الجامعة التكنولوجية

قسم الهندسة الكيمياوية

المرحلة الثانية

علم وهندسة المواد

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Course Title
Syllabus/Text

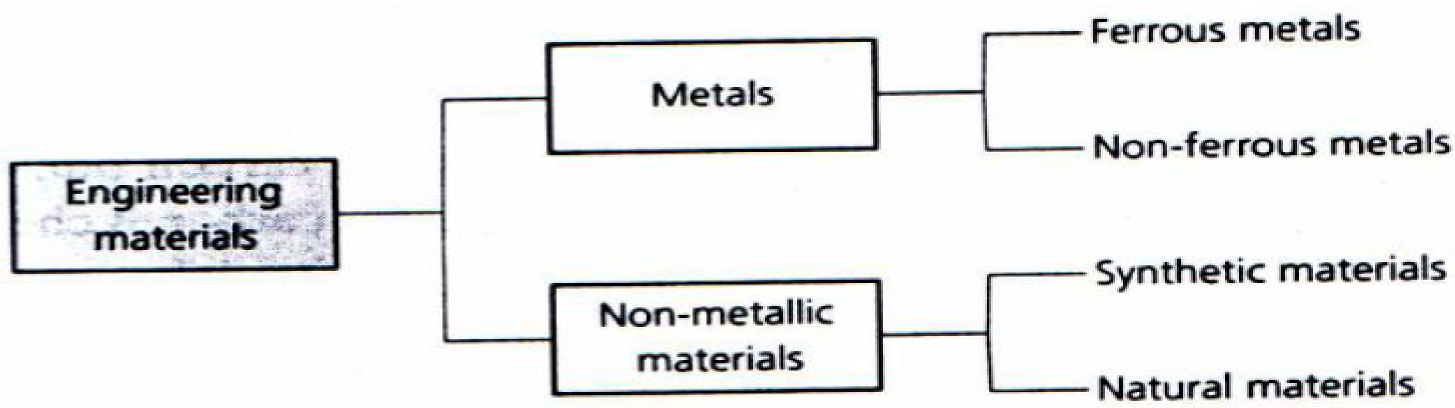
Material Eng. (I)

No.	Contents	Duration
1	**Classification of Materials** Classification of materials, classification of materials based on structure and its application.	4hr
2	**Mechanical Properties of Materials** Stress-strain behavior, ductility, brittleness, toughness, modulus of resilience, poison's ratio, hardness, effect of temperature.	6hr
3	**Atomic structure** The structure of atom, atomic bonding, bonding energy and inter-atomic spacing	6hr
4	**Atomic order in solids** Types of atomic or ionic arrangements, crystal structure, lattice,unit cells, crystal systems, crystal direction and crystal planes , diffraction techniques for crystal structure analysis	8hr
5	**Thermal and electrical properties of materials** Heat capacity, thermal expansion, thermal conductivity, thermal stress, Glass transition temperature, Creep resistance, electrical conductivity, electron mobility, electrical resistivity of metals	6hr

1-Donaled R. Askeland, The science and engineering of materials, international student edition, 2006 .
2-William D. Callister, Jr. , Materials science and engineering, Fifth edition, 2000.
3-Lawrence H. Vanvlack , Elements of materials science and engineering, Fifth edition, 1987.

Engineering materials:

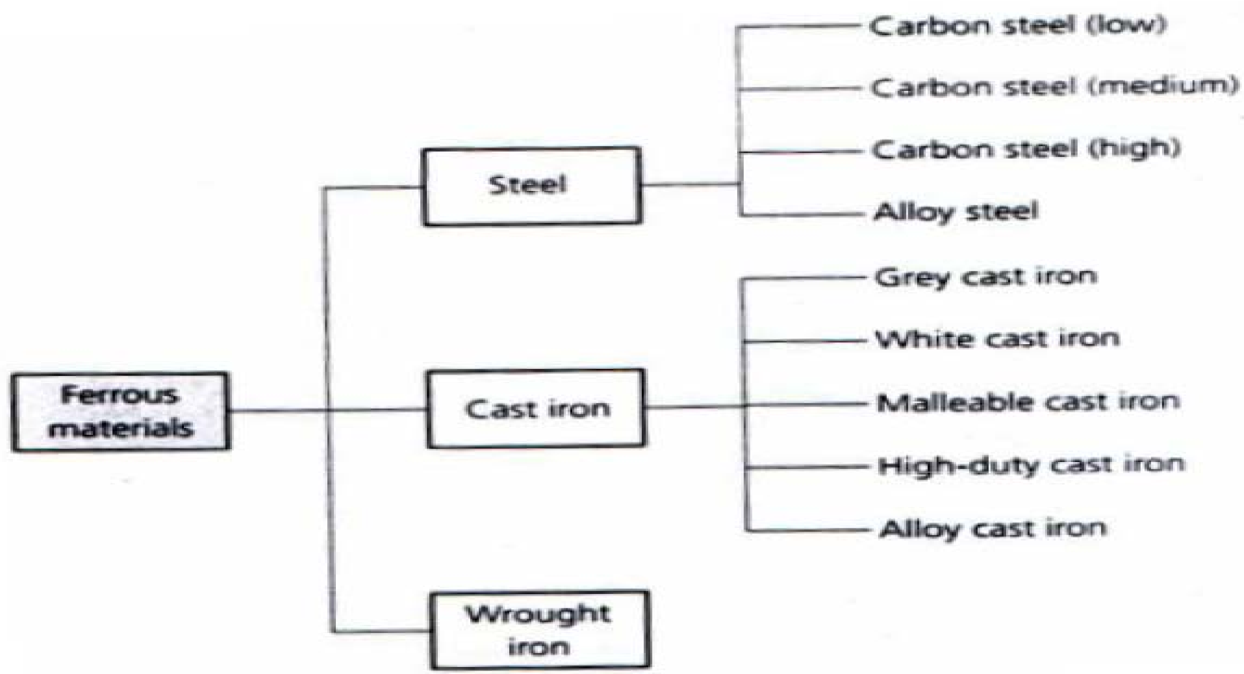
Almost every substance known to man has found its way into the engineering workshop at some time or other. The most convenient way to study the properties and uses of engineering materials is to classify them into 'families' as shown in figure below:



1. Metals

1.1 Ferrous metals

- These are metals and alloys containing a high proportion of the element iron.
- They are the strongest materials available and are used for applications where high strength is required at relatively low cost and where weight is not of primary importance.
- As an example of ferrous metals such as : bridge building, the structure of large buildings, railway lines, locomotives and rolling stock and the bodies and highly stressed engine parts of road vehicles.



1.2 Non – ferrous metals

- These materials refer to the remaining metals known to mankind.
- The pure metals are rarely used as structural materials as they lack mechanical strength.
- They are used where their special properties such as corrosion resistance, electrical conductivity and thermal conductivity are required. Copper and aluminum are used as electrical conductors and, together with sheet zinc and sheet lead, are use as roofing materials.
- They are mainly used with other metals to improve their strength.

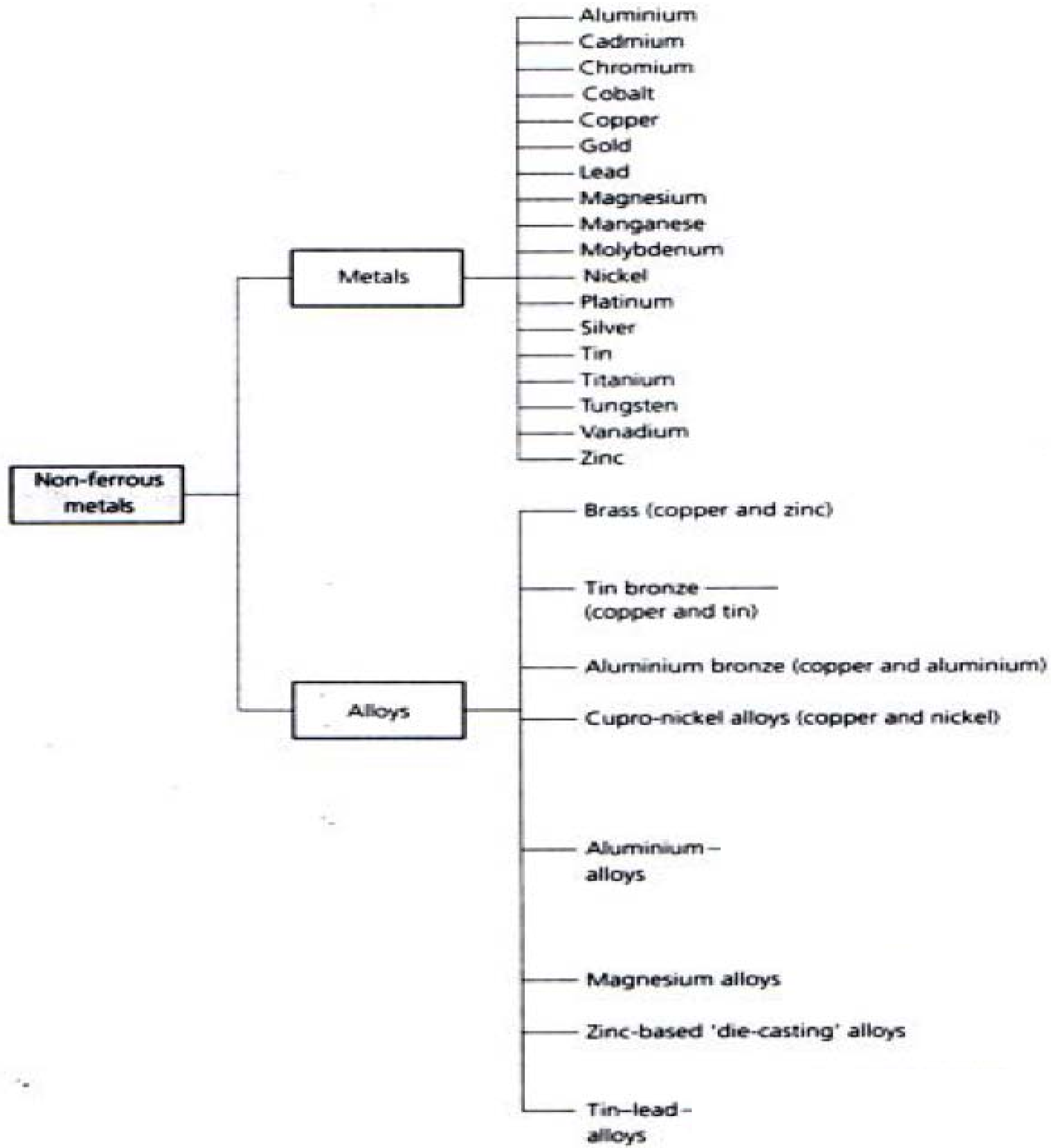


Figure 3. Classification of non-ferrous metals and alloys.

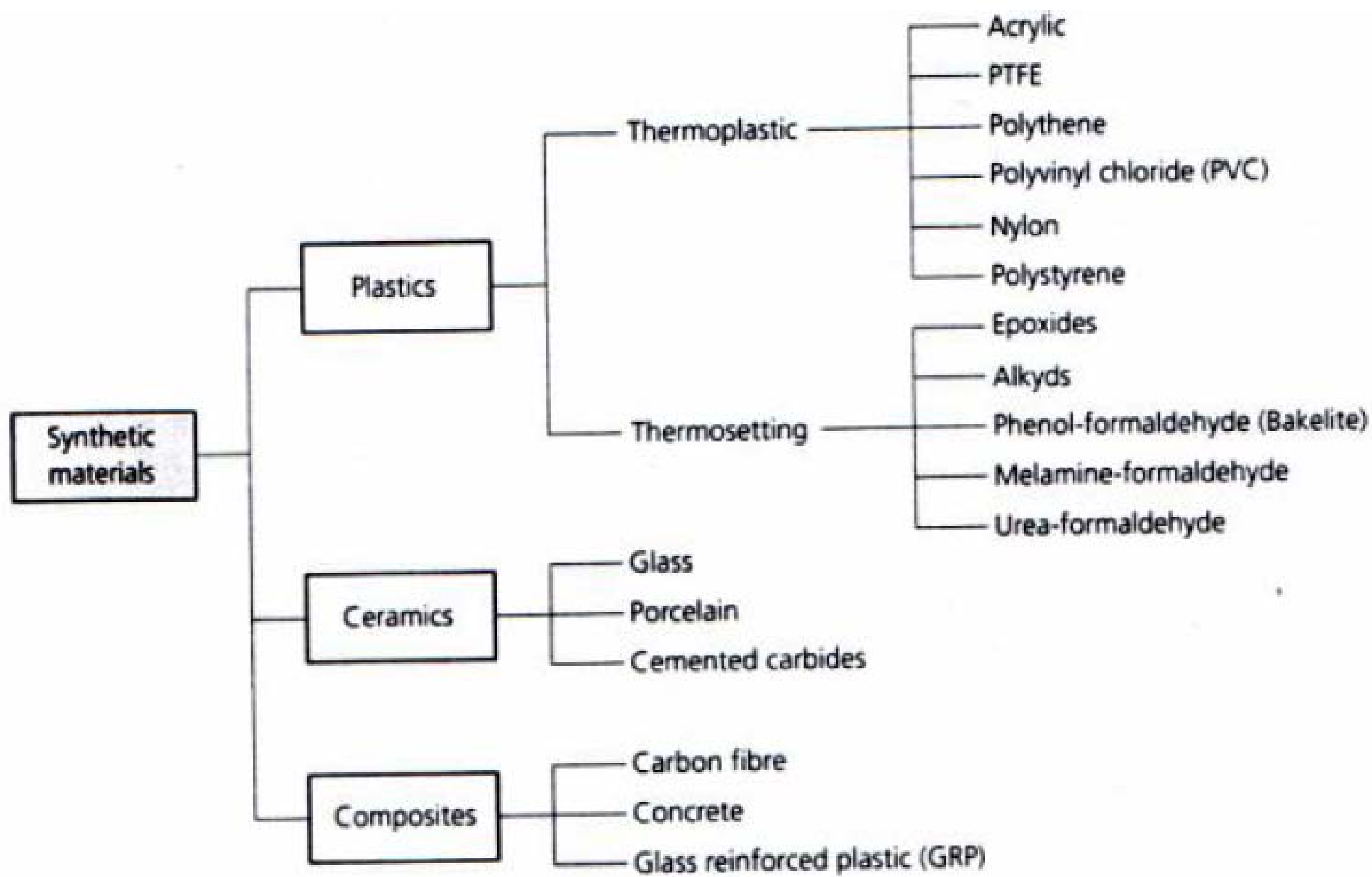
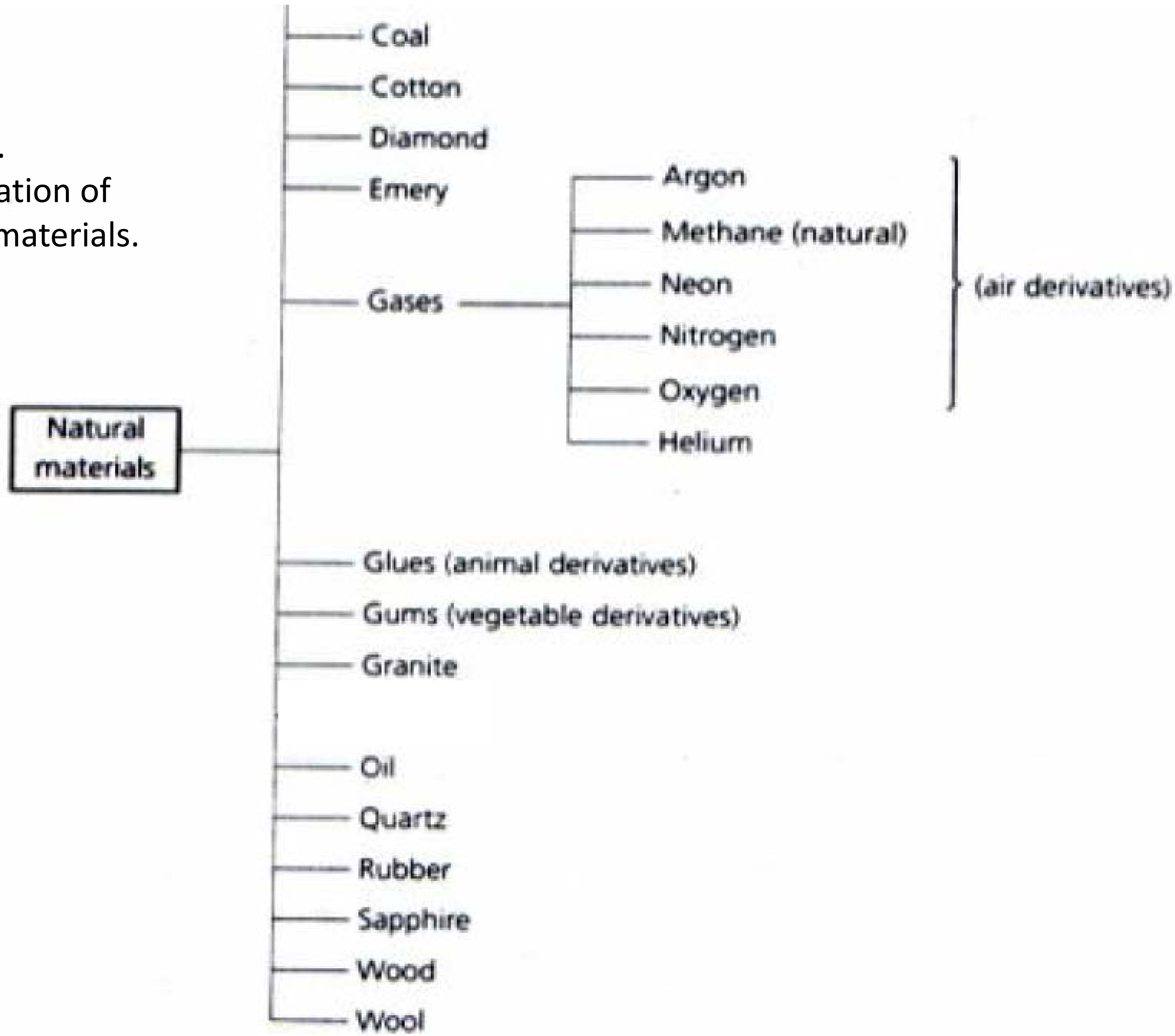


Figure 4. classification of synthetic materials.

Figure 5.
Classification of natural materials.



CHAPTER ONE

Classification of Materials

1-1 Classification of engineering materials

a-Metals and Alloys

Metals are inorganic materials th

at are normally combination of metallic elements

-They usually have a crystalline structure and are good thermal and electrical conductions.

-Many metals have high strength and high elastic module.

--They also have sufficient ductility, which is important for many engineering applications.

-They are least resistance to corrosion.

-An alloy is a mixture of two or more elements in solid solution in which the major component is a metal .Combining different ratios of metals as alloys modify the properties of pure metals to produce desirable characteristics. The aim of making alloys is generally to make them less brittle , harder,and resistant to corrosion. Examples of alloys are steel (iron and carbon) ,brass (copper and zinc), and bronze (copper and tin).

b-Ceramics and glasses

They are inorganic materials consisting of both metallic and non-metallic elements bonded together chemically.

-They can be crystalline (ceramics),non-crystalline (glasses) or mixture of both (glass-ceramics).

-They are good electrical and thermal insulators.

-They have high hardness ,high moduli , and high temperature strength.

-They are resistant to high temperature and corrosive environments.

-They are very brittle.

c-Polymers

They are organic materials which consist of long molecular chain and they are chemically based on carbon and hydrogen.

-Most polymers are non-crystalline ,but some consist of mixtures of both crystalline and non-crystalline regions.

-They are generally have low density and are not stable at high temperatures.

-They generally have a good strength to weight ratio.

-Most of them are corrosion resistant, but cannot be used at high temperatures.

-They provide a good electrical and thermal insulation.

-Polymers may be either ductile(thermoplastic) or brittle(thermosetting).

d-Semiconductors

They have electrical properties intermediate between metallic conductors and ceramic insulators.

-Silicon is the most commercially important semiconductors.

-Semiconductors may be elemental materials such as silicon and germanium,or alloys such as silicon germanium.

-The semiconductor devices are combined with simpler components,such as semiconductor capacitors and resistors,to produce a variety of electronic devices.

e-Composite materials

Materials where two or more of the above materials are brought together.They are designed to combine the best properties of each of its components.

-usually they consist of a matrix and a reinforcement.

-Fiber,a combination of glass and a polymer,is an example.Concrete is other familiar composites.

1-2 Classification of materials based on structure

a-Crystalline materials

- -single crystals
- -polycrystalline

b-Amorphous materials

1-3 Classification of materials based on the function

a-Mechanical material b-Electronic material c-Magnetic material d-Optical material e-Medical material .

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CHAPTER TWO

Mechanical Properties of Materials

2-1 Stress

It is a measure of force acting on the unit area over which the force is applid.

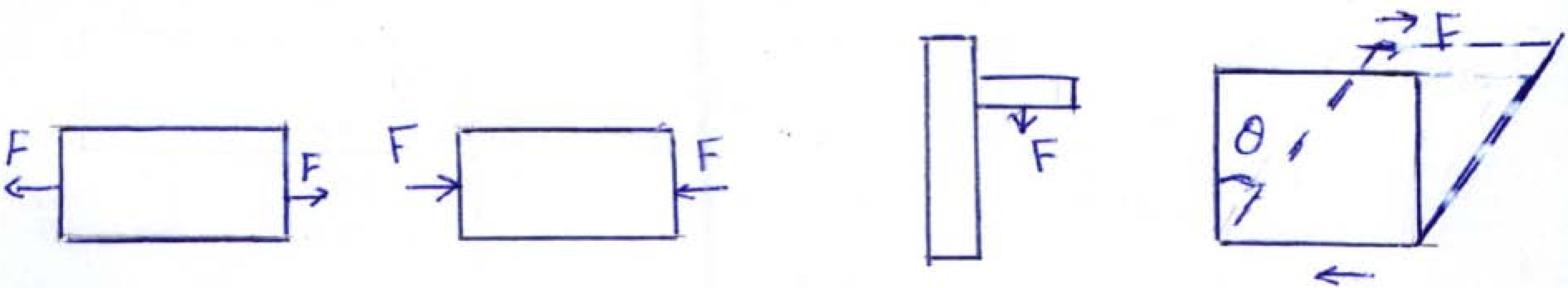
$$\sigma = F/A_0$$

Where F: force(N)

A_0: original area(m^2)

σ:stress (N/m^2)

There are tensile, compressive ,shear, and bending stresses illustrated in fig(2-1).



Tensile Stress · Compressive Stress · Bending Stress · Shear Stress

2-2 Strain

It is the deformation of material.

$$\epsilon = \Delta l / l_0$$

Where ϵ: strain , Δl :change in length, l_0:original length.

-Strain is expressed as a fraction (or percent).

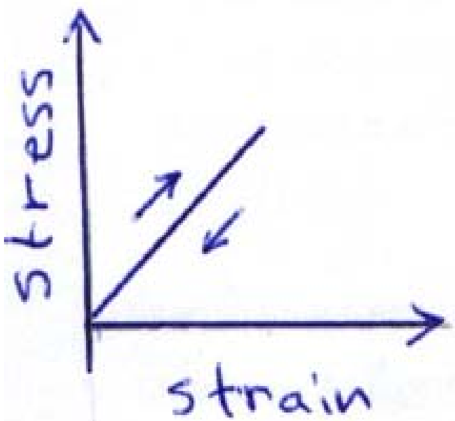
-Strain may elastic or plastic as shown in fig (2-2).

1- Elastic Strain .

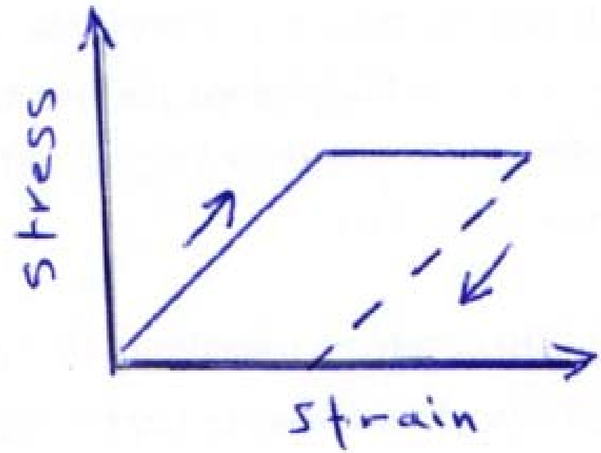
It is reversible ,that is, when the stress is removed,the strain disappears.Elastic strain is commonly alinear function of stress obeying Hooks' law of physics.

2-Plastic Strain

It is apermanent deformation in a material.In this case ,when the stress is removed,the material does not go back to its original shape.



Elastic Strain



Plastic Strain

Fig (2-2)

2-3 Stress-Strain Diagram

For most metals that are stressed in tension and at relatively low levels , a plot of stress versus strain results in a linear relationship , as shown in fig (2-3).Stress and strain are proportional to each other throughthe relationship: $\sigma = E \epsilon$

This is known as Hooks' law,and the constant of proportionality E is the **modulus of elasticity** , or **young s' modulus** .

The slope of the linear segment correspond to the modulus of elasticity.

The modulus of elasticity is:-

a-A measure of stiffness, the greater the modulus, the stiffer the material.

b-A material s' resistance to elastic deformation ,the greater the modulus, the smaller the elastic strain.

c-A measure of the resistance to separation of adjacent atoms, that is, the interatomic bonding forces.So:

$$E_{ceramic} > E_{metal} \text{ and } E_{polymer}$$

The proportionality of stress to strain ends at the **proportional limit** , which is defined as the level of stress above which the relationship between stress and strain is not linear. Deformation in which stress and strain are proportional is called elastic deformation .

2-3-1 Some Concepts Developed From The Stress-Strain Diagram

1-The elastic limit:it is the critical stress value needed to initiate plastic deformation.

2-yield point:at which there is an appreciable elongation or yielding of the material without any corresponding increase of load; indeed, the load may actually decrease while the yielding occurs. However, the phenomenon of yielding is peculiar to some materials and other material do not posses this point as shown in fig (2-4).

3-yield strength: closely associated with yield point. For materials which do not have a well defined yield point, yield strength is determined by the offset method. This consists of drawing a line, parallel to the linear portion of the stress-strain curve ,this line being started at some specified strain offset, usually 0.002. As shown in fig .(2-5),the intersection of this line with the stress-strain curve is called **the yield – strength**. The magnitude of the yield strength for the a metal is a measure of its resistance to plastic deformation.

4-ultimate or tensile strength: it is the maximum tensile stress a material can withstand before failer.It is a feature of the engineering stress-strain curve and cannot be found in the true stress-strain curve. However, at this maximum stress, a small contraction or neck begins to form at some points, all subsequent deformation is confined at this neck.fig.(2-6).

5-rupture or fracture strength (engineering breaking strength): it is the stress at fracture,it is computed by dividing the fracture load by the original cross-sectional area, so its some what lower than tensile strength.

6-actual rupture strength or true fracture strength :it is the true stress at fracture which is defined as the load divided by the instantaneous cross-sectional area(A_i) over which deformation is occurring (i.e.,the neck,past the tensile point). The true stress-strain curve is compared with the stress-strain curve in fig.(2-3).it can be seen that the true stress continues to increase after necking because, although the load required decreases, the area decreases even more.

$\sigma_T = F / A_i$ where σ_T = True fracture strength.

$\epsilon_T = \int dl / l = \ln l_i / l_0 = \ln A_0 / A_i$ where ϵ_T =True fracture strain.

If no volume change occurs during deformation , that is, if $A_0 l_0 = A_i l_i$,then:-

$\sigma_T = F / A_i = l_i F / A_0 l_0 = \sigma\, l_i / l_0 = \sigma\, [(l_0 + \Delta l) / l_0] = \sigma\,(1+\epsilon)$

and

$\epsilon_T = \ln l_i / l_0 = \ln [(l_0 + \Delta) / l_0] = \ln (1+\epsilon)$

The above equations are valid only to the onset of necking.

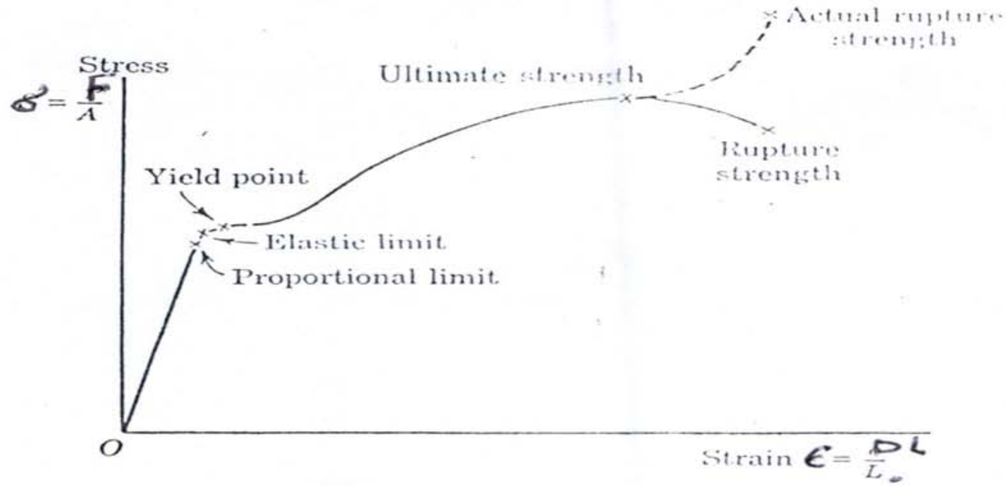


Fig. 2-3 — Stress-strain diagram.

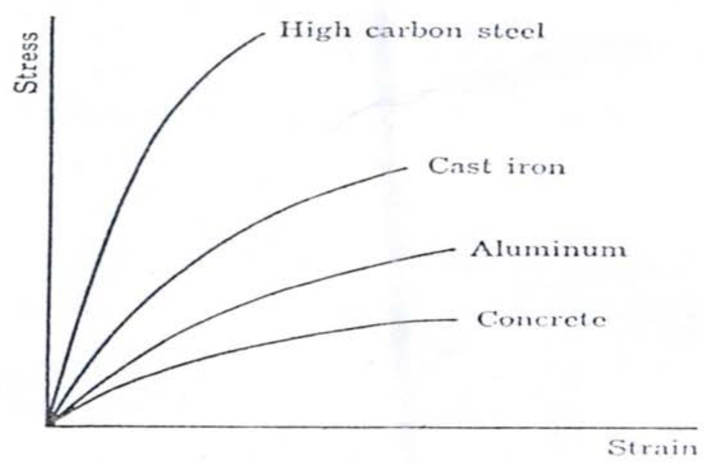


Fig. 2-4 — Comparative stress-strain diagrams for different materials.

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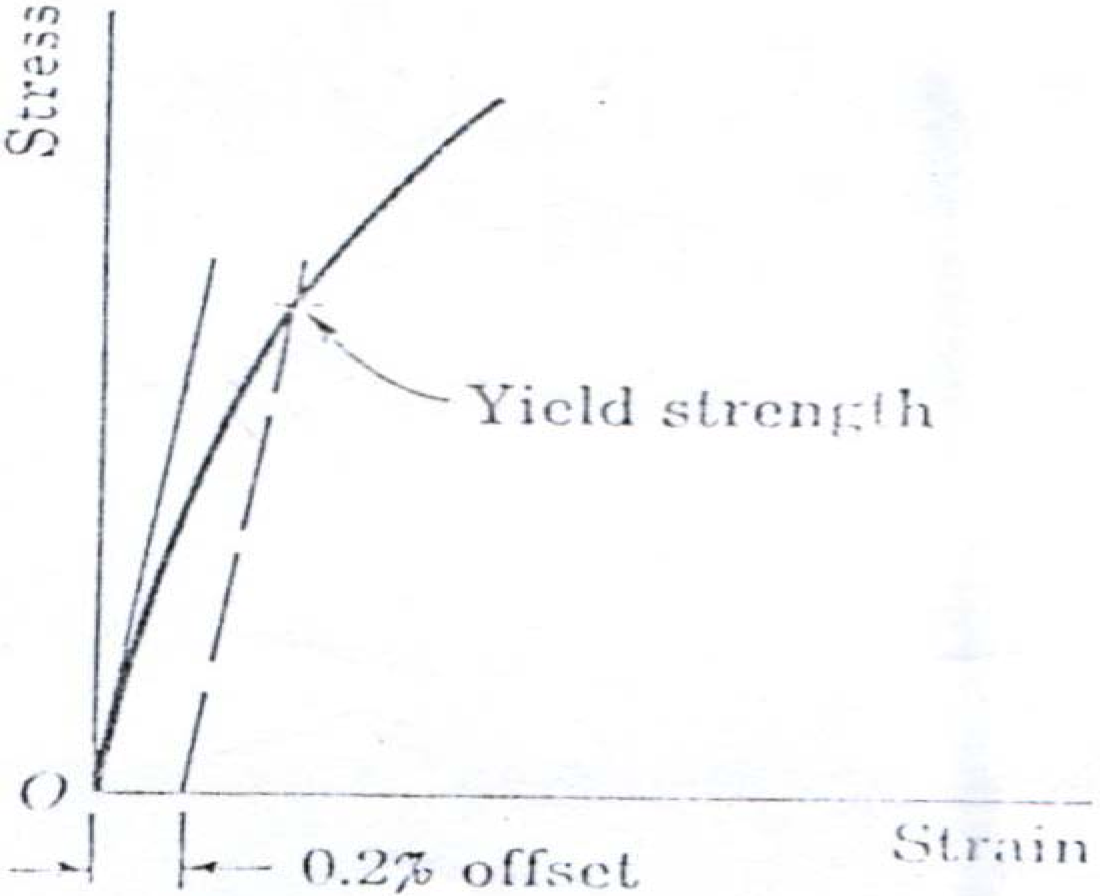

Fig. 2-5 — Yield strength determined by offset method.

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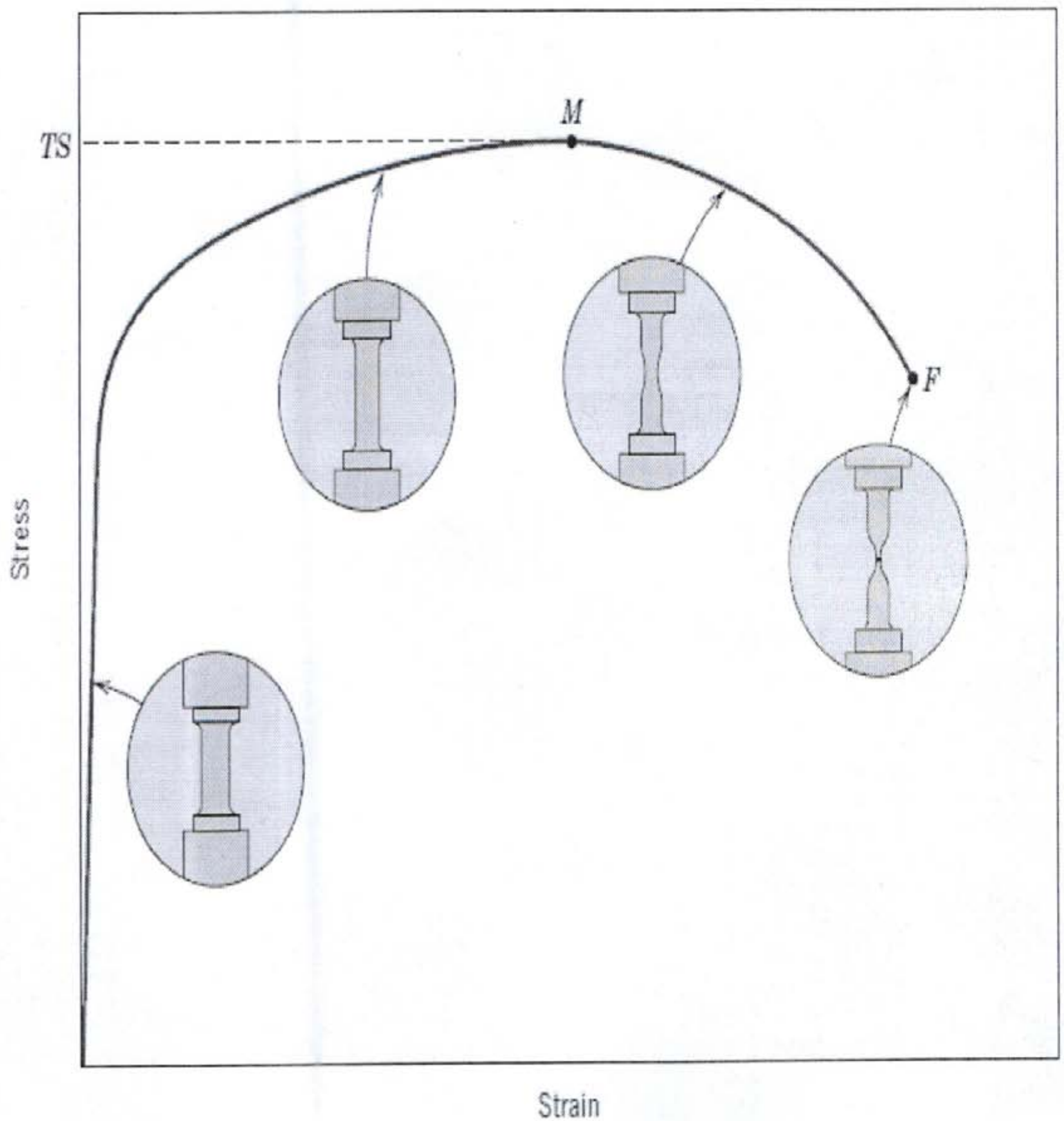
Figure 2.6 Typical engineering stress–strain behavior to fracture, point *F*. The tensile strength *TS* is indicated at point *M*. The circular insets represent the geometry of the deformed specimen at various points along the curve.



Elongation (Elastic) Computation

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?

Solution

Since the deformation is elastic, strain is dependent on stress according to Equation 6.5. Furthermore, the elongation Δl is related to the original length l_0 through Equation 6.2. Combining these two expressions and solving for Δl yields

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

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

The values of σ and l_0 are given as 276 MPa and 305 mm, respectively, and the magnitude of E for copper from Table 6.1 is 110 GPa (16×10^6 psi). Elongation is obtained by substitution into the expression above as

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

2-4 Ductility :-It is a measure of the total plastic strain that accompanies fracture.

Ductility may be expressed as:- ϵ_T

1- Elongation which is commonly expressed as percent.

$$EL\% = (l_f - l_0) / l_0 \times 100\%$$

2-Reduction in area (R of A) at the point of fracture:

$$R \text{ of } A = (A_0 - A_f) / A_0$$

Ahighly ductile material has high values of EL and R of A .

2-5 Brittle material :- It is the material that experiences very little or no plastic deformation ,upon fracture.In more brittle materials ,failer occurs at the maximum load,where tensile strength and breaking strength are the same.Fig(2-7)

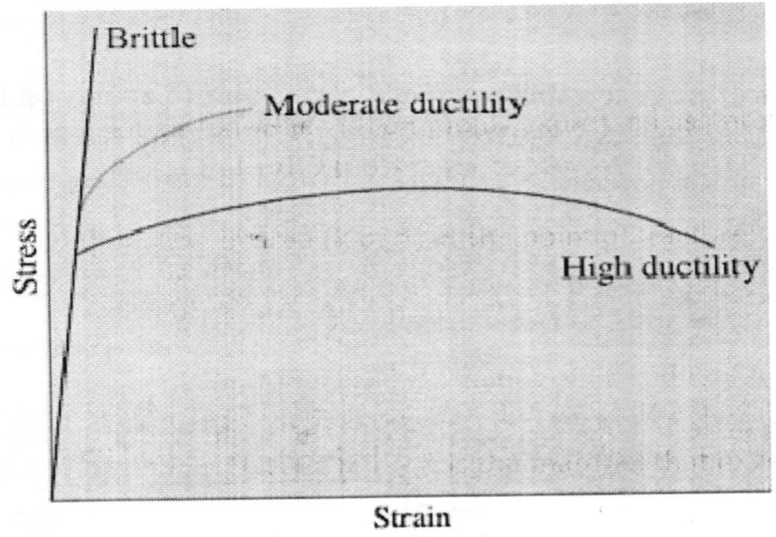


Figure 2-7
The stress-strain behavior of brittle materials compared with that of more ductile materials.

Ductility and True-Stress-At-Fracture Computations

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

Solution

(a) Ductility is computed using Equation 6.12, as

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

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

(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

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

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

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 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)

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 6.12, to facilitate this computation. The slope of this linear region is the rise over the run, or the change in stress divided by the corresponding change in strain; in mathematical terms,

$$E = \text{slope} = \frac{\Delta\sigma}{\Delta\epsilon} = \frac{\sigma_2 - \sigma_1}{\epsilon_2 - \epsilon_1} \tag{6.10}$$

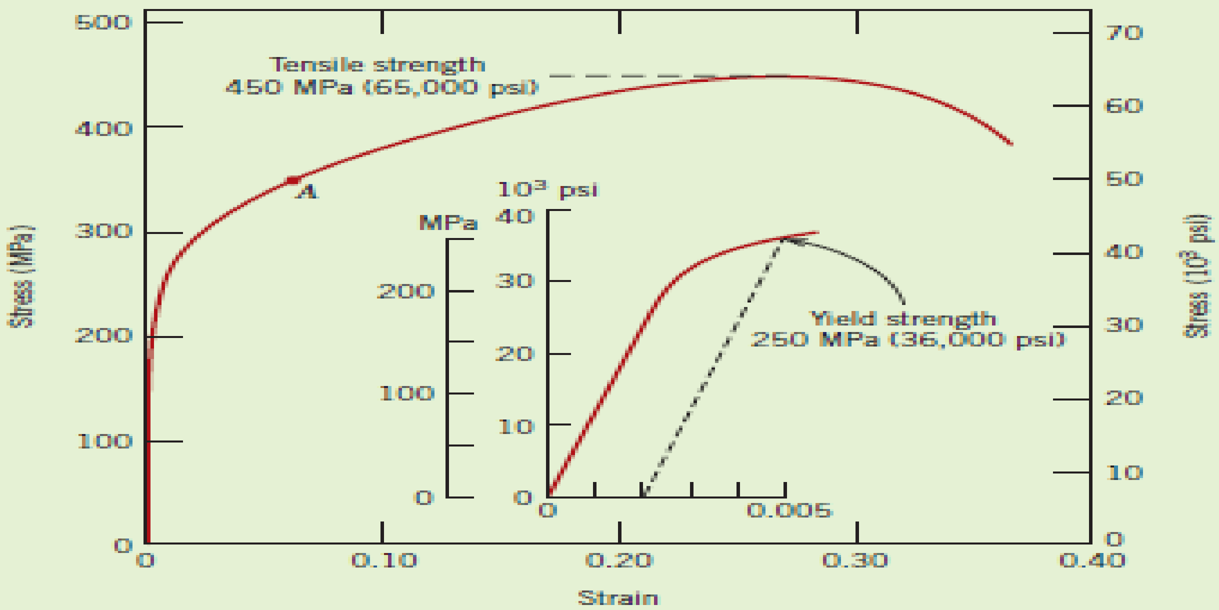


Figure 6.12 The stress–strain behavior for the brass specimen

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,

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

(b) The 0.002 strain offset line is constructed as shown in the inset; its intersection with the stress–strain curve is at approximately 250 MPa (36,000 psi), which is the yield strength of the brass.

(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, 450 MPa (65,000 psi). Solving for F, the maximum load, yields

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

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

(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 345 MPa. 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 $l_0 = 250$ mm, we have

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