MATERIALS OF CONSTRUCTION

Introduction

The engineering structures are composed of materials. These materials are known as the engineering materials or building materials or materials of construction. It is necessary for the civil engineer to become conversant with the properties of such materials.

The service conditions of buildings demand a wide range of materials and various properties such as water resistance, strength, durability, temperature resistance, appearance, permeability, etc. are to be properly studied before making final selection of any building material for a particular use.

Classification of Engineering material

The factors which form the basis of various systems of classifications of materials in material science and engineering are: *(i)* the chemical composition of the material, *(ii)* the mode of the occurrence of the material in the nature, *(iii)* the refining and the manufacturing process to which the material is subjected prior it acquires the required properties, *(iv)* the atomic and crystalline structure of material and *(v)* the industrial and technical use of the material.

Common engineering materials that falls within the scope of material science and engineering may beclassified into one of the following six groups:

(i) Metals (ferrous and non-ferrous) and alloys

(ii) Ceramics

(iii) Polymers

(iv) Composites

NOTES:

(vii) Advanced Materials

Properties of Engineering Materials

It is possible to classify material properties as follows- :

1- **Physical properties:**

Density, specific gravity, porosity, water absorption, etc....

2- **Mechanical properties:**

Tensile strength, compressive strength, rigidity, hardness. Creep, fatigue ...... etc.

3- **Thermal properties:**

Thermal conductivity, thermal expansion and other.......

4- **Chemical properties:**

Resistance to acids, alkalis, brines and oxidation.

5- **Economic characteristics:**
   Cost savings
6- **Aesthetic properties**:
   Color, surface smoothness, the reflection of light…

Physical properties

Density (ρ : Density is defined as mass per unit volume for a material. The derived unit usually used by engineers is the kg/m^3. Relative density is the density of the material compared with the density of the water at 4˚C.

NOTES:

The formula of density and relative density are:

Density of the material ***(ρ)*** = M / V

Relative density (d) = Density of the material / Density of pure water at 4˚C

where;

M is material mass g, kg,…etc

V is material volume m^3, cm^3,…etc

Density units : kg / m^3,gr / cm^3, …etc

There aretwotypesofdensity:

1- bulk density ρb: It is the ratio of material mass to total volume of material, including spaces.

$\rho b = M / V$

$V = Vs + Vv$

•$Vs = Volume\ of\ solids$

•$Vv = volume\ of\ voids$

V,M =total volume and total mass

- $M = Ms + Mw$

- $Ms = solid\ Mass$ • $Mw = water\ mass$

Table (1) gives densities for some materials in kg/m^3.

Materials	Bulk density (kg/m^3)
Brick	1700
Mastic asphalt	2100
Cement:sand	2306
Glass	2520
Concrete 1:2:4	2260

NOTES:

Limestone	2310
Granite	2662
Steel	7850
Aluminum	2700
Copper	9000
lead	11340
Hardwoods	769
softwood, plywood	513

2-Solid density ρs

It is theratio of themassofsolidmaterialtothe volume ofsolidmaterialwithout any spaces.

ρs = Ms / Vs

Unit weight γ

It is theratio of materialweight tomaterial volume.

$$\gamma = \frac{W}{V}$$

γ = *Unit weight* (N/mm^3)

W= weight (N)

V = volume (m^3)

γ = (M .g) / V $\gamma = \rho .g$

γ is the specific weight of the material (weight per unit volume, typically N/m^3 units)

ρ is the density of the material (mass per unit volume, typically kg/m^3)

NOTES:

g is acceleration of gravity (rate of change of velocity, given in m/s^2)

4- specific gravity(G_s)

A ratio of soliddensityof material anddensity ofdistilledwaterat a temperature of4c^o.

$G_s = \rho_s / \rho_w$

porosity (n)

It is the ratio of the volume of the spaces in the material to the over all volume.

$$n = \frac{Vv}{V}$$

Vv = Volume of voids

voids ratio (e)

It is theratiobetweenthesizeofvoidstothe volume ofsolidmaterial.

$$e = \frac{Vv}{Vs}$$

Water absorption

It denotes the ability of the material to absorb and retain water. It is expressedaspercentage in weight or of the volume of dry material:

Ww =M1- M / M× 100

Wv =M1 - M / V× 100

where M1 = mass of saturated material (g)

M = mass of dry material (g)

V = volume of material including the pores (mm^3)

Water absorption by volume is always less than 100 per cent, whereas that by weight ofporous material may exceed 100 percent.

NOTES:

The properties of building materials are greatly influenced when saturated. The ratio ofcompressive strength of material saturated with water to that in dry state is known as *coefficientof softening* and describes the water resistance of materials. For materials like clay which soakreadily it is zero, whereas for materials like glass and metals it is one. Materials with coefficientof softening less than 0.8 should not be recommended in the situations permanently exposedto the action of moisture.

Weathering resistance

It is the ability of a material to endure alternate wet and dry conditionsfor a long period without considerable deformation and loss of mechanical strength.

Water permeability

It is the capacity of a material to allow water to penetrate under pressure.Materials like glass, steel and bitumen are impervious.

Frost Resistance

It denotes the ability of a water-saturated material to endure repeated freezingand thawing with considerable decrease of mechanical strength. Under such conditions thewater contained by the pores increases in volume even up to 9 percent on freezing.

Mechanical Properties

The properties which relate to material behavior under applied forces define as mechanical properties. The common mechanical properties: Tensile strength, compressive strength, rigidity, hardness. Creep, fatigue ...... etc.

- ***Strength*** is the ability of the material to resist failure under the action of stresses caused by loads.

-***Stress***(σ)is the applied force *P* divided by the original area A_o.

($\sigma = P / A_o$).See Fig.1.

NOTES:

There are several types of stress which depend on types of applied load. These stresses can be classified as:

1- Compression stress
2- Tension stress
3- Shear stress
4- Bending stress
5- Torsion stress

When bar is stretched, stresses are **tensile** (taken to be positive)

If forces are reversed, stresses are **compressive** (negative)

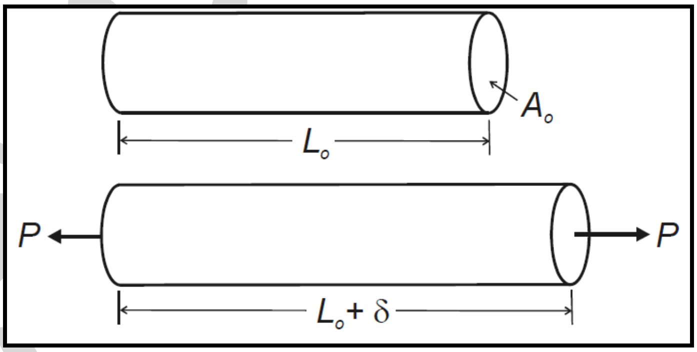

Fig.(1)Bar under tensile force

Example: Steel bar has a circular cross-section with diameter *d* = 50 mm and an axial tensile load *P* = 10 kN. Find the normal stress.

$$\sigma = \frac{P}{A_o} = \frac{P}{(\pi d^2/4)} = \frac{4(10\times10^3)}{\pi(50\times10^{-3})^2}\frac{N}{m^2} = 5.0929\times10^6\frac{N}{m^2}$$

Units are force per unit area = N / m^2 = **Pa** (pascal). One Pa is very small, so we usually work in **MPa**(mega-pascal, Pa x 10^6).

σ = 5.093MPa

NOTES:

Note that N / mm2 = MPa.

$$\frac{N}{mm^2} = \frac{N}{mm^2}\left(\frac{10^3 mm}{m}\right)^2 = \frac{N}{m^2}\times 10^6 = Pa\times 10^6 = MPa$$

- **Strain** (ε) is the change in length δ divided by the original length *Lo* (ε = δ / *Lo*). See Fig.1.

When bar is elongated, strains are **tensile** (positive).

When bar shortens, strains are **compressive** (negative).

Example:

Steel bar has length *Lo* = 2.0 m. A tensile load is applied which causes the bar to extend by δ = 1.4 mm.

Find the normal strain.

Greek letters
δ (delta)
σ (sigma)
ε (epsilon)

$$\varepsilon = \frac{\delta}{L_o} = \frac{1.4\times 10^{-3}}{2.0}\ \frac{m}{m} = 0.0007$$

Units: none, although sometimes quoted as με (microstrain, ε x 10^{-6}) or % strain

$$\varepsilon = 0.0007 = 7\times 10^{-4} = (7\times 10^2)(10^{-4}\times 10^{-2}) = 700\times 10^{-6}$$

$$\varepsilon = 700\ \mu\varepsilon$$

$$\varepsilon = 0.0007 = 0.07\%\ \text{strain}$$

The Poisson Effect

A positive (tensile) strain in one direction will also contribute a negative (compressive) strain in the other direction, just as stretching a rubber band to make it longer in one direction makes it thinner in the other directions (see Fig. 2). This

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lateral contraction accompanying a longitudinal extension is called the **Poisson effect**.

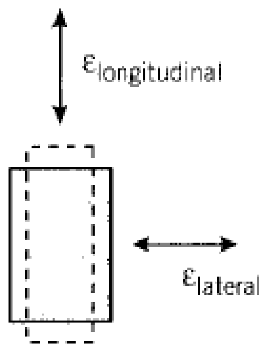

Figure (2) The Poisson Effect

So there is a tensile strain in the axial direction and a compressive strain in the other two (lateral) directions.

The ratio of lateral strain of material to axial strain within elastic limit define as **Poisson's ratio.**

ν= (lateral strain/ axial strain)=($\varepsilon_{lateral}/\varepsilon_{longitudinal}$)

Greek letter ν (nu)

The Poisson's ratio is a dimensionless parameter that provides a good deal of insight into the nature of the material. The major classes of engineered structural materials fall neatly into order when ranked by Poisson's ratio;

Material Class	Poisson's Ratio ν
Ceramics	0.2
Metals	0.3
Plastics	0.4
Rubber	0.5

NOTES:

Example:

Two points fixed on steel bar of 10 mm diameter, the distance between points was 50 mm. tensile force applied on its ends (8 kN).The distance increased by 0.025 mm and the diameter decreased by 0.0015 mm.

Determine:

1-Normal stress

2- Longitudinal and lateral strains

3- Poisson's ratio

$$A=\frac{\pi D^2}{4} = \frac{\pi 10^2}{4}$$

$=78.57 \quad mm^2$

$$\sigma = \frac{P}{A} = \frac{8*10^3}{4}$$

$= 101.82$ MPa

$$\varepsilon_{longitudinal}=\frac{\Delta L}{L\circ} = \frac{0.025}{50}$$

$= 0.0005$

$$\varepsilon_{lateral}=\frac{\Delta D}{D\circ} =\frac{0.0015}{10}$$

$= 0.0015$

$$\nu = \frac{\varepsilon lateral}{\varepsilon longitudinal} = \frac{0.00015}{0.0005} = 0.3$$

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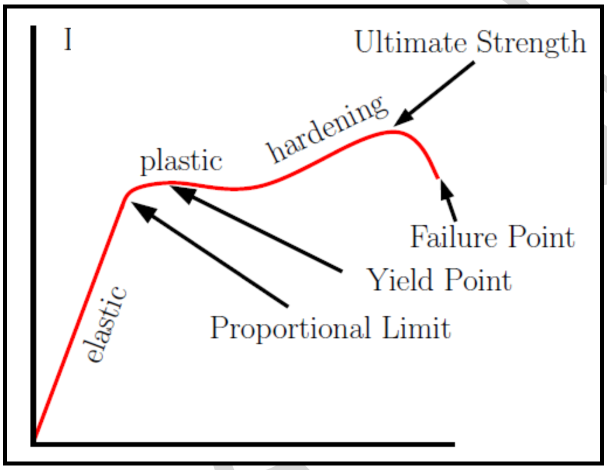
Stress – Strain Relationship

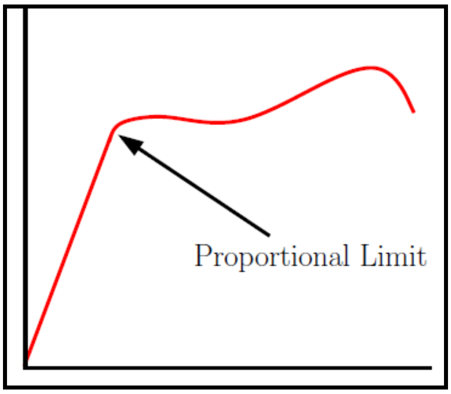
The relation between stress and strain is an extremely important measure of amaterial’smechanicalproperties. Stress - strain curve is graphical representation of it.



Stress-Strain Curve

1- The proportional limit

Up to the proportional limit for the material, the graph is a straight line and so the stress is proportional to elastic strain and Hooke’s Law applies.



NOTES:

Proportional limit on Stress-Strain Curve

- Load is proportional to deformation .
- Stress is proportional to strain, material behaves ***elastically*****,** There is no permanent change to the material; when the load is removed, the material resumes its original shape
- After the proportional limit, the graph changes from a straight Line

Hooke's Law

Within the elastic region of the stress-strain diagram, stress is linearly proportional to

strain (up to proportional limit).

- That relationship was formalized by Robert Hooke in 1678

- In mathematical terms Hooke's Law

$$\sigma = E\varepsilon$$

σ (sigma) is the axial/normal stress

E is the elastic modulus or the Young's modulus

ε (epsilon) is the axial/normal strain

For shear stress in the same region Hooke's Law

$$\tau = G\gamma$$

τ (tau) is the shear stress

G is the shear modulus or the modulus of rigidity

γ (gamma) is the shear strain

Modulus of Elasticity or Young's Modulus(E)

It is the slope of the initial linear portion of the stress-strain diagram. In other words it is the ratio of stress to elastic strain.

$$E = \sigma / \varepsilon$$

NOTES:

The modulus of elasticity may also be characterized as the "**stiffness**" or ability of a material to resist deformation within the linear range.

E (Steel) ≈ 200 x 10^3MPa

E (Aluminum) ≈ 70 x 10^3MPa

E (Concrete) ≈ 30 x 10^3MPa

Tangent Modulus (Et)

It is the slope of the stress-strain curve above the proportional limit. In other words it is the ratio of stress to strain above the proportional limit. There is no single value for the tangent modulus; it varies with strain.

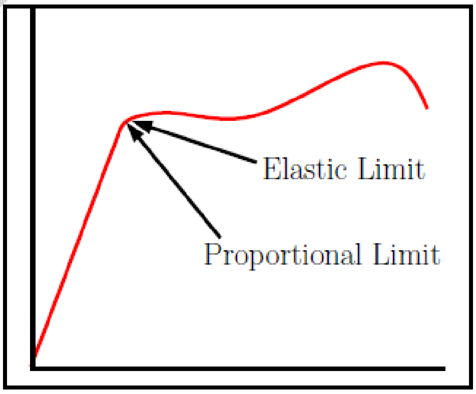
Shear Modulus the modulus of rigidity (G)

It is the slope of the initial linear portion of the shear stress-strain diagram. In other words it is the ratio of shear stress to elastic shear strain,

$$G = \tau / \gamma$$

2- **The Elastic Limit**

It is the point after which the sample will notreturn to its original shape when the load is released.



Elastic limit on stress strain curve

- The proportional limit and the elastic limit are very close. For most purposes,

NOTES:

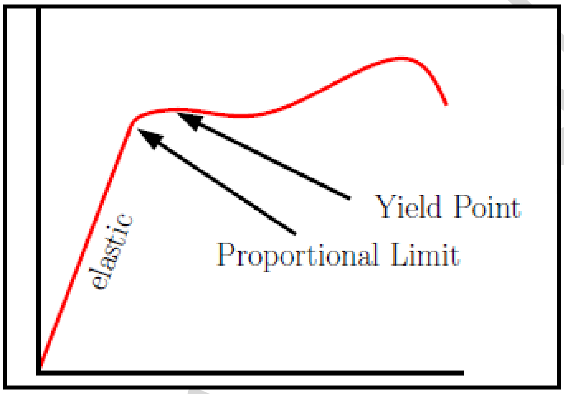
we may consider them to be the same point.

- There is permanent change to the structure of the material.

3- **Yield point**

There may be a region of increased deformation without increased load

This point is known as the *yield point*. The stress at this point is called the *yield strength.*



Yield point on stress strain curve

- After yield point, the material behaves ***plastically***(when the load is removed, the sample does not return to its original shape)

- It is not always easy to identify the yield point from the stress-strain (load-deformation) curve. In these cases the ***offset method*** is used.

  1- An offset for the material is given.

  For the tension and compression labs, we use the following offsets:

  For steel, use 0.2% strain

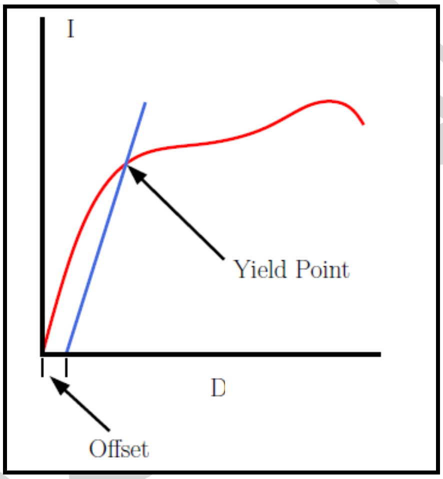
  For brass, use 0.35% strain

  For cast iron, use 0.05% strain

NOTES:

2- It is marked on the deformation (strain) axis.

3- A line through the offset point, parallel to the straight (proportional) part of the curve,is drawn. The intersection of the line with the stress-strain curve is taken to be the yield point.



offset method

<u>4- The Strain-Hardening</u>

After the yield point, there may be a region of where increased load is necessary for increased deformation, This is the <u>strain-hardening region</u>

<u>5- Ultimate strength</u>

Load (stress) rises to a maximum; this is the **ultimate strength** of the material

<u>6- Failure point</u>

Load required for further deformation is reduced as the **failure** or **breaking point** is approached.

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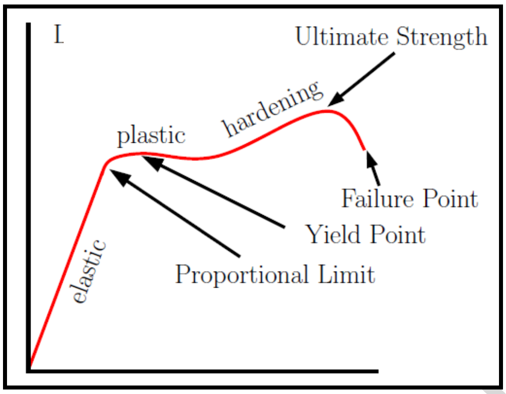
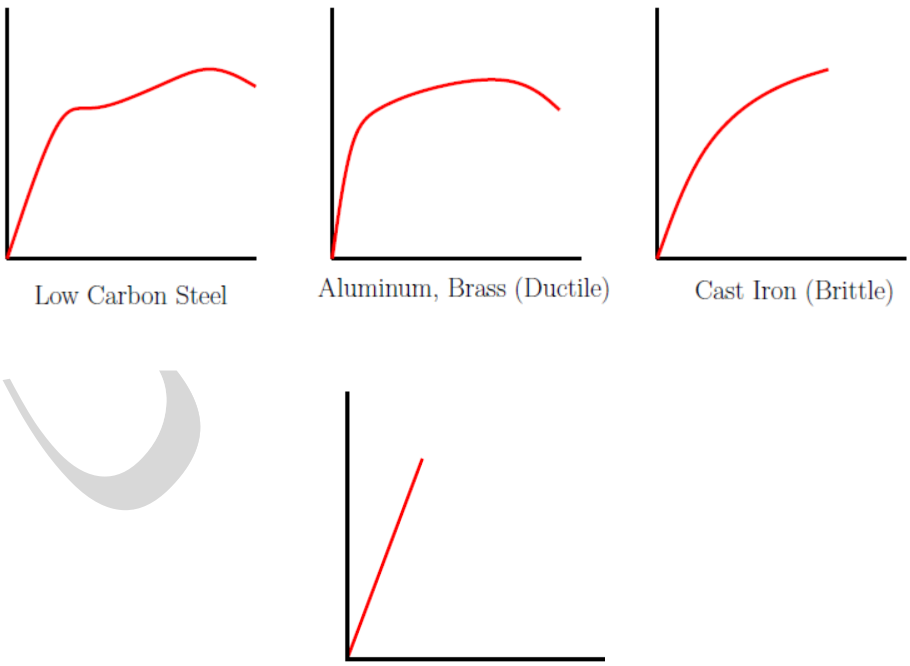


Hardening strain, ultimate strength
and failure point on stress strain curve

Ductile and Brittle Materials

Each material has its own stress-strain curve, with different characteristics, examples:



Glass (Brittle)

1- Ductile Material

NOTES:

Materials that are capable of undergoing large strains (*at normal temperature*) before failure.

An advantage of ductile materials is that visible distortions may occur if the loads be too large. Ductile materials are also capable of absorbing large amounts of energy prior to failure.

Ductile materials include mild steel, aluminum and some of its alloys, copper, magnesium, nickel, brass, bronze and many others.

2- **Brittle Material**

Materials that exhibit very little inelastic deformation. In other words, materials that fail in tension at relatively low values of strain are considered brittle.

Brittle materials include concrete, stone, cast iron, glass and plaster.

Modulus of Elasticity Determination

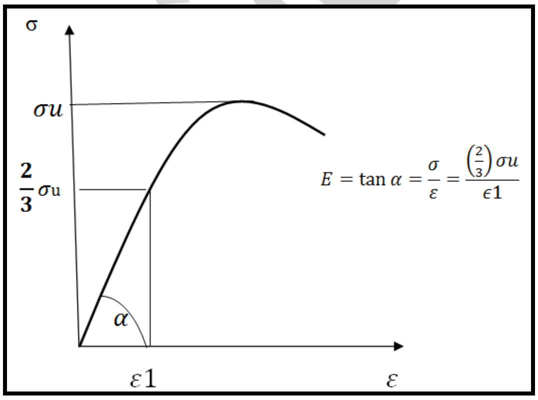
- Ductile Material, the modulus of elasticity is the slope of straight line of stress strain curve.

$$E = \sigma / \varepsilon$$

- Brittle materials, use one of followings:

1- Secant modulus

The slope of straight line between origin point and point on curve has stress equal to (2/3) of ultimate stress.



2- Initial tangent modulus

The tangent slope of stress-strain curve at origin point.

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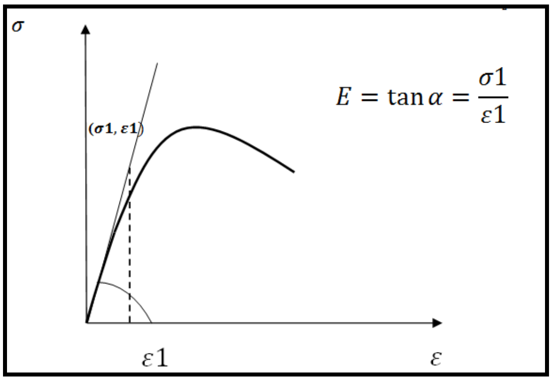
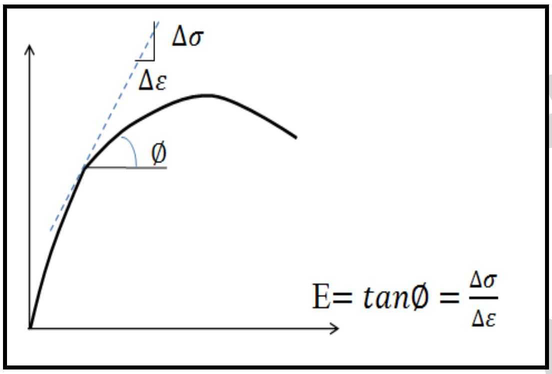


3- Tangent modulus



The tangent slope of stress-strain curve at any point in elastic range, usually at yield point.

Example

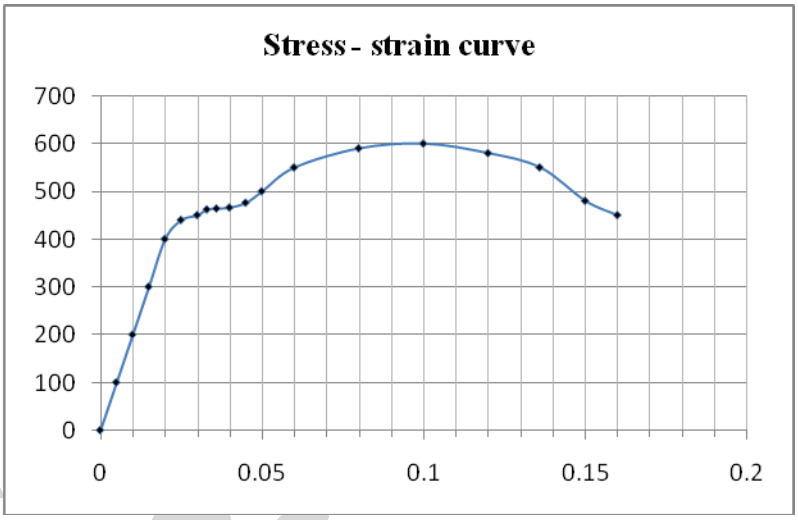
The following information obtained in tension test on a material as the sectional area of the sample is 50 mm^2 and length 1000 mm, draw the stress - strain curve and then determine the value of proportional limit , yield stress and ultimate strength, failure stress and modulus of elasticity.

Load (KN)	**50**	**100**	**150**	**200**	**220**	**225**	**231**	**232**	**233**
Extension (mm)	5	10	15	20	25	30	33	36	40
Load (KN)	**238**	**250**	**275**	**295**	**300**	**290**	**275**	**240**	**225**
Extension (mm)	45	50	60	80	100	120	136	150	160

NOTES:

Solution

Load, P (kN)	Stress =P/A (MPa)	Extention δ mm	Strain = δ /L
0	0	0	0
50	100	5	0.005
100	200	10	0.01
150	300	15	0.015
200	400	20	0.02
220	440	25	0.025
225	450	30	0.03
231	462	33	0.033
232	464	36	0.036
233	466	40	0.04
238	476	45	0.045
250	500	50	0.05
275	550	60	0.06
295	590	80	0.08
300	600	100	0.1
290	580	120	0.12
275	550	136	0.136
240	480	150	0.15
225	450	160	0.16



Example

The following information obtained in compression test on concrete cylinder, draw the stress - strain curve and then determine ultimate compressive strength

Stress (MPa)	٠	٥	١٠	١٥	**20**	**15**
Strain x10^{-4}	٠	٢	٥	٩	15	**21**

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