University of technology
Building and construction department
Technology of building material

First year
For all branches

Atomic structure

Atoms are recognized as the basic continents of materials joining together in a collagenous manner to form crystalline or amorphous structure.

This assemblage of atoms may be in the form of gasses, liquid or solid. Specific difference between atoms and the way they behave mechanically, physically and chemically are due principally to their individual atomic or electronic structure.

Structurally, the core of an atom "it's nucleus" is composed of positively charged particles known as Proton and uncharged particles called Neutrons. The number of Proton is also known as the atomic number (Z). The sum of Protons and Neutrons in the nucleus determines the atomic weight.

The nucleus is surrounded by the Electrons with mass equal to 1/1836 of mass of Proton. The charge is equal in magnitude, but opposite in sign to the charge of Proton.. Also the number of electrons in an atom equals the number of Proton.

The energy of Electron becomes progressively greater as their distance from the nucleus increase. Thus it is convenient to separate the Electrons into shells containing different energy characteristics. However the Electron in specific shell posses approximately the same energy.

The distribution of Electrons in each of the shells of a given atom is governed by these rules:

- The maximum number of Electrons in each level is given as ($2n^2$) where n is the number of shell.
- A- An outermost or highest energy level can contain no more than eight Electrons.
- B- A next to outermost energy level can contain no more than eighteen Electrons

Types of bonding

A significant feature of the structure of atom is the number of Electrons in the outermost shell. These are called valence electrons. They are important in determine the ability of an atom to bond with other atoms.

1. **Covalent Bonding:**

   Some times, an atom will share valence Electrons with a neighboring atom in order to satisfy such a stable configuration. This sharing of Electrons produces very strong attractive forces between the atoms and is termed **Covalent bonding.**

   The best known example of this type of bonding is the hydrogen molecule (H_2). Try to describe this bond?

2. **Ionic Bonding:**

   This type of atomic bonding results from mutual attraction of positive (+) and negative (-) charges. It depends on the ability of the atoms to gain or lose electrons.

   If an electron is removed from the outer shell, the atom becomes positively charge (electropositive). When an electron is added to outer shell, the atom becomes negatively charge (electronegative).

   An atom which has lost or gained an electron is called ion and the atoms are said to ionized. Electropositive and electronegative ions attract each other and ionic bond is established between them.

   The negative charged ion is now attracted to a positive ion, thus, forming the basic for ionic bonding. Both types of ions have achieved a more stable electron configuration by the transfer of valence electrons, and in so doing, they have been mutually attracted. Compound that format ionic bonds include NaCl , $CaCl_2$, Al_2O_3 and MgO. The ionic bond for typical compound is show in Fig. below:
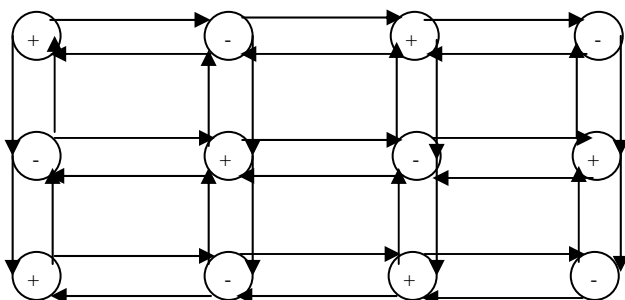
3. Metallic bond:

The covalent or ionic bonds are almost exclusively found in non metallic materials.

Unlike the covalent or ionic bonds, the metallic bond can not exist simply between a few atoms, it is found only where there are a large number of atoms in close approximately. In a piece of metal, the valence electrons of all. The atoms are shared mutually in complex system. The metallic bond in crystals is shown in Fig. below:

Delocalized valence electrons

Positive core = Kernel
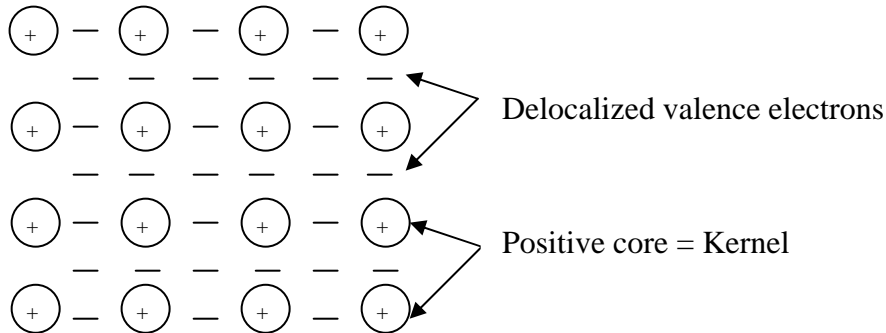
Kernel = nucleus + extra nuclear electrons (the inner shells)

The combination of positively charged cores and the surrounding electron cloud or gas produces the attractive forces of the metallic bond. The detached valence electrons or electron cloud are responsible for such metallic characteristics as:

1. High thermal conductivity
2. High electrical conductivity
3. Opaqueness to light

4. Van der Waal's Forces:

Van der Waal's inter atomic attraction is relatively week, and therefore is not considered extremely important with respect to engineering materials. However, sometimes, Van der Waal's forces are the only that operate between atoms.

H.W.

1. Describe the ionic bonding between magnesium (Atomic No. is 12) and chlorine (Atomic No. is 17)

2. Describe the covalent bonding for (H_2O)

3. Describe the covalent bonding for (SiO_2)

An important consideration in the choice of a material is the way it behave when subjected to force. The mechanical properties of a material are a measure of the resistance it show to the application of the basic type of force:

1. Tensile force
2. Compressive force
3. Shear Force

Stress

Normal stress :

The application of an external force to a body cause internal resisting force within the body, whose resultant is equal in magnitude but opposite in direction to the applied force.

If the a bar subjected to a longitudinal axial force causing internal resisting force distributed continuously over the cross section of the bar as shown in the free diagram. If the applied force passes through the centered of the cross section of the bar, the resisting force will be distributed uniformly over the cross section for resisting loads of geometrically similar members. The uniform distribution of internal resisting can be express in the form of force per unit area as:

Stress ($\mathbf{\delta}$) = F/A

Where F – The applied force
        A- cross sectional area

And if the cross sectional area is normal to the direction of the load, the stress called "Normal stress"
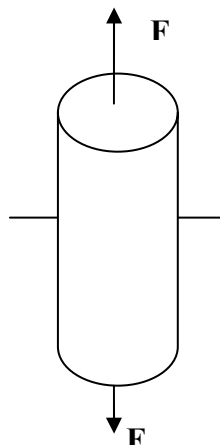
Bearing stress:

Bearing stress occurs when there is contact between two bodies. The external applied force is known as bearing and the pressure between the two bodies is known as a bearing stress. Bearing stress occurs between the post and plate, the plate and footing and between the footing and soil.
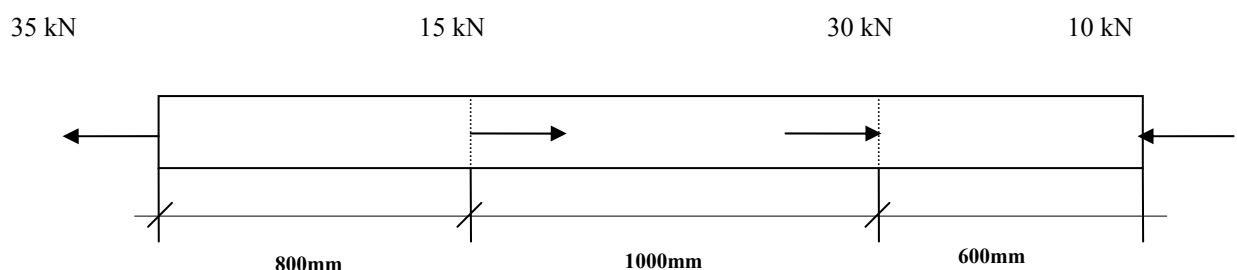
Shearing stress:

Shearing stresses occur when the force being resisted act in the plane of the reacting area.
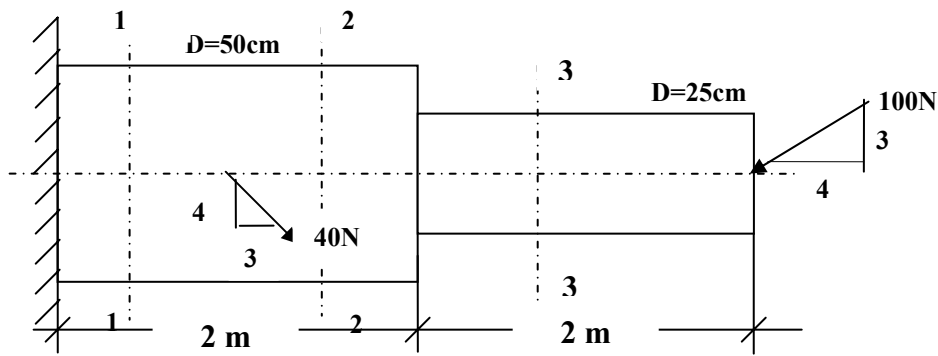 T = Shearing force/ Area being sheared

H.W.:

1.An aluminum bar having a cross sectional area of 160 mm2 carries the axial loads at the positions shown in Fig. below., compute the stress at each parts of aluminum

| 35 kN | 15 kN | 30 kN | 10 kN |

800mm   1000mm   600mm

2. Determine the stress in each section shown in Fig below

Deformation

When an engineering material is subjected to forces, their atoms may be change their equilibrium positions. The total change in a dimension due to an applied force is known as deformation (Δ).

1. Elastic deformation :

If the atom can resume their equilibrium positions when the imposed force are released, the deformation is termed elastic. Elastic deformation that is recoverable and indicates the relative resistance of a material.

Elasticity: is the property of a material to return to its initial form and dimension after the deforming force is removed.
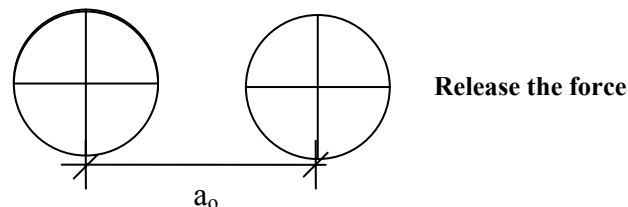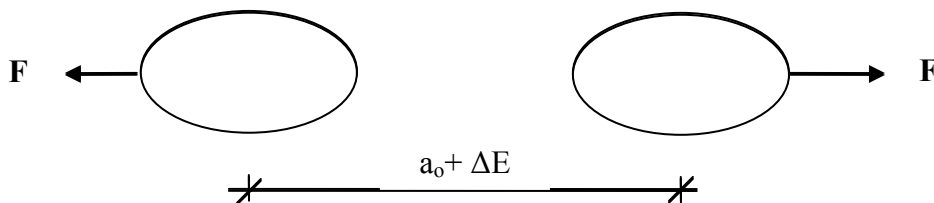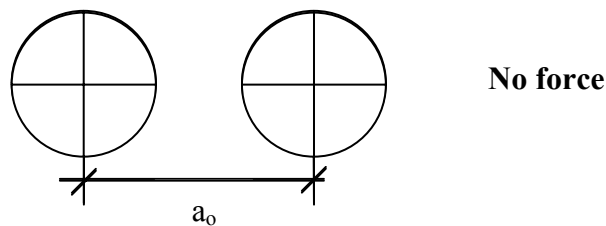
## 2. Plastic deformation:

If an engineering undergoes deformation which exceed the elastic capacity (elastic deformation), the deformation is permanent and termed plastic. Plastic deformation is non recoverable and leaves the atoms permanently displaced from their original positions when the forces are released. The process of plastic deformation is shown below:

No force

a_o

F ← ... → F $\Delta T = \Delta E + \Delta P$

$a_o + \Delta T$

Release the force

$a_o + \Delta P$
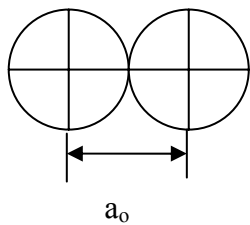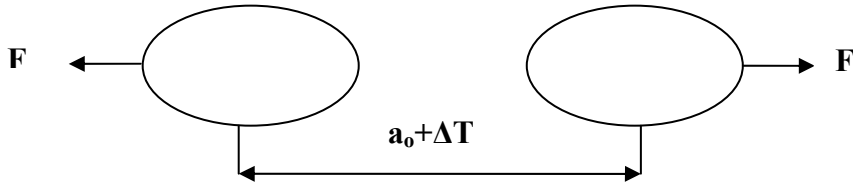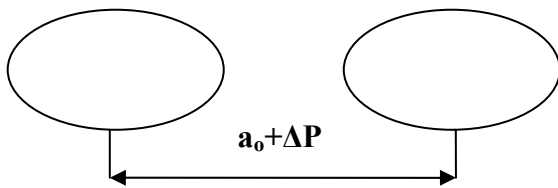
Strain

Engineering strain:

When a member is subjected to a tensile or compressive stress, it undergoes a deformation (Δ). Tensile force causes an elongation of the body, while compressive causes a shortening of the dimension of the body in the direction of the force. The elongation (or shortening) per unit length is called strain (ϵ).

Average strain (ϵ) = Δ / Lo , mm/mm dimensionless
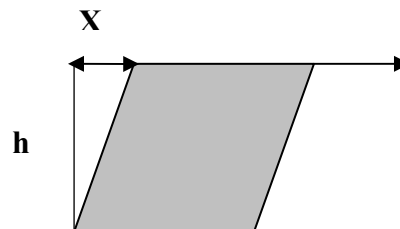
Where Lo – is the original length

The strain at any position is more correctly named as true strain, i.e. the ratio of the change in dimensions to the instantaneous dimensions.

ϵ true = ln (ϵ +1)

Shear strain :

It is defined as the ratio of displacement (X) to the distance between the planes (h).

Shear strain = X/h = tan Θ

Modulus of elasticity (E)

Hook's law states that in elastic bodies stress is proportional to strain provided that the elastic limit is not exceeded.

Б ά Є

$$Б = E\ Є$$

Where E- is the constant of proportionality relating stress and strain. It is some times known as Young's modulus or more commonly the modulus of elasticity. E has the same units of stress.

Stress/ strain = E

(F/A) = (ΔL/ L) * E

$$\Delta L = F* L/\ E * A$$

Modulus of rigidity (G)

Where G- is the constant of proportionality relating shear stress and shear strain. It is some times known as the modulus of rigidity. G has the same units of stress.

T ά Shear strain

$$T = G* \text{ Shear strain}$$

Poisson's ratio (μ)

Because of the constancy of volume, when a material is deformed in one direction, there is a corresponding displacement or deformation in a direction perpendicular to it.

For example, consider the bar in Fig. below. If the axial load is applied, the elongates in the X-direction. The ratio of the strain in Y- direction to the strain in X- direction is termed {Poisson's ratio (μ)}. And expressed as :

$$\mu = Єy/Єx$$

Where:

μ- Poisson's ratio

Єy- Lateral strain

Єx – Direct strain

H.W. :

1. A steel bar 6m long is 5cm in diameter for 3m of it's length and 2.5cm in diameter for the second 3m as shown in Fig. below. The smallest diameter part of the bar is with 11 N/mm^{2}tensile stress due to the applied load. Find the final diameters of the two parts after applied load. E of the steel is 200*103 N/mm^2 and μ of the steel is 0.28
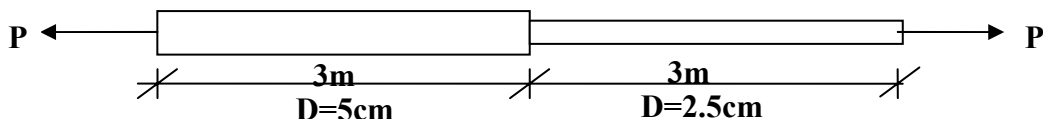
General expression for strain

We can obtain a general expression for the strain on an element subjected to tensile force in three perpendicular directions as shown in Fig. :
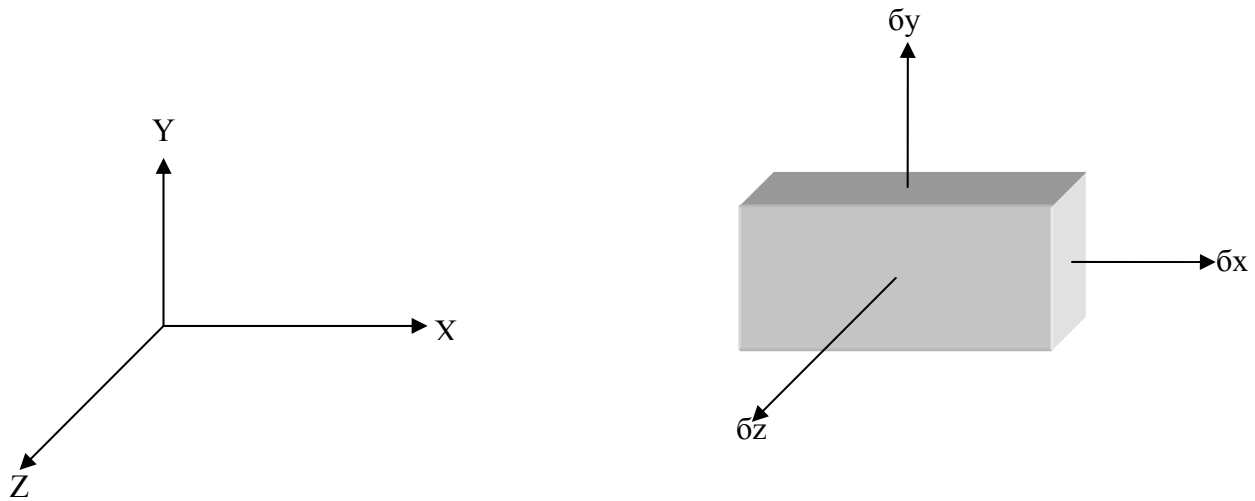
Case 1 : When the tensile stress effect in X- direction only :

    A – Direct strain $\epsilon\, x = +\, \sigma\, x/\, E$

    B – Induced strain due to X- stress:

    1. Induced strain in X – direction due to X- stress = 0

    2. Induced strain in Y – direction due to X- stress ($\epsilon\, y = -\, \mu\, \epsilon\, x = -\, \mu\, (\sigma\, x/\, E)$

    3. Induced strain in Z – direction due to X- stress ($\epsilon\, z = -\, \mu\, \epsilon\, x = -\, \mu\, (\sigma\, x/\, E)$

Case 2 : When the tensile stress effect in Y- direction only :

    A – Direct strain $\epsilon\, y = +\, \sigma\, y/\, E$

    B – Induced strain due to Y- stress:

    1. Induced strain in X – direction due to Y- stress ($\epsilon\, x = -\, \mu\, \epsilon\, y = -\, \mu\, (\sigma\, y/\, E)$

    2. Induced strain in Y – direction due to Y- stress = 0

    3. Induced strain in Z – direction due to Y- stress ($\epsilon\, z = -\, \mu\, \epsilon\, y = -\, \mu\, (\sigma\, y/\, E)$

Case 3 : When the tensile stress effect in Z- direction only :

    A – Direct strain $\epsilon\, z = +\, \sigma\, z/\, E$

    B – Induced strain due to Y- stress:

    1. Induced strain in X – direction due to Z- stress ($\epsilon\, x = -\, \mu\, \epsilon\, z = -\, \mu\, (\sigma\, z/\, E)$

    2. Induced strain in Y – direction due to Z- stress ($\epsilon\, y = -\, \mu\, \epsilon\, z = -\, \mu\, (\sigma\, z/\, E)$

    3. Induced strain in Z – direction due to Z- stress = 0

    Therefore, generalized Hook's law equations in tensions are:

    $\epsilon\, x = +\, (\sigma\, y/\, E) - \mu\, (\sigma\, y/\, E) - \mu\, (\sigma\, z/\, E)$

    $\epsilon\, y = -\, \mu\, (\sigma\, x/\, E) + (\sigma\, y/\, E) - \mu\, (\sigma\, z/\, E)$

    $\epsilon\, x = -\, \mu\, (\sigma\, x/\, E) - \mu\, (\sigma\, y/\, E) + (\sigma\, z/\, E)$

    Generalized Hook's law equations in compression are:

    $\epsilon\, x = -\, (\sigma\, y/\, E) + \mu\, (\sigma\, y/\, E) + \mu\, (\sigma\, z/\, E)$

    $\epsilon\, y = +\, \mu\, (\sigma\, x/\, E) - (\sigma\, y/\, E) + \mu\, (\sigma\, z/\, E)$

    $\epsilon\, x = +\, \mu\, (\sigma\, x/\, E) + \mu\, (\sigma\, y/\, E) - (\sigma\, z/\, E)$

Temperature stresses

    If a bar is not restrained in any way, an increase in temperature will cause an increase in it's dimensions, and decrease in temperature will cause a decrease in it's dimensions. It is usual to describe the dimensional change due to due to temperature changes in terms of the change in a linear dimensions. Thus, the change in length of a bar, ΔL, is directly proportional to both the temperature change of the bar, ΔT, and the original length of the bar, L_0:

$$\Delta L = \acute{\alpha} L_0 (\Delta T)$$

The constant of the proportionality is called the linear coefficient of expansion ($\acute{\alpha}$) which is defined as change in length per unit length for a one degree change in temperature.

The final length : $L_f = L_0 + \Delta L$

$$L_f = L_0 + \acute{\alpha} L_0 (\Delta T)$$
$$L_f = L_0 \{ 1 + \acute{\alpha} (\Delta T) \}$$

$$\Delta A = 2\acute{\alpha} W_0 H_0 (\Delta T)$$

Thus the coefficient of expansion of area expansion can be taken as twice the coefficient of linear expansion.

$$\Delta V = 3\acute{\alpha} W_0 H_0 L_0 (\Delta T)$$

The coefficient of expansion of volume expansion can be taken as three times the coefficient of linear expansion.

Thermal strain

Besides stresses, changes in temperatures can cause deformation of materials. For homogenous isotropic materials, a changes in temperature of ΔT degree causes uniform linear strain in every direction. Expressed as an equation, the thermal strain are:

$$\epsilon x = \epsilon y = \epsilon z = \acute{\alpha} \Delta T$$

Where $\acute{\alpha}$ – the coefficient of linear of thermal expansion

The linear thermal strain for small strains is directly additive to linear strains due to stress. On this basis a typical modification of the equation:
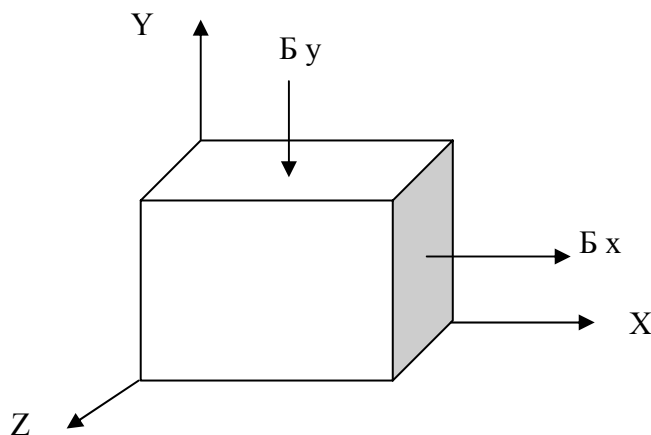
$\epsilon x = + (\sigma y / E) - \mu (\sigma y / E) - \mu (\sigma z / E)$

To include thermal strain is:

$$\epsilon x = + (\sigma y / E) - \mu (\sigma y / E) - \mu (\sigma z / E) + \acute{\alpha} \Delta T$$

H.W.:

1. Derive the generalized Hook's law equation for the body shown in fig.

2. A rod 2m long expands by 1mm when heated from 8 °C to 70 °C. What is the coefficient of linear expansion of the material from which the rod is made?

Ceramic are made from admixture of mineral material (quartz sand) and clay binder with impurities such as chalk, dolomite and sulphates, mixing water. The mixture is shaped, dried and fired. During firing water, carbon dioxide and other gases are driven off, re-crystallization takes place and glass is formed producing a hard insoluble material.

Properties:

1. Ceramics very widely in degrees of the frost resistance and external chemical attack. Moisture content of ceramics effect greatly the size of ceramics due to drying contraction after manufacturing (Drying stage).

2. Increasing in firing temperature produce more complete re-crystallization and an increase in the formation of glass, which give greater density, hardness, strength, resistance to chemical and to frost.

3. After firing, expansion may occurred due to absorption of water by clay in ceramics particularly in floor and wall tiling.

The main ceramics products used in building are:
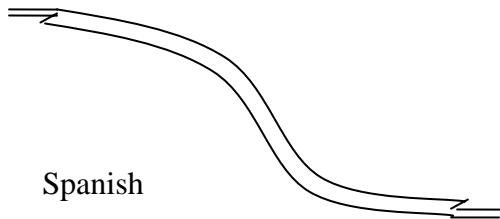
1. Fired clay and shale: Including ordinary bricks and clay roof tiles such as:
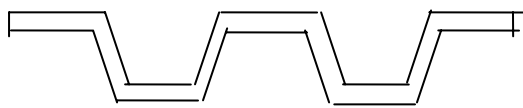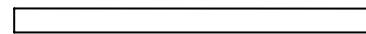

French   Mission

Spanish

Shingle

2. Terracotta: is made from yellow to brownish-red clays such as ordinary bricks and vitrified wall tiles.
3. Faience: is a glazed form of terracotta or stone ware. It is used where it is likely not to receive heavy knocks. Rounded corners rather than sharp places are suitable to use it. It must be avoid the salt crystallization or frost action inside the ceramics.
4. Fireclay: It is a simple products used in places where fire resistance is required, in which a high kaolin content in the clay binder provides high fire resistance.
5. Earthen ware: The raw material blended from different sources, may contain a considerable proportion of limestone. It is used as the body for the glazed wall tiles.

The tensile test

The tensile test is the most important of the mechanical tests used to obtain data on the properties of materials. The test is usually performed by slowly and steadily applying a tensile load to standardize test specimen shown in Fig. below. After the sample has been loaded in tension and broken, the two halves are held firmly together and the distance between the marks is again measured.
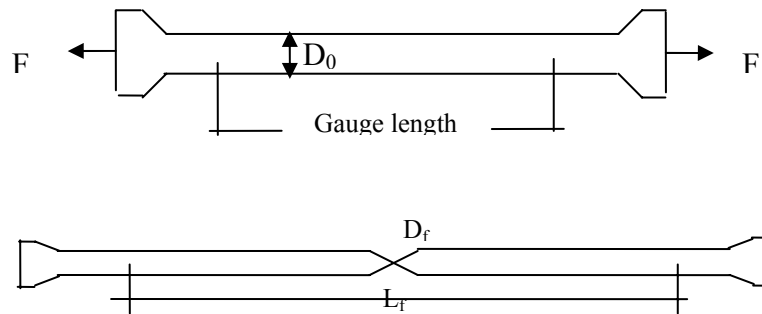
Fig.1

The stress – Strain curve in tension

After testing the specimen, it is necessary to represent the data in the form of stress – strain diagram. The stress is defined as the load divided by the cross sectional area of the specimen at the start of the test. As the test proceeds, the actual cross sectional area decreases. The stress based upon the initial area is not the true stress, but it is generally used. The strain used is the elongation of a unit length of the test specimen taken over the gauge length. Typical stress – strain diagram are shown in Fig. below:
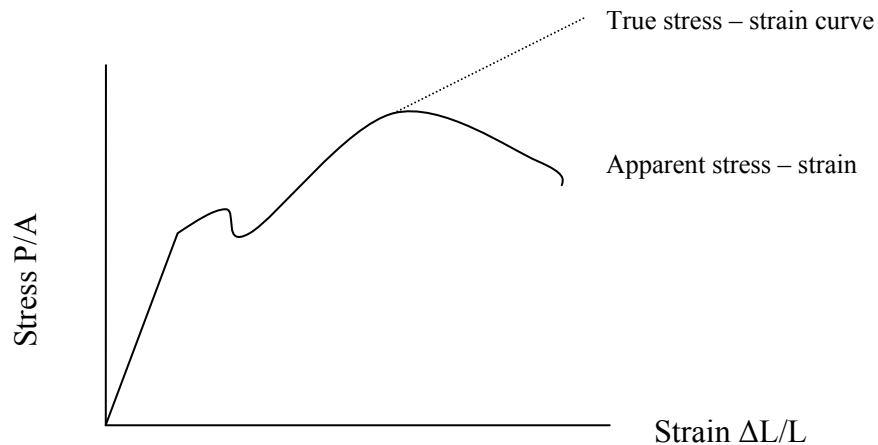
Stress – Strain curve for low carbon steel

Stress – Strain curve for non ductile material –
Cast iron (no plastic deformation)
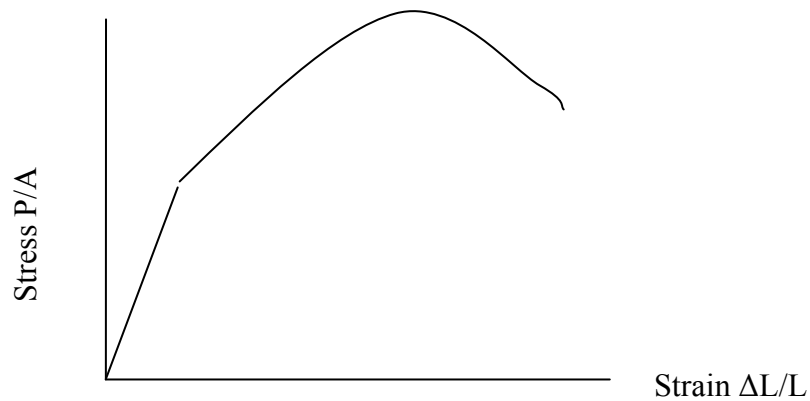
Stress – Strain curve for Aluminum –
Ductile material

Proportional limit

It is the greatest stress that the material is capable of developing without deviation from Hook's law of stress – strain proportionality.

In order to determine the proportional limit, it is necessary to use very sensitive extensometer to detect the slightest deviation from a straight line in the tensile test diagram. Certain materials such as concretes and copper do not have the straight line portion of the stress – strain curve that steel does. For these materials a value known as Johansson's apparent elastic limit. Johansson's apparent elastic limit is defined as that stress at which rate of deformation is 50% greater than the initial rate of deformation as shown for concrete.
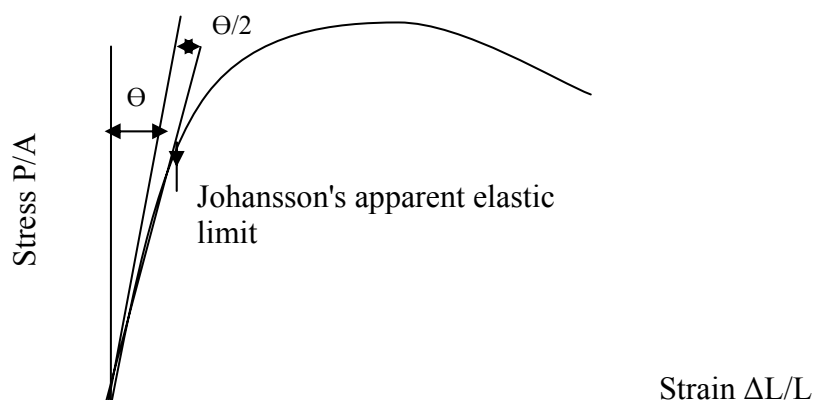
Modulus of elasticity

It is a measure of the stiffness of the ductile material. The slope of the initial straight portion of stress – strain diagram represents the modulus of elasticity or Young's modulus.

$$E = \tan \Theta = \text{Stress/ strain}$$

When no straight portion is present in the stress – strain curve, as in the case of concrete material, the modulus of elasticity can be obtained by one of the following methods:

1. Initial tangent modulus:

It is the tangent to the curve at the original, but it is little practical importance.

2. Tangent modulus

It is the tangent at any point on the stress – strain curve, but this modulus applies only to very small changes in load above or below the load at which the tangent modulus is considered.

3. Secant modulus

It is the slop of the line drawn from the origin to any point on the stress – strain curve. There is no standard method of determining the secant modulus, in some laboratories; it is measured at stress ranging from 3 to 14 N/mm^2, in others at stresses representing 15, 25, 33 or 50% of the ultimate strength.

Yield strength

Yield point is defined as the stress at which a marked increase in strain occurs without a concurrent increase in applied stress.

Many materials do not exhibit well defined yield points and the yield points and the yield strength is defined as the stress at which the material exhibits a specified limiting permanent set of 0.2 % (0.002 strain). The yield strength is therefore the stress corresponding to the intersection of a line parallel to the straight line portion of the stress – strain curve.

Ultimate strength

It is obtained by dividing the maximum load reach before the specimen breaks by the initial cross sectional area of the specimen. It is commonly used as basic for established working stresses for a material.

$$\text{Ult. Str. For apparent stress – strain curve} = \text{max. Load/ } A_0$$

$$\text{Ult. Str. For true stress – strain curve} = \text{max. Load/ } A_f$$

Elongation

Percentage of elongation is the measure of the ability of a material to undergo deformation without rupture. It is a measure of the ductility of material.

$$\% \text{ Elongation} = (L_f - L_0) / L_0 * 100$$

Where:

L_f – Final length

L_0 – Initial length

Breaking Strength (Rupture strength, fracture strength)

$$\text{Breaking strength} = \text{Load at time of failure} / A_0$$

The breaking strength on this basis is less than the ultimate stress of the data based on true area. While the true stress of failure is the maximum stress on the material. For the test interval between the ultimate stress and the breaking stress, the specimen continues to elongate even though the resisting stress based on the original area decrease.

Reduction of area

As the load on the test material is increased, the original cross sectional area decrease until it is a minimum at the instant of fracture. It is usual to express this reduction in area as the ratio of the change in area to the original specimen cross sectional area expressed as a percentage.

$$\% \text{ reduction in area} = \{(A_0 - A_f)/ A_0\} * 100$$

Where - A_f – Final cross sectional at the point of failure

A_0 – Original cross sectional

Ductility

Is the property of a material of being deformed by stretching without recovery of shape upon removed of stretching force. Ductility of metals is ordinarily determined by measuring the elongation and reduction of cross sectional area of a tensile strength test specimen.

Toughness

The resistance to impact. Toughness is also considered to mean resistance to fracture when the material is deformed above the elastic limit.

It is a measure of the work required to cause fracture to occur. The area under stress – strain curve represent modulus of toughness.

$$\text{Modulus of toughness} \angle 2/3 \ (\epsilon_f * \sigma_f)$$
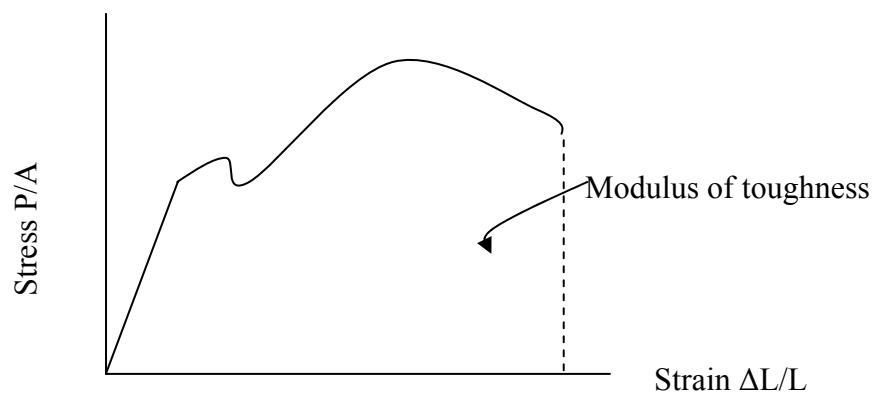
Brittleness

Is the opposite of toughness and ductility and refers to small resistance to sudden blow. A brittle meta breaks suddenly without appreciable permanent deformation or warning of approaching failure.

Resilience

Is that property of an elastic body by which energy can be stored up in the body by loads applied to it and given up in recovering it\s original shape when the loads are removed. The area under the straight portion of stress - strain curve represent the modulus of resilience.

$$\text{Modulus of resilience} = 1/2 \ (\epsilon_{P.L.} * \sigma_{P.L.})$$
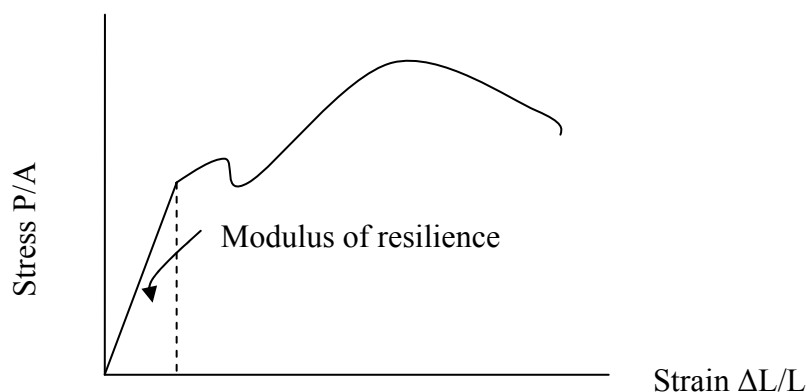
Plasticity

Is the property by which a body, when deformed by the application of forces, remains in the deformed shape without recovering the original shape, when the force is removed.

H.W.:

The following data where obtained during the tensile test of mild steel circular bar 12.75 mm diameter and 203.2 mm gauge length. Determine the following:

1) The apparent stress at each point
2) Strain at each point
3) True stress at each point (Assume D at failure is 8,51 mm and D at max. load is 11.15 mm)
4) Draw stress – strain curved based on:
    a) Original cross sectional area
    b) True cross sectional area
5) Proportional limit
6) Modulus of elasticity
7) Upper and lower yield point
8) Ultimate strength
9) Breaking strength based on the original cross sectional area and on true cross sectional area
10) Percentage of elongation
11) Percentage of reduction in cross sectional area.
12) Ductility
13) Resilience and toughness

Load (N)	4393	16902	29357	33360	33627	35584	41366	48839	52709	55378	56356	43768
Deformation (mm)	0.0254	0.127	0.228	0.305	0.356	3.81	6.35	11.68	16.76	26.92	43768	42.42

Compressive strength

Compressive strength should be determined on cylinders with a height equal to about two times the diameter. The ends of the cylinders should be carefully prepared to be parallel and plane surfaces.

For steels it is possible to determine the ultimate compressive strength only for brittle steels, since all ductile steel are greatly deformed under load and show no well defined fracture.
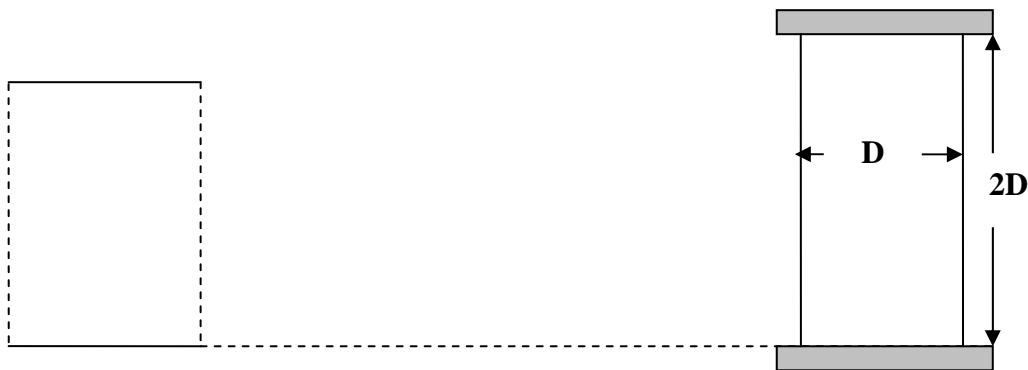

Ductile metal under the test

Compressive strength = P/A

Where P- Load at failure
A- Cross sectional area normal to load

Brittle material such as concrete is much weaker in tension and in shear than in compression, and failures of concrete specimens under compressive load are essentially shear failures on oblique planes. When the strength of concrete is high and lateral expansion at the end bearing surfaces is relatively unrestrained, the specimen may separate into columnar fragments what is known as a splitting fracture. Often failure occurs through a combination of shear and splitting.
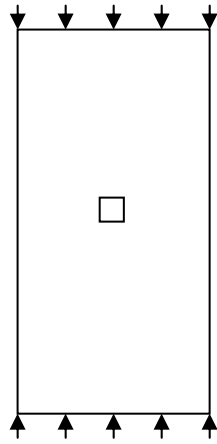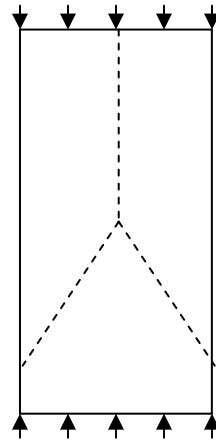
Shear Failure Combination Splitting Failure
shear Failure
and splitting
failure
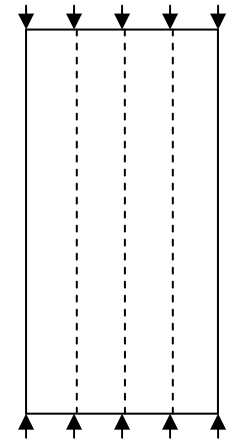
Flexural strength

In flexural test, the beam may be tested on simple supports. When a materials is subjected to being tensile and compressive stresses and in may cases direct shear stresses are developed.

Flexural strength is expressed in term of " modulus of rupture " which is the maximum tensile (or compressive) stress at rupture computed from the following formula :
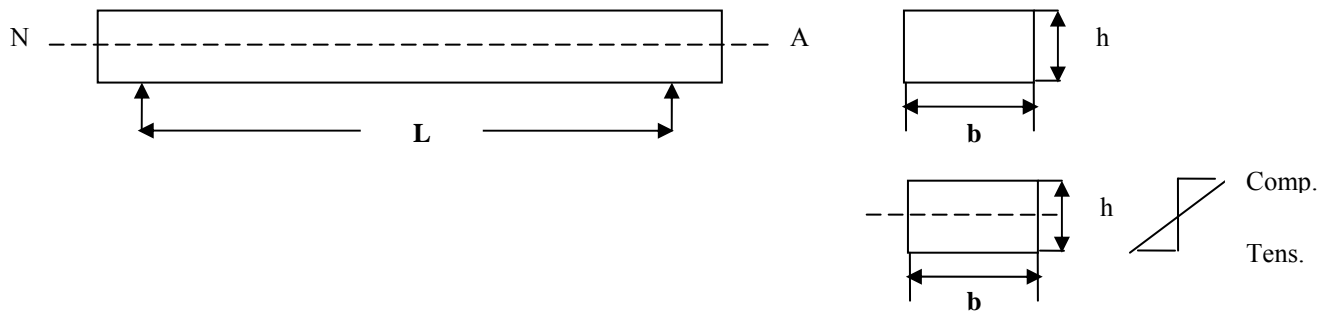
$$S_b = MC/I$$

Where S_b – Stress in the fiber farthest from the neutral axis

M- Bending moment at the section

I- Moment of inertia of the cross section

C- Distance from neutral axis farthest fiber

The modulus of rupture is a good index for comparing different grades and glasses of materials. The beam test in flexural in a given series of tests should be of the same shape and size so that the modulus of rupture values can compared directly.

The flexural strength of a metal directly depends upon the tensile and compressive properties of that metal. If the section is symmetrical, the failure will occur on the tension side if the metal is not ductile and on the compression side if it is ductile.

Torsion test

The torsion test is conducted by twisting a solid cylinder specimen. The torque and the angle of twist are measured. The intensity of the shearing stress due to torsion on any section of a cylinder shaft varies directly as the distance from the axis of the shaft and the maximum intensity of shearing stress is found at circumference. The mathematical expression for the maximum shearing stress in the extreme fiber of circular shaft is :

$$T_{max.} = 2T/\Pi\, r^3$$

Where T – is the torque
r- the radius of the section
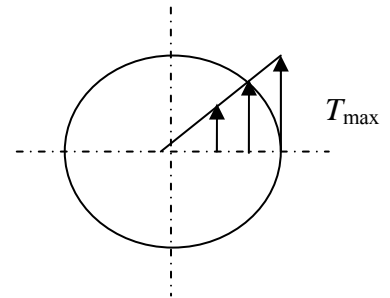
The cracking was developed in the direction parallel to the shear plane. This plane may be parallel or perpendicular to the longitudinal axis of the specimen. It is probable that failure occurs in the plane making an angle with longitudinal axis as shown in Fig. below:
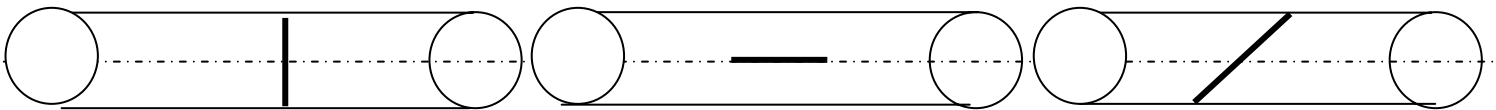
Shear plane perpendicular
to the longitudinal axis

Shear plane parallel
to the longitudinal axis

Shear plane making an angle
with longitudinal axis

H.W. :
1. Differentiate between the behavior of ductile and brittle metal during compressive test?
2. Explain this sentences "The flexural strength of a metal directly depends upon the tensile and compressive properties"?
3. Determine the property of the metal that torsion test results depend upon?

Impact test

Impact tests may be performed for two purposes:
1. to determine the ability of the material to resist impact under service conditions.
2. to determine weather a metal has resistance to failure due to brittleness under service conditions in a machine or structure.

Impact tests may be classified into two groups:
1. <u>Utility impact tests:</u>
Utility impact tests for detecting the presence of brittleness or determining the comparative toughness of material are applied to steel rails, pipes, as well as to non-metal materials such as concrete, stone, wood …etc.
2. <u>Standard impact tests:</u>
The charpy and Izod impact testing machines are the two most common machines for conducting standard impact tests on metals. These machines determine the amount of work necessary to fracture a small test specimen by impact. They consist essentially of a weighted pendulum, suitable holders or supports for the specimen, and a device for recording the angular swing of the pendulum.

Charpy method

This method is well adapted for examining metals that break with a relatively low absorption of energy. The presence of notch eliminates the influence of surface effects.

Fracture surface
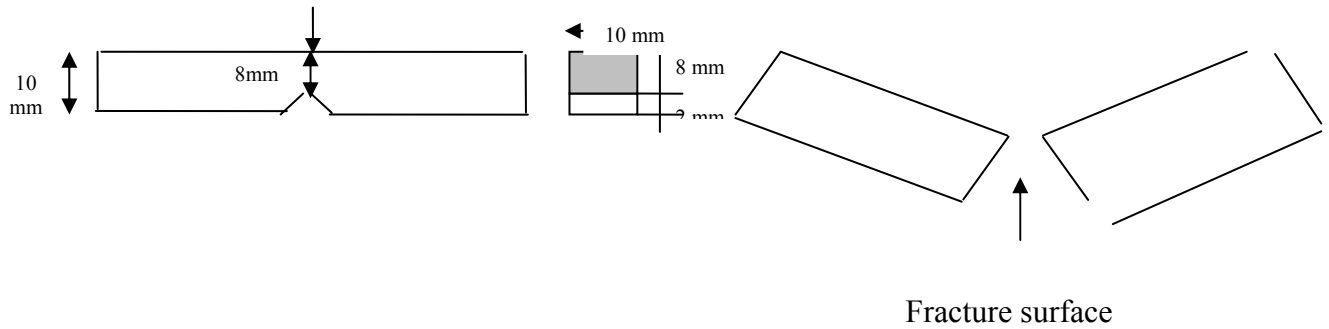
Izod method

For tough metals the notched Izod type of specimen tested as a cantilever is used. For extremely brittle metal that test specimen requires no notched, because the first suddenly applied stress causes a brittle failure.

Fracture surface

Hardness

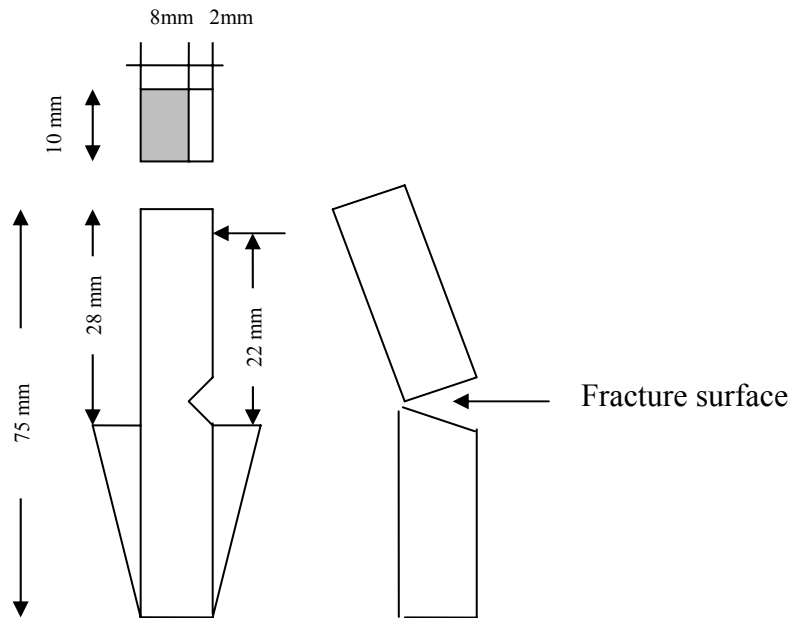Hardness is resistance to plastic deformation. Thus a hard material may have a high elastic limit. Other meanings are given to term, however, such as resistance (1) to abrasion, (2) to scratching, or (3) to indentation of a cone or ball.

Hardness of metals is determined by measuring the resistance to penetration of a ball, cone, or pyramid.

The brinell method is based upon determining the resistance offered to indentation by a hardened sphere that is subjected to a given pressure. The pressure used in testing steel is 3000 kg and a diameter of the ball is 10mm. When softer materials a pressure of 500 kg is used. Brinell numbers can be computed by the formula:

$$BHN = 2P/\pi D(D - (D^2 - d^2))$$

Where P- pressure in kg
      D- Diameter of the ball
      d- Diameter of the impression, mm

The harder the steel, the smaller the indentation under the load and the greater the BHN.
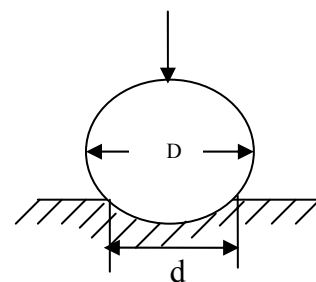
Creep

We have discussed the mechanical properties of materials on room temperature. Many structures, particularly these associated with energy conversion, like turbines, reactors, steam and chemical plant operate at much higher temperature.

As the temperature is raised, materials under loads continuous deformation with time, i.e. start to creep, the strain instead of depending only on the stress, now depends on temperature and time also.

$$\text{€} = f (S,t, T)$$

The temperature at which materials start to creep depends on their melting point. As a general rule, it is found that creep starts when:

T > 0.3-0.4 Tm for metals
T > 0.4-0.5 Tm for ceramic
Where Tm – the melting temperature in degree Kelvin

Creep testing and creep curves:

Creep tests require careful temperature control. Typically, a specimen is loaded in tension or compression usually at constant load, inside a furnace which is maintained at a constant temperature, T- The tension is measured as a function of time. Fig. below shows a typical set of results from such a test. Metals polymers, and ceramic, all show creep curves of this general shape.
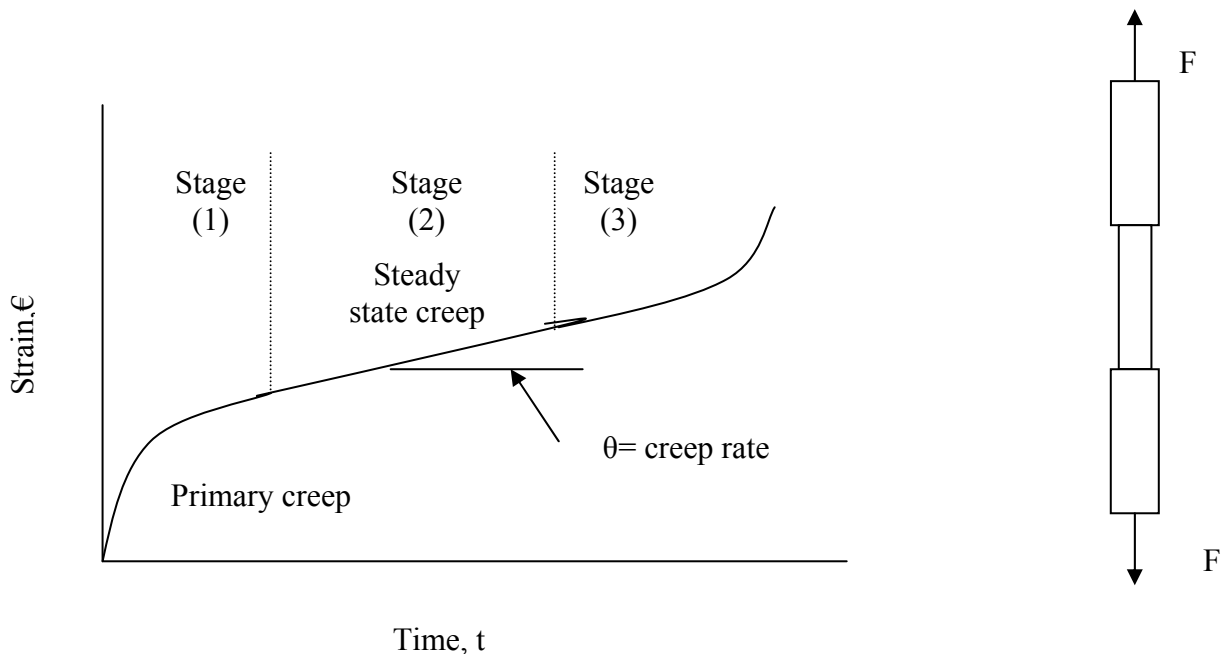
Creep occurs in three stages:
Stage 1 – Primary creep stage
Consist of a short part during which strain increases rapidly
Stage 2 – Secondary creep stage
Consist of a long period where the rate is much slower and constant
Stage 3 – Tertiary creep stage
At this stage the creep rate increases and the material fractures

Creep damage and creep fracture:

During creep, damage, in the form of internal cavities, accumulates. The damage first appears at the start of the tertiary stage of the creep curve reflects this as the holes grows. The section of the sample decreases and (at constant load) the strains goes up and the creep rate goes up even faster than the stress does.
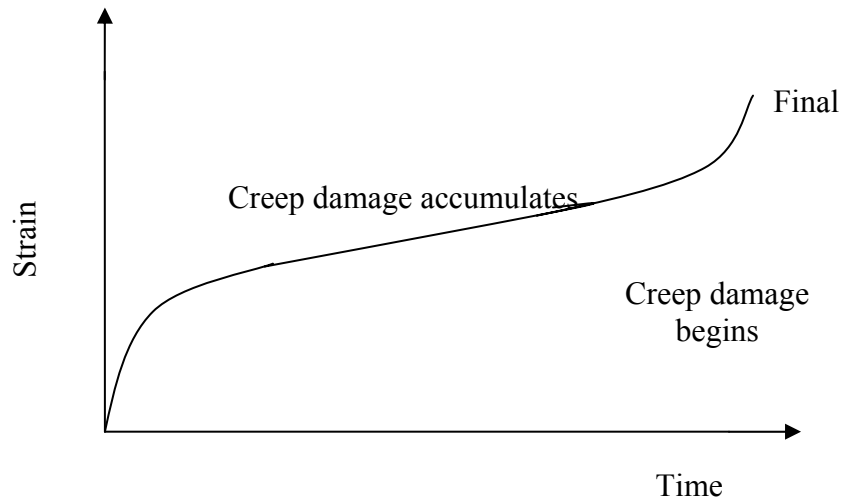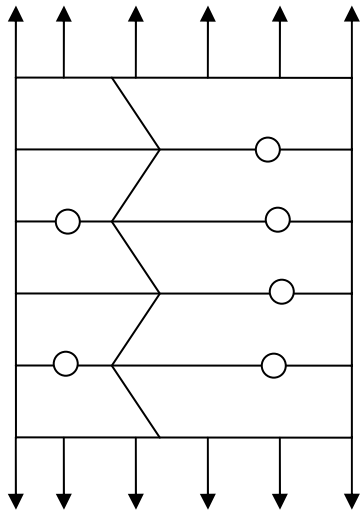
In high temperature design it is important to make sure:
a. That the creep strain during the design life is acceptable.
b. That the creep strain at failure is adequate to cope with the acceptable creep strain.
c. That the time to failure, at the design loads and temperatures is longer (by a suitable factor) than the design life.

Fatigue strength

We have considered so far only the strength of material under static loading. In many structures, repeated loading is applied, and when a material fails under a number of repeated loads, each smaller than the ultimate strength, failure in fatigue is said to take place.

The results of fatigue test are represented by a relationship between stress and number of cycles to failure.

Number of cycles to cause failure
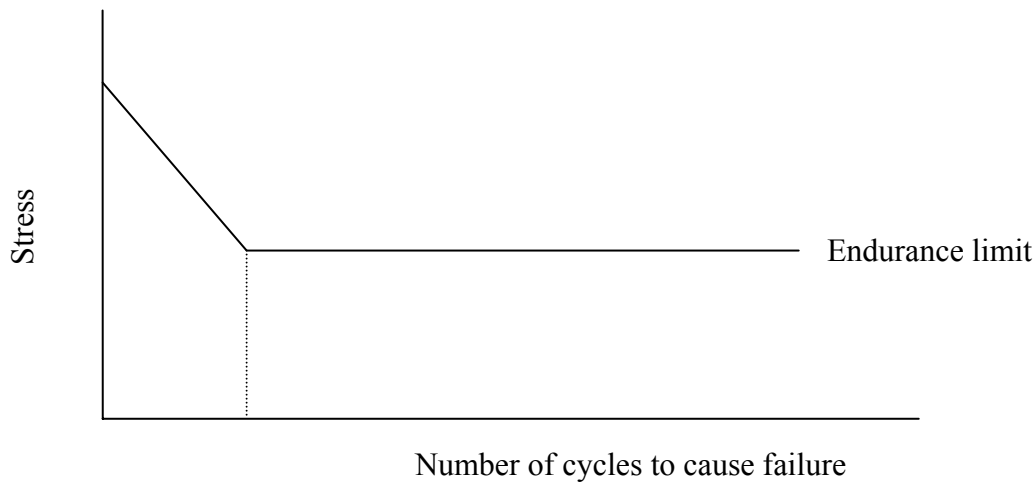
S-N diagram for ferrous metals

At the beginning the stress decreases as the number of cycles increases. After several million cycles the curve becomes horizontal line whose stress value is known as the endurance limit. While almost all ferrous materials exhibit an endurance limit, most nonferrous alloys do not.

Stress

Fracture

Number of cycles to cause failure
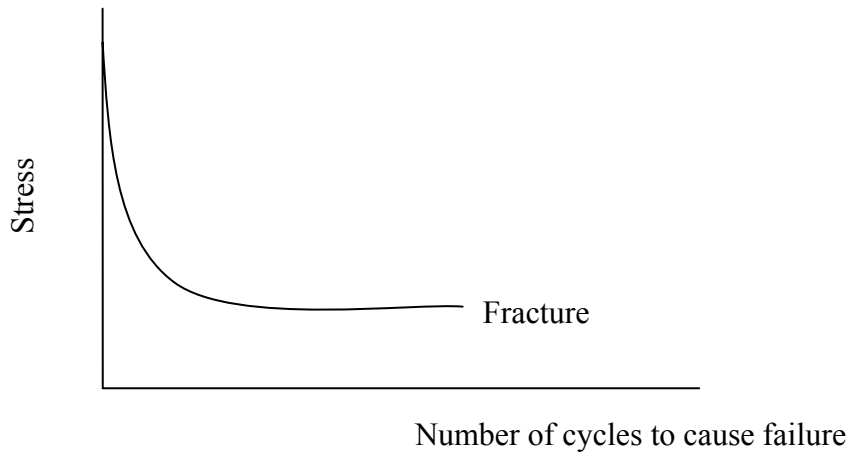
S-N diagram for nonferrous metals

Stress

Number of cycles to cause failure
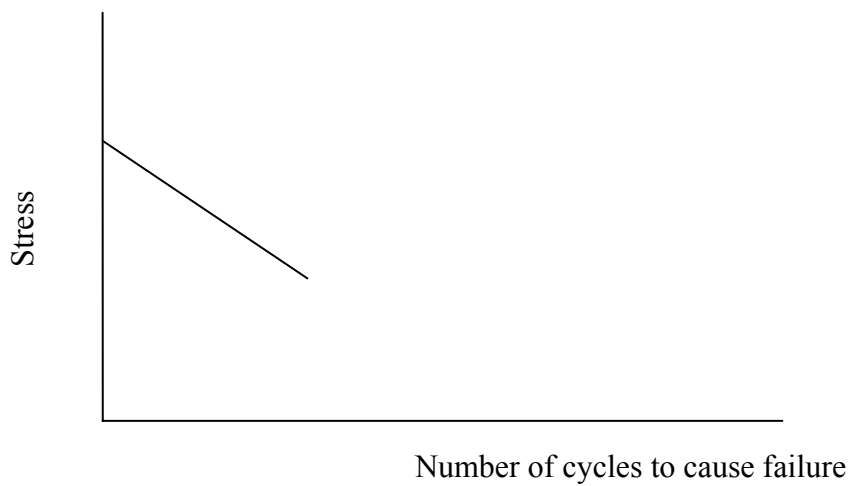
S-N diagram for concrete materials

Endurance limit:
The stress below which a material can withstand an indefinitely large number of repetition of stress without failure.

Fatigue strength:
The stress which exceed the endurance limit and at which failure may occur after indefinite number of repeated cycles.

Fatigue failure:
Fatigue failure appears to begin with a crack at a point of weakness in the material, with the crack. Progressing long crystal boundaries. During the stress cycle, these small cracks open and close. The cracks cause highest stress at the base of the crack as compared to the stress if there is no crack. Under this repeated concentration of stress, the cracks will gradually extend a cross the section of the member, finally causing complete failure of the member.

Metals are used for various engineering purposes. They are used for making structural members, doors, windows, roofing materials, pipes and many other products. In order to find the suitability of various metals to be used for a specific work, it is essential to study their composition and properties.

Classification of metals

All the metals used in engineering works can be classified into two categories:

a. Ferrous metals

Ferrous metals are those metals in which the chief constituent is iron. Besides iron, other constituents like carbon, sulpher, manganese and phosphorus etc. also exist in varying proportions. The ferrous metals which find their common are:

    1. Cast iron   2. Wrought iron   3. Steel

b. Non ferrous metals

Non ferrous metals are those, which do not contain iron, and are used widely in building industry. The important non ferrous metals are copper, lead, tin, zinc and aluminum.

<div align="center">

Ferrous metals

</div>

1. Cast iron

Besides iron, cast iron contains carbon, silicon, sulpher, phosphorus and manganese in varying proportions:

Iron – 92-95%

Carbon – 2- 4.5 %

Silicon- 1-3 %

Properties:

Cast iron possesses the following important properties:

1. It has fibrous crystalline structure.
2. Brittle and has low resistance to tension and high strength in compression. Tensile and compressive strength of an average quality of cast iron are 150 N/mm^2 and 500 N/mm^2 respectively.
3. Its melting point is about 1200 °C.
4. It can not withstand sudden shocks.
5. Because of being brittle, it can not be welded.
6. Its specific gravity is 7.5.
7. It can not be magnitude.
8. It's neither malleable, nor ductile.
9. It does not rust easily.

Uses:

1. It is used for manufacture of steel and wrought iron.
2. Its high compressive strength makes it suitable for use in making such parts which are subjected to compressive stresses such as supports of heavy machinery.
3. Since it does not rust easily, therefore it is used for parts generally exposed to atmosphere such as lamp posts.
4. It is also used for making rail chairs and carriages wheels.

2. Wrought iron

It is the purest form of iron and it contains:

Iron about 98 %

Carbon – 0.1-0.25 %

Slag – 2-3 %

Sulpher, manganese, phosphorus, silicon are present in traces.

Properties:
1. It has fibrous structure with a silky luster.
2. Its melting point is about 1500 °C.
3. It can withstand sudden shocks.
4. Its ultimate tensile strength is about 400 N/mm^2.
5. Its ultimate compressive strength is about 200 N/mm^2.
6. Its specific gravity is 7.25.
7. Its brinell hardness number is 105.
8. It can not be form permanent magnets, but can be temporary magnetized.
9. It is malleable and has got high ductility.
10. It can rust more easily than cast iron.
11. It softens at about 1000°C and then it can be hammered to any desired shape.

Uses:
1. It is used for making agricultural implements.
2. It is used for making rails, crane hooks and any article capable of withstand sudden loads.
3. Because it is extremely easy to weld, it is largely used in ornamental iron work.
4. It is used as a raw material for the manufacture of steel.

3. Steel

Steel is the most important material for engineering construction. It contain carbon from 0.15 % (very soft steel) to 1.5 % (very hard steel). It also contains small amount of other elements.

It contains from:

Iron = 99 %

Carbon content – 0.15 – 1.5 %

Phosphorus and sulpher less than o.1 %

Manganese up to 0.5 %

Silicon up to o.3 %

The higher is the percentage of the carbon, the harder and tougher is the steel. Depending upon the percentage of carbon contents, Steel can be classified into different groups as under:
1. Very low carbon steel – having percentage of carbon below 0.15 %.
2. Low carbon steel or mild steel –Carbon contents 0.15 – 0.3 %.
3. Medium carbon steel–Carbon contents range from 0.3 – 0.6 %.
4. High carbon steel or hard steel–Carbon contents range from 0.6 – 1.5 %.

Low carbon steel – mild steel

The percentage of carbon in mild steel varies from 0.15 to 0.3, sulpher, phosphorus, manganese, silicon are present only in minute quantities.

Properties:
1. It has a bright dark bluish color.
2. It has fibrous structure.
3. Its melting point is about 1400 °C.
4. It can withstand sudden shocks.
5. Its tensile strength is high.
6. Its specific gravity is 7.8.
7. It is malleable, ductile and elastic.
8. It can form permanent magnets.
9. It can rust easily and rapidly.
10. It can take a good amount of compression.
11. It can easily forge and welded.

Uses:

The chief uses of mild steel are:
1. It is used for making rolled structural steel sections like girders, angle sections, channel and T-sections… etc.
2. It is extensively used for making bars and rods which are used as a reinforcing material in reinforced concrete.
3. It is used for making refrigerators and air conditioners.
4. It is used for making plain and corrugated sheets.

5. Structural mild steel is most commonly used for general construction purposes of buildings, bridges, towers and industrial buildings.
6. It also used for making tubes.

High carbon steel

These are also termed as hard steels and contain carbon varying from 0.6 to 1.5 %. Besides carbon, small percentage of sulpher, phosphorus, manganese and silicon are also present.

Properties:

1. It has granular structure.
2. It is very hard.
3. Its specific gravity is 7.9.
4. It can not easily forge and welded.
5. It can absorb shocks and vibrations in better way.
6. It is more elastic than mild steel.
7. It is brittle and less ductile than mild steel.
8. It rusts readily.
9. It can form permanent magnets.
10. It can not take much of compression.

Uses:

1. It is used for parts of structures and machinery where hard, tough, elastic, shock- proof and durable material is required.
2. It is used in pre stressed concrete.
3. It is used for making knifes, needles, bolts and surgical instruments.

Factors affecting physical properties of steel

1. **Carbon content**
   a. The strength and hardness of steel increases as a percentage of carbon increases up to 1.5 %.
   b. The elongation decreases as the carbon content increases and the metal becomes less resistance to impact.
   c. The elastic range remains nearly on the same linearity, indicating that the modulus of elasticity is nearly the same and can be considered constant for various types of steel.
   d. The plastic region decreases as the carbon content increases and appears to be nil for hard steel (high carbon steel).
   e. The area under stress – strain curve varies with carbon content, it decreases as the percentage of carbon increases. This area represents the amount of work stored in specimen.

2. **The percentage of impurities**

The impurities present in steel are:
   a. **Silicon :** If percentage of silicon is less than 0.2%, it has no appreciable effect on physical properties of steel, but when silicon content is between 0.3-0.4%, the strength and modulus of elasticity are increased without decreasing ductility.
   b. **Sulpher :** If sulpher content is between 0.02-0.1%, it has no effect on ductility and strength, but when the percentage of sulpher is higher than 0.1%, the strength and ductility decreases.
   c. **Phosphorus :** If the percentage of phosphorus exceed 0.12%, the strength, ductility and resistance to impact are decreased.
   d. **Manganese :** When the manganese content is between 0.3-1 %, it helps to improving the strength of mild steel, but when it's content exceeds 1.5%, the steel becomes brittle and losses it's structural value.

3. **Heat treatment**

It is possible to alter the properties of steel by heating and cooling steel under controlled conditions. The term heat treatment is used to indicate the process in which the heating the heating and cooling of solid steel is involved to change the structural and physical properties of steel. The purpose of heat treatment are:
   a. To alter magnetic properties of steel.
   b. To change the structure of steel.
   c. To increase resistance to heat and corrosion.
   d. To increase surface hardness.
   e. To make steel easily workable.
   f. To vary strength and hardness.

Tensile requirements – ASTM – A615 – 86

Tensile requirements	Grade	
	Grade 300	Grade 400
Tensile strength, min., MPa	500	600
Yield strength, min., MPa	300	400
Elongation in 200mm, min., % For bar diameter(mm):		
10	11	9
15,20	12	9
25	-	8
30	-	7
35	-	7
45,55	-	7

Bar for grade 300 fabricated with diameter 10-20 mm only

Tensile properties – B.S. 4449-1988

Grade	Nominal size of bar mm	Specified Characteristic strength, N/mm^2	Minimum elongation of gauge length*, %
250	All sizes	250	22
460/425	6 up to and including 16 over 16	460 425	12 14

* Gauge length is fife times the diameter of the bar

Classification of bricks according to constituent raw material:
1. Clay bricks
2. Lime – sand bricks
3. Concrete bricks

1. Clay bricks:

1.1 Raw materials:

a. Alumina

Alumina is main constituent of every clay. Loam soil (adhesive soil) form a good clay. In absence of sand, pure clay will develop cracks due to shrinkage on drying and burning. A good clay bricks should contain about 20% of alumina.

b. Silica

Free silica (sand), if added to clay in suitable proportion makes hard and prevents it from warping and shrinkage on drying. Silica, if present in greater proportion, makes a brick brittle. Silica present in the combined form (aluminum silicate) does not form good bricks, as it will shrink and develop cracks. Both silica and alumina should be in free form.

c. Lime

This also should be present in small quantities in the brick earth. It should be in a finely produced condition and it should not be in the form lamps or clods.

Lime prevents shrinkage of raw bricks. It helps fusion of sand at the kiln temperature. This fused sand will bind the bricks particles fast.

d. Iron oxide

A small quantity of oxide of iron (5-6%) is desirable. It helps the fusion of sand like lime. It gives red colure to burn bricks. Excess of iron oxide imparts dark blue or blackish colure to brick, while, a lower percentage of iron oxide makes the brick yellow in colure. Iron oxide makes the bricks hard and strong.

e. Magnesia

A small amount of magnesia helps to decrease the shrinkage of bricks. This gives a yellow tint to the bricks. But excess of magnesia is not desirable as it tends to produce the decay of bricks.

1.2 Composition of good clay brick:

A good clay brick should contain the following:
1. Clay or alumina – Al_2O_3 – 20%
2. Sand or silica – SiO_2 – 60%
3- Remaining ingredients, such as:
- Lime
- Iron oxide
- Magnesia   }—20%
- Manganese

1-3 Harmful ingredients in clay bricks:

a. Excess of lime:

Excess of lime makes the colure of the brick yellow instead of red. Lumps of limestone remaining in the finished brick are undesirable because, when such a brick comes in contact with water, lime will begin to slake. During slaking, lime expands and also generates heat. Due to this, stresses will be produced, which will result in producing cracks in bricks.

b. Iron pyrites:

These will decompose and oxide the clay during the burning of bricks. After oxidation a black discoloration will be produced on the bricks, making it look ugly.

c. Pebbles:

The presence of pebbles, girt, gravel etc. will be undesirable because they prevent the clay from being mixed well. They prevent the manufacture of smooth and regular, standard bricks. They also spoil the appearance of the bricks. Pebbles, gravel, grit, etc., should be removed before mixing and pugging of clay are done.

e. Organic matter:

This includes leaves, twigs. Etc. of plants, roots, grass, bones of animals etc. These if prevent and burnt along with bricks, produced empty pockets or pores and will produce porous bricks.

f. Alkalis (MgO , K$_2$O):

    I. It lowers the fusion temperature and molts bricks.

    II. Changes the shape of bricks or get twisted.

    III. These salts have hygroscopic action, they absorb moisture, present in the atmosphere and keep brick damp which is harmful for health and decays the structure.

$$MgO + H_2O \rightarrow Mg (OH)_2$$
$$K_2O + H_2O \rightarrow 2 KOH$$
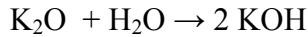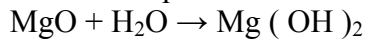
g. Salts:

Salts such as sodium sulphate cause efflorescence.

1.4 Manufacture of bricks:

Manufacture of clay bricks involves the following operation:

1.4.1 Preparation of clay:

a. Removal of loose soil:

The top layer of loose disintegrated soil up to about 20 cm depth has to be removed as this contains a lot of impurities.

b. Digging, spreading and cleaning:

Next, the earth has to be dug up. For small quantity, digging may be done manually. For large scale work, it may be done by machine.

c. Weathering:

The earth is left to weather for a few weeks, this is necessary to increase the plasticity of soil and improves its quantity.

d. Blending:

This refers to mixing the clay, after making it loose and adding any required ingredients to the top of the heap.

e. Tempering:

This is necessary to make the clay fully consistent, and fit for molding into raw bricks, by adding the required amount of water to make it plastic.

1.4.2 Molding:

Molds required for making a brick are made of rectangular blocks slightly large in size (10% larger than the burnt bricks). It is done to allow for the shrinkage of the molded brick on drying and burning. The molding is improved by the following process:

a. Dry press process:

In this method, clay is not made sufficiently plastic, but only small amount of water is mixed with clay as to form a damp powder. With plunger machines, this powder is compressed in the mold, in the form of bricks. Such bricks are directly burned, no drying is needed, but care is to be taken during burning where the temperature should be raised gradually.

b. Stiff mud process:

In this process the clay is only sufficiently moist to process the required coherence under moderate pressure, which results in economy of time in drying and fuel in burning. Such clay is forced to come out of any opening having dimensions equal to length of bricks, by means of a wire. Hence these are also known as wire cut bricks.

c. Soft mud process:

This process is used where the clay is too wet, there for, it must be dried before molding. Bricks are molded under pressure in a soft mud brick machine, which tempers the clay in its pigging chamber, sands or wets the molds, presses the clay into 4 to 9 molds at a time, strikes off the excess clay, bumps the molds uniformly and dumps the bricks into a pallet. The pallets of bricks are carried away to the dryer as fast as made.

1.4.3 Drying:

As wet clay bricks come from different brick machine, they contain from 7-50% moisture depend on whether dry press stiff mud or soft mud process has been used moisture in clay may be classified as:

- Equilibrium moisture: is that moisture in the material which exerts a vapor pressure equal to that exerted by the surrounding air of a given temperature and humidity.
- Free moisture: is held strongly in the pore spaces.

Most of the free water is removed in the drying process and the remaining moisture during the burning process. Mechanical dryer, who permit of automatic control of temperature, humidity and air velocity, have come into general use. As the free water of the clay body is removed, the clay particles tend to coalesce causing shrinkage. The general effect of such shrinkage is to increase the resistance to moisture flow in the dried layers. If the drying is carried on too rapidly as by means of hot dry air, the moisture is removed from the surface of the solid more rapidly than the interior of the solid so that the surface harden and cracking occur. It is desirable to dry clay with moist air, reducing the drying rate to the point where diffusion of water to the surface can keep up with the vaporization at the surface. The average time necessary for drying clay brick is about 3 days, and the temperature required is from 38 ºC to 149 ºC.

1.4.4 Burning:

The burning of clay in a kiln requires an average time of 3 to 4 days. The process of burning may be divided into the following stages:

a. Water smoking:

During this period which remove most of the water in the clay under temperature ranging from 125 ºC to 175 ºC.

b. Dehydration:

Dehydration consists of expelling chemically combined water by breaking down the clay molecules. It begins at about 425 ºC and complete at about 750 ºC.

c. Oxidation:

Oxidation begins during the dehydration stage. All combustible matter is consumed, carbon is eliminated, the fluxing materials are changed to oxides, and sulfur is removed.

1.5 Classification of clay bricks in accordance with Iraqi standard No. 25 / 1988:

Bricks used in construction works are classified into three grades:

Grade A:

Intended for use in building construction and footing subjected to loads and exposed to sever abrasion by weathering action.

Grade B;

Intended for use in building construction subjected to loads and not exposed to sever abrasion by weathering action, such as exterior walls not exposed to penetration of water.

Grade C:

Intended for use in building construction not subjected to loading such as interior masonry walls and partitions, not exposed to sever abrasion by weathering action.

Appearance:

A good brick should be rectangular in shape with smooth and even surfaces. They shall be free from cracks and flows and nodules of free lime.

Dimensions:

A good brick shall have standard dimensions as shown below:
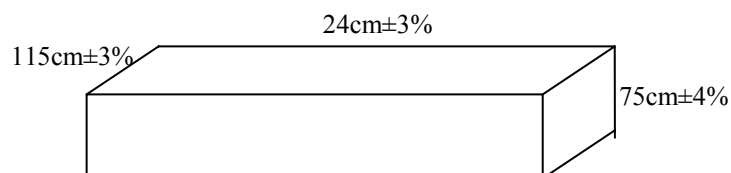
1.6 Properties of bricks:

The raw materials and the manner and degree of burning influence the physical properties greatly and therefore wide ranges in values are to be expected for each property.

1.6.1 Compressive strength:

The test is carried out in accordance with Iraqi standard No. 24. The brick placed between two plywood sheets and carefully centered between plates of the compression testing machine. The load shall be applied at a uniform rate until failure occurs.

Compressive strength = Load at failure/ Cross sectional area subjected to load
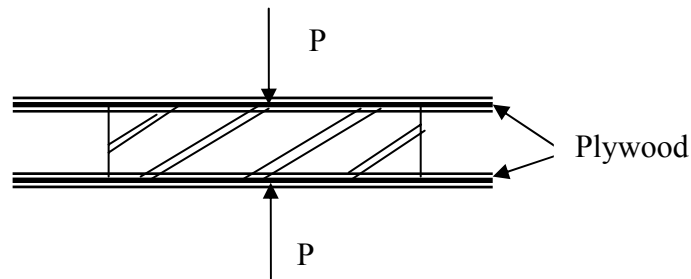
1.6.2 Water absorption:

The absorption of water by brick is often considered to be indicative of its probable durability. The test also provides a means of checking on the consistency of the bricks produced by one factory. In this test the specimen shall be dried to constant weight in a ventilated oven at 110 ºC to 115 ºC for about 48 hours. Next the specimen shall be completely immersed in clean water for 24 hours. Each specimen shall then be removed, the surface water wiped off with a damp cloth and the specimen weight.

Water absorption = { (W2-W1)/W1 } *100%

Where W2 – weight of brick after 24 hours in water
       W1– weight of dry brick

1.6.3 Effloresce:

Soluble salts, if present in bricks, will cause effloresce on the surface of bricks. Effloresce test is carried out in accordance with Iraqi standard No. 24.The test is very useful for comparing samples of bricks from different sources, such as when we want to test bricks from several different factories at one time. In this test take a representative sample of 10 bricks and place them on end in the pan containing distilled water to a depth of 2.5 cm for 7 days. Allow the bricks to dry for 3 more days in similar pan not containing water.
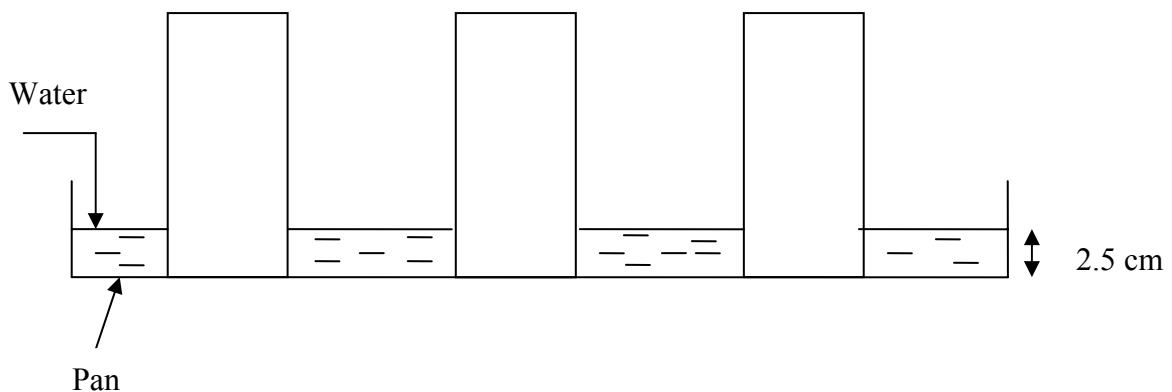
The effloresce shall reported as:

Nil – No effloresce visible.

Slight- A thin deposit of salts on less than 10% of the area of the brick.

Moderate- A heavier deposit of salts covering between 10-50% of the area of the brick, but no powdering or flaking of the surface.

Heavy – A heavy deposit of salts covering more than 50% of the area, but no powdering or flaking of the surface.

Serious – A heavy deposit of salts and some powdering and flaking of the surface.

1.7 Compressive strength, water absorption and effloresce according to Iraqi standard No. 25/1988:

Grade	Effloresce	Minimum compressive strength N/mm^2		Maximum water absorption %	
		For one brick	Average for 10 bricks	For one brick	Average for 10 bricks
A	Slight	16	18	22	20
B	Slight	11	13	26	24
C	-	7	9	28	28

2. Sand – Lime bricks:
2.1 Raw materials:

The raw materials required for manufacture of sand – lime bricks are as follow:

2.1.1 Sand

The sand used in sand – lime brick should meet the physical and chemical requirements of Iraqi standard No. 572:
a. Contain not less than 70% silica.
b. Well graded between 0.005 – 0.5 mm.
c. Free from impurities such as organic matter, rock, minerals and soluble salts.
d. The percentage of clay not more than 10%
e. Iron compounds not more than 1.5%.
f. Gypsum content not more than 1%.
g. (CaO + MgO) not more than 5%.

2.1.2 Lime:

The lime used in sand lime brick should meet the requirements of Iraqi standard No. 572:
a. Activity of lime shall not be less than 83%.
b. The percentage of lime retaining on 75 μm sieves should not be greater than 2%.

2.1.3 Water:

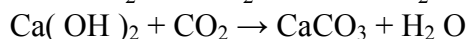Water used in sand lime brick should be fit for drinking.

2.1.4 Pigment:

To make colored sand lime bricks, suitable coloring pigment should be added in the mixture of sand and lime. The quantity of pigment varies from o.2 to 3% of the total weight of the brick.

2.2 Mix proportion:

The percentage of lime should be between 9-15% of the weight of sand.

2.3 Manufacture:
a. Sand, lime and pigment are taken in suitable proportions and they are thoroughly mixed with a required quantity of water.
b. The material is then molded in the shape of the bricks under mechanical pressure (150-200 kg/cm^2).
c. Bricks are then placed in closed chamber and subjected to saturated steam pressure of about 8.5-16 kg/cm^2 for 6-12 hours to speed up the interaction between lime and sand. The process is known as autoclaving.

$$CaO + H_2O + SiO_2 \rightarrow CaO.SiO_2. H_2O \text{ " Tobermorite " " Hydrous calcium silicate "}$$
$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

2.4 Properties of lime sand brick:
a. The raw materials of these bricks do not contain any soluble salt. Hence the trouble of effloresces does not arise.
b. If plaster is to be provided on sand lime bricks, the quantity of mortar required will be less as bricks are uniform in size and shape.
c. These bricks are hard and strong.
d. These bricks are uniform in colure and texture.
e. Sand lime bricks are used for ornamental work.

3. Concrete bricks:

These bricks are manufactured from a mixture of Portland cement and aggregate for use in brick masonry. Typical aggregate include sand, gravel, crushed stone and blast furnace slag. Mix proportion varies from 1:2:4 to 1:8:16 according to the required bearing capacity. These bricks are often made

hollow for economical purposes and to reduce the weight of the brick. The dimensions of the brick are as follow:
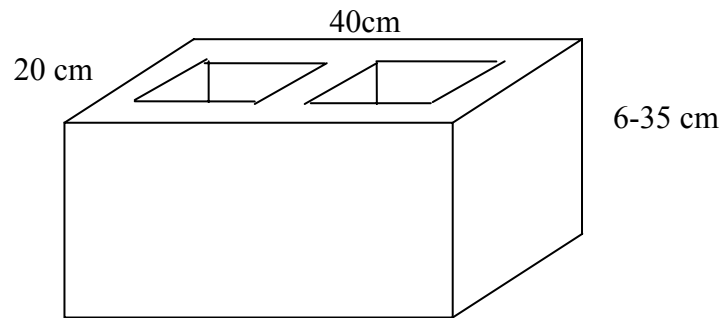
3.1 Uses:
     Concrete bricks are widely used for construction purposes especially in areas where soils are not suitable for manufacture of clay bricks and may be used in the construction of bricks panels for light weight structures and multistory formed structures.
3.2 Properties of concrete bricks:
a. The using of these bricks save time and effort as brick are light in weight and big in size.
b. These bricks give good bonding with plastering materials used in their construction.
c. These bricks have accurate size and shape.
d. These bricks can produced with various bearing capacity according to the cement content used in their production.
e. The weight of bricks can be controlled by varying the size of openings.

Material with adhesive and cohesive properties which make it capable to bond mineral fragments into a compact whole. This definition embraces a large variety of cementing materials, among them:
1. Gypsum plaster
2. Lime
3. Cement

1. Gypsum plaster:

Gypsum plaster comprise all that class of plastering and cementing materials which are obtained by partial or complete dehydration of natural gypsum and to which contain materials that serve as retarders or hardeners, or that impart greater plasticity to the product, may not have been added during or after calcinations.

1.1 Raw materials – Gypsum rocks:

Pure gypsum is a hydrous lime sulfate ($CaSO_4 . 2H_2O$), the composition of which by weight is:

Lime sulfate

Lime CaO   – 32.6%

Sulfur trioxide SO_3 – 46.5%

Water H_2O – 20.9

Total =   – 100 %

Natural deposit of gypsum are very seldom pure, the lime sulphated being adulterated with silica, alumina, iron oxide, calcium carbonate and magnesium carbonate. The total of all impurities varies from a very small amount up to a maximum of about 6%.

1.2 Manufacture of gypsum plaster:

1.2.1   Process of manufacture:

There operations are involved in the process of manufacturing plaster. Crushing, grinding and calcinations. Rock gypsum is crushed to fragments about 25mm in diameter, which are passed through a finishing mill. The grain gypsum is then calcined in rotary kilns.

1.2.2   Theory of calcinations:

If pure gypsum is subjected to any temperature above 100 ºC, but not exceeding 190 ºC, three-fourth of the water of combination originally present is driven off:

$$CaSO_4.2H_2O \xrightarrow{\text{100-190 ºC}} CaSO_4 .\tfrac{1}{2} H_2O + 1\tfrac{1}{2} H_2O$$
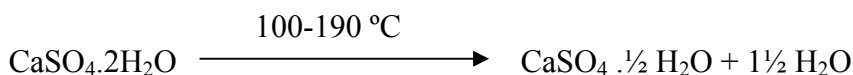
The resultant product is called plaster of Paris ($CaSO_4 .\tfrac{1}{2} H_2O$). Plaster of Paris readily recombines with water to form gypsum, hardening in a very few minutes:

$$CaSO_4 .\tfrac{1}{2} H_2O + 1\tfrac{1}{2} H_2O \rightarrow CaSO_4.2H_2O$$
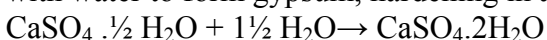
If the gypsum is calcined at temperature much above 190 ºC it losses all its water of combination, becoming an anhydrous sulfate of lime:

$$CaSO_4.2H_2O \xrightarrow{\text{T > 190 ºC}} CaSO_4 + 2 H_2O$$
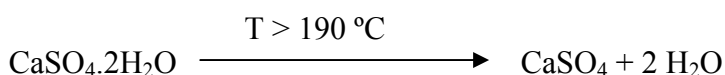
1.3 Gypsum products:
  1.3.1   Plaster of Paris:

Produced by calcinations of a pure gypsum, no foreign materials being added either during or after calcinations.

    1.3.1.1 Uses:

a. It is used as a wall plaster in finish coat.

b. It is used as a mortar for masonry construction.

c. It is used for casting ornamental work.

    1.3.1.2 Chemical requirements in accordance with Iraqi standard No. 28/1988:

a. The sum of soluble salts expressed as (Na_2O+MgO) not more than 0.25% by weight of plaster.

b. The percentage of chemically combined water should be between 4-9%.

c. The percentage of impurities not more than 5%.

d. The percentage of SO_3 not less than 45%

e. The percentage of CaO not less than 30%.

    1.3.1.3 Physical requirements in accordance with Iraqi standard No. 28/1988:

a. Fineness: The percentage retained on 1.18mm sieve not more than 0%.

b. Setting time should be between 8-25 minute.

c. Mechanical resistance: The diameter impression resulted by a dropping ball not more than 5mm.

d. Compressive strength: Not less than 5MPa for standard cube 50*50*50mm.

e. Modulus of rupture: Not less than 1.5MPa

  1.3.2   Ordinary plaster:

It is a hemi hydrate product ($CaSO_4 .\frac{1}{2} H_2O$), produced by the calcinations of a gypsum containing certain natural impurities or by the addition to a calcined pure gypsum of certain materials which serve to retard the set or render the product more plastic.

    1.3.2.1 Uses:

a. It is used as a wall plaster in first coat.

b. It is used as a mortar for masonry construction.

    1.3.2.2 Chemical requirements in accordance with Iraqi standard No. 28/1988:

a. The percentage of SO_3 not less than 35%.

b. The percentage of CaO not less than 25%.

c. The sum of soluble salts expressed as (Na_2O+MgO) not more than 0.25% by weight of plaster.

d. The percentage of chemically combined water not more than 9%.

e. The percentage of loss of ignition not more than 9%

    1.3.2.3 Physical requirements in accordance with Iraqi standard No. 28/1988:

a. Fineness: The percentage retained on 1.18mm sieve not more than 8%.

b. Setting time should be between 8-25 minute.

c. Compressive strength: Not less than 3MPa for standard cube 50*50*50mm.

  1.3.3   Technical plaster:

It is produced by mixing two types of plaster: Hemi hydrate product ($CaSO_4 .\frac{1}{2} H_2O$) and anhydrous product ($CaSO_4$) with 50% for each.

    1.3.3.1 Uses:

a. It is used as a wall plaster in first coat.

b. It is used as a mortar for masonry construction.

    1.3.3.2 Chemical requirements in accordance with Iraqi standard No. 28/1988:

a. The percentage of SO_3 not less than 50%.

b. The percentage of CaO not less than 27%.

c. The sum of soluble salts expressed as (Na_2O+MgO) not more than 0.25% by weight of plaster.

d. The percentage of chemically combined water not more than 9%.

e. The percentage of loss of ignition not more than 9%

    1.3.3.3 Physical requirements in accordance with Iraqi standard No. 28/1988:

a. Fineness: The percentage retained on 1.18mm sieve not more than 5%.

b. Setting time should be between 12-20 minute.

c. Compressive strength: Not less than 6MPa for standard cube 50*50*50mm.

d. Modulus of rupture: Not less than 2MPa

e. Mechanical resistance: The diameter impression resulted by a dropping ball not more than 5mm.

1.3.4 Anhydrous plaster:

It is produced by the complete dehydration of gypsum, the calcinations being carried on at temperature exceeding 180 ºC. It has low solubility in water compared with ordinary plaster, thus certain material can be added during the grinding process to increase its ability to react with water.

1.3.4.1 Uses:
a. As wall plaster in all coats.
b. It is used as a mortar for masonry construction.

1.3.5 Keen cement:

It is anhydrous plaster produced the calcinations, at a red heat or over, of gypsum to which certain substances, usually ($Al_2(SO_4)_2.18H_2O$) had been added.

1.3.5.1 Properties:
a. Its set is extremely slow, usually between 1-7 hours.
b. It gains in strength very gradually, but ultimately attains a great degree of hardness and a strength exceeding that of any ordinary gypsum plaster.
c. Its plasticity is high.
d. Its resistance to water is higher than ordinary plaster.

1.3.5.2 Uses:
a. It is used as a wall plaster in finishing coat and corners.
b. It is used as a wall plaster in areas exposed to moisture instead of cement and lime.

1.4 Properties of gypsum plasters:

1.4.1 Setting and hardening:
The term " setting " is meant the initial loss of plasticity, whereas " hardening " means the subsequent gain in strength and in ability to resist indentation or abrasion. The setting of plaster of Paris and other gypsum plasters is a process recombination of the partly or totally dehydrated lime sulfate or gypsum.

1.4.2 Percentage of water in plaster:
The water-plaster ratio is greatly affecting the strength of plaster. The higher the water plaster ratio, the greater are the plasticity and flow ability of plaster, but when it exceed the optimum value, part of water remain between paste particles and tends to pull the particles apart, reducing the cohesion between them and between the plaster and building units and leading to a reduced strength and durability.

1.4.3 Condition of setting:
The strength of plaster drops to a large degree when the plaster remains wet for a long period exceeding 3-days after setting. The reason is due to decomposition of some of plaster crystals in water, leading to reduced chemical adhesion.

2. Lime:

2.1 Definition and classification:

2.1.1 Quick lime:
Is the name applied to the commercial form of calcium oxide CaO, obtained by the calcinations of a stone in which the predominating constituent is calcium carbonate $CaCO_3$, often replaced, to a greater or less degree by magnesium carbonate $MgCO_3$, this product being one that will slake on the addition of water.

2.1.2 Hydrated lime:
Is quick lime has been chemically satisfied with water during manufacture.

2.2 Raw materials – Lime stone rocks:
Pure lime stone rocks consist entirely of $CaCO_3$. Pure calcium carbonate consists of 56 parts by weight of CaO to 44 parts of CO_2.

Lime stones encountered in practice depart more or less from this theoretical composition. Part of the lime is almost always replaced by a certain percentage of magnesia MgO. In addition to magnesia, silica, iron, oxide and alumina are usually present and too slight extent, sulfur, and alkalies.

The physical character of the lime stone has an effect upon the burning temperature. A naturally, coarse, porous stone is acted upon by heat much more rapidly than a dense, finely crystalline stone, and may be burned more rapidly and at a lower temperature.

2.3 Manufacture of lime – Theory of calcinations:
The burning or calcinations of lime accomplishes three objects:
a. The water in the stone is evaporated.
b. The lime stone is heated to the request temperature for chemical dissociation.
c. The CO_2 is driven off as a gas, leaving the oxides of calcium and magnesium.

2.4 Uses of quick lime:

Lime may be used as:

a. Building materials.

b. Finishing materials.

2.5 Properties of quick lime:

2.5.1 Plasticity:

The term " plasticity " is commonly used to describe the spreading quality of the material of the material in plastering. If it spreads easily and smoothly, it is plastic, if it sticks under the trowel, or cracks, and drops behind the trowel, it is non plastic.

2.5.2 Sand- carrying capacity:

Practically all lime used structurally is made up in the form of mortar by the addition of sand to lime paste for the following reasons:

a. Sand is cheaper than lime.

b. To diminish the great shrinkage which accompanies the setting and hardening of lime, and to prevent the consequent cracking.

c. To counteract the extreme stickiness' of some high- calcium limes.

It is important that the "sand- carrying capacity" of the lime be properly established. If too little sand is used, excessive shrinkage will cause a weakening of bond between the plaster or mortar and the masonry materials or plastered surface. On the other hand, too much sand produces a non plastic and weak mortar.

2.5.3 Setting time:

The setting of lime and lime mortar is a chemical process involving the evaporation of the large excess of water used in forming the lime paste, followed by the gradual replacement of the water of hydroxide by CO_2 in the atmosphere, causing the lime hydrate to revert to the original calcium carbonate.

$$CaO + H_2O \rightarrow Ca(OH)_2$$
$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$
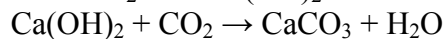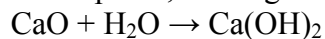
2.5.4 Tensile and compressive strength of lime mortars:

The physical properties of lime mortar vary with the:

a. Chemical composition of the lime: Magnesia lime makes it stronger than calcium limes.

b. Character of the sand: Fine sand makes stronger mortar than coarse sand.

c. The amount of water: Suitable amount of water produces stronger lime mortar.

d. The conditions under which the mortar sets: The humidity and amount of CO_2 in the atmosphere influence the rate of setting of lime drying the air and charging it with carbon dioxide, greatly accelerating the setting process.

2.6 Hydrated lime:

2.6.1 Process of manufacture:

Hydrated lime is a dry powder resulting from the hydration, at the place of manufacture, of ordinary quick lime. Three stages of manufacture characterize the preparation of hydrated lime:

a. The quick lime is crushed or pulverized to a fairly small size.

b. The crushed materials are thoroughly mixed with a sufficient quantity of water.

c. The slaked lime is, by air separation, screening, or other wise separated from lumps of anhydrate lime and impurities, or the entire mass must be finely pulverized.

2.6.2 Uses:

Hydrated lime may be used as:

a. Building materials.

b. Finishing materials.

2.6.3 Properties:

a. Mortar prepared from hydrated lime is generally inferior to those prepared from quick lime from the stand point of plasticity and sand – carrying capacity.

b. The strength of hydrated lime mortars, both in tension and in compression, is some what higher than that of the corresponding quick lime mortars.

c. Hydrated lime mortars are more quickly setting than from ordinary quick lime mortars.

Timber has been one of the primary materials of engineering construction; it is widely used for structural purpose.

The engineering should have some knowledge of the classification of trees and of their growth and structure in orders to understand the fundamentals of the physical and mechanical properties of timbers.

Classification of trees:

For the engineering purposes, trees are classified according to their mode of growth:

Trees : a. Endogenous
        b. Exogenous :
        b.1 Soft woods
        b.2 Hard woods

a. Endogenous trees:

This group is confined largely to tropical semitropical regions. Timber from these trees has very limited engineering applications. Example of endogenous tress is:

- Palms: because of their long, straight stems are some times locally used as piles.
- Bamboo: Is used structurally to a considerable extent.

b. Exogenous trees:

These trees increase in bulk growing outer bark and annual rings are formed in the horizontal section of such a tree. Timber which is mostly used for engineering purpose belongs to this category. This timber can be divided into two groups:

a. Soft woods: Such as deodar
b. Hard woods: such as oak and teak.

Structure of wood:
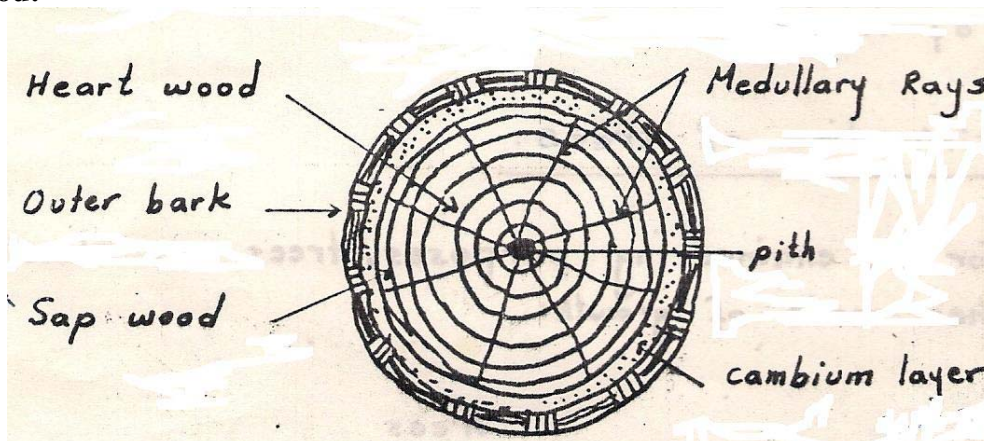
Cross section of an exogenous tree
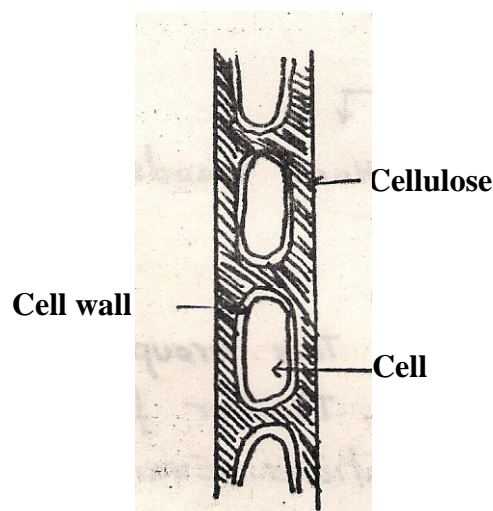
Longitudinal section of an exogenous tree

Structural axes of wood:
1. Longitudinal axis: Parallel to the length of the fiber
2. Tangential axis: Perpendicular to the fibers and tangential growth rings.
3. Radial axis: Perpendicular to the fibers and to the growth rings. i.e. parallel to the wood rays that radiate from the center of a tree as seen in cross section.
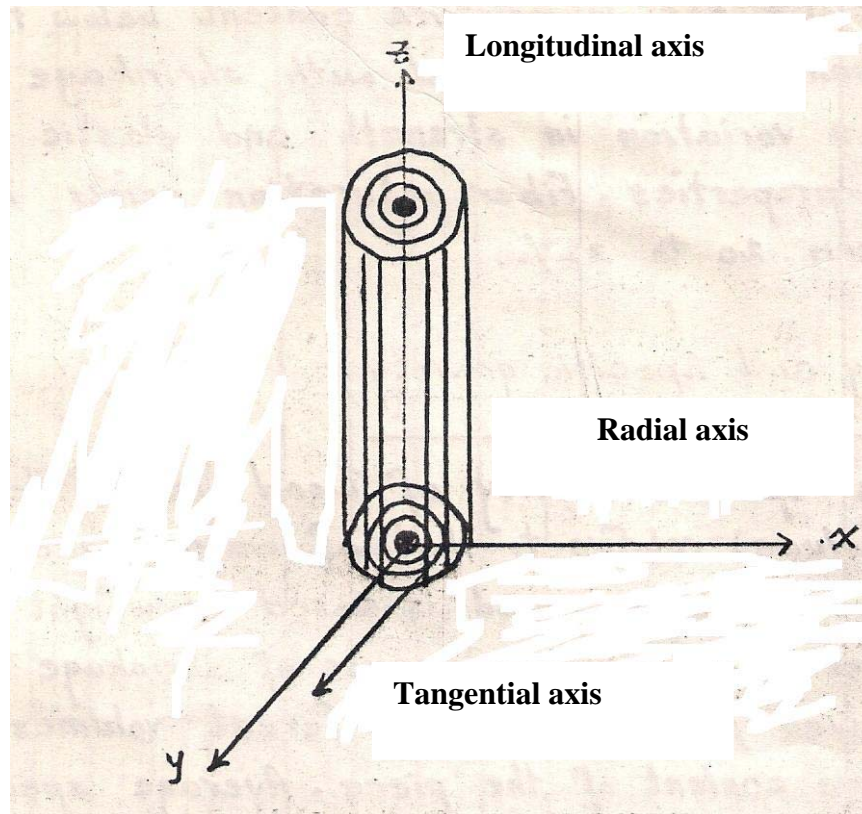
Moisture of timber:
Freshly cut wood from live trees is said to be in green condition. Green wood contains moisture in two general forms:
a. Free moisture: contained in the cell cavities of the walls.
b. Hygroscopic moisture: held in submicroscopic capillaries of the cell walls.
In the green condition, the cell walls of wood are almost saturated but the amount of free water varies widely between the species and even between sapwood and heartwood of the same species. Moisture content is expressed as a percentage of the oven dry weight of wood.

Fiber Saturation point:
The moisture content at which all free water is removed (i.e. cell cavities empty) while the cell walls are fully saturated. Changes in moisture content below the fiber saturation point are associated with shrinkage and swelling, as well as variation in strength and elastic properties and other properties. Fiber saturation point in range general between 20 to 32%.

Density and specific gravity:
The specific gravity of wood is its density (weight per unit volume) relative to that of water. By convention, the specific gravity of wood is based on weight of oven dry only per unit volume. Because of shrinkage the oven dry in a given piece occupies different volumes, depending on moisture content of the piece. Average specific gravities of woods based on oven dry weight and volume range between 0.13 to 1.20 while the specific gravity of wood substance itself, is about 1.5, regardless of species. Consequently the specific gravity of any particular species of wood is a measure of the relative amount of solid substance per unit volume, e.g. wood with a specific gravity of a contains ⅓ solid wood substance, the remainder of its volume being occupied by cell cavities, intercellular species and cell wall capillaries.

Seasoning of wood:
As a result of daily and seasonal fluctuations in relative humidity and temperature, most wood in service continually gaining or losing moisture. The most practical means of minimizing trouble some variations in moisture content is by seasoning timber prior to its fabrication finished products or used structurally so the object of seasoning is to lower the moisture content of the wood a point at which the swelling and shrinkage is reduced a minimum for given conditions.

Seasoning process:

There are two principle methods of seasoning timber:

a. Natural seasoning: This consists of stacking the timber the air, and allowing it to dry naturally, the water being expelled gradually and shrinkage occurring informally. This process takes from two to four years to complete.

It is necessary to stack the timber with intervals between each so that the air can circulate all around.

b. Artificial seasoning: Avery large proportion of commercial timber is now dried by the kiln methods more particularly in the case of hardwoods. The advantages of kiln drying lie in the rapidity of the process and in the possibility of controlling the various factors influencing the correct seasoning results.

The three principle factors concerned in these methods are:

a. The temperature of the process.
b. The moisture.
c. The circulation.

Proper kiln can control the rate and degree of drying, that the tendency during drying to warp and split is reduced minimum. Uneven shrinkage may occur when the loss of moisture from the surface is greater than that from the interior. This shrinkage can be controlled by supplying moisture inside the kiln which assists in keeping the surface soft until the heat has penetrated to the interior, so that warping and cracking are prevented.

In artificial drying, temperatures of 70 to 82ºC are useful employed for a period depending on the type of wood.

Shrinkage, warping and checking in drying:

The **shrinkage** of woods in drying is due to the loss of moisture from the walls of the cells. Shrinkage from green to oven dry condition in different species ranges as following:

Volumetric   7 to 21%
Longitudinal   0.1 to 0.3%
Radial   2 to 8%
Tangential   4 to 14%

The amount of shrinkage varies in different direction being small longitudinal in the direction of the fibers, contractively large radial, and greatest tangentially. The different between tangential and radial shrinkage is explained by the fact that bands of dense summerwood are continuous in tangential direction and shrink a great deal forcing the loc of springwood along with them. However, in a radial direction summerwood bands alternate with bands of less dense springwood, and the total shrinkage is the summation of shrinks of summerwood and springwood which is smaller than for all summerwood.
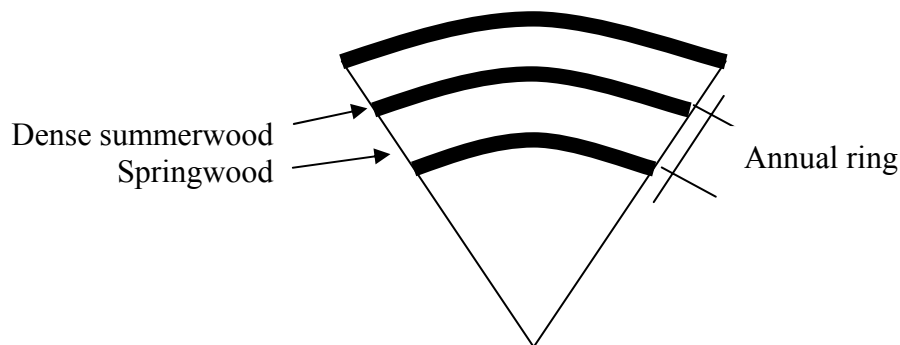
The **warping** of lumber is due either to unequal drying different portions or to unequal shrinkage of both radial and tangential direction. The warping can be classified into:
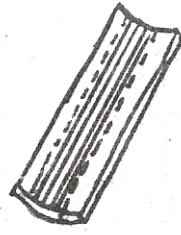
a. Bow:

This defect is indicating by the curvature formed in the direction of length of timber as shown in Fig.:
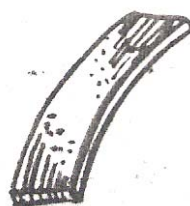
b. Cup:
This defect is indicating by the curvature formed in the transverse direction of timber as shown in Fig.:

c. Cup:
When a piece of timber has spirally distorted along its length, it is known as twist:

Checking of timber in drying is a result of the inability of the timber to accommodate strains consequent upon unequal shrinkage.

Types of checking:

Temporary checking:
A great many small checks occur particularly in the ends of timbers, owing to the more rapid drying from the cross section and the consequent extent of shrinkage of the end portion. These checking are considered temporary, because they close up and becomes impressible as the inner portion of the timber dries and shrink.

Permanent checking:
Large checking, caused by the shrinkage of timber in a longitudinal direction along the rings which is greater than that along the radius.

Case hardened checking:
Some woods, mostly hardwoods, become case hardened when rapidly dried in the kiln, that is the outer port dries and shrinks, and commonly checks, while the interior is still in its original conditions. The drying of the interior is thus retarded, but when it does occur great internal strains are set up, resulting in the formation of large or numerous radial checks follow the rays. When these checks are comparatively small, but numerous, the wood is said to be honeycombed. Case hardening of timber may be avoided by air seasoning before placing in the kiln or by admitted steam to the kiln.

Natural defects in timber:
1.   Knots: one of the most common defects, they originate in the timber cut from the stem or branches of a tree because of the encasement by the successive annual layers of wood.

Knots can be classified as:
- Pin knots – does not exceed 6.5mm.
- Small knots – between 6.5-20mm.
- Medium knots – between 20-40mm.
- Large knots – greater than 40mm.
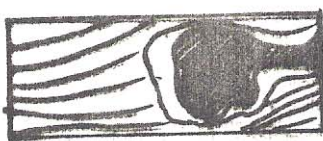
| Large knot | Small or medium knot | Pin knots |

Effect of knots:

In structural beams the effect of knots on the bending strength largely depends upon their location. Knots in the tension side of a beam near point of maximum stress will have a significant effect on the maximum load a beam will sustain, whereas knots on the compression side are somewhat less serious. Knots in any position have little effect on shear. Stiffness of beams is not greatly affected by knots.

In long columns, in which stiffness is the controlling factor, knots are not of importance. In short or intermediate columns, the reduction in strength caused by knots is approximately proportional to the size of the knot, although large knots have a somewhat greater affect than small ones.

Knots increases hardness and strength in compression perpendicular to grain. Knots are harder to work and machine than the surrounding wood, may project from the surface when shrinkage occurs, and are a cause of twisting.
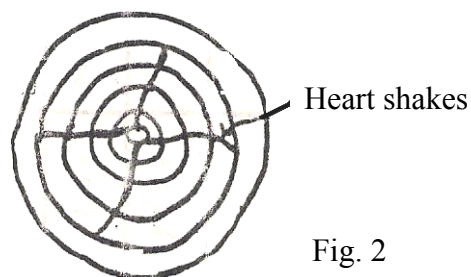
2.   Shakes:

These are cracks which partly or completely separate the fibers of wood. Shakes can be classified into:

- Cup shakes – These are caused by the rupture of tissue in a perpendicular direction as shown in Fig. 1:

Cup shakes

Fig. 1
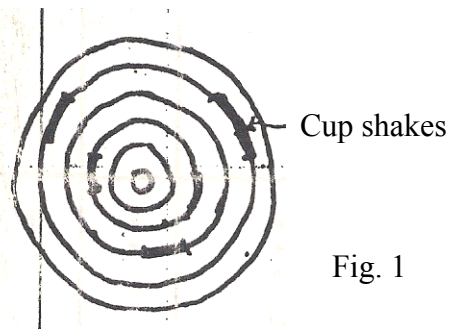
- Heart shakes – These cracks occur in the center of cross- sectional of tree and they extend from pith to sap wood in the direction of modularly rays as shown in Fig. 2. These cracks occur due to shrinkage of interior part of tree. Heart shakes divide the tree cross sectional into two to four parts.

Heart shakes

Fig. 2

- Ring shakes – When cup shakes cover the entire ring, they are known as radial shakes, Fig. 3.

Ring shakes

Fig. 3
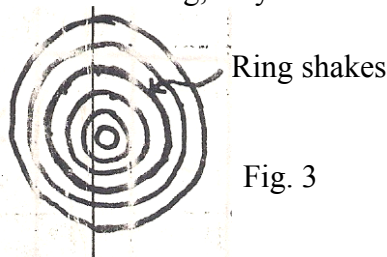
- Star shakes – These are cracks which extend from bark towards the sap wood. They are usually confined up to the place of sap wood. They are usually formed due to extreme heat or frost, Fig. 4.

Star shakes

Fig. 4
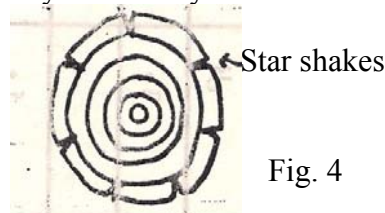
- Radial shakes – These are similar to star shakes, but they are fine, irregular and numerous. They usually occur when tree exposed to sun for seasoning after being felled down. They run for a short distance from bark towards the center, Fig. 5.
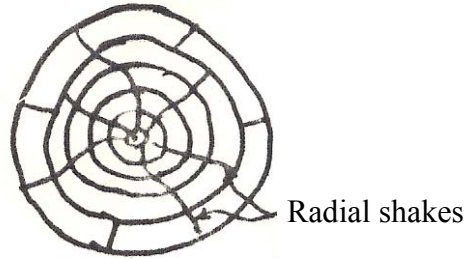

Radial shakes

Fig. 5

- Wind shakes – If wood is exposed to atmospheric agencies, its exterior surface shrinks. Such a shrinkage results into cracks as shown in Fig. 6.
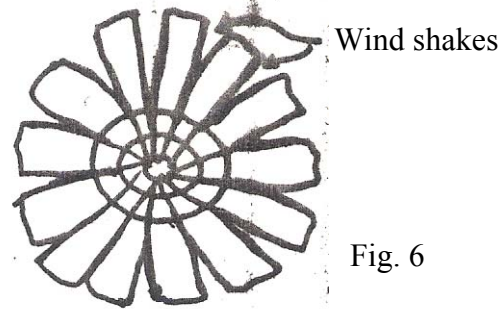

Wind shakes

Fig. 6

Mechanical properties of woods:

The intelligent use of wood for any structural purpose requires a general knowledge of the mechanical properties of different woods, in order that one selected may conform in its structure qualities to the requirements imposed, and in order that a given purpose may be served at a minimum expense.

1. Tensile strength: Timber in construction is practically never subjected to pure tensile stresses for the simple reason that the end connections cannot be so devised that they do not involve either shear along the grain or compression across the grain.

Failure in tension across the grain involves principally the resistance offered by the thinner – walled wood elements to being tern apart longitudinal.

2. Compressive strength: The compressive strength of wood in a direction normal to the grain is simply a matter of the resistance offered by the wood elements to being crushed or flattened. The cells with thinnest walls collapse first, end the action proceeds gradually.

Compression ⊥ to grain
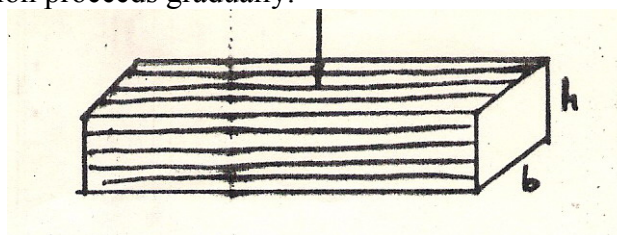
The compressive strength of wood in a direction // to the grain depends upon the internal structure and the moisture content of the wood and the manner of failure is fixed by these same factors. The individual fibers of wood act as so many hallow columns bound firmly together, and failure involves either buckling or bending of the individual fibers or bundles of elements.

Compression // to grain

3. Flexural strength: The flexural strength of timber is determined by the following formula:
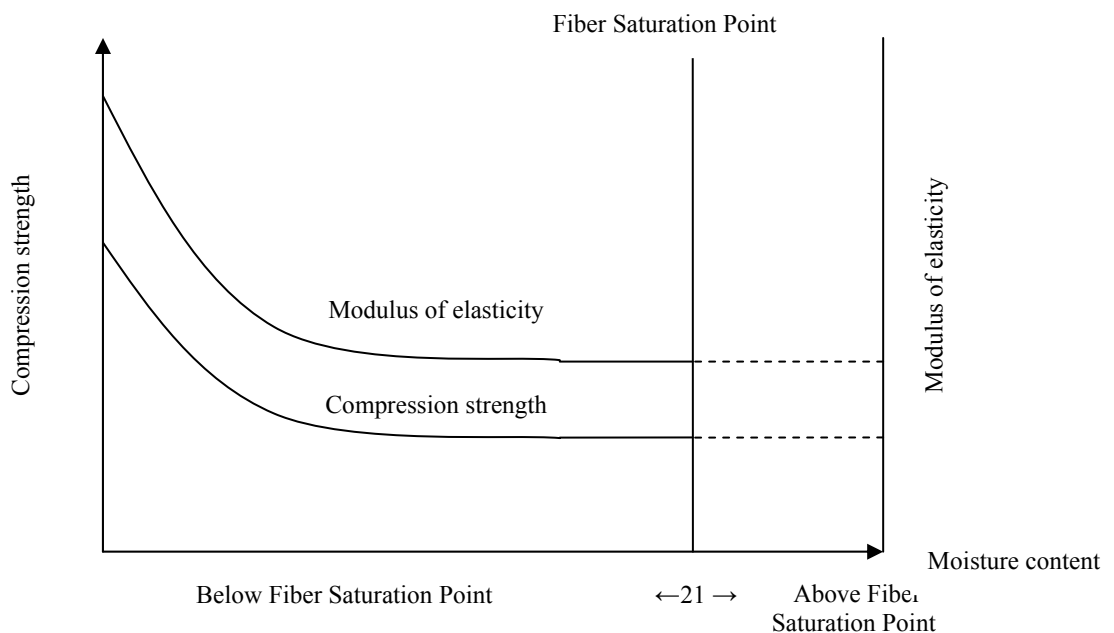
$$S_b = 3/2 \ (PL/ bh^2)$$
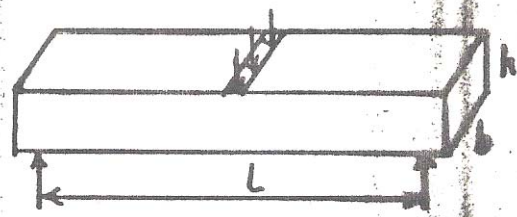
The tensile strength of all timber is greatly an excess of its compressive strength (about 3 times as much the average), and the latter will usually be the determining factor in limiting the cross- breaking strength. (Compressive strength will always be the determining factor, assuming there exist no defects such as knots or uneven grain on the tension side of the beam).

4. Stiffness: Stiffness of timber largely upon the same factors as strength. Dense woods are always stiffer than open, porous woods, and heavy woods are stiffer than light woods.

Moisture and strength:

All woods gain in strength and in stiffness when thoroughly air seasoning or kiln dried. The extent of this effect depend upon the size and type of the timbers dried only by air seasoning, even through the process is prolonged for several months or even years, seldom lose sufficient moisture to benefit their strength to more than a slight degree. Such timbers, therefore, cannot be safely depended upon to show any greater strength than if they where in the original green condition. The explanation of this fact is that a great part of the moisture which is first evaporated from wood is water which exists only as " free water " in the cell cavities, whereas only variation in the moisture content of the walls of the wood element affects strength in any way.

The relationship between strength and moisture content can be seen in Fig. below:

UNIVERSITY OF TECHNOLOGY
Building and construction department
Building Materials Technology
First year   2008 – 2009 Final exam 1st Attempt   Time / 3 hours

Note: Answer only FOUR questions from the following questions

Q1 / A- A steel rod is used to support a weight of 20 kN as shown in Fig 1. If the allowable stress is 138 N/mm^2. Determine the diameter of the rod and its final length. The length of the bar is 61 cm, and the modulus of elasticity for steel is 206.85*10^{3}N/mm^2 (16 %)

Q1/ B – Give the reasons for the followings:
   I.   Alkalis are considered harmful ingredients in clay bricks
   II.   The problem of efflorescence does not arise in sand – lime bricks.
   III. A small quantity of iron oxide in clay bricks (5-6%) is desirable.   **(9%)**

Q2/A – The steel block shown in Fig. 2 is subjected to a compressive force F on all faces. If the change of X- direction is (-2 mm). Determine the change in the length of the other two directions. E for steel = 200*10^3 N/mm^2 and μ = 0.28   **(15 %)**

Q2/B – Draw the following and write full details on the sketch:
   I.   Johansson's apparent elastic limit for materials that do not have straight line portion of the stress- strain curve.
   II.   Stress – strain relationship for steel of various carbons content.   **(10 %)**

Q3/A- Find total change in length and diameter for the bar shown in Fig.3. If E= 200*10^3 N/mm^2, α= 12*10^{-6}mm/mm. °C, cross sectional area of the bar is 400 mm^2, Poisson's ratio (μ) is 1/3 and change in temperature = 60°C (increase).   **(17%)**

Q3/B- Draw the following and write full details on the sketch:
   I.   Metallic bonding for aluminums.
   II.   Plastic deformation.   **(8%)**

Q4/A- Determine the stress in each material shown in Fig. 4.   **(20%)**
Q4/B- Explain tangent modulus method to find modulus of elasticity   **(5%)**

Q5- Fig. 5 represent stress- strain curve for a metal. If D$_0$= 12mm and D$_f$ = 10mm. Find:
   1. Modulus of elasticity
   2. Modulus of toughness
   3. Modulus of resilience
   4. Maximum load
   5. True stress at failure
   6. Maximum load without permanent deformation.
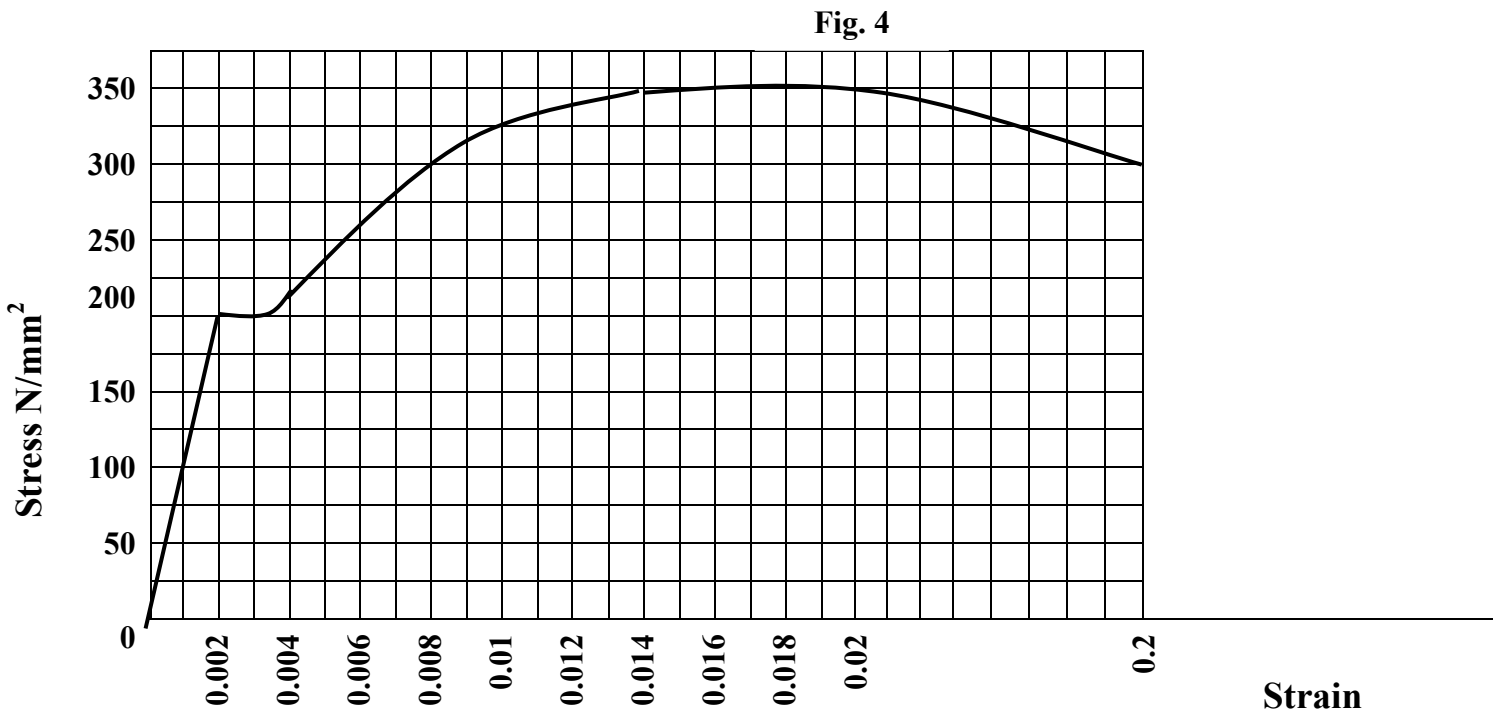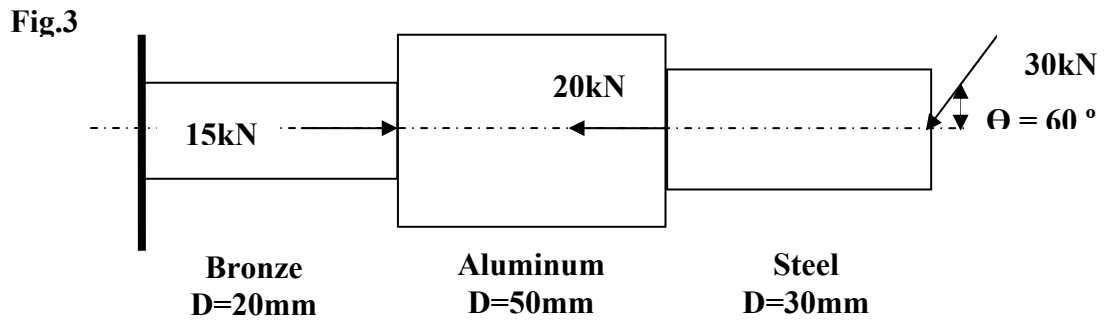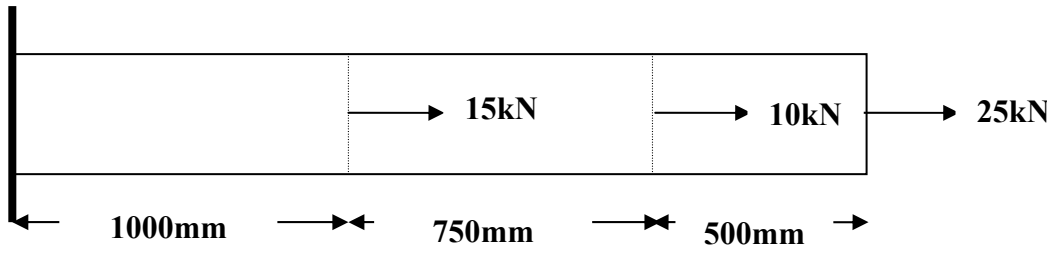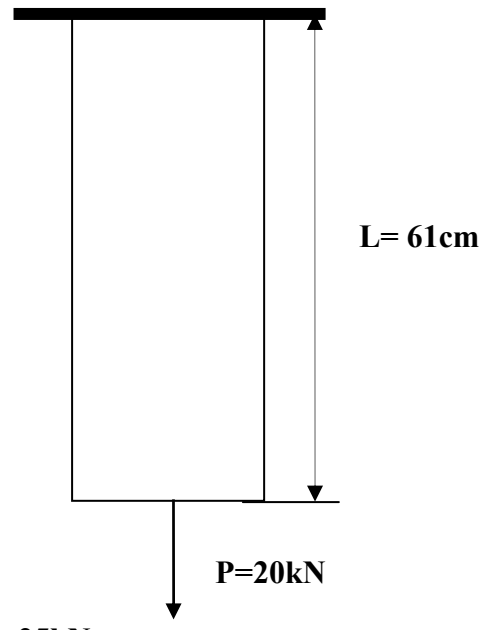   7. Percentage of elongation   **(25%)**

إقلب الصفحه

Y

F

80mm

20mm

40mm

F

X

Z

F

Fig. 2

L= 61cm

P=20kN

Fig. 1

15kN

10kN

25kN

1000mm

750mm

500mm

Fig.3

20kN

30kN

15kN

Θ = 60 °

Bronze
D=20mm

Aluminum
D=50mm

Steel
D=30mm

Fig. 4

Stress N/mm²

350

300

250

200

150

100

50

0

0.002 0.004 0.006 0.008 0.01 0.012 0.014 0.016 0.018 0.02 0.2

Strain

Fig. 5