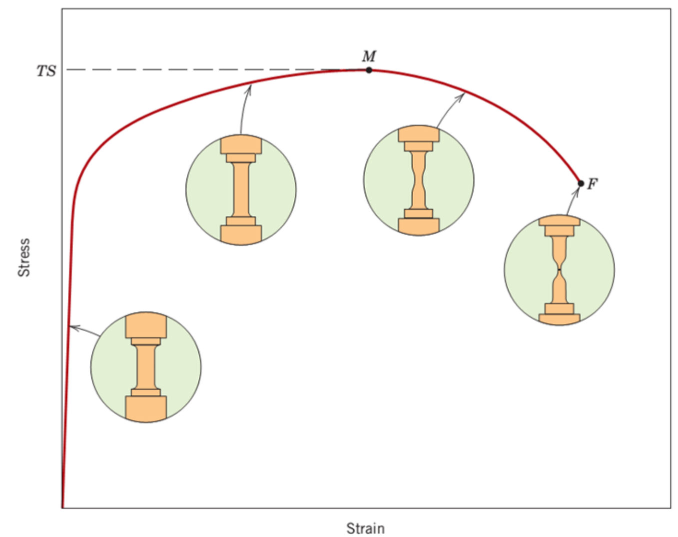
- True stress-strain curve gives a **true indication** of deformation characteristics because it is based on the **instantaneous** dimension of the specimen.
- In **engineering stress-strain curve**, stress drops down **after necking** since it is based on the original area.
- In true stress-strain curve, the stress however increases after necking since the cross-sectional area of the specimen decreases rapidly after necking.
- The flow curve of many metals in the region of uniform plastic deformation can be expressed by the simple **Power Law**

$$\boxed{\sigma_T = K (\varepsilon_T)^n}$$

Where, K is the strength coefficient
n is the strain hardening exponent
n = 0 perfectly plastic solid
n = 1 elastic solid
For most metals, 0.1< n < 0.5



True Stress-strain curve



Conventional Stress-strain curve

Reference: W.D Callister, 7 Ed.

- **True Stress** , $\sigma_T = \frac{Load}{Instantaneous\ Area} = \sigma\,(1+\epsilon)$

where σ , ε are Engineering Stress and Strain respectively.

- **True strain,** $\epsilon_T = \int_{L_o}^{L} \frac{dl}{l} = \ln\left(\frac{L}{L_o}\right) = \ln(1+\epsilon)$

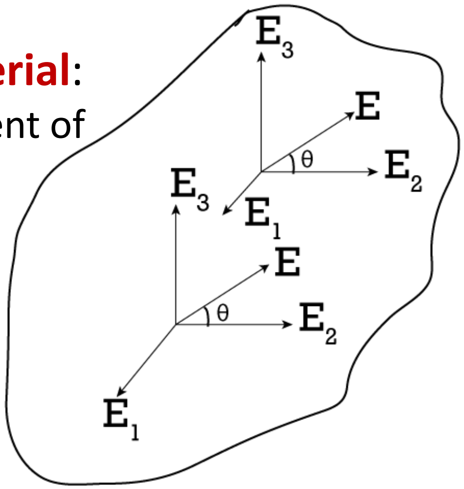
$$= ln\left(\frac{A_o}{A}\right) = 2\ln\left(\frac{D_o}{D}\right)$$

or Engineering Strain (ϵ) = $e^{\epsilon_T} - 1$

The volume of the specimen is assumed to be constant during plastic deformation. [∵ $A_oL_o = AL$]. It is valid till the neck formation.

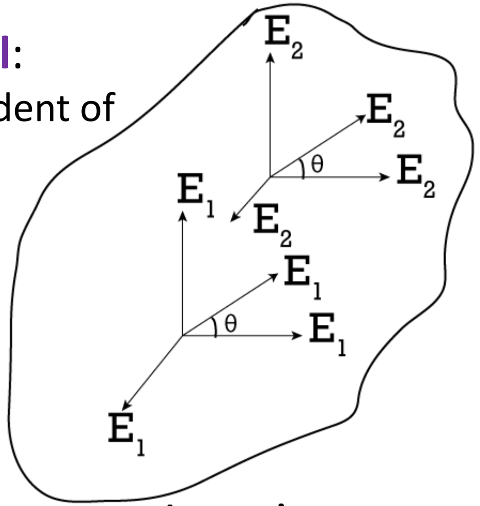
Material Categories

Homogenous material:
Properties independent of point.



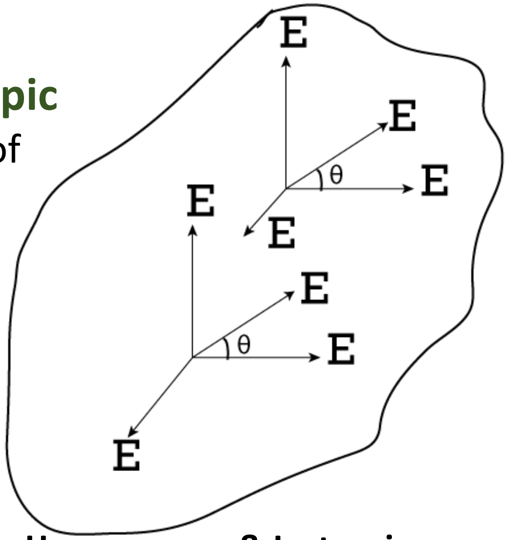
Homogenous

Isotropic material:
Properties independent of direction



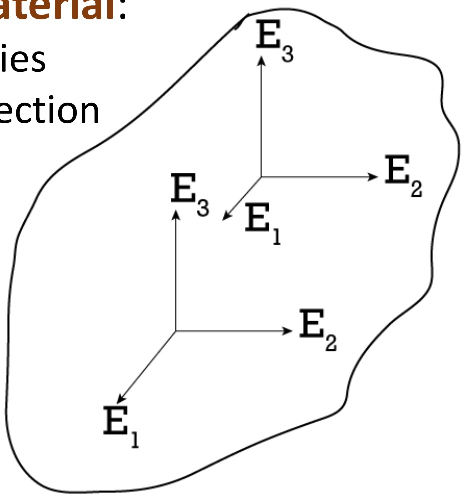
Isotropic

Homogenous & Isotropic
Properties independent of point & direction.



Homogenous & Isotropic

Orthotropic material:
Different properties in orthogonal direction



Orthotropic

Relationship between Elastic constants

$$\boxed{E = 2G(1+\vartheta) = 3K(1-2\vartheta) = \frac{9KG}{3K+G}}$$

Where, K = Bulk Modulus,
ϑ = Poisson's Ratio,
E= Young's modulus,
G= Modulus of rigidity

- For a **linearly elastic, isotropic and homogeneous material**, the number of elastic constants required to relate stress and strain is **two**. i.e. any two of the four must be known.
- If the material is **anisotropic** then the elastic moduli will vary with additional stresses appearing since there is a coupling between shear stresses and normal stresses for an anisotropic material. There are **21 independent elastic constants for anisotropic materials**.
- If there are axes of symmetry in 3 perpendicular directions, material is called Orthotropic materials. **An orthotropic material has 9 independent elastic constants**.

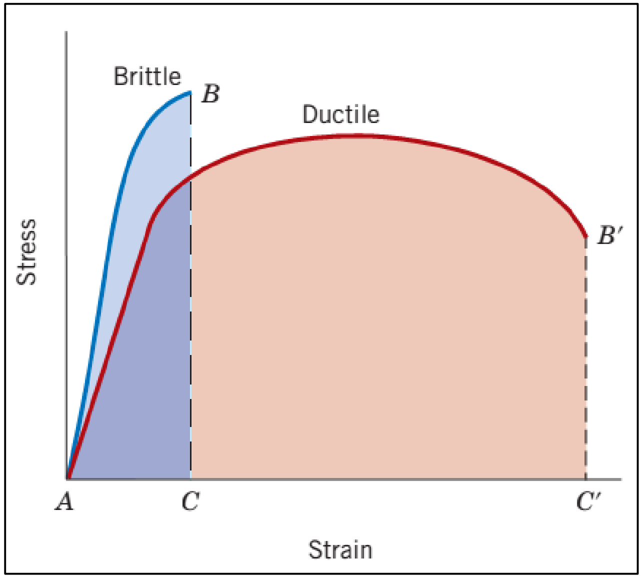
Mechanical Properties (Contd.)

Ductility : Measure of the degree of plastic deformation that has been sustained at fracture.

- Strain at failure is, $\varepsilon \geq 0.05$, or percent elongation greater than 5%.
- Well defined yield point.

Brittleness : A material that experiences very little or no plastic deformation upon fracture.

- Strain at failure is, $\varepsilon \leq 0.05$ or percent elongation less than 5%.
- Do not exhibit an identifiable yield point.



Stress-Strain behaviour
(W.D Callister, 7 Ed.)

Ductile failure - cup & cone

Brittle failure – flat surface

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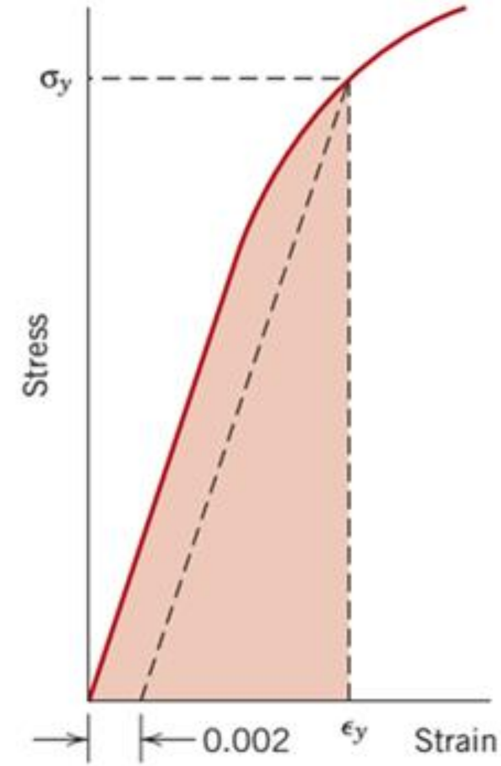
Image courtesy: www.virginia.edu

Resilience

- Resilience is the capacity of a material to **absorb energy** when it is **deformed elastically** and then, **recovering same upon unloading**.
- **Modulus of resilience**, which is the **strain energy per unit volume** required to stress a material from an unloaded state up to the point of yielding.
- **S.I** unit is **J/m³ .**

$$\boxed{U_r = \frac{1}{2}\sigma_y \epsilon_y = \frac{1}{2}\sigma_y\left(\frac{\sigma_y}{E}\right) = \frac{\sigma_y^2}{2E}}$$

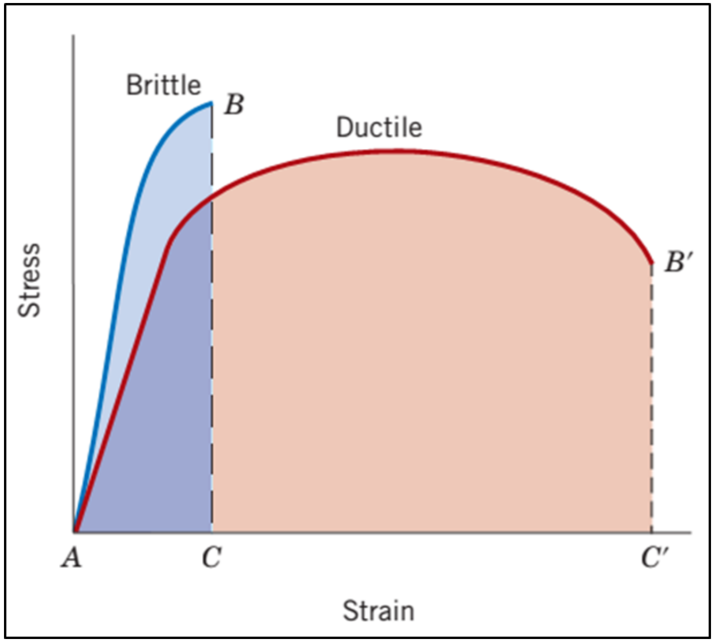


Resilience
(W.D Callister, 7 Ed.)

- Resilient material have high yield strength and low modulus of elasticity, example : Beryllium copper.
- Used in **spring applications**

Toughness

- It is a measure of the ability of a material to **absorb energy up to fracture**.
- Represented by the total area under stress-strain curve up to the fracture point.
- Brittle material has comparatively high yield and tensile strength but low toughness due to lack of ductility.
- **Ductile material are tougher than brittle ones.**

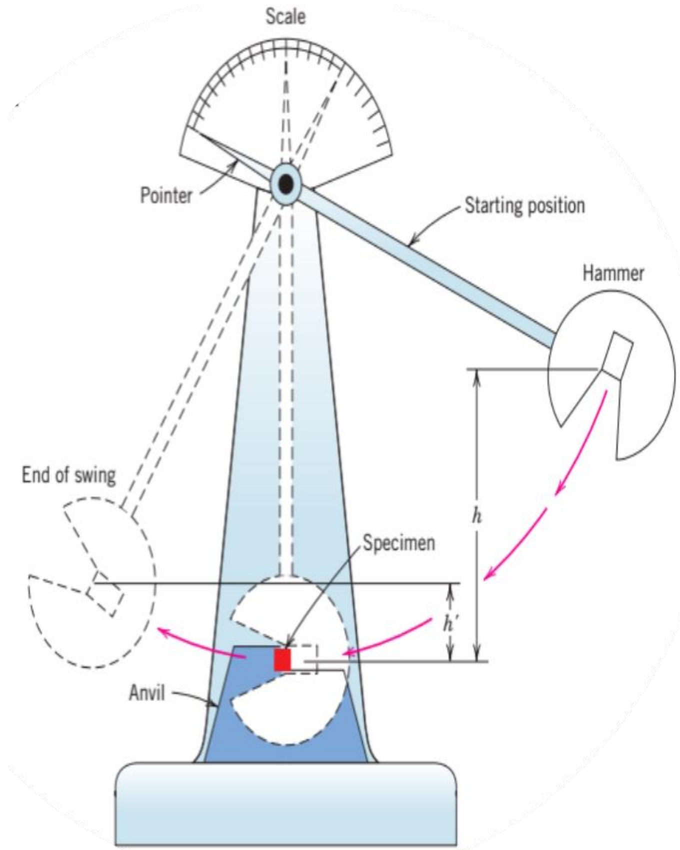


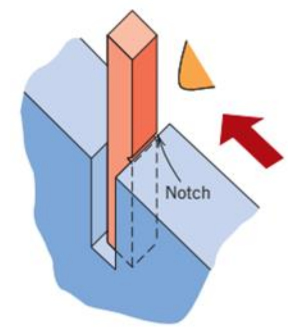
Stress-Strain behaviour

(W.D Callister, 7 Ed.)

Impact Testing - Izod Test

- In these tests a **load swings** from a given height to **strike** the **specimen**, and the **energy dissipated** in the **fracture** is measured.
- Metallic samples tend to be square in cross section, while polymeric test specimens are often rectangular.
- Izod test sample have a **V-notch** cut into them.
- The test piece is clamped vertically with the notch facing the striker.
- The impact energy is calculated based on the height to which the **striker** would have **risen** if **no test specimen** was in place, and this is **compared** to the height to which the **striker actually rises**.

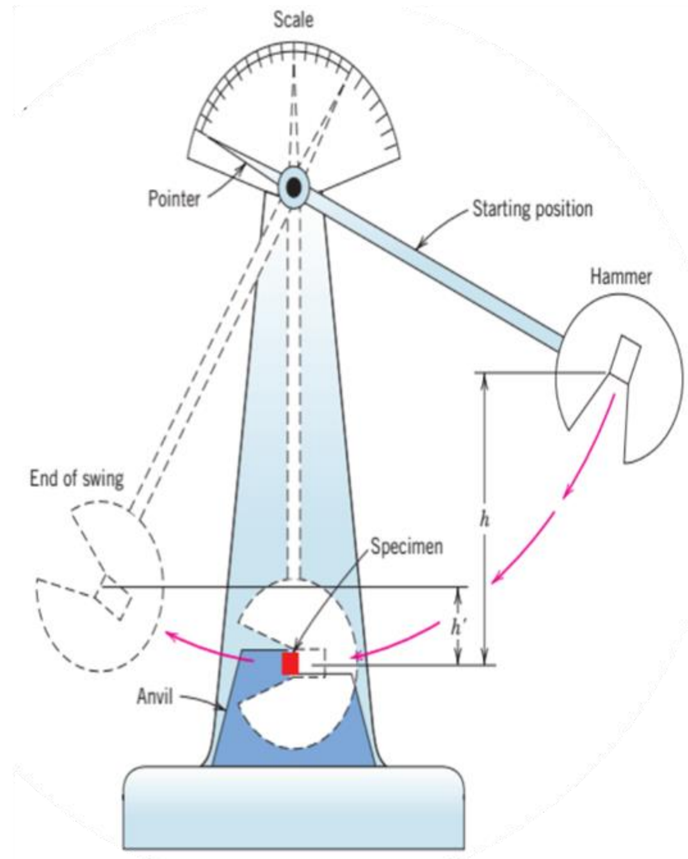


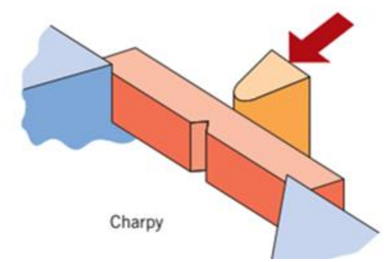


Izod Test
(W.D Callister, 7 Ed.)

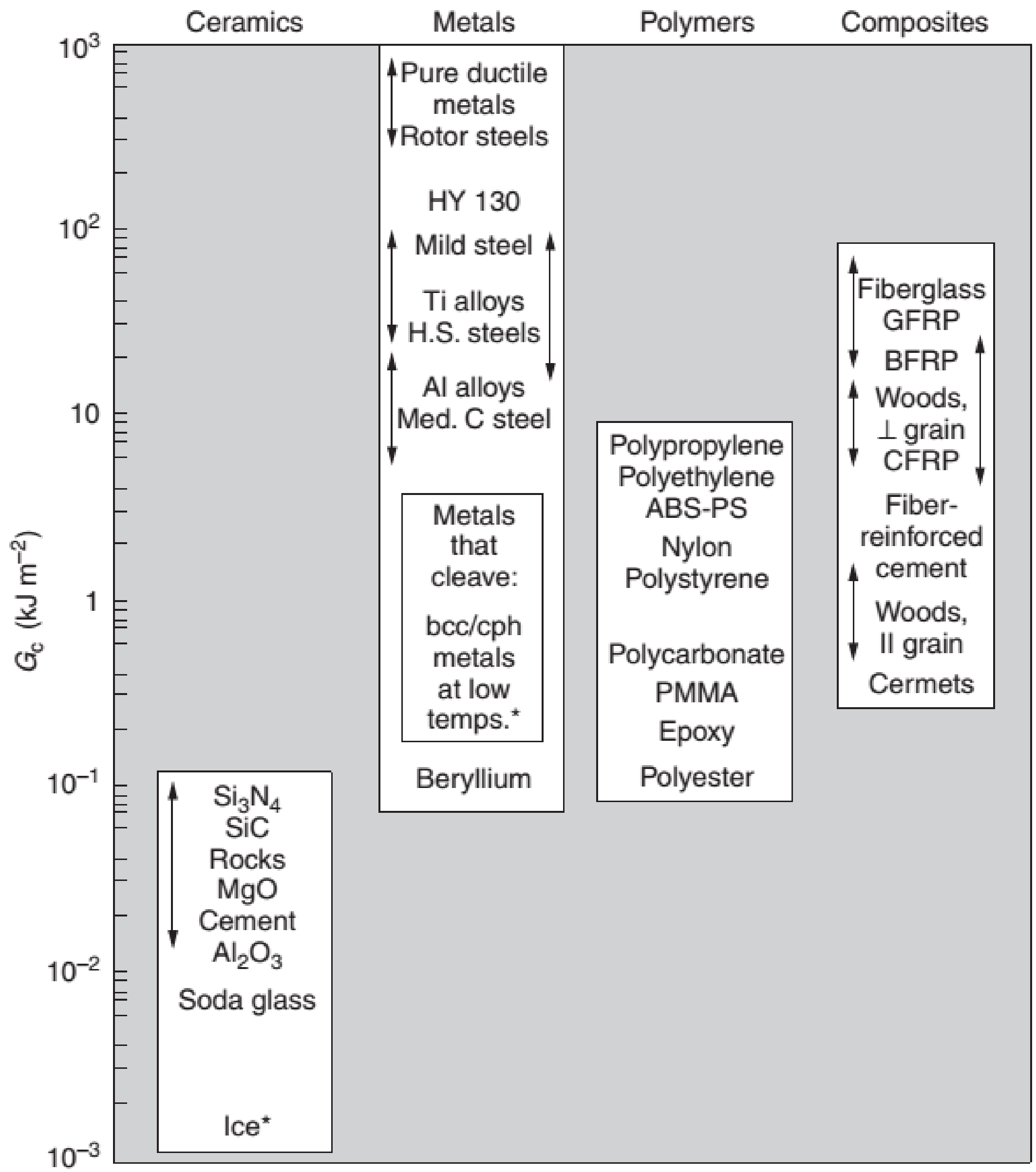
Impact Testing - Charpy Test

- The primary **difference** between the Charpy and Izod technique lies in the manner of **specimen support**.
- The test piece is fixed in place at both ends and the **striker impacts** the test **piece** immediately **behind** a machined **notch**.





Charpy Test
(W.D Callister, 7 Ed.)



The Charpy and Izod impact tests are typical measures of toughness.

Reference: Engineering Materials 1: Ashby & Jones, 4th Ed.

Factors Affecting Impact Energy

1. For a given material the **impact energy** will be seen to decrease if the **yield strength** is increased.
2. The **notch** serves as a stress concentration zone and some materials are more sensitive towards notches than others.
3. Most of the impact energy is absorbed by means of plastic deformation during the yielding. Therefore, factors that affect the yield behavior (*and hence ductility*) of the material such as **temperature** and **strain rate** will affect the impact energy.

In the **next lecture**, we will learn:

- **Other mechanical properties**
  - ✓ Hardness
  - ✓ Creep
  - ✓ Damping

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