4. Mechanical Properties of Metals

4. 1 Introduction
(mechanical behavior of a material)

- Response or deformation VS load or force
- Key mechanical design properties
  stiffness/strength/hardness/ductility and toughness
- Standardized testing techniques

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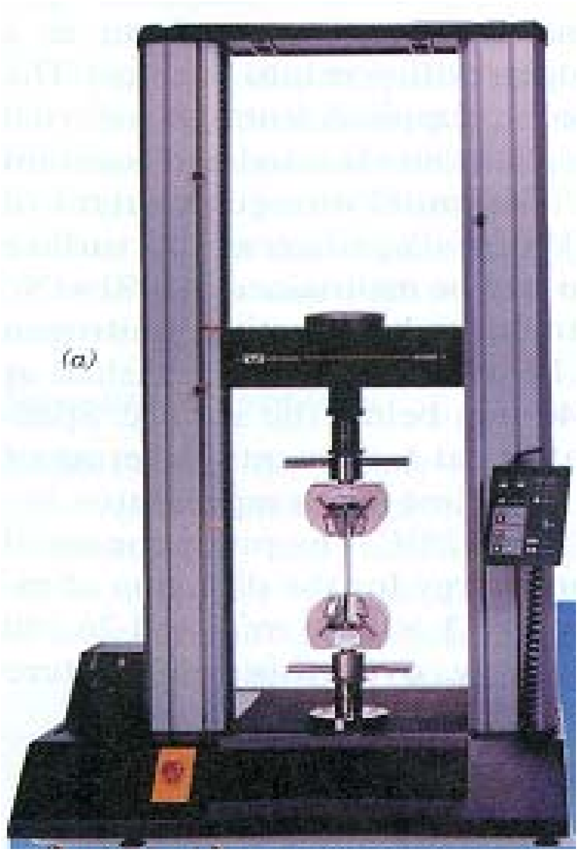
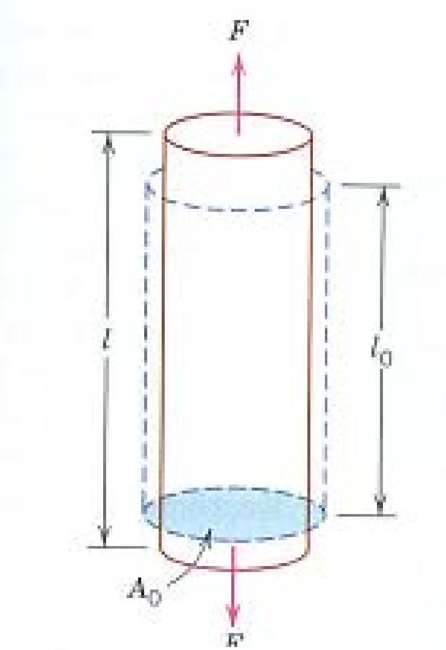
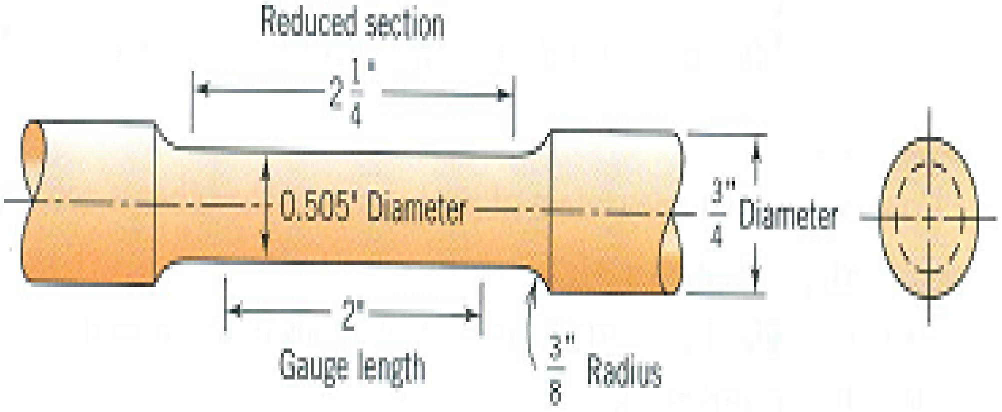
4.1 Tension Tests







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4.1 Tension Tests

Engineering Stress

$$\sigma = \frac{F}{A_0}$$

Engineering Strain

$$\epsilon = \frac{l_i - l_0}{l_0} = \frac{\Delta l}{l_0}$$

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4.1.1 Stress-strain behavior

$$\sigma = E\epsilon$$

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

	Modulus of Elasticity		Shear Modulus		
Metal Alloy	*GPa*	*10^6 psi*	*GPa*	*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

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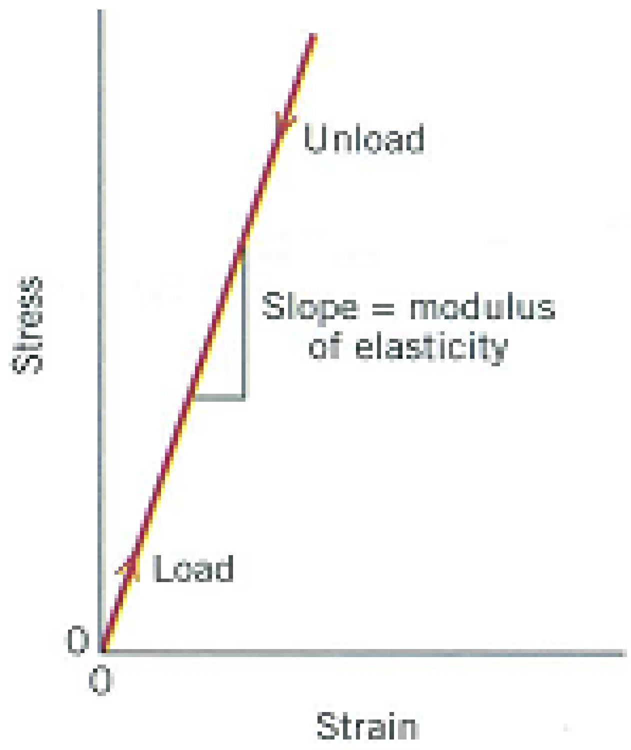
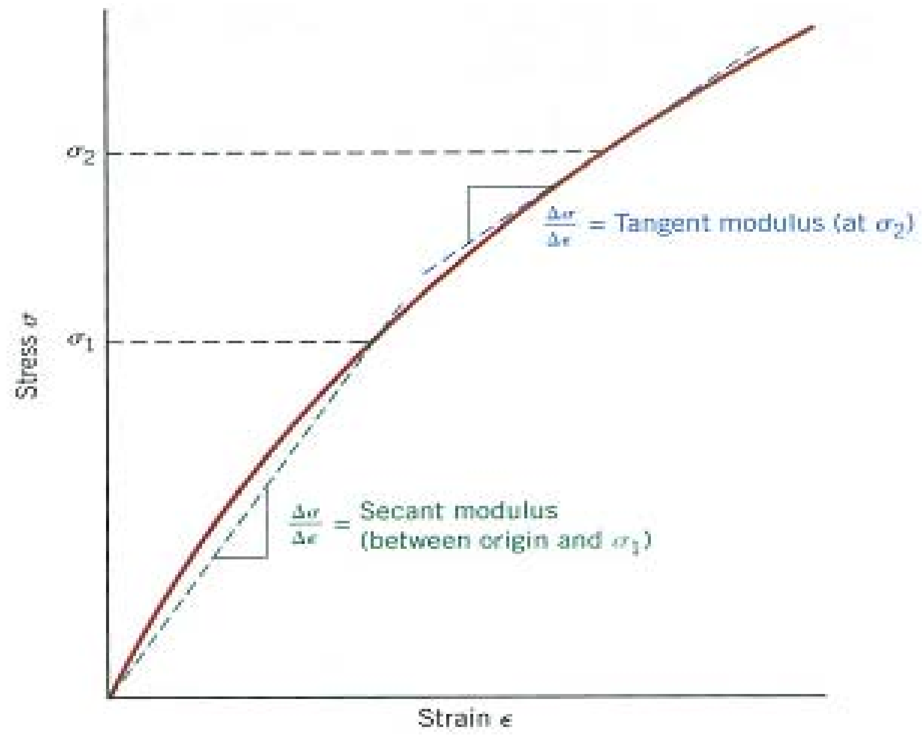


Linear elastic deformation



nonlinear elastic deformation

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4.1.2 Tensile Properties

Elastic deformation: Deformation that is nonpermanent–that is ,tonally recovered upon release of an applied stress. In which stress and strain are proportional.

plastic deformation: deformation that is permanent or nonrecoverable after release of the applied load. It is accompanied by permanent atomic displacements

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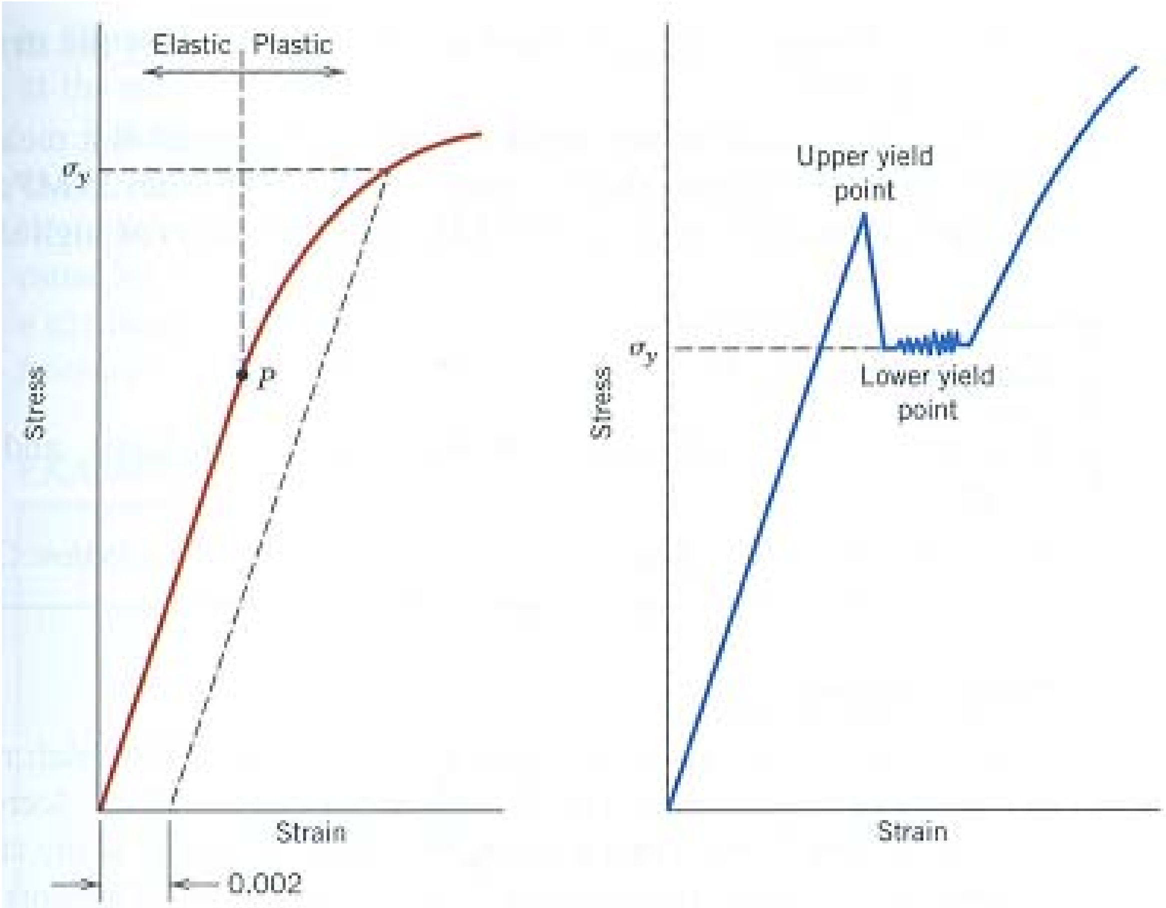
4.1.2 Tensile Properties



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4.1.2 Tensile Properties

yielding: the onset of plastic deformation.

Proportional limit: the point on a stress-strain curve at which the straight line proportionality between stress and strain cease.

Yield strength: the stress required to produce a very slight yet specified amount of plastic strain; a strain offset of 0.002 is commonly used.

tensile strength: the maximum engineering stress, in tension, that may be sustained without fracture. often termed ultimate (tensile) strength.

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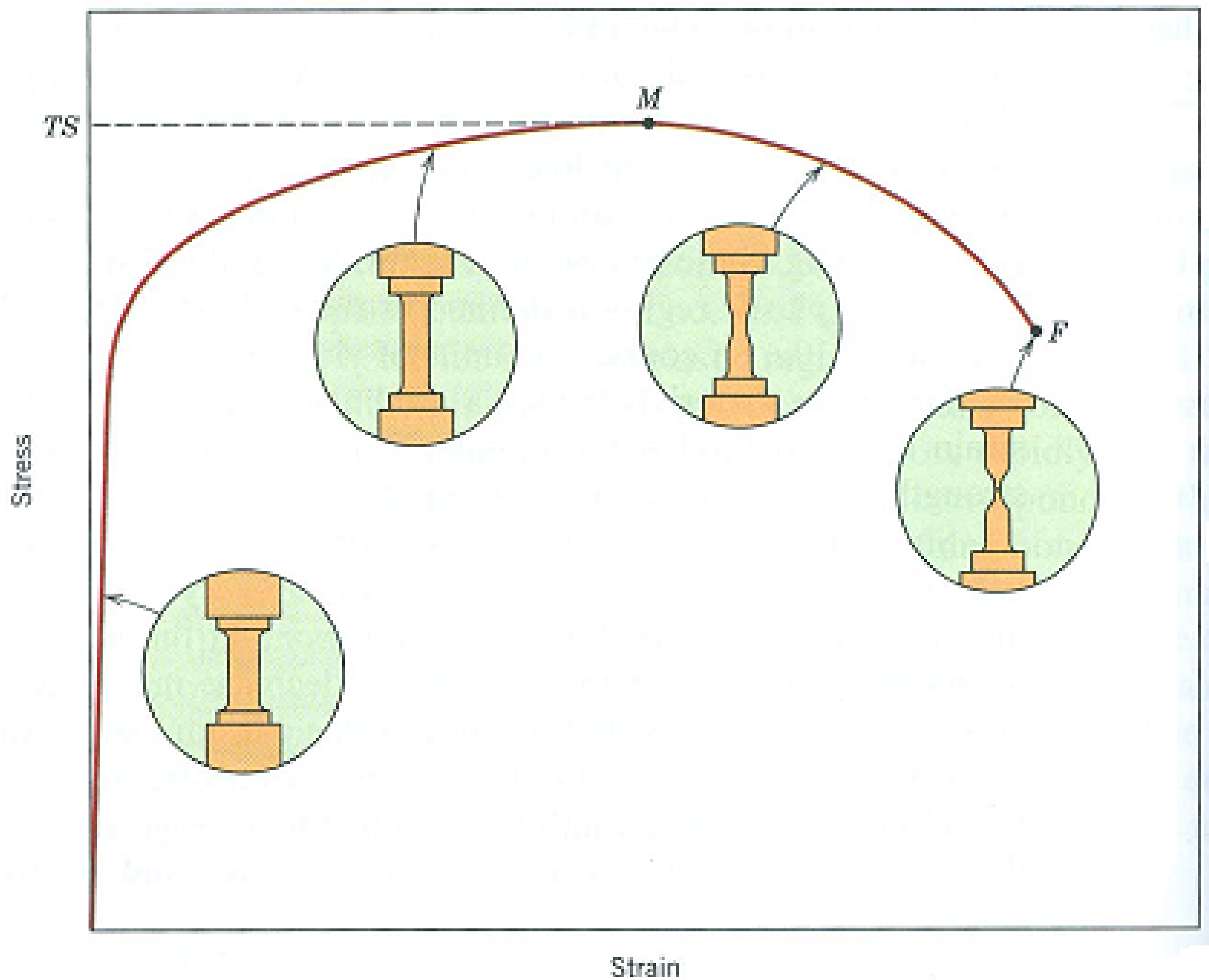
4.1.2 Tensile Properties



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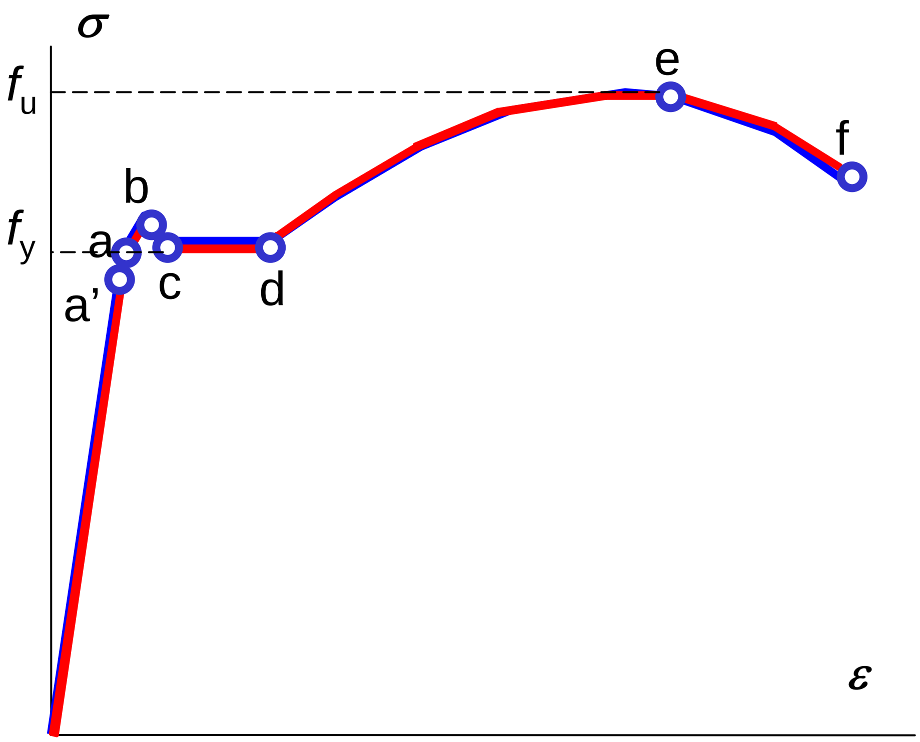
Stress-Strain Relation

Rebar with yield point



a' proportional limit

$$\sigma = E_s \varepsilon$$

a elastic limit

b upper yield strength

c lower yield strength

cd yield plateau

de strain hardening stage

e ultimate tensile strength

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EXAMPLE PROBLEM

Mechanical Property Determinations from Stress-Strain Plot

From the tensile stress-strain behavior for the brass specimen shown in Figure 6.12, determine the following:

(a)The module of elasticity

(b)The yield strength at a strain offset of 0.002

(c)The maximum load that can be sustained by a cylindrical

(d)specimen having an original diameter of 12.8mm(0.505in.) The change in a tensile of a specimen originally 250mm(10 in.) long that is subjected to a tensile stress of 345 MPa(50,000psi)

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EXAMPLE PROBLEM

Solution

(a) The modulus of elasticity is the slope of the elastic or initial linear portion of the stress–strain curve. The strain axis has been expanded in the inset, Figure to facilitate this computation. The slope of this linear region is the

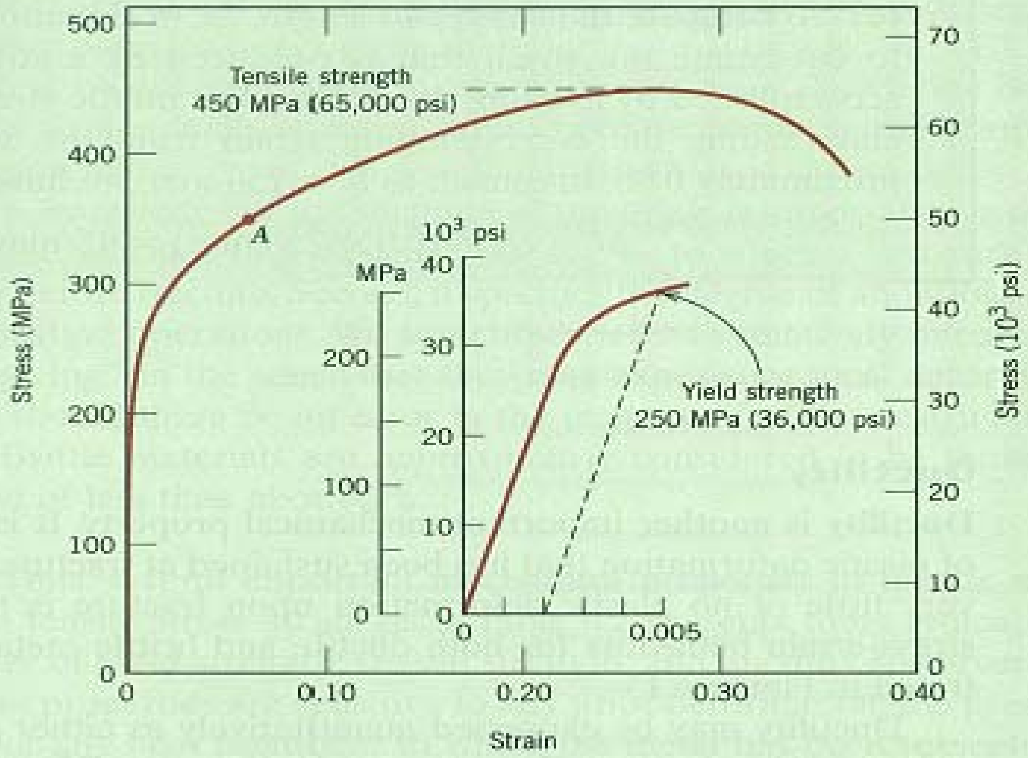

Figure The stress–strain behavior for the brass specimen discussed in Example Problem

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EXAMPLE PROBLEM

Rise over the run, or the change in stress divided by the corresponding change in strain ; in mathematical terms,

$$E = \text{slope} = \frac{\Delta\sigma}{\Delta\epsilon} = \frac{\sigma_2 - \sigma_1}{\epsilon_2 - \epsilon_1}$$

Inasmuch as the line segment passes through the origin, it is convenient to take both σ_1 and ϵ_1 as zero .If σ_2 is arbitrarily taken as 150 MPa, then ϵ_2 will have a value of 0.0016. Therefore,

$$E = \frac{(150 - 0)\text{MPa}}{0.0016 - 0} = 93.8\text{GPa}(13.6 \times 10^6 psi)$$

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EXAMPLE PROBLEM

(b)The 0.002 strain offset line is constructed as in the inset;

its intersection with the stress-strain curve is at

approximately 250 MPa(36,000psi),which is the yield

strength of the brass.

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EXAMPLE PROBLEM

(c) The maximum load that can be sustained by the specimen is calculated by using Equation 6.1, in which σ is taken to be the tensile strength, from Figure 6.12, 450MPa (65,000psi).Solving for F, the maximum load, yields

$$F = \sigma A_0 = \sigma \left(\frac{d_0}{2}\right)^2 \pi$$

$$= (450 \times 10^6\, N/m^2)\left(\frac{12.8 \times 10^{-3} m}{2}\right)^2 \pi = 57{,}900N(13{,}000lb_f)$$

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EXAMPLE PROBLEM

4.2 Tension Tests

(d)To compute the change in length , Δl ,in Equation 6.2, it is first necessary to determine the strain that is produced by a stress of 345MPa .This is accomplished by locating the stress point on the stress-strain curve, point A, and reading the corresponding strain from the strain axis, which is approximately 0.06. Inasmuch as l_0=250mm, we have

$$\Delta l = \epsilon l_0 = (0.06)(250\text{mm}) = 15\text{mm}(0.6\text{in})$$

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4.3 Ductility

ductility : A measure of a material' ability to undergo appreciable plastic deformation before fracture; it may be expressed as percent elongation (%EL) or percent reduction in area (%RA) from a tensile test

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

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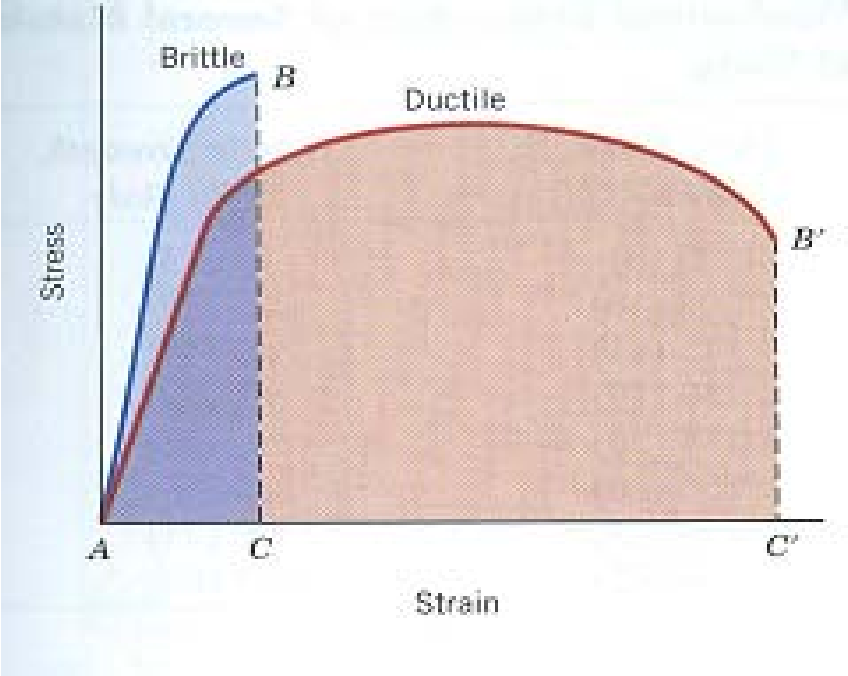
4.3 Ductility



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

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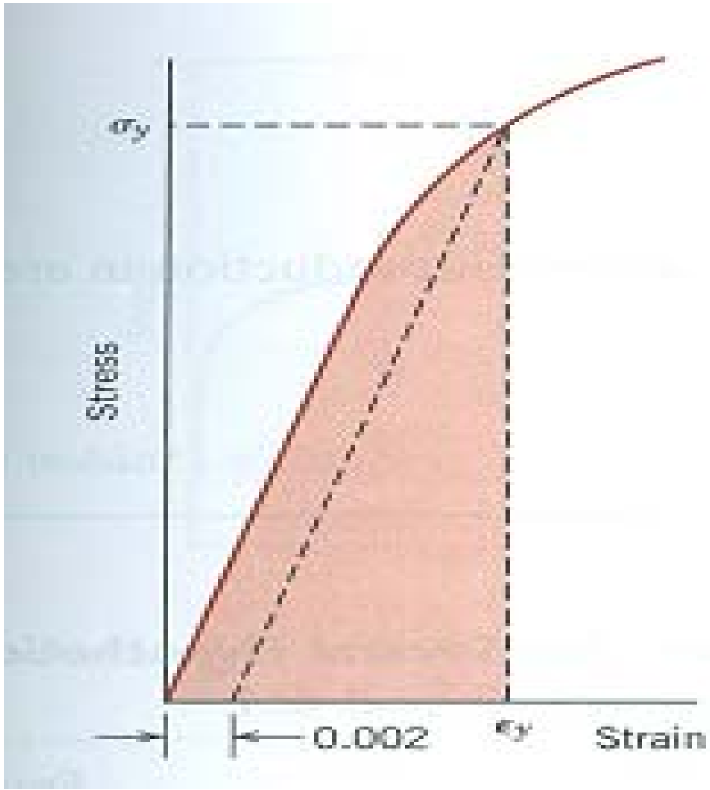
4.4 Resilience

Resilience: the capacity of a material to absorb energy when it is elastically deformed.

$$U_r = \int_0^{\epsilon_y} \sigma \, d\epsilon$$

$$U_r = \frac{1}{2}\sigma_y \epsilon_y$$

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



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4.5 Toughness

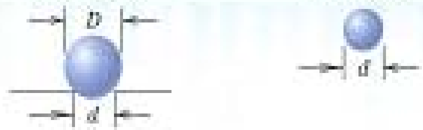
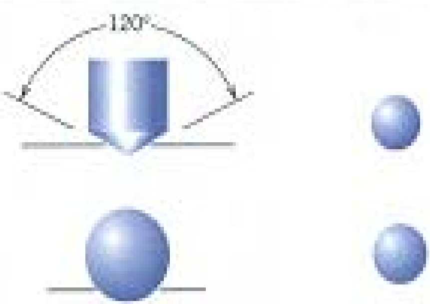
Toughness: A mechanical characteristic that may be expressed in three contexts:

1. The measure of a material' resistance to fracture when a crack (or other stress-concentrating defect) is present
2. The ability of a material to absorb energy and plastically deform before fracturing
3. The total area under the material's tensile engineering stress-strain curve taken to fracture

Structural metallic materials

4.6 HARDNESS

Hardness: the measure of a material' resistance to deformation by surface indentation or by abrasion

Test	Indenter	Shape of Indentation: Side View	Shape of Indentation: Top View	Load	Formula for Hardness Number[a]
Brinell	10-mm sphere of steel or tungsten carbide			P	$HB = \dfrac{2P}{\pi D[D - \sqrt{D^2 - d^2}]}$
Vickers microhardness	Diamond pyramid			P	$HV = 1.854P/d_1^2$
Knoop microhardness	Diamond pyramid			P	$HK = 14.2P/l^2$
Rockwell and superficial Rockwell	Diamond cone; $\frac{1}{16}$, $\frac{1}{8}$, $\frac{1}{4}$, $\frac{1}{2}$ in.-diameter steel spheres			60 kg, 100 kg, 150 kg: Rockwell; 15 kg, 30 kg, 45 kg: Superficial Rockwell	

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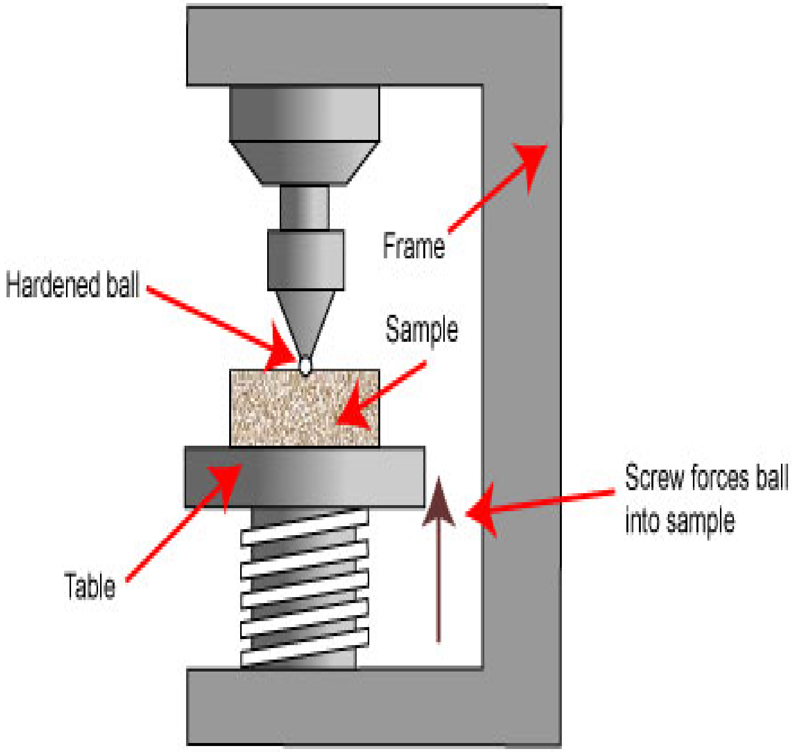
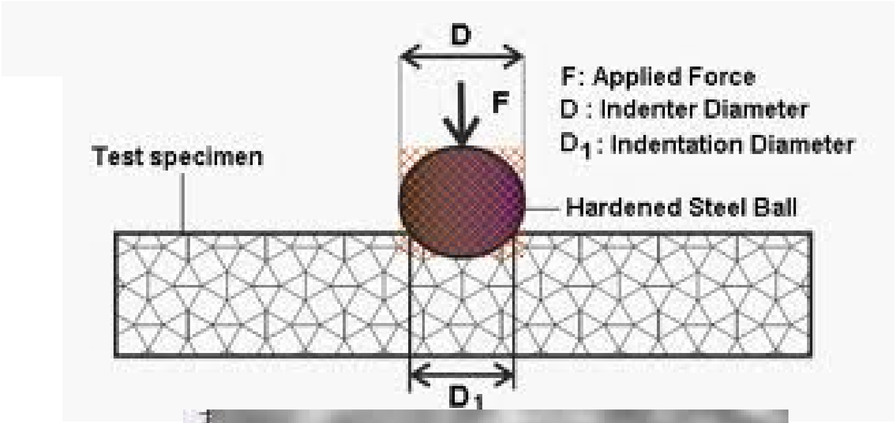
4.6 HARDNESS----Brinell Hardness (HB)





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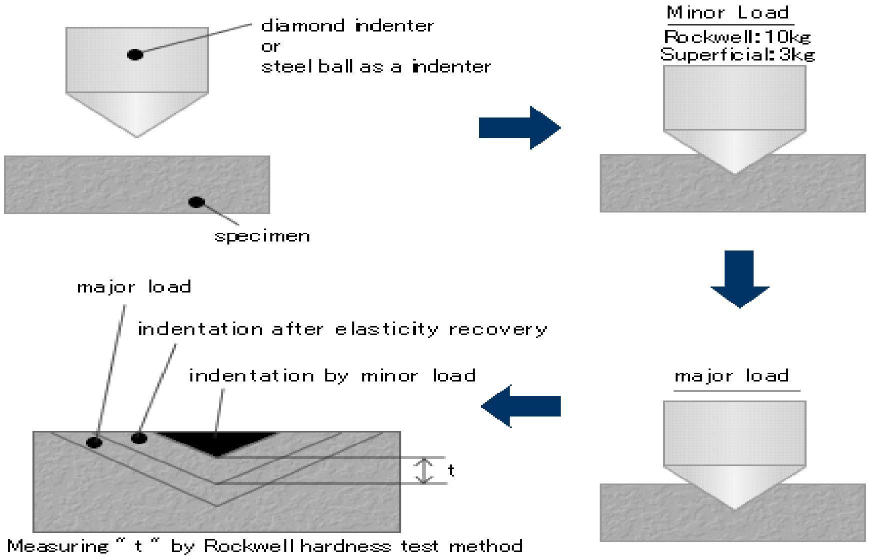
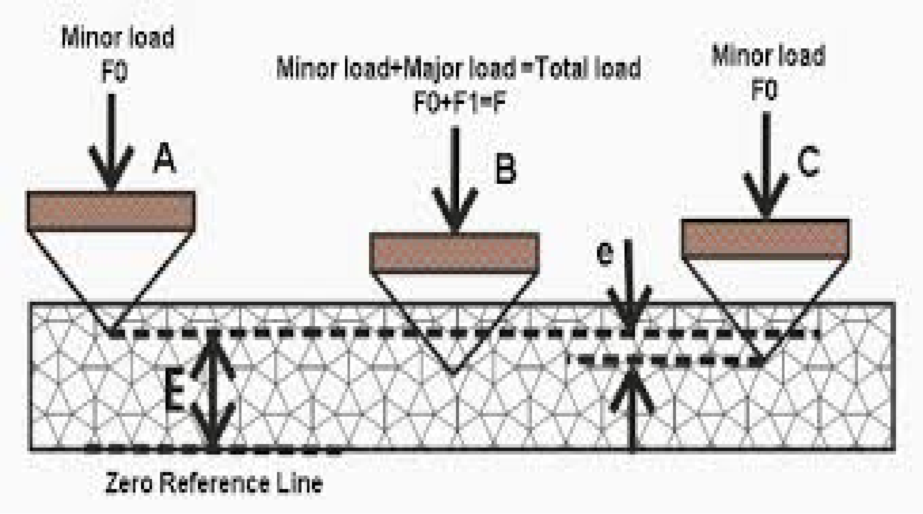
4.6 HARDNESS------Rockwell Hardness(HRC)





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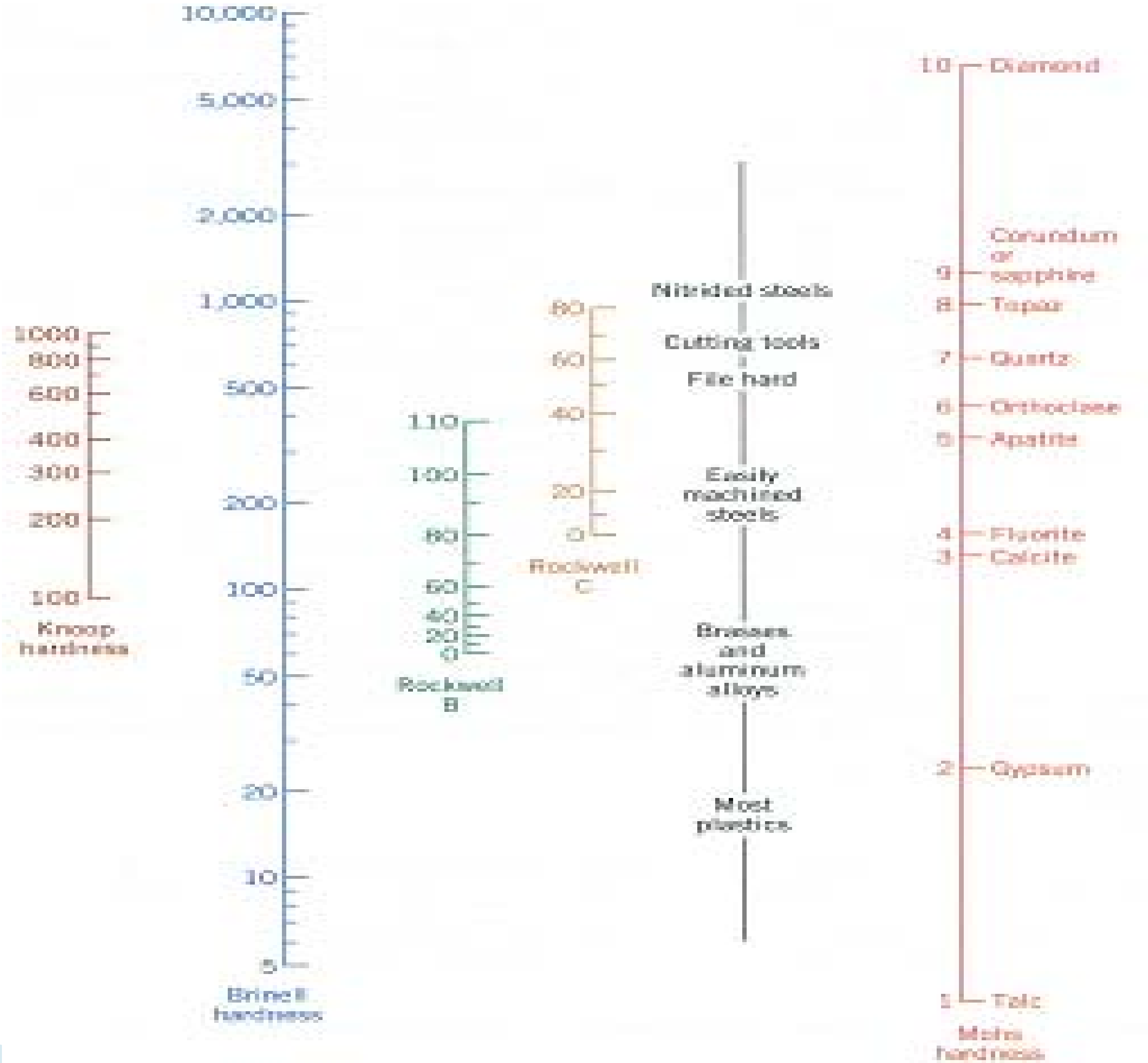
4.6 HARDNESS



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