Material Science
ME 221

Fall 2020

Dr. Raed Alharbi

Chapter 6: Mechanical Properties of Metals

- Why Study Mechanical Properties of Metals?
- Introduction
- Concepts of Stress and Strain
- Elastic Deformation

Materials Contents in this Slides adapted from : Materials science and engineering: an introduction / William D. Callister, Jr., David G. Rethwisch.–8th ed.

Why Study Mechanical Properties of Metals?

- In mechanical design, engineer should understand the significance of mechanical properties of materials.
  - stiffness, strength, ductility, and toughness.

Processing/Structure/Properties/Performance

INTRODUCTION

- Mechanical behavior of a material
  - Relationship between its response (deformation) to an applied load or force

Stiffness
Strength
Hardness
Ductility
Toughness

} Key mechanical design properties

Materials Contents in this Slides adapted from : Materials science and engineering: an introduction / William D. Callister, Jr., David G. Rethwisch.–8th ed.

INTRODUCTION

- Factors affect mechanical properties of materials:
  - Type of the load: tensile, compressive, or shear
  - Time: constant with time or time variant
  - Temperature

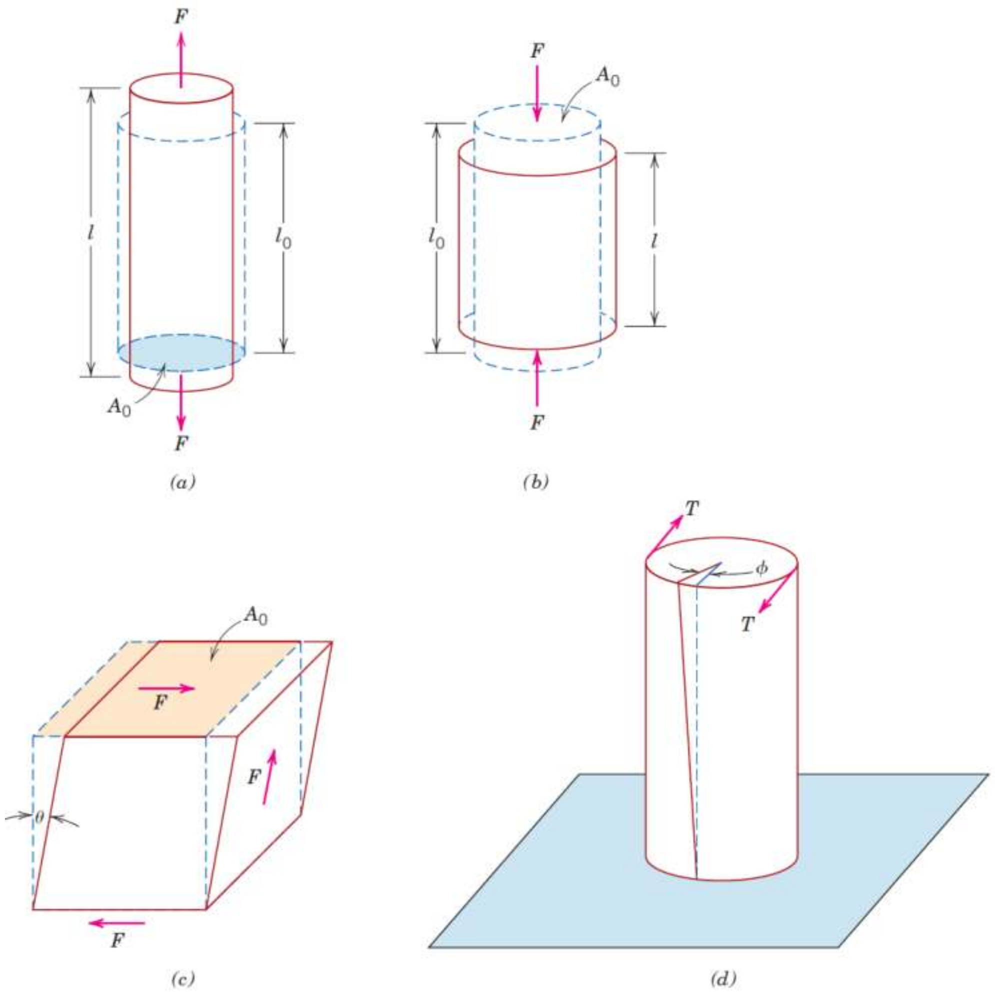
- Structural engineers:
  - Stresses Analysis

- Materials and metallurgical engineers:
  - Material Processing

Materials Contents in this Slides adapted from : Materials science and engineering: an introduction / William D. Callister, Jr., David G. Rethwisch.–8th ed.

CONCEPTS OF STRESS AND STRAIN

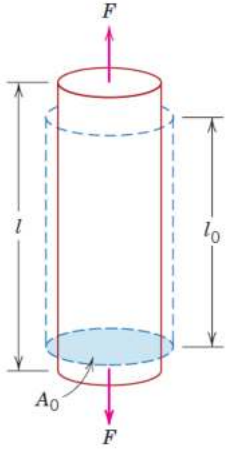
- Principle ways of applied loads:
  - Tension
  - Compression
  - Shear
  - Torsional



Materials Contents in this Slides adapted from : Materials science and engineering: an introduction / William D. Callister, Jr., David G. Rethwisch.–8th ed.

CONCEPTS OF STRESS AND STRAIN

- **Tension Tests**
  - Several mechanical properties of materials that are important in design, such as elastic modulus can be determine through tensile test.

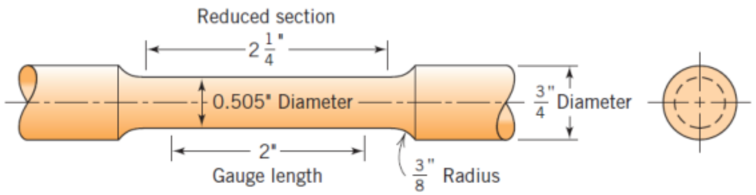


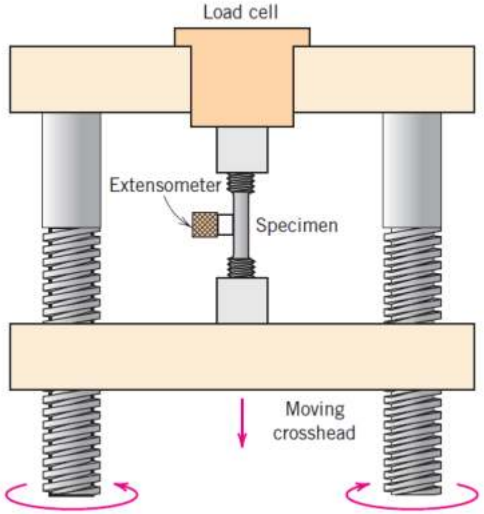
$$\sigma = \frac{F}{A_0}$$

Engineering stress

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

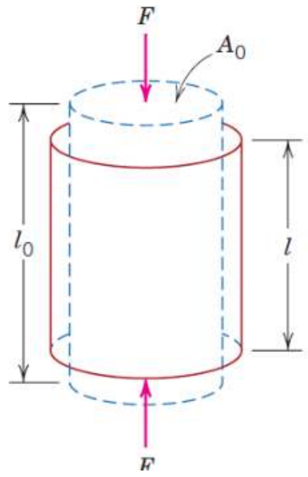
Engineering strain





CONCEPTS OF STRESS AND STRAIN

- **Compression Tests**
- Like the tensile test, however, force is compressive and the specimen contracts along the direction of the stress

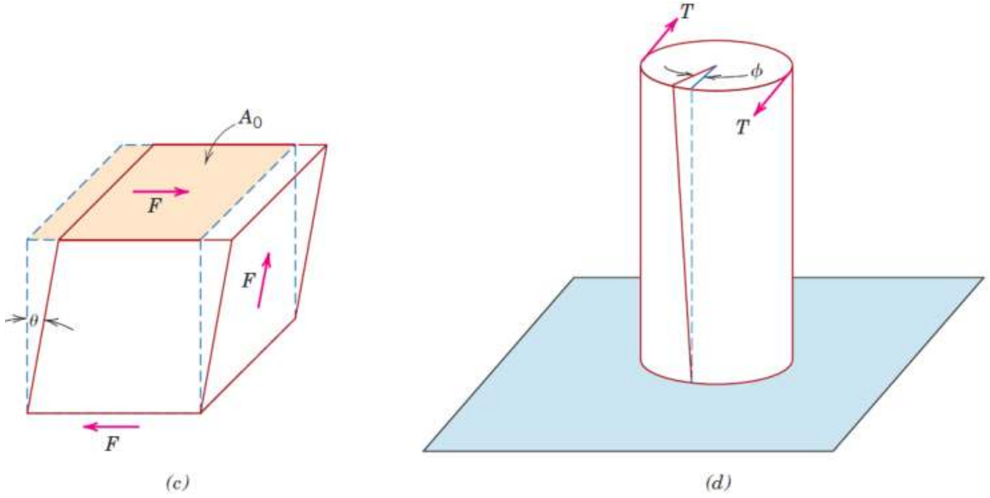


Materials Contents in this Slides adapted from : Materials science and engineering: an introduction / William D. Callister, Jr., David G. Rethwisch.–8th ed.

CONCEPTS OF STRESS AND STRAIN

- **Shear and Torsional Tests**

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

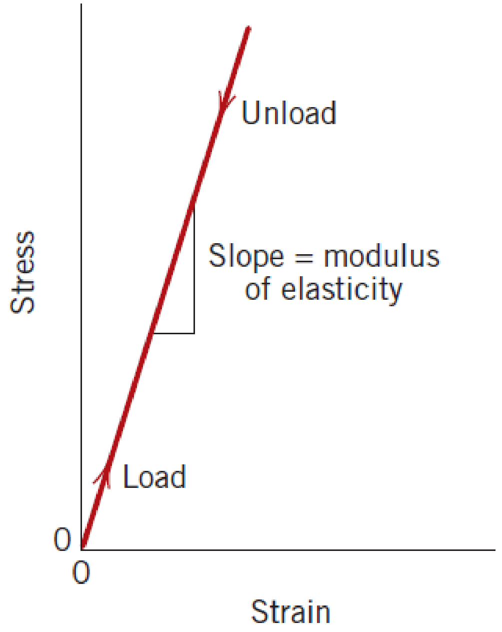


- Torsion: structural member is twisted
- Shear Strain is related to the angle of twist.

ELASTIC DEFORMATION

- **STRESS–STRAIN BEHAVIOR**
  - The magnitude of an imposed stress affects the degree of structure deformation or strains

Hooke's law $$\sigma = E\epsilon$$



- *E :* **modulus of elasticity,** or *Young's modulus* (GPa or psi)

ELASTIC DEFORMATION

- **Modulus of elasticity (E)** measure material's resistance to elastic deformation (Stiffness)
- Under given stress application:

The greater the modulus → the stiffer the material → the smaller of the elastic strain

Some materials have nonlinear behavior in the elastic region such as :

gray cast iron, concrete, and many polymers

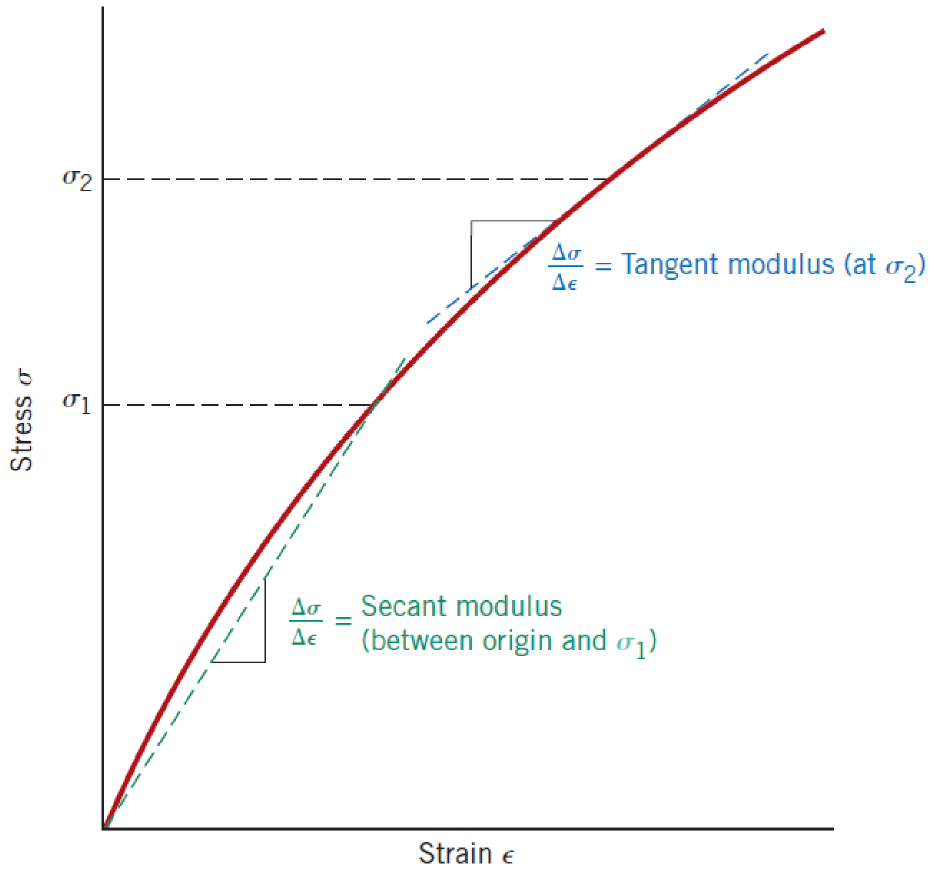
Their stiffness is measured using *tangent* or *secant modulus*

ELASTIC DEFORMATION

- *Tangent* or *secant modulus*

At specified level of stress

At interested point of stress, where the line drawn from origin



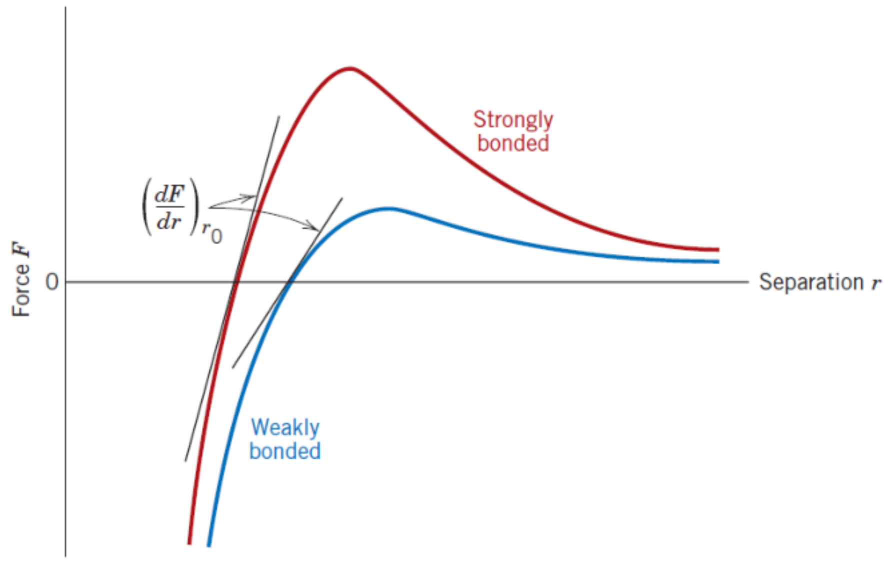
Materials Contents in this Slides adapted from : Materials science and engineering: an introduction / William D. Callister, Jr., David G. Rethwisch.–8th ed.

ELASTIC DEFORMATION

- Modulus of elasticity at atomic scale.

"elastic strain is manifested as small changes in the interatomic spacing and the stretching of interatomic bonds"

E: measure of the resistance to separation of adjacent atoms (interatomic bonding forces)
Therefore, materials have different E due to differences in nature of their atomic bonds.



ELASTIC DEFORMATION

- Shear stress-strain behaviour.

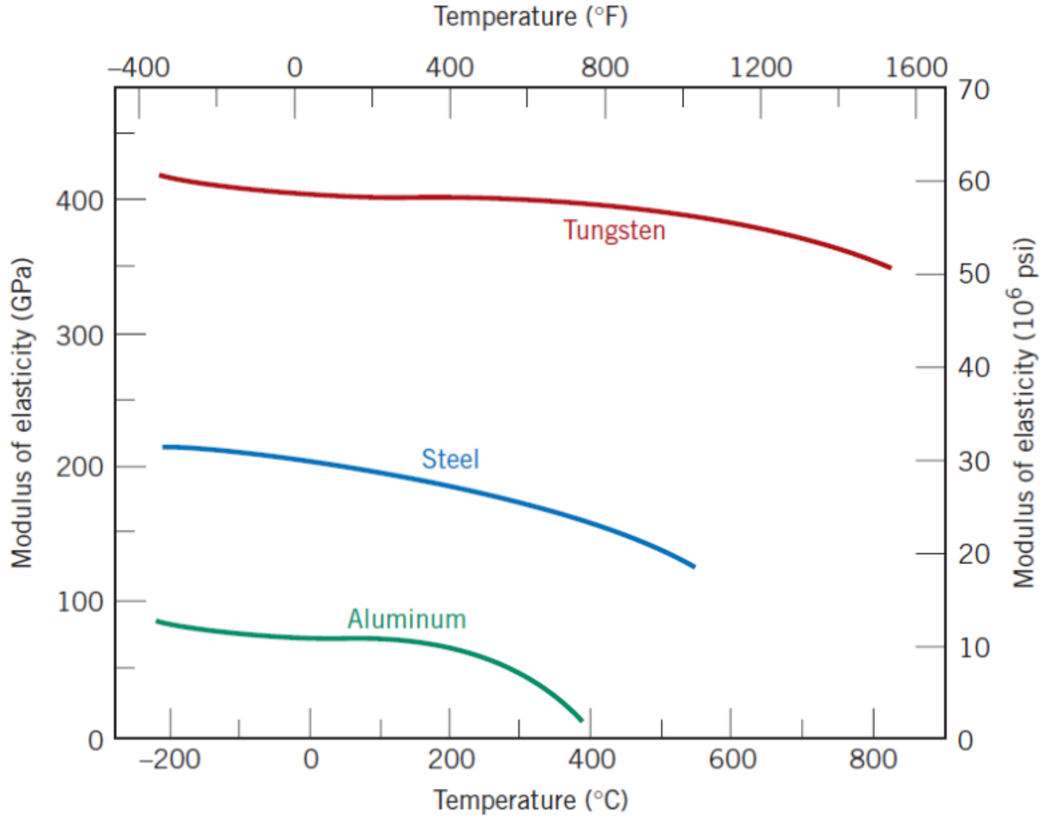
G: *shear modulus (* the slope of the linear elastic region of the shear stress–strain curve)

$$\tau = G\gamma$$

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

ELASTIC DEFORMATION

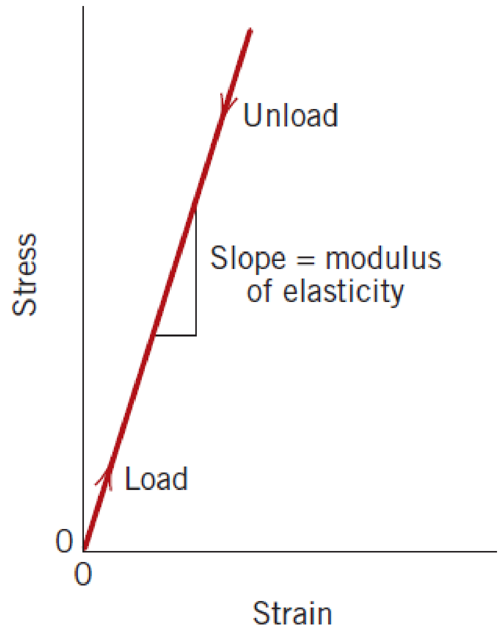
- Temperature affect E value:



Materials Contents in this Slides adapted from : Materials science and engineering: an introduction / William D. Callister, Jr., David G. Rethwisch.–8th ed.

ANELASTICITY

- Some finite time is required for complete Recovery after load release.
- For metals
  - anelastic component is neglected (normally small)



Materials Contents in this Slides adapted from : Materials science and engineering: an introduction / William D. Callister, Jr., David G. Rethwisch.–8th ed.

Example

A piece of copper originally 305 mm (12 in.) long is pulled in tension with a stress of 276 MPa (40,000 psi). If the deformation is entirely elastic, what will be the resultant elongation?

$$\sigma = \epsilon E = \left(\frac{\Delta l}{l_0}\right) E$$

$$\Delta l = \frac{\sigma l_0}{E}$$

$$\Delta l = \frac{(276 \text{ MPa})(305 \text{ mm})}{110 \times 10^3 \text{ MPa}} = 0.77 \text{ mm } (0.03 \text{ in.})$$

Materials Contents in this Slides adapted from : Materials science and engineering: an introduction / William D. Callister, Jr., David G. Rethwisch.–8th ed.

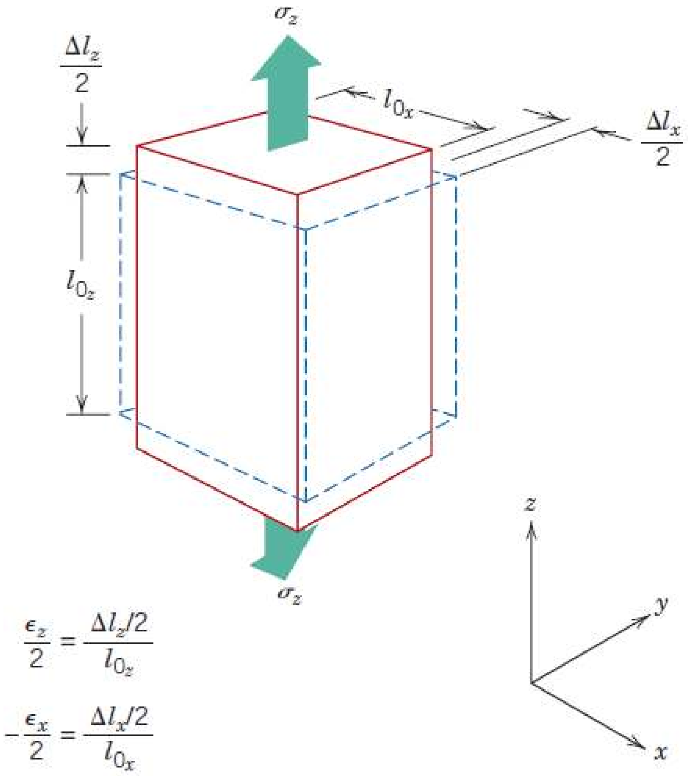
ELASTIC PROPERTIES OF MATERIALS

- **Poisson's ratio**
  - **- For isotropic material**

$$\nu = -\frac{\epsilon_x}{\epsilon_z} = -\frac{\epsilon_y}{\epsilon_z}$$

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

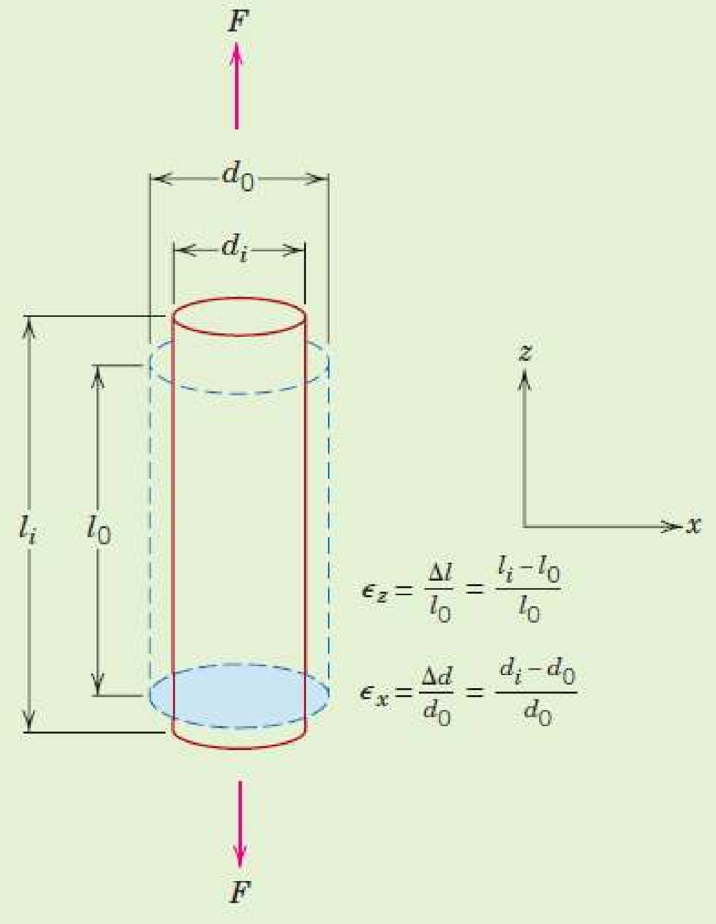
$$E = 2G(1+\nu)$$



Example

A tensile stress is to be applied along the long axis of a cylindrical brass rod that has a diameter of 10 mm (0.4 in.). Determine the magnitude of the load required to produce a 2.5×10^{-3} mm (10^{-4} in.) change in diameter if the deformation is entirely elastic.

A tensile stress is to be applied along the long axis of a cylindrical brass rod that has a diameter of 10 mm (0.4 in.). Determine the magnitude of the load required to produce a 2.5×10^{-3} mm (10^{-4} in.) change in diameter if the deformation is entirely elastic.



$$\epsilon_x = \frac{\Delta d}{d_0} = \frac{-2.5 \times 10^{-3}\ \text{mm}}{10\ \text{mm}} = -2.5 \times 10^{-4}$$

$$\epsilon_z = -\frac{\epsilon_x}{\nu} = -\frac{(-2.5 \times 10^{-4})}{0.34} = 7.35 \times 10^{-4}$$

From table 6.1

$$\sigma = \epsilon_z E = (7.35 \times 10^{-4})(97 \times 10^3\ \text{MPa}) = 71.3\ \text{MPa}$$

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

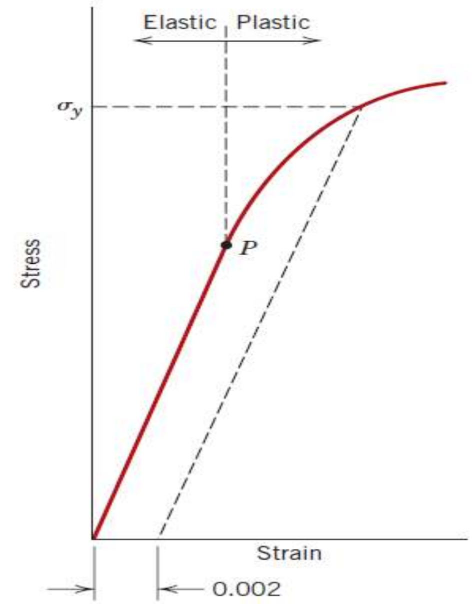
$$= (71.3 \times 10^6\ \text{N/m}^2)\left(\frac{10 \times 10^{-3}\ \text{m}}{2}\right)^2 \pi = 5600\ \text{N}\,(1293\ \text{lb}_\text{f})$$

Materials Contents in this Slides adapted from : Materials science and engineering: an introduction / William D. Callister, Jr., David G. Rethwisch.–8th ed.

PLASTIC DEFORMATION

Atomic perspective : breaking and re-forming bonds between atoms

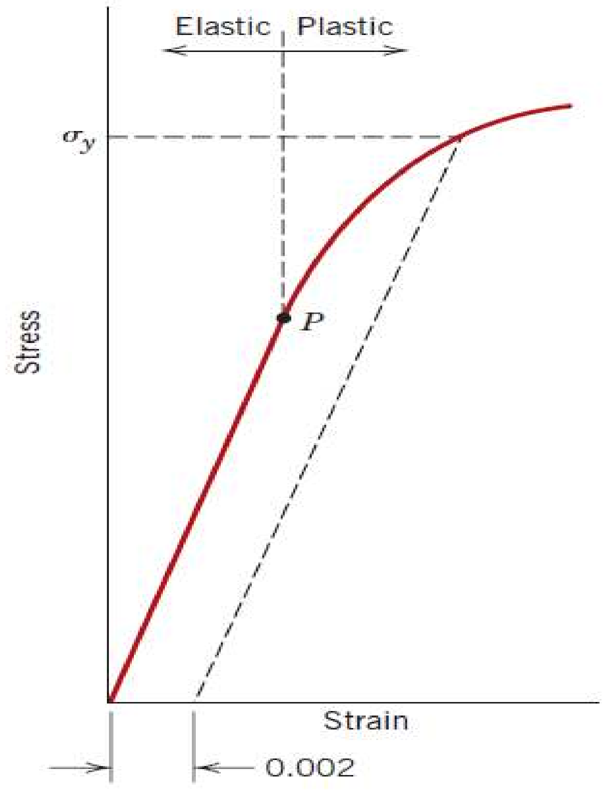
- After load releasing, they do not come back to the original positions.



Materials Contents in this Slides adapted from : Materials science and engineering: an introduction / William D. Callister, Jr., David G. Rethwisch.–8th ed.

TENSILE PROPERTIES

- **Yielding:** start plastic deformation
- **Proportional limit:** start nonlinear curve
  in the stress-strain diagram.
- **Yield Strength:** it is difficult to define the
  yield strength precisely, so,
  the strain 0.002 offset is used.

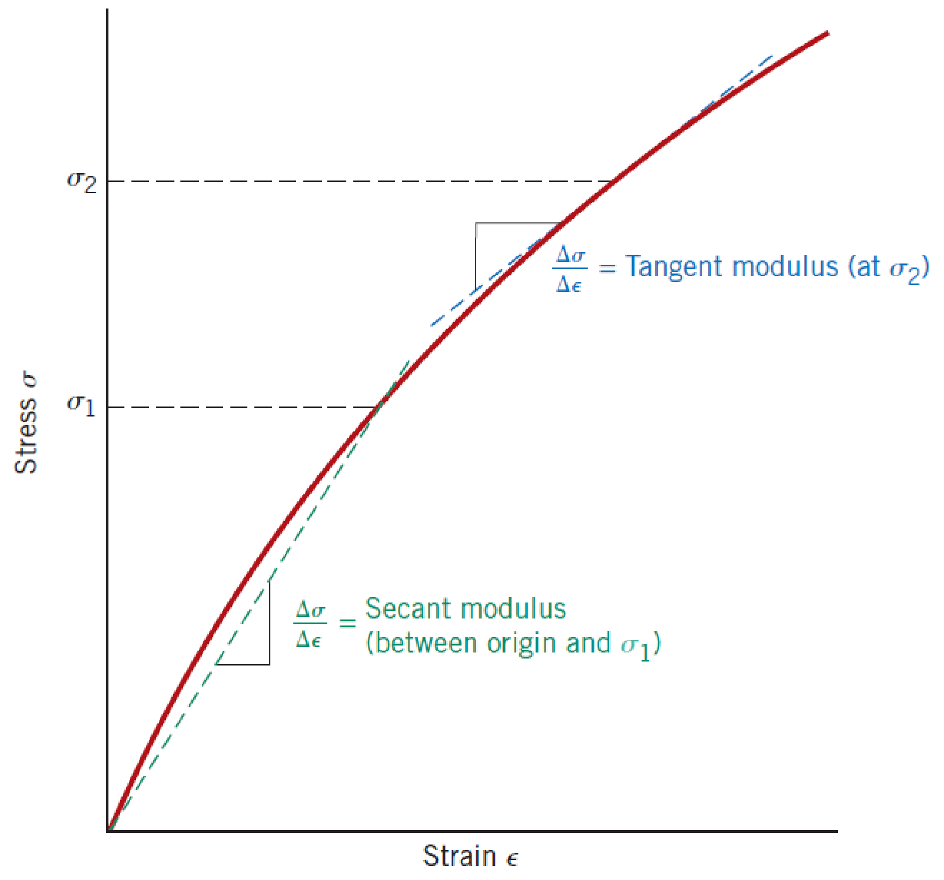


Materials Contents in this Slides adapted from : Materials science and engineering: an introduction / William D. Callister, Jr., David G. Rethwisch.–8th ed.

TENSILE PROPERTIES

- Materials having a nonlinear elastic region:

Yield strength is the stress that causes 0.005 strain.



Materials Contents in this Slides adapted from : Materials science and engineering: an introduction / William D. Callister, Jr., David G. Rethwisch.–8th ed.

TENSILE PROPERTIES

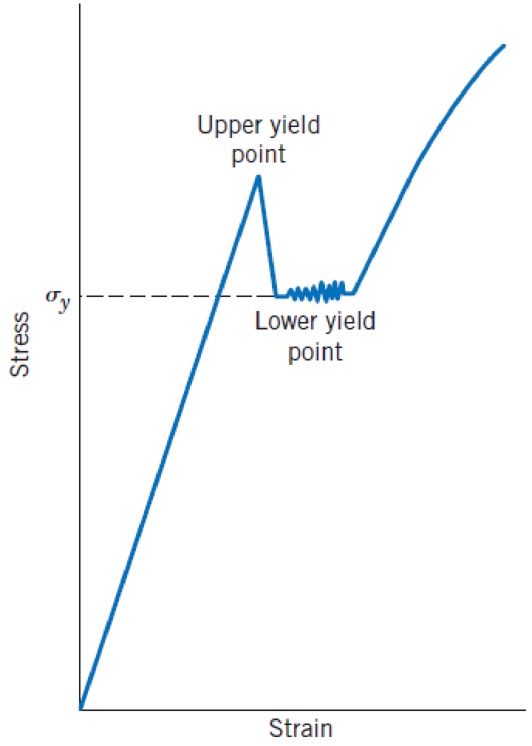
- ***yield point phenomenon:***

Some steels and others materials has

Upper and lower yield points.

The yield strength is the average values at

Lower yield point (no need for 0.002 offset)



Materials Contents in this Slides adapted from : Materials science and engineering: an introduction / William D. Callister, Jr., David G. Rethwisch.–8th ed.

TENSILE PROPERTIES

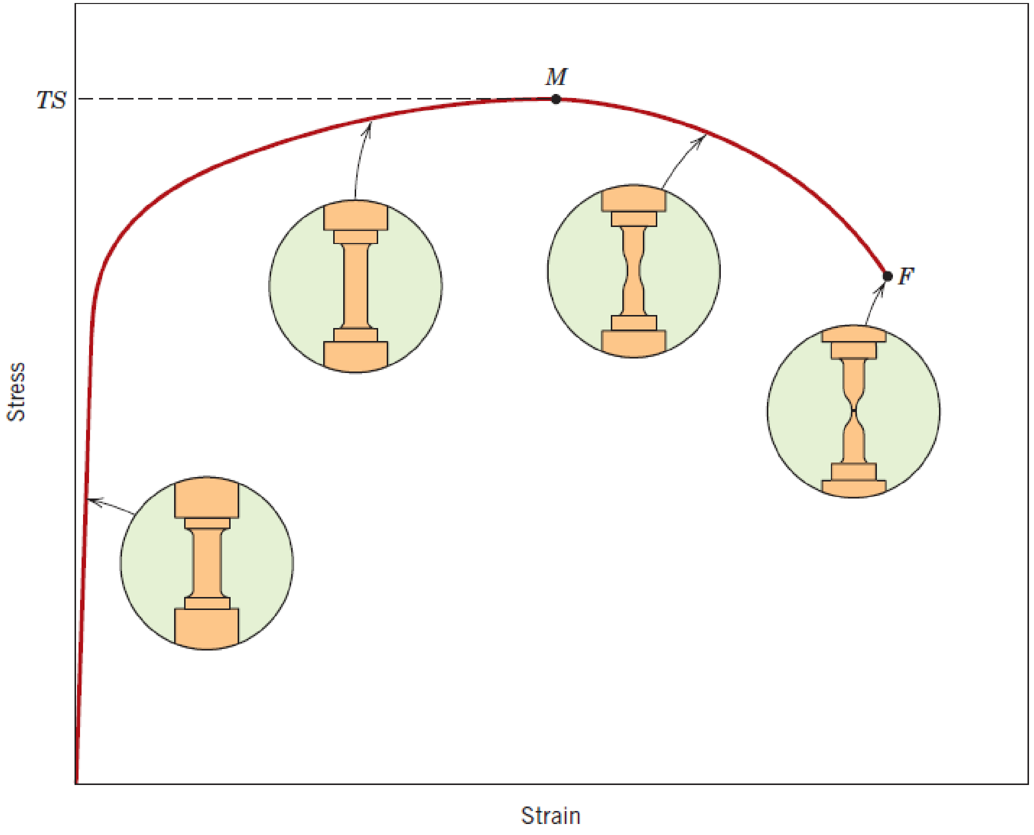
- Yield strength is a measurements of material resistance to plastic deformation.

- For metals;
    - 35 MPa (5000 psi) for a low strength aluminum
    - 1400 MPa (200,000 psi) for high-strength steels.

Materials Contents in this Slides adapted from : Materials science and engineering: an introduction / William D. Callister, Jr., David G. Rethwisch.–8th ed.

TENSILE PROPERTIES

- **Tensile Strength**



Materials Contents in this Slides adapted from : Materials science and engineering: an introduction / William D. Callister, Jr., David G. Rethwisch.–8th ed.

Example

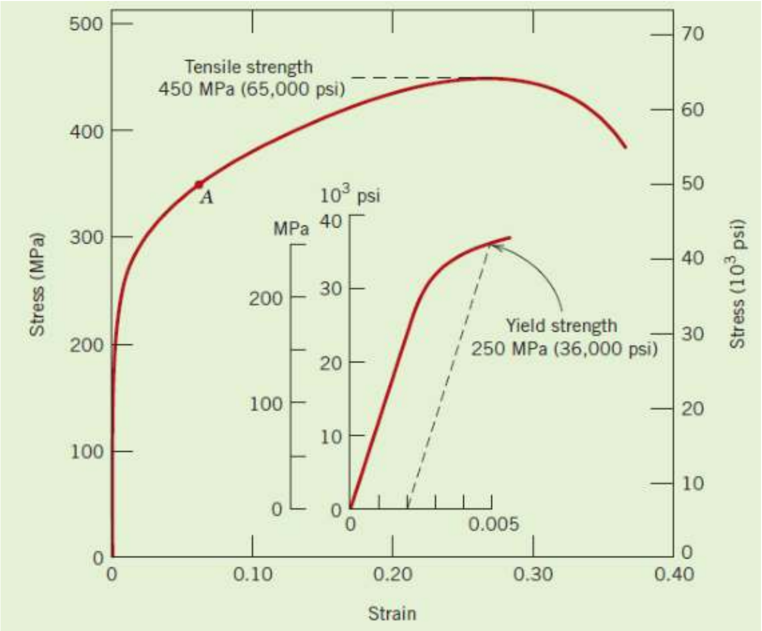
From the stress-strain diagram determine the following:

(a) The modulus of elasticity

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

(c) The maximum load that can be sustained by a cylindrical specimen having an original diameter of 12.8 mm (0.505 in.)

(d) The change in length of a specimen originally 250 mm (10 in.) long that is subjected to a tensile stress of 345 MPa (50,000 psi)



Materials Contents in this Slides adapted from : Materials science and engineering: an introduction / William D. Callister, Jr., David G. Rethwisch.–8th ed.

(a)

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

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

(b) yield strength = 250 MPa

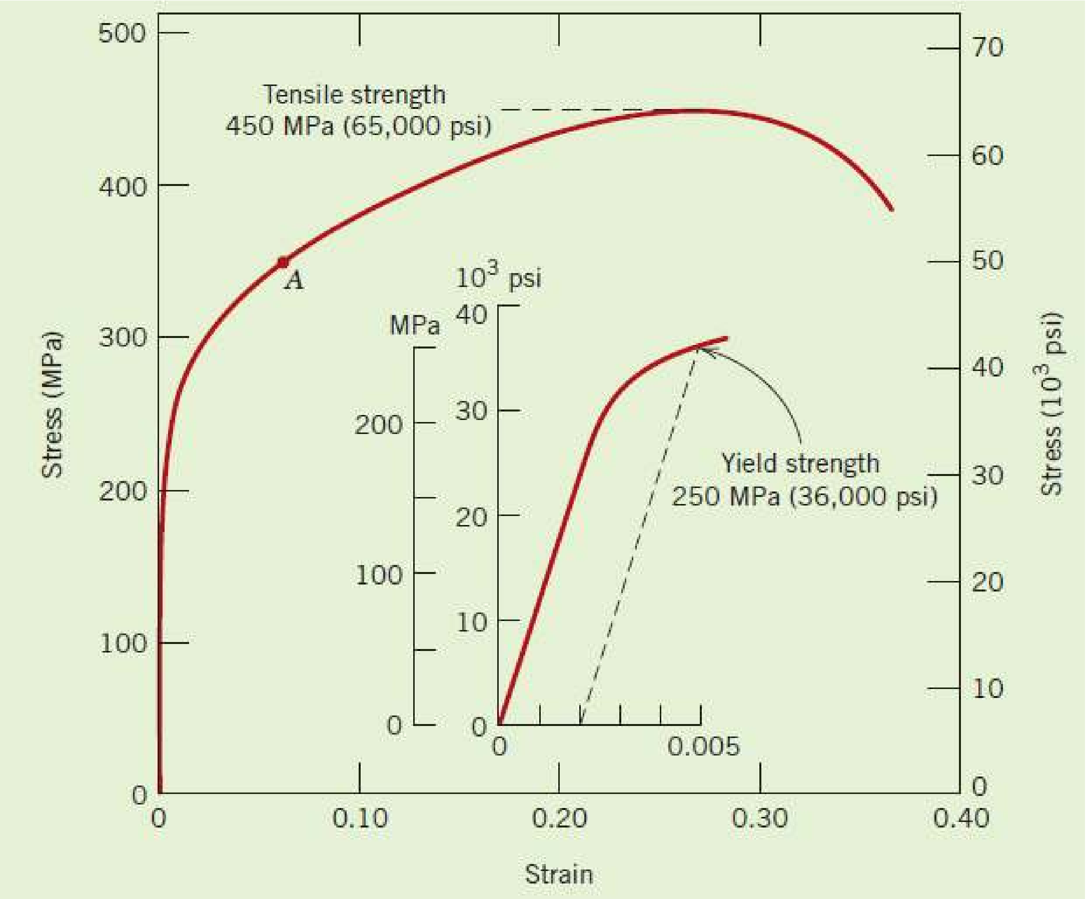
(c)

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

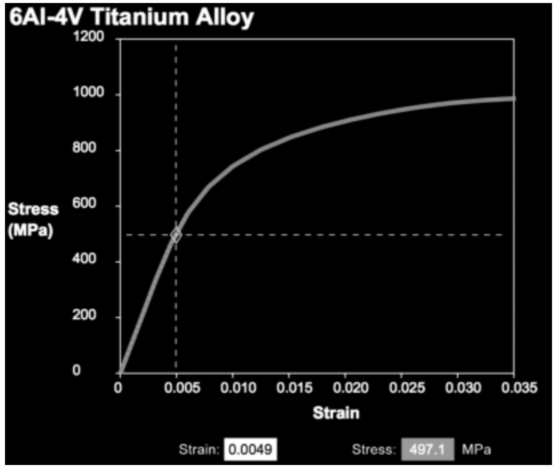
$$= (450 \times 10^6\ \text{N/m}^2)\left(\frac{12.8 \times 10^{-3}\ \text{m}}{2}\right)^2 \pi = 57{,}900\ \text{N}\ (13{,}000\ \text{lb}_f)$$

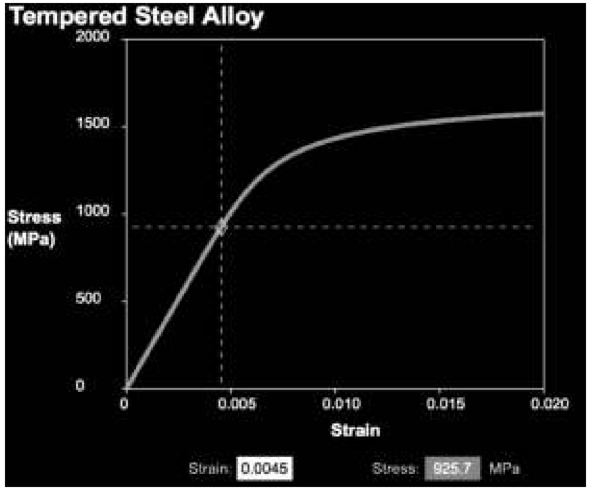
(d)

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

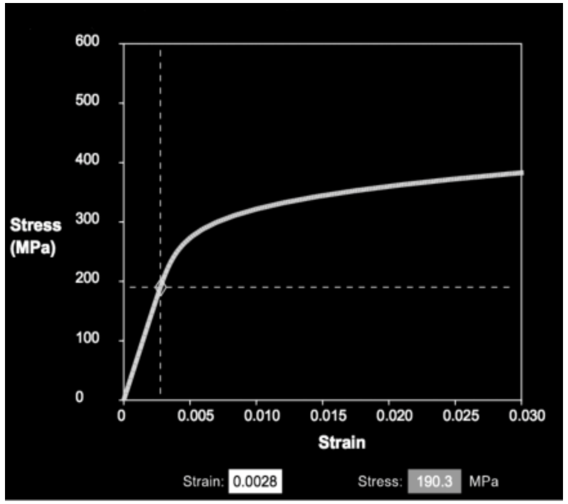


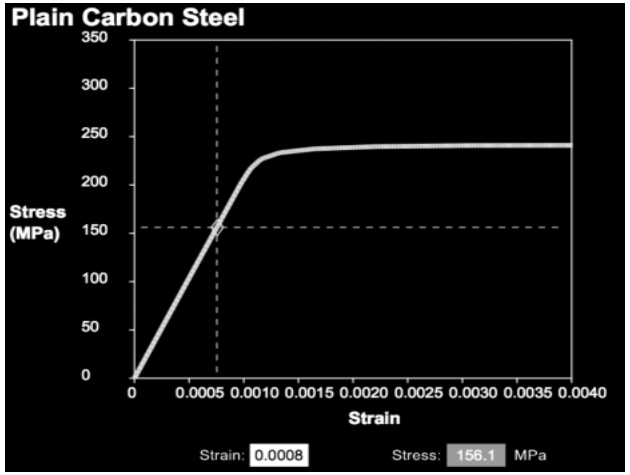
Class Exercise   E = ? In GPa (5 – 10 mins)





Al



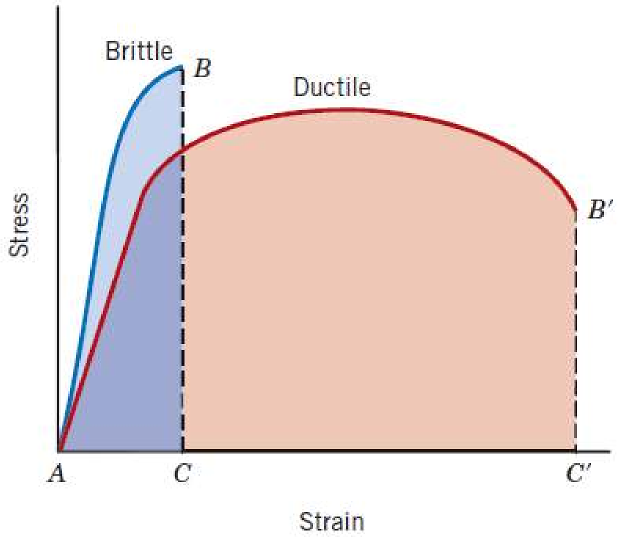


Materials Contents in this Slides adapted from : Materials science and engineering: an introduction / William D. Callister, Jr., David G. Rethwisch.–8th ed.

TENSILE PROPERTIES

- **Ductility :** **"**measure of the degree of plastic deformation that has been sustained at fracture"
- **Brittle** material: very little or no plastic deformation upon fracture

  "Brittle materials are *approximately* considered to be those having a fracture strain of less than about 5%."



Materials Contents in this Slides adapted from : Materials science and engineering: an introduction / William D. Callister, Jr., David G. Rethwisch.–8th ed.

TENSILE PROPERTIES

- **Ductility measurement:**
  - **Percent Elongation:**

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

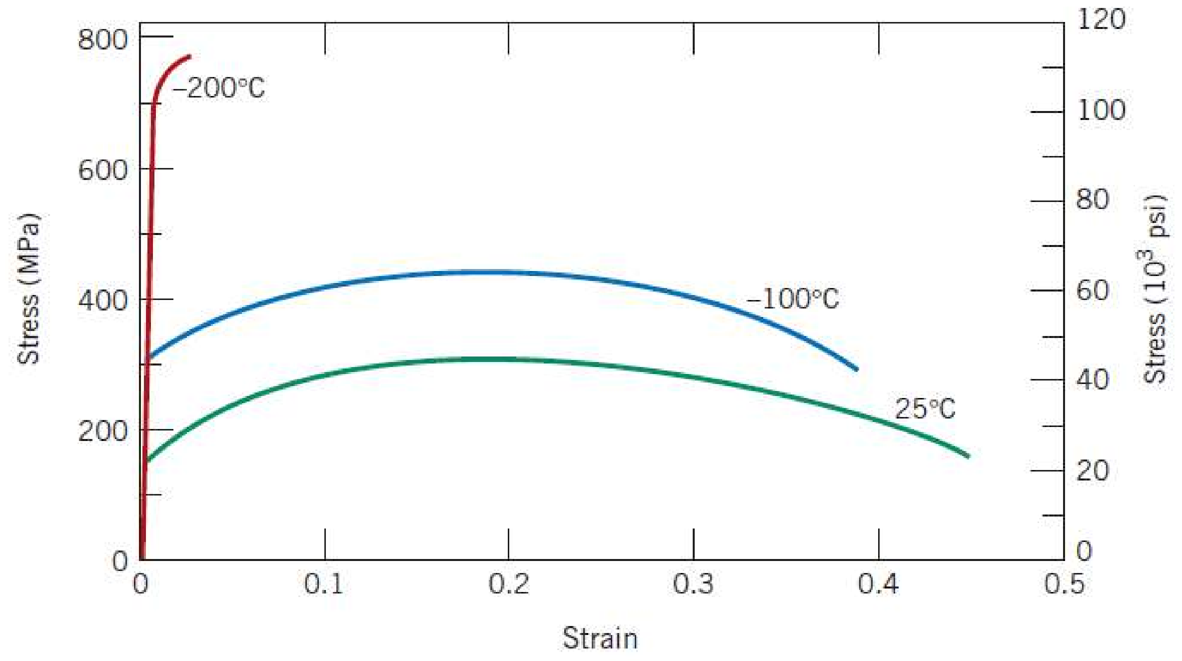
  - **Percent reduction in area:**

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

Materials Contents in this Slides adapted from : Materials science and engineering: an introduction / William D. Callister, Jr., David G. Rethwisch.–8th ed.

TENSILE PROPERTIES

Stress-Strain behaviour for iron at different temperatures.



Materials Contents in this Slides adapted from : Materials science and engineering: an introduction / William D. Callister, Jr., David G. Rethwisch.–8th ed.

TENSILE PROPERTIES

Table 6.2 **Typical Mechanical Properties of Several Metals and Alloys in an Annealed State**

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

TENSILE PROPERTIES

- **Resilience:** "capacity of a material to absorb energy when it is deformed elastically and then, upon unloading, to have this energy recovered"
- ***Modulus of Resilience, Ur:*** *"*strain energy per unit volume required to stress a material from an unloaded state up to the point of yielding"

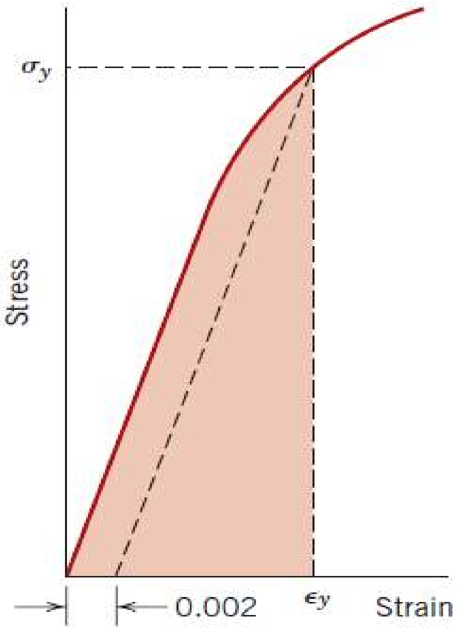
$$U_r = \int_0^{\epsilon_y} \sigma \, d\epsilon$$

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

Assuming linear elastic region

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

"Resilient materials are those having high yield strengths and low moduli of elasticity"
(spring applications)



Materials Contents in this Slides adapted from : Materials science and engineering: an introduction / William D. Callister, Jr., David G. Rethwisch.–8th ed.

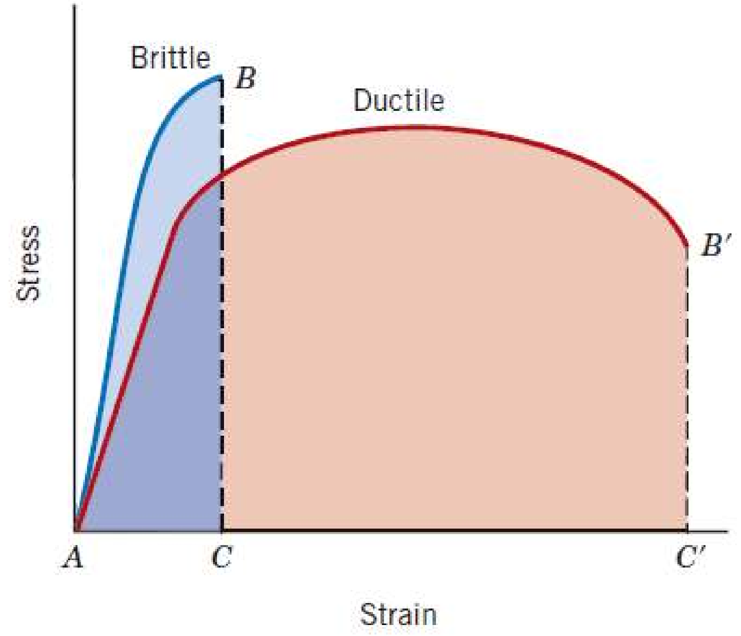
TENSILE PROPERTIES

Toughness (or Fracture Toughness)

- Material's resistance to fracture when a crack is present

or

- Ability of a material to absorb energy and plastically deform before fracturing



Area under the stress-strain curve up to the point of fracture

Materials Contents in this Slides adapted from : Materials science and engineering: an introduction / William D. Callister, Jr., David G. Rethwisch.–8th ed.

TENSILE PROPERTIES

Table 6.3 Tensile Stress–Strain Data for Several Hypothetical Metals to Be Used with Concept Checks 6.2 and 6.4

Material	*Yield Strength (MPa)*	*Tensile Strength (MPa)*	*Strain at Fracture*	*Fracture Strength (MPa)*	*Elastic Modulus (GPa)*
A	310	340	0.23	265	210
B	100	120	0.40	105	150
C	415	550	0.15	500	310
D	700	850	0.14	720	210
E	Fractures before yielding			650	350

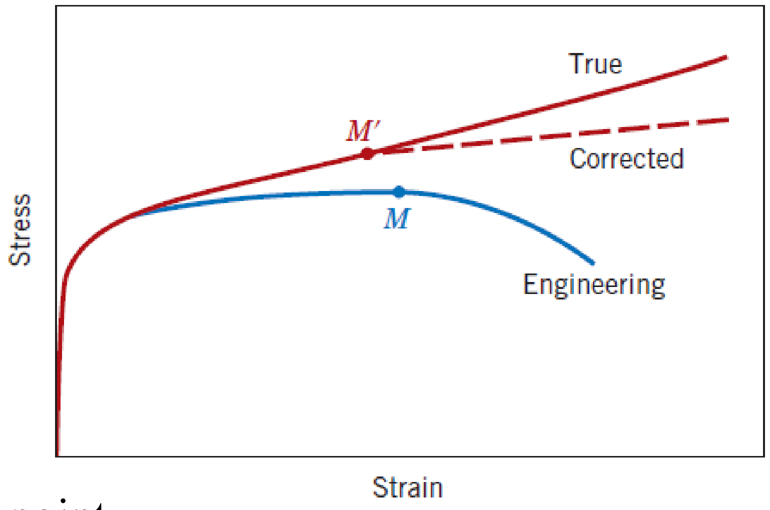
Materials Contents in this Slides adapted from : Materials science and engineering: an introduction / William D. Callister, Jr., David G. Rethwisch.–8th ed.

TRUE STRESS AND STRAIN

$$\sigma_T = \frac{F}{A_i}$$

True stress: load divided by the instantaneous cross-sectional area over which deformation is occurring (i.e., the neck, past the tensile point)

$$\epsilon_T = \ln\frac{l_i}{l_0}$$



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

$$A_i l_i = A_0 l_0$$

$$\epsilon_T = \ln(1 + \epsilon)$$

"Valid only to the onset of necking; beyond this point true stress and strain should be computed from actual load, cross-sectional area, and gauge length measurements"

Materials Contents in this Slides adapted from : Materials science and engineering: an introduction / William D. Callister, Jr., David G. Rethwisch.–8th ed.

TRUE STRESS AND STRAIN

For some metals and alloy, form yield point to necking;

$$\sigma_T = K\epsilon_T^n$$

n: strain hardening exponent

Table 6.4 Tabulation of *n* and *K* Values (Equation 6.19) for Several Alloys

		K	
Material	*n*	*MPa*	*psi*
Low-carbon steel (annealed)	0.21	600	87,000
4340 steel alloy (tempered @ 315°C)	0.12	2650	385,000
304 stainless steel (annealed)	0.44	1400	205,000
Copper (annealed)	0.44	530	76,500
Naval brass (annealed)	0.21	585	85,000
2024 aluminum alloy (heat-treated—T3)	0.17	780	113,000
AZ-31B magnesium alloy (annealed)	0.16	450	66,000

Materials Contents in this Slides adapted from : Materials science and engineering: an introduction / William D. Callister, Jr., David G. Rethwisch.–8th ed.

Example

A cylindrical specimen of steel having an original diameter of 12.8 mm (0.505 in.) is tensile-tested to fracture and found to have an engineering fracture strength σ_f of 460 MPa (67,000 psi). If its cross-sectional diameter at fracture is 10.7 mm (0.422 in.), determine:

(a) The ductility in terms of percent reduction in area

(b) The true stress at fracture

(a) Ductility is computed using Equation 6.12, as

$$\%\text{RA} = \frac{\left(\frac{12.8\text{ mm}}{2}\right)^2\pi - \left(\frac{10.7\text{ mm}}{2}\right)^2\pi}{\left(\frac{12.8\text{ mm}}{2}\right)^2\pi} \times 100$$

$$= \frac{128.7\text{ mm}^2 - 89.9\text{ mm}^2}{128.7\text{ mm}^2} \times 100 = 30\%$$

(b) True stress is defined by Equation 6.15, where in this case the area is taken as the fracture area A_f. However, the load at fracture must first be computed from the fracture strength as

$$F = \sigma_f A_0 = (460 \times 10^6\text{ N/m}^2)(128.7\text{ mm}^2)\left(\frac{1\text{ m}^2}{10^6\text{ mm}^2}\right) = 59{,}200\text{ N}$$

Thus, the true stress is calculated as

$$\sigma_T = \frac{F}{A_f} = \frac{59{,}200\text{ N}}{(89.9\text{ mm}^2)\left(\frac{1\text{ m}^2}{10^6\text{ mm}^2}\right)}$$

$$= 6.6 \times 10^8\text{ N/m}^2 = 660\text{ MPa (95,700 psi)}$$

Problem

A cylindrical specimen of a titanium alloy having an elastic modulus of 107 GPa (15.5 $\times 10^6$ psi) and an original diameter of 3.8 mm (0.15 in.) will experience only elastic deformation when a tensile load of 2000 N (450 lb_f) is applied. Compute the maximum length of the specimen before deformation if the maximum allowable elongation is 0.42 mm (0.0165 in.).

$L_0 = ?$ during elastic deformation.

$$\varepsilon = \frac{\Delta L}{L_0} \rightarrow L_0 = \frac{\Delta L}{\varepsilon}, \quad \varepsilon \rightarrow \frac{\sigma}{E}$$

$$\therefore L_0 = \frac{\Delta L E}{\sigma}, \quad \sigma \rightarrow \frac{F}{A_0}$$

$$\therefore L_0 = \frac{\Delta L E A_0}{F} = \frac{\Delta L E \pi d_0^2}{4F}, \quad A_0 \rightarrow \pi\left(\frac{d_0}{2}\right)^2$$

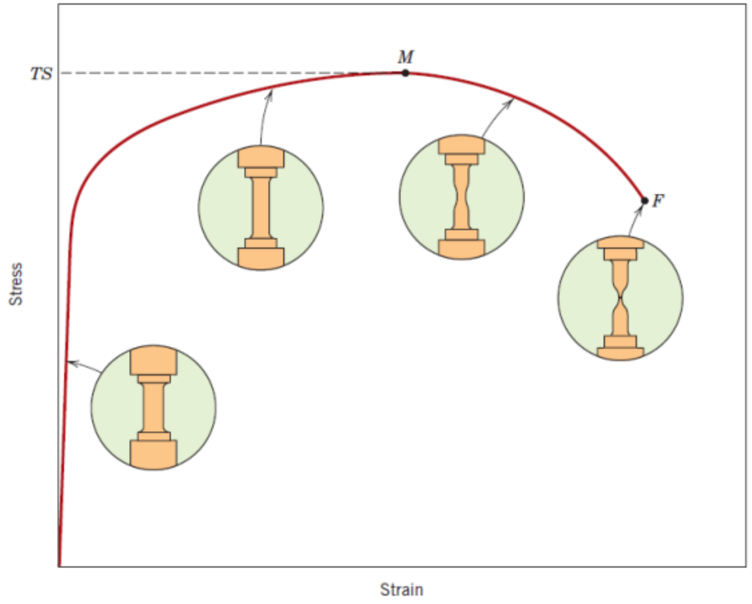
$\Delta L = 0.42$ mm

$d_0 = 7.8$ mm

$$\therefore L_0 = 0.255 \text{ m.}$$

COMPRESSIVE, SHEAR, AND TORSIONAL DEFORMATIONS

Same stress-strain diagram as for tensile test except for the compression test.



HARDNESS

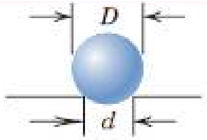
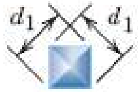
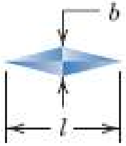
Material's resistance to localized plastic deformation.

Hardness test:

- Small indenter is forced into the surface of a material
- The depth or size of the resulting indentation is measured
- Calculate the hardness number

"the softer the material, the larger and deeper the indentation, and the lower the hardness index number"

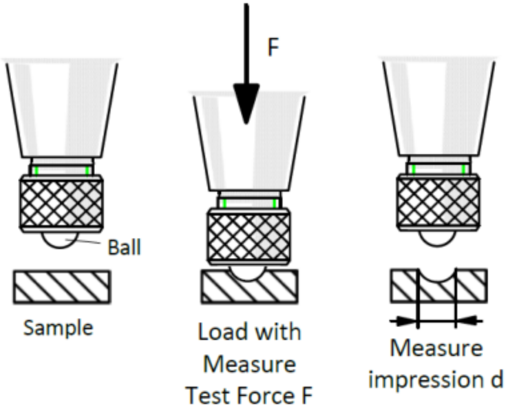
Table 6.5 Hardness-Testing Techniques

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	$HB = \frac{2P}{\pi D[D - \sqrt{D^2 - d^2}]}$
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	

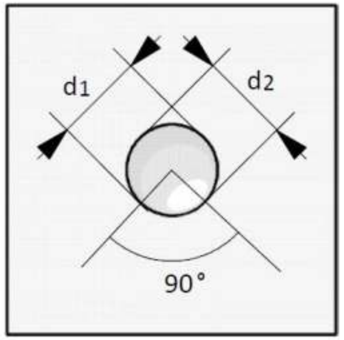
[a]For the hardness formulas given, P (the applied load) is in kg, whereas D, d, d_1, and l are all in mm.

Source: Adapted from H. W. Hayden, W. G. Moffatt, and J. Wulff, *The Structure and Properties of Materials*, Vol. III, *Mechanical Behavior*. Copyright © 1965 by John Wiley & Sons, New York. Reprinted by permission of John Wiley & Sons, Inc.

Brinell Hardness



Hardness testing according to Brinell



Measure the ball impression

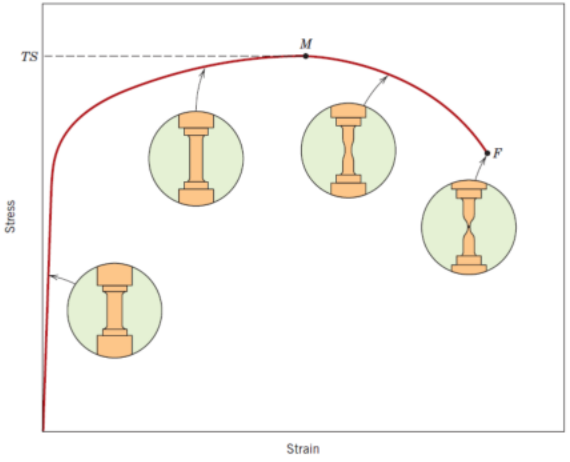
$$d = \frac{d_{1+}d_2}{2}$$

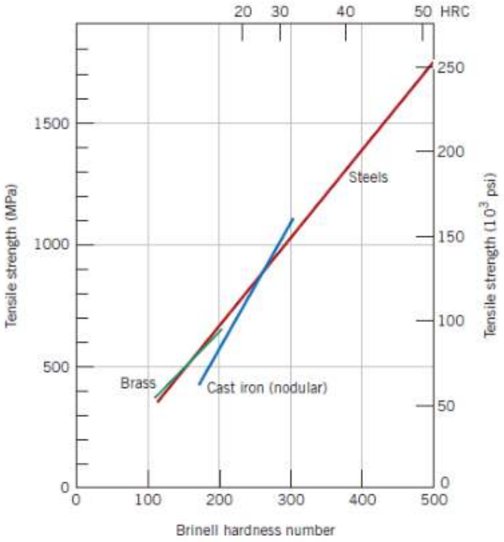
$$HB = \frac{0.102 \times F}{A_B} = \frac{0.102 \times F}{0.5\ \pi\ D\ (\ D - \sqrt{D^2 - d^2})}$$

HARDNESS

Correlation between Hardness and Tensile Strength

"Both tensile strength and hardness are indicators of a metal's resistance to plastic deformation"





$$TS(\text{MPa}) = 3.45 \times \text{HB}$$

$$TS(\text{psi}) = 500 \times \text{HB}$$

For most steels

Materials Contents in this Slides adapted from : Materials science and engineering: an introduction / William D. Callister, Jr., David G. Rethwisch.–8th ed.

VARIABILITY OF MATERIAL PROPERTIES

"Even if we have a most precise measuring apparatus and a highly controlled test procedure, there will always be some scatter or variability in the data that are collected from specimens of the same material"

- Therefore, the engineer should ask "What is the probability of failure of this alloy under these given circumstances?" instead of "What is the fracture strength of this alloy?"
- Thus, statistical and probability analysis must be considered in measuring material properties.

VARIABILITY OF MATERIAL PROPERTIES

Computation of Average and Standard Deviation Values

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$$

Average value

$$s = \left[\frac{\sum_{i=1}^{n} x_i - \bar{x}2\ ^{2}}{n-1} \right]^{1/2}$$

Standard deviation

Materials Contents in this Slides adapted from : Materials science and engineering: an introduction / William D. Callister, Jr., David G. Rethwisch.–8th ed.

Example

The following tensile strengths were measured for four specimens of the same steel alloy:

Sample Number	*Tensile Strength (MPa)*
1	520
2	512
3	515
4	522

(a) Compute the average tensile strength.
(b) Determine the standard deviation.

(a) The average tensile strength ($\overline{TS}$) is computed using Equation 6.21 with $n = 4$:

$$\overline{TS} = \frac{\sum_{i=1}^{4}(TS)_i}{4} = \frac{520 + 512 + 515 + 522}{4} = 517 \text{ MPa}$$

(b) For the standard deviation, using Equation 6.22,

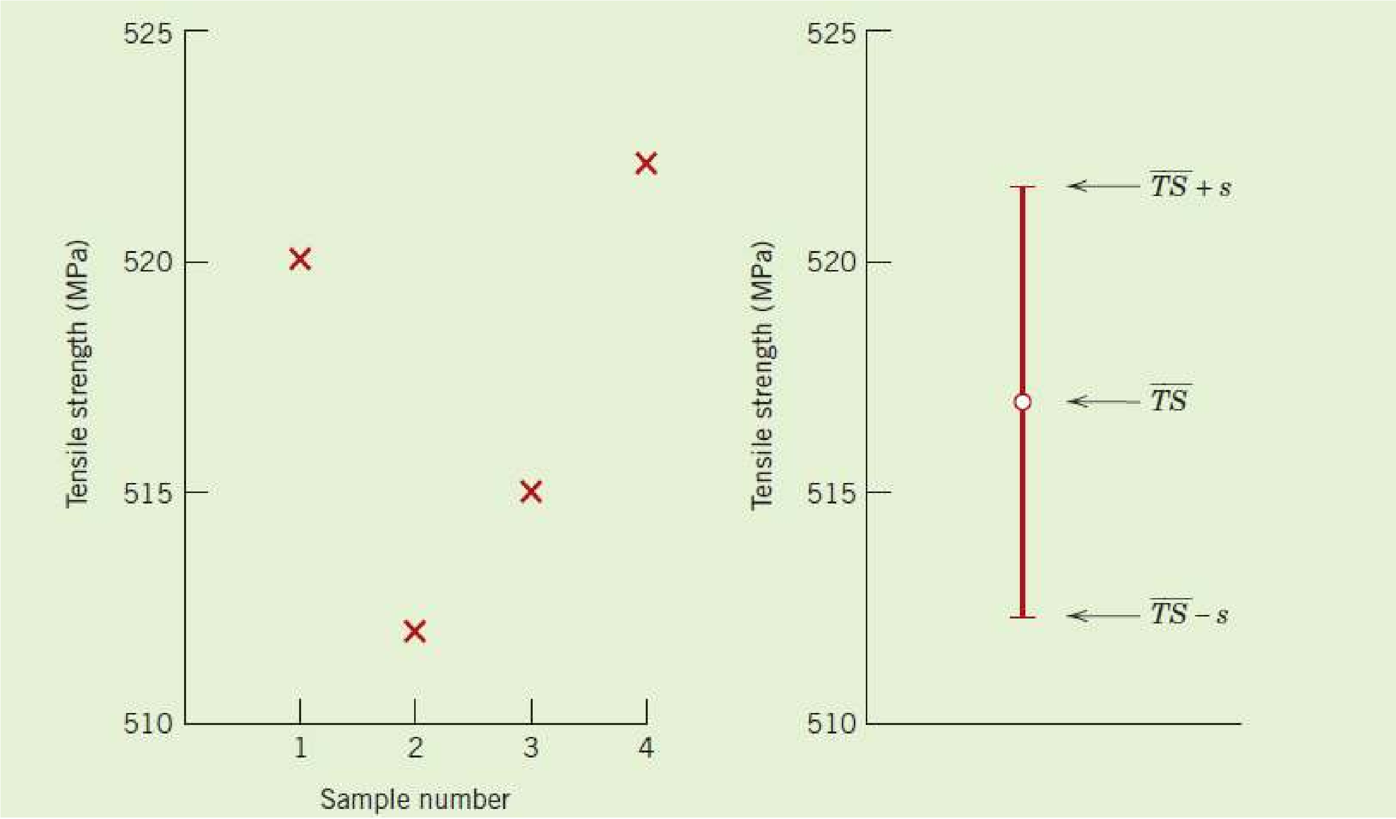
$$s = \left[\frac{\sum_{i=1}^{4}\{(TS)_i - \overline{TS}\}^2}{4-1}\right]^{1/2}$$

$$= \left[\frac{(520-517)^2 + (512-517)^2 + (515-517)^2 + (522-517)^2}{4-1}\right]^{1/2}$$

$$= 4.6 \text{ MPa}$$

Materials Contents in this Slides adapted from : Materials science and engineering: an introduction / William D. Callister, Jr., David G. Rethwisch.–8th ed.

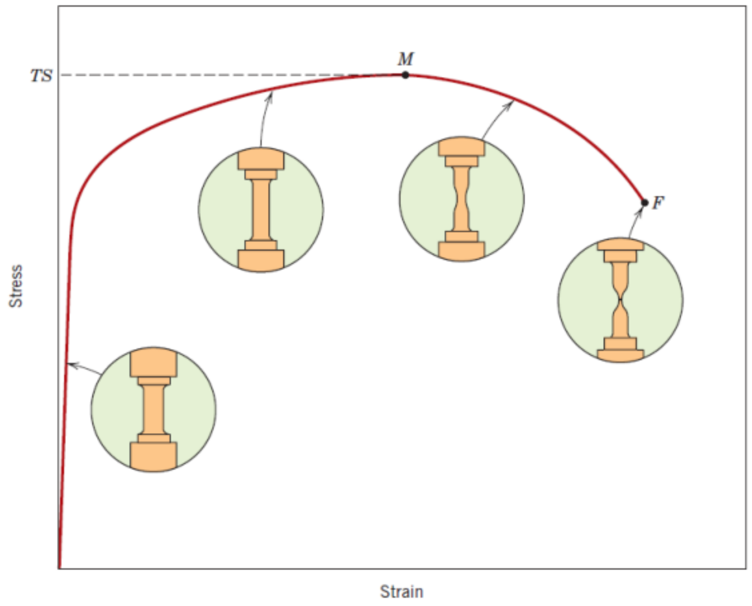
Example



525
520
515
510
Tensile strength (MPa)
1
2
3
4
Sample number
525
520
515
510
Tensile strength (MPa)
$\overline{TS} + s$
$\overline{TS}$
$\overline{TS} - s$

DESIGN/SAFETY FACTORS

$$\sigma_w = \frac{\sigma_y}{N}$$



Design Example

A tensile-testing apparatus is to be constructed that must withstand a maximum load of 220,000 N (50,000 lb_f). The design calls for two cylindrical support posts, each of which is to support half of the maximum load. Furthermore, plain-carbon (1045) steel ground and polished shafting rounds are to be used; the minimum yield and tensile strengths of this alloy are 310 MPa (45,000 psi) and 565 MPa (82,000 psi), respectively. Specify a suitable diameter for these support posts.

Consider factor of safety (N) = 5

Design Example

$$\sigma_w = \frac{\sigma_y}{N} = \frac{310\text{ MPa}}{5} = 62\text{ MPa (9000 psi)}$$

$$A_0 = \left(\frac{d}{2}\right)^2 \pi = \frac{F}{\sigma_w}$$

$$d = 2\sqrt{\frac{F}{\pi\sigma_w}} = \sqrt{\frac{110{,}000\text{ N}}{\pi(62 \times 10^6\text{ N/m}^2)}} = 4.75 \times 10^{-2}\text{ m} = 47.5\text{ mm (1.87 in.)}$$

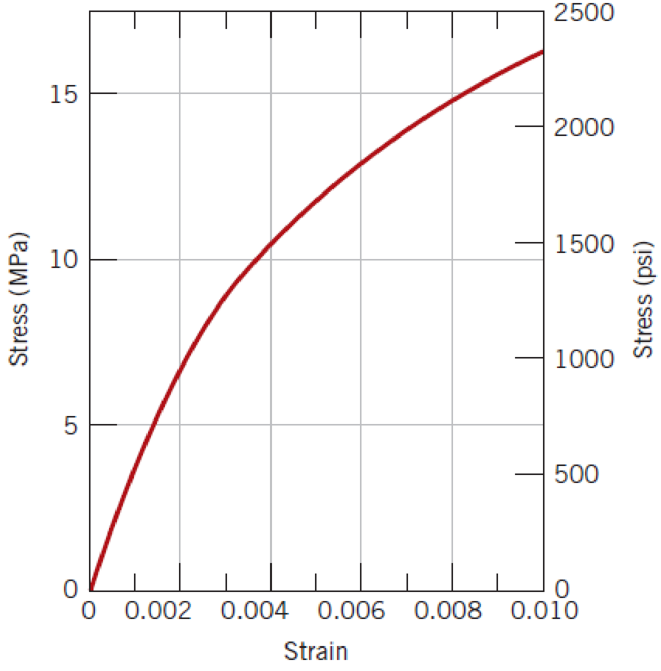
Homework

Q1. *A cylindrical specimen of a titanium alloy having an elastic modulus of 107 GPa (15.5 $\times 10^6$ psi) and an original diameter of 3.8 mm (0.15 in.) will experience only elastic deformation when a tensile load of 2000 N (450 lb_f) is applied. Compute the maximum length of the specimen before deformation if the maximum allowable elongation is 0.42 mm (0.0165 in.).*

Q2. *A steel bar 100 mm (4.0 in.) long and having a square cross section 20 mm (0.8 in.) on an edge is pulled in tension with a load of 89,000 N (20,000 lb_f), and experiences an elongation of 0.10 mm (4.0 $\times 10^{-3}$ in.). Assuming that the deformation is entirely elastic, calculate the elastic modulus of the steel.*

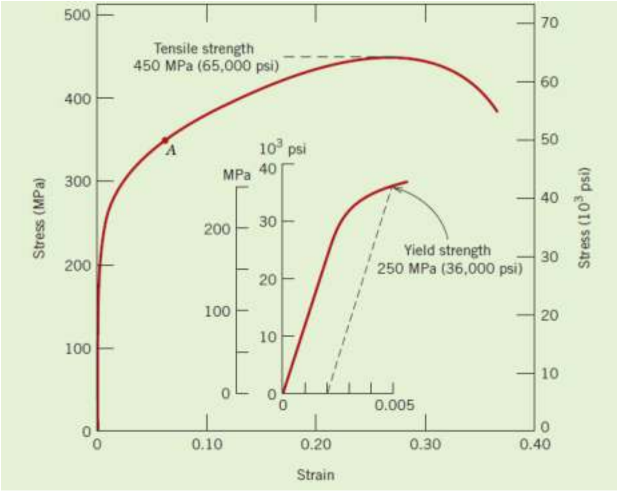
Homework

Q3. *Figure below shows, for a gray cast iron, the tensile engineering stress–strain curve in the elastic region. Determine (a) the tangent modulus at 10.3 MPa (1500 psi), and (b) the secant modulus taken to 6.9 MPa (1000 psi).*



Homework

Q4. *Consider the brass alloy for which the stress-strain behavior is shown below. A cylindrical specimen of this material 6 mm (0.24 in.) in diameter and 50 mm (2 in.) long is pulled in tension with a force of 5000 N (1125* lb_f*). If it is known that this alloy has a Poisson's ratio of 0.30, compute: (a) the specimen elongation, and (b) the reduction in specimen diameter.*



Materials Contents in this Slides adapted from : Materials science and engineering: an introduction / William D. Callister, Jr., David G. Rethwisch.–8th ed.