

## Engineering Materials:

Materials are divided into 3 types.

- i) Elasto plastic materials: Exhibits elasticity and rigidity.
  - \* Substance having both elastic as well as Plastic properties. Eg: Structural materials i.e. steel doesn't break until a certain extent, as it has elasticity.
- ii) Viscoelastic materials.
  - Substance having properties of fluid as well as elasticity.
  - Behaves Like a Liquid and a Solid. Eg: Metals at high temperature.
- iii) Elastic materials.
  - They get back to their original state after being stretched by an external force.

Eg: Rubber band.

## STRESS :

→ When a force is applied on any type of material, the material experiences stress. Unit of stress is (psi)

Force acting per unit area is stress

$$\sigma = \frac{F}{A} \rightarrow \text{Force}$$

$\longrightarrow$  Area

According to mode of application force can be static (or) dynamic.

Static force remains constant.

Dynamic force can lead to changes.

It is of 3 types:

→ Impact forces

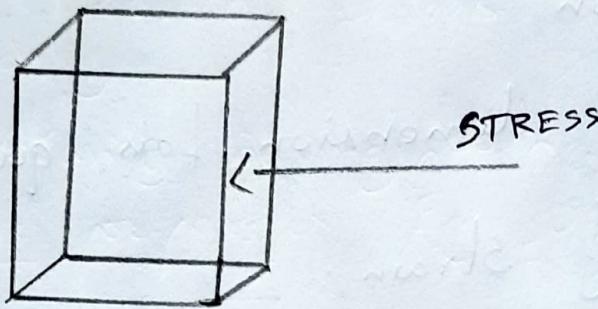
→ Alternative forces

→ Reverse forces.

There are 3 states of Stress:

i) Uniaxial:

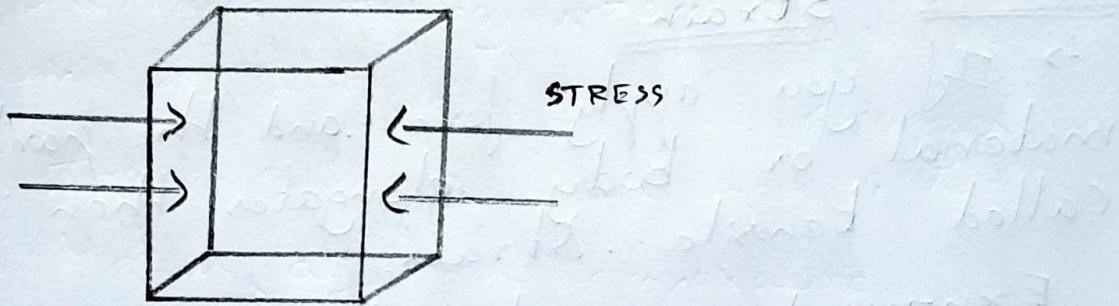
Stress is applied only in one direction.



ii)

Biaxial:

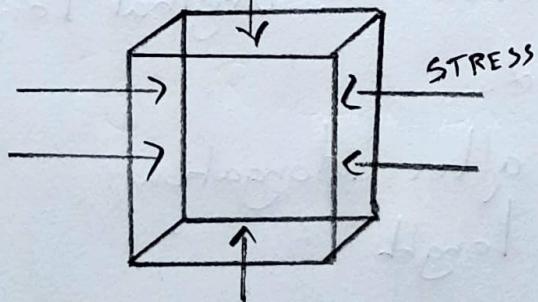
Stress / force is applied in two directions.



iii)

Triaxial:

Stress from all three sides i.e. from three directions.



## STRAIN:

→ When stress is applied and it causes change or alteration in the materials then it is called strain or deformation.

→ It is a dimension-less quantity.

3 Types of strain :

⇒ Tensile strain

⇒ Compressive strain

⇒ Shear strain

### Tensile strain:

→ If you apply force and the particular material or body elongates then it is called tensile strain.

Expressed as elongation per unit length

$$\epsilon_t = \Delta L / L_0$$

Here,

$$\epsilon_t \rightarrow \text{deformation in Original Length.}$$

$$\Delta L = L - L_0$$

$L \rightarrow$  Length after elongation

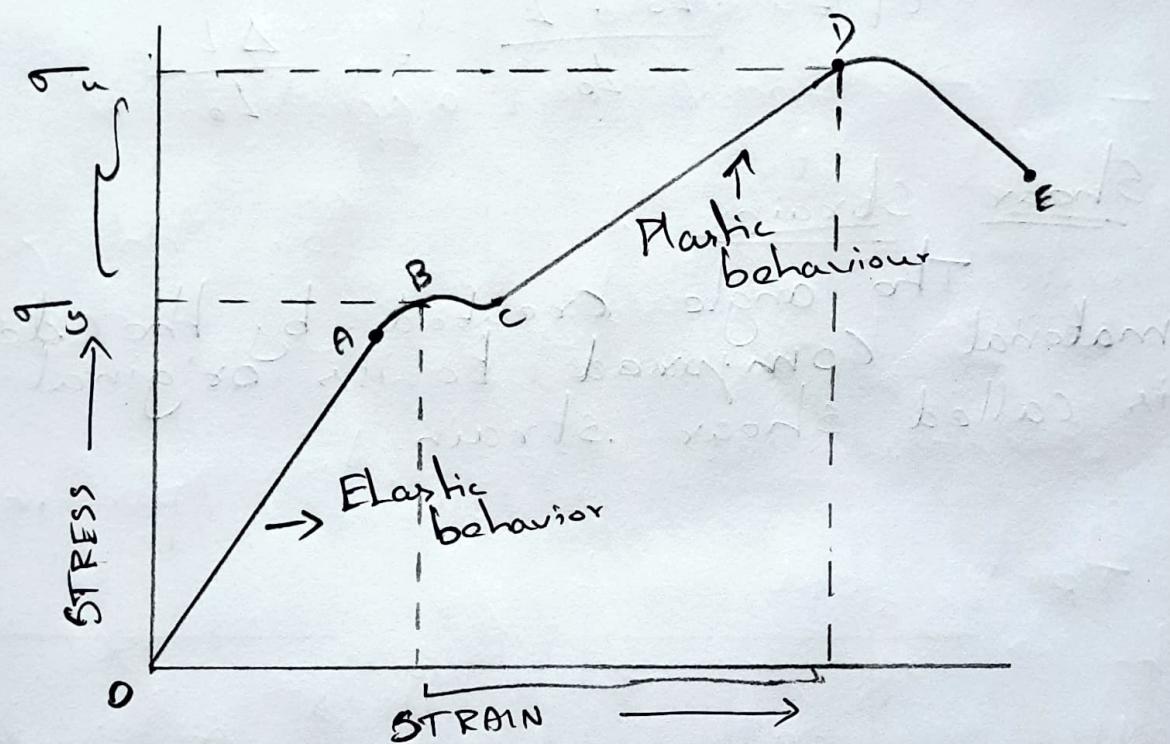
$L_0 \rightarrow$  Initial Length.

## DEFORMATION:

The change in shape or volume or both due to stress is called deformation.

If deformation due to stress is disappeared when the stress is removed it is called elastic strain.

⇒ RELATION BETWEEN STRESSES AND STRAIN.



- It indicates key properties of the material
- It shows how a given material deforms with increasing stress.

## Compressive Strain

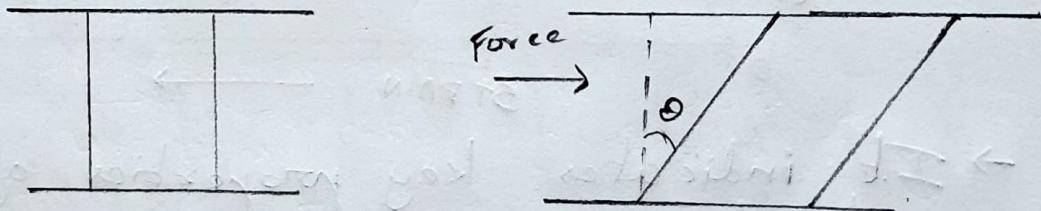
→ It is kind of opposite of tensile strain. Here when you apply stress and if the material compresses strain. Then it is called Compressive Strain.

→ It is the ratio of concentration to the original length.

$$\epsilon_t = \frac{L_0 - L}{L_0} = \frac{\Delta L}{L_0}$$

## Shear Strain

The angle created by the deformed material compared to its original position is called shear strain.



Bottom fixed point.

$$\tan \theta = \frac{\Delta L}{H} = \frac{\text{opp}}{\text{adj}}$$

- Region OA → Here, Stress - Strain Curve is straight and therefore Linear.
- Solid behaves as an elastic body in the region.
- When the applied stress is removed from the material it returns back to its original state due to its elasticity.
- If obeys Hooke's Law, which states that Stress is directly proportional to Strain

Stress  $\propto$  Strain

A → Proportional Limit.

- Region AB → The Line is not a straight line.

→ This does not obey Hooke's Law

→ But, the body returns to the original state when stress is removed.

→ Body still has elastic properties.

The strength is represented as "o".

→ This is the final Limit till there the body / material maintains elasticity and beyond this point, it won't return to its original state.

B → Elastic Limit / yield point.

Region BD → Here, even if there is a small change in stress, the strain increases rapidly.

- Consider a point 'C', here when the force is removed it doesn't go back to the form and the material has a "Permanent set".
- Then the elastic limit is crossed. permanent deformation of the material occurs.
- Exhibits plastic behaviour. (or) plastic deformation.

The strength is represented as " $\sigma_u$ ".

- Beyond the point 'D' any amount of force will cause the breaking of the material at point 'E'.

E → Fracture point.

- If D & E are close to each other, then the material is said to be "Brittle".
- It doesn't break, but prone to breakage.

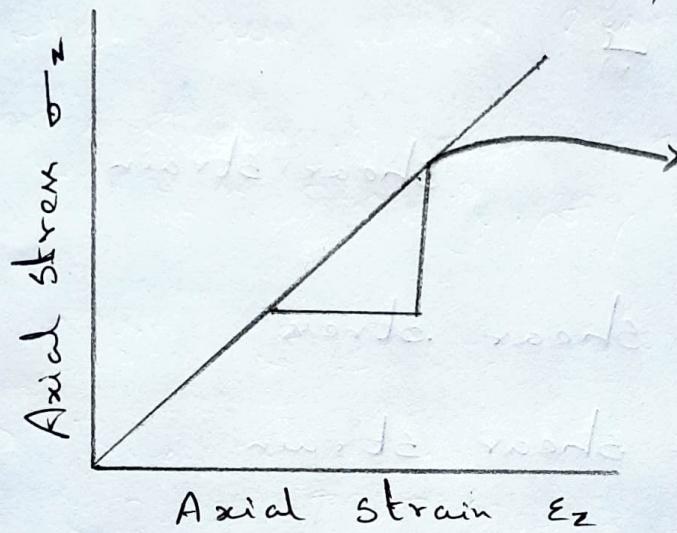
Equation for Stress-strain.

$$\boxed{\sigma = E \epsilon}$$

$E$  - proportionality constant, Young's Modulus  
 Different ways to express stress-strain in a geometrical way

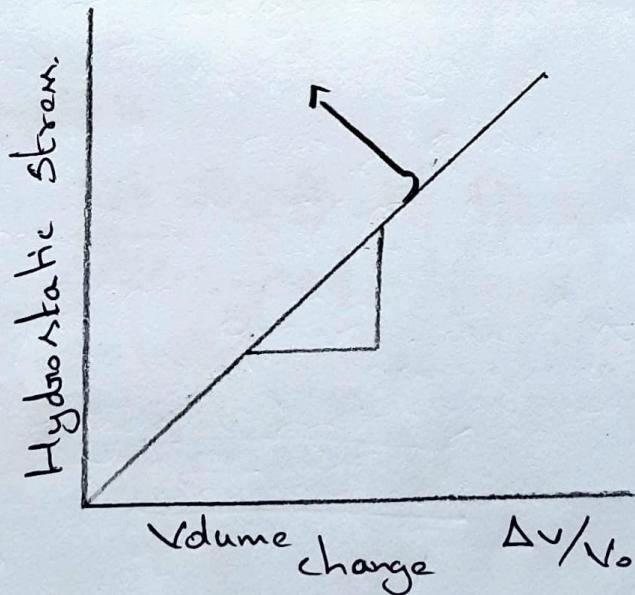
⇒ Young's MODULUS:

$$E = \sigma / \epsilon$$

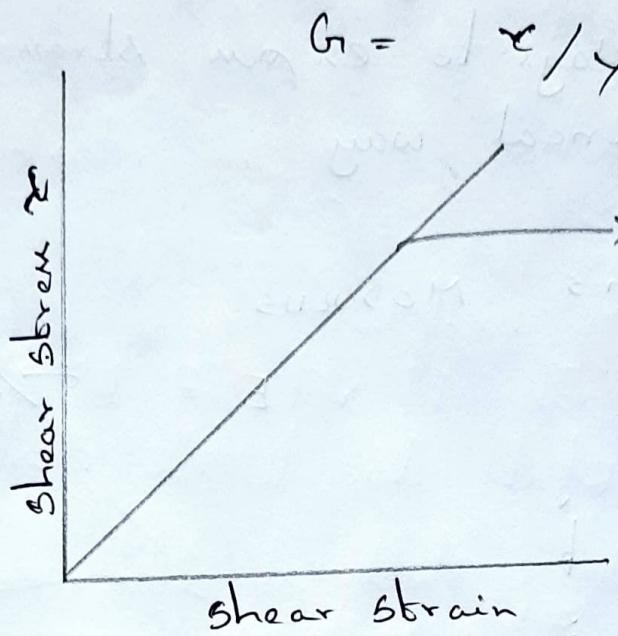


Bulk Modulus:

$$k = -\sigma_{hyd} / \Delta V / V_0$$



$\Rightarrow$  SHEAR MODULUS:



$\tau$  - shear stress

$\gamma$  - shear strain

$\Delta V/V_0$  - Fractional Volume expansions (or) Contraction

$\sigma$  - uni axial tensile (or) compressive stress.

## CREEP

→ Creep is the slow and progressive deformation of a material with time, under constant stress.

Stress = Force acting per unit area ( $F/A$ )

deformation = change in shape / Volume of a material due to stress.

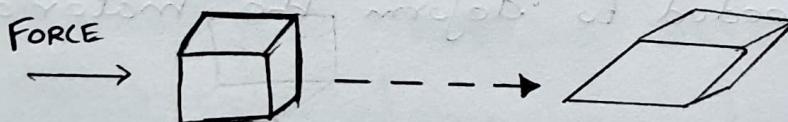
→ To test the creep of a material. We can carry out a creep test. keep the material at constant temperature and apply constant tensile stress. Then, measure how much the material deforms over time.

→ Creep is determined in:

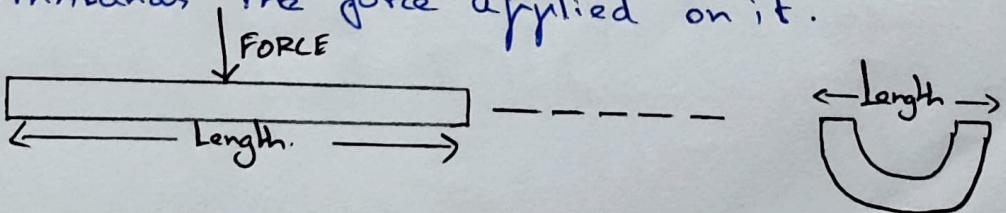
1) Compression: Reduction of Volume of material

due to stress.

2) Shear: Deformation of a material along a Plane.



3) Bending: change in Length of a material as it withstands the force applied on it.



## Stages of Creep

- Primary, Secondary, and Tertiary
- Creep is dependent on:
  - 1) Temperature (increase in temp, increase in creep)
  - 2) Material properties
  - 3) Applied Load
  - 4) Exposure time

Cold flow: Permanent deformation that increases with time under constant load (or) stress.

- Due to large external mechanical stress.

### Primary Creep:

- Strain rate is high, and decreases over time.

Strain Rate: Rate at which a material deforms.

- This occurs because the material has an increase in creep resistance, which means that the local stress needed to deform the material is more.

## Secondary Creep:

- Also called steady-state creep.
- Longest and most understood stage of creep.
- Strain rate nearly becomes constant as there is a balance between work hardening (the material becomes stronger) and annealing (reduce in hardness of the metal).
- The two opposing phenomenon balance each other out.

## Tertiary Creep:

- Acceleration of rate of deformation of the materials and possibility of failure (the material breaks).
- The strength of the material is lost in this stage, and the shape of the material is changed permanently.
- Strain rate increases exponentially due to the "necking phenomenon", which is the point of fracture of the material.
- Acceleration of creep in this stage eventually leads to failure.

## IMPACT STRENGTH :-

- \* Impact strength is defined as its ability to resist a sudden applied load (or) force.
- \* Its classical definition is defined as the "energy required to fracture a given volume of material."
- \* Materials having high impact strength are high density polythene, stainless steel, polythysul phone.
- \* Unit -  $J/cm^2$  (Joules/cubic centimeter)

## FACTORS AFFECTING IMPACT STRENGTH :-

### - TEMPERATURE :-

- \* Impact strength can be affected by temperature.
- \* It's true for carbon steels and other metal with a body centered cubic (BCC) or Hexagon crystal (HCP) structure.
- \* Metals such as steel, copper & aluminium which have Face cubic structure (FCC) strengthen slightly at low temperature.

### - MATERIALS THICKNESS :-

- \* When the thickness of the material increases, the impact strength decreases.

### - NOTCH RADIUS :-

- \* When the thickness of the material
- \* When the notch tip radius is small, impact strength is low.

## -MORPHOLOGY :-

\* Impact strength is universally proportional to the material crystallinity, amount of voids, molecular weight, etc,

## IMPACT TESTS :-

There are two types of impact tests,

\* Charpy impact test

\* Izod test

## Hardness:

→ Hardness is defined as resistance of a material to localized plastic deformation induced by either mechanical indentation or abrasion in general. Different materials differ in their hardness. For example metals, such as Titanium and Beryllium are harder, whereas sodium and metallic tin are softer.

→ Hardness depends upon ductility, elasticity, stiffness, plasticity, strain, strength, toughness, visco elasticity and viscosity.

Hardness is specified according to the following codes :

- 1) ASTM International (ASTM)
- 2) American National Standards Institute (ANSI)
- 3) International standards organization (ISO)

## Fatigue:

→ Fatigue is the phenomenon of initiation and propagation of cracks in a material due to cyclic loading. Once a fatigue crack is initiated, it grows with each loading cycle, thereby producing striations on some parts of fracture surface. The crack will continue to grow until reaches a critical size. This stage occurs when the stress intensity factor of the

Crack exceeds the fracture toughness of material which causes the complete fracture of structure.

→ In metal alloys when there are no macroscopic or microscopic discontinuities, the process starts with dislocation movements at the microscopic level, which eventually form persistent slip bands that become the nucleus of short cracks.

Materials, such as ceramics, plastics and composites experience fatigue-related failure.



## → Composite Materials:

- A composite material may be defined as a material system consisting of a mixture of 2 or more constituents, which are mutually insoluble, which differ in form or composition and form distinct phases.

Constituents of Composites

Matrix phase (or) Matrix Resin :  
continuous body constituent which encloses the composite

Dispersed phase (or) Reinforcement :  
constituent which provides high strength, rigidity and enhances the property

### • Matrix Phase :

#### Functions :

- i) Binds the fibres together
- ii) Protects individual fibres from surface damage, mechanical abrasion, or chemical reaction with environment
- iii) Separates individual fibres. Acts as a barrier to prevent crack propagation from fibre to fibre, so prevents total fracture.



## Matrix Materials :

(i) Polymer Matrix - Polymers are used due to light weight, desirable mechanical properties and easy processability.

Eg : Thermosetting Polymers and Thermoplastics

(ii) Metal-Matrix Material -

Lighter Metals : Eg - Aluminium, Magnesium, Titanium

used due to high strength, ductility, high temperature resistance

High Temperature Applications : Eg - Cobalt, Cobalt-Nickel Alloys

(iii) Ceramic Matrix Material - Used due to high melting point, good corrosion resistance and high comprehensive strength.

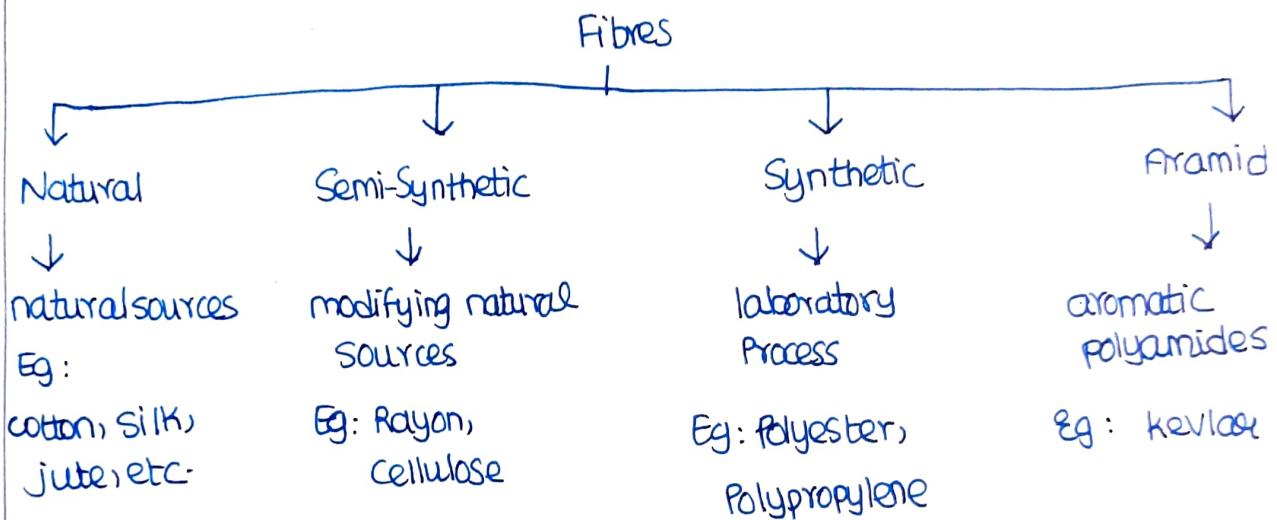
Eg : Alumina, Silica, Zirconia

## • Dispersed Phase:

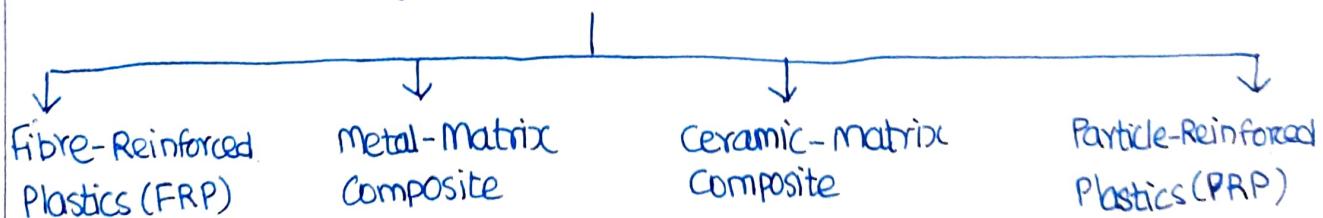
(i) Whiskers - Single crystal fibres having large length to diameter ratio. Strongest known materials. Whiskers of metals, oxides, carbides, etc. are used.



(ii) Fibres - long thin filament of any macromolecular substance, such as polymers, metal or ceramics with high length to diameter ratios (100:1). They possess high tensile strength and high stiffness. It lowers the density of composites.



• Types of Composite Materials





- Fibre Reinforced Plastics (FRP) :

Composites composed of fibres reinforced in polymer matrix. Fibre is the main source of strength, and polymer matrix glues them together.

Reinforcing Agents - Glass Carbon (graphite), quartz, steel, polyamides, asbestos, aluminium oxide, boron carbide, beryllium oxide

Polymer matrices - Polyethylene (PE), Polypropylene (PP), Polyethylene Terephthalate (PET), Polyester, Epoxy Resins

### Properties -

- They have high strength
- Reinforcing fibre prevents slip and crack propagation
- Possess high heat resistance
- Don't conduct electricity
- Corrosion resistant
- Light weight

### Uses -

- Cars & Aircraft manufacturing due to light weight
- Fibre glass composite is used to make cars & boats due to corrosion resistance.



- Metal Matrix Composite:

Preparation - MMC can be prepared by reinforcing 20-50% volume of silicon carbide, boron, boro silico carbide in the matrices of Aluminium, Magnesium, Copper & Titanium.

Eg - Carbon Fibre Aluminium Composites have better tensile strength, Properties - hardness & wear resistance than Aluminium.

(i) Thermal Stability

(ii) High strength, high stiffness, low specific weight

(iii) Can be used at higher temperatures

(iv) Can resist corrosion

(v) High impact strength

Uses -

(i) Automotive Industry

(ii) Turbine Engines & Combustion Chambers

(iii) Disc craft components

(iv) Space systems

(v) Tank armours

(vi) Biomedical industries



- (iii) Used to make rorotaries
- (iv) Graphite Epoxy composites are used to make bridges
- (v) Used in car leaf springs
- (vi) Building insulation, acoustic paneling, furnace, AC units
- (vii) Fibre glass ladders are used in electrical work
- (viii) Carbon reinforced polymer replaces aluminium sheets as it reduces weight (25%) and component (92%)

### Processing -

- (i) Filament winding: fibre is wound to form desired pattern cured after passing through resin & spinning on mandrel.
- (ii) Pultrusion: continuous fibre bundle is impregnated with thermosetting resin and pulled through a die and cured to produce final shape. Used to produce rods, tubes, beams, etc.
- (iii) Pre-Impragnation of fiber: pre-impragnate fiber with partially cured polymer resin. Calendering process is used.



- **Ceramic Matrix Composites:**

Consist of ceramic fibres embedded in ceramic matrix.

Carbon, Silicon Carbide, Alumina fibres were used. The matrix material is usually the same.

Eg: Carbon Fibre reinforced Silicon Carbide matrix composites have various properties - applications in automobile & aerospace industries.

- (i) High fracture & crack resistance
- (ii) Extremely high thermal shock resistance
- (iii) High load capability
- (iv) Good corrosion resistance at high temps.

### Applications:

- (i) Components for high temp gas turbines, such as combustion chambers and exhaust blades
- (ii) Components for nozzles, flame holders & hot gas ducts
- (iii) Components for slick bearings under heavy loads
- (iv) Used in brake disks
- (v) Heat shield systems for space vehicles



- Particle Reinforced Plastics (PRP):

Consists of particles of one material dispersed in a matrix of a second material. Particles may have any shape or size.

Preparation -

Prepared by dispersing small particles uniformly in the dispersed phase with heat treatment. This is called precipitation hardening or age hardening. Composite develops strength as it ages.

Eg : Al-Cu, Cu-Be, Mg-Al, Cu-Sn alloys

Properties -

- i) High strength & modulus
- ii) Low density & coefficient of thermal expansion
- iii) Excellent resistance to fatigue, creep & fatigue rupture
- iv) Corrosion & wear resistant

S.No	Particle	Matrix	Properties
1.	Concrete	Cement	Harder & stronger
2.	Oxide Coatings	Chromium	Good strength & shock resistance
3.	Carbide Coatings	Cobalt & Nickel	High surface hardness & abrasion resistance



## Types -

(i) Large Particle Composites : particle size is larger. Particle diameter is in the order of a few microns & they carry a major portion of the load. Eg - Automobile Tyres : Carbon black particles added in matrix of polyisobutylene polymer.

(ii) Dispersion Strengthened Composites : particles are small (10-100 nm). The composite is thus harder, stronger & resists matrix deformation. The matrix carries the major portion of the load.

## Applications -

- (i) Road Surfaces
- (ii) Hardness of cement increased by adding gravel as reinforcing filler.

Unit-5X-ray Photo Electron Spectroscopy (XPS)

X-ray photoelectron spectroscopy (XPS), also known as Electron spectroscopy for chemical Analysis (ESCA), is used to determine quantitative atomic composition and chemistry.

A sample is irradiated with monochromatic X-rays, resulting in the emission of photoelectrons whose energies are characteristic of the elements within the sampling volume (2 to 5 nm).

An XPS spectra is created by plotting the number of electrons versus their binding energy.

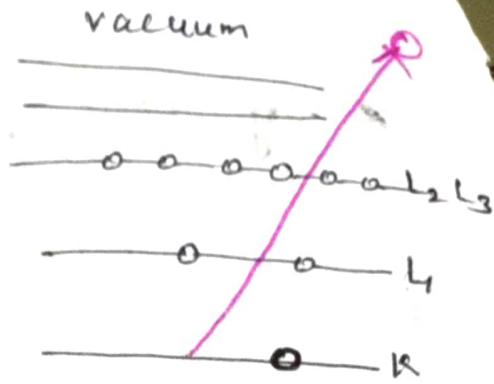
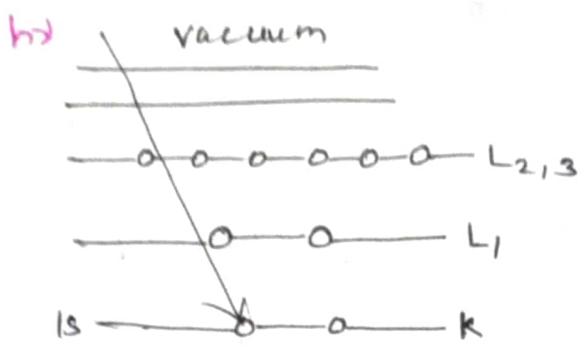
Kai Siegbahn developed XPS in the 1960s XPS, based on Einstein's photoelectric effect. (many materials emit electrons when light shines upon them)

An X-ray beam usually comprised of K-alpha X-rays is focused on the sample.

The absorption of incident X-rays results in the ejection of electrons.

The energy of the ejected electrons is measured by the detector. (Electron analyzer)

An electron energy analyzer produces an energy spectrum of intensity versus binding energy. Each prominent energy peak on the spectrum corresponds to a specific element.



$$E_K = h\nu - E_b - \phi_{sp}$$

$E_K$  = kinetic energy

$E_b$  = binding energy

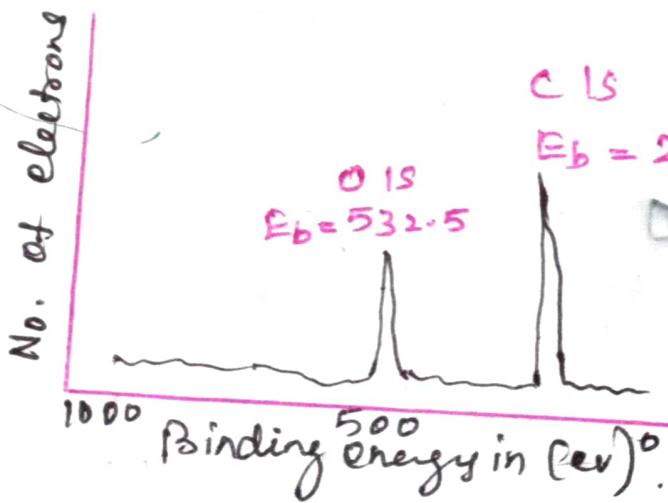
$h$  = Planck's constant

$\nu$  = frequency of x-rays

$\phi_{sp}$  = spectrometer work function.

- ⇒ Each atom has a ~~is~~ unique XPS spectra.
- ⇒ Spectrum:

In the spectrum given below, there is a peak at 284.6 electronvolts which corresponds to carbon, and a peak at 532.5 ev, which corresponds to oxygen. Therefore, we know that this sample contains carbon and oxygen.



Besides identifying elements in the specimen, the intensity of the peaks can also tell how much of each element is in the sample.

Each peak area is proportional to the number of atoms present in each element.

The specimen's chemical composition is obtained by calculating the respective contribution of each peak area.

By applying relative sensitivity factors and appropriately integrating peak areas, it can be determined that the sample below is 25% oxygen and 75% carbon.

By studying the energy of the carbon peak It can also be determined if the surface of this material corresponds to a C-O single bond (ethers, alcohols) or a much stronger C=O double bond (carboxylates, ketones).

Core level shifts are important in determining valence states in metals, transition metal oxides, and actinide materials.

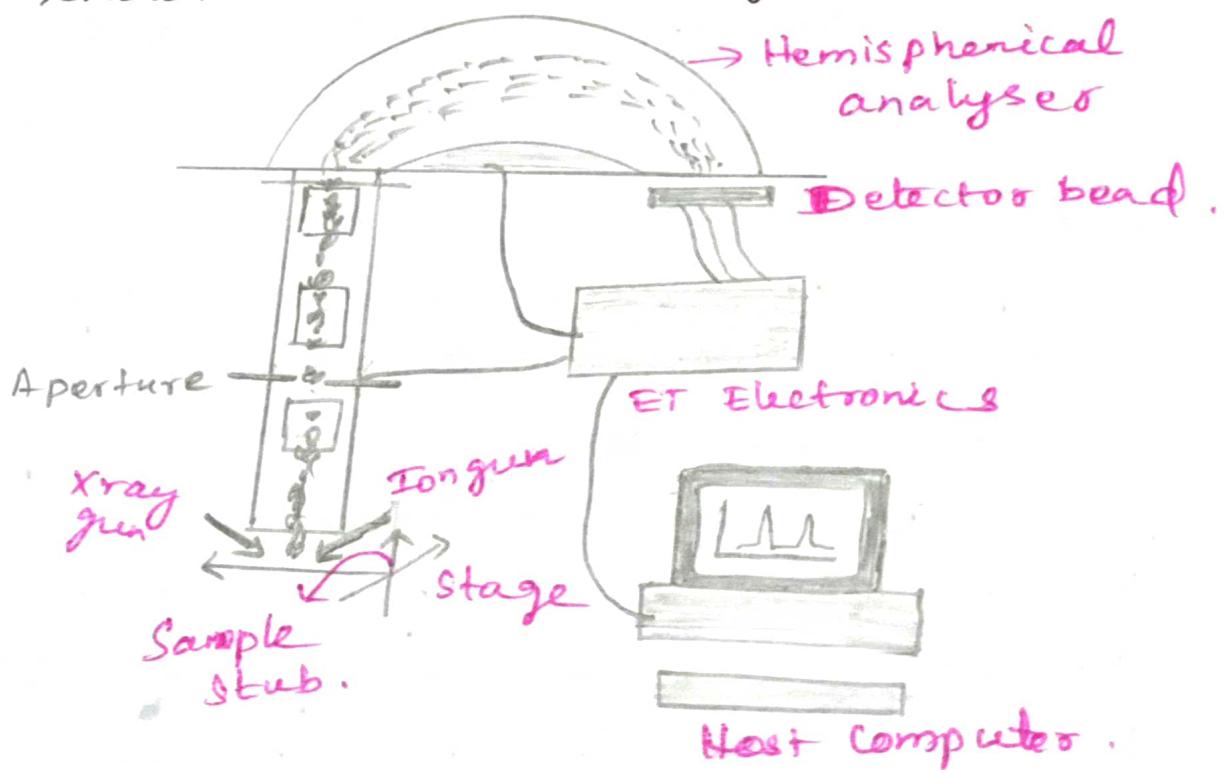
## XPS Instrumentation:

XPS is conducted in ultrahigh vacuum (UHV) conditions, around  $10^{-9}$  millibar (cmbar).

Atmospheric pressure is about 1 bar, which means that the number of atoms of gas in a UHV chamber is one-trillionth that of air per unit of volume.

The ambient atmosphere that a sample is exposed can change its properties.

The components of an XPS - instrument are shown in the following figure.



When X-rays are illuminated through the sample under study, it causes the ejection of electrons having different range of energies and directions.

These emitted electrons are collected by a set of electrostatic and or magnetic lens units and transferred through the apertures and focused onto the analyzer entrance slit.

Electrostatic fields within the hemispherical analyzer (HSA) are established in such a way that it allows electrons of a given energy to arrive at the detector slits and onto the detectors for recording.

### Applications:

1. XPS is primarily used for analysing the surface chemistry of a material.
2. It is used for the surface analysis of organic and inorganic materials.
3. It is used to study the surface analysis of copper.
4. It is used to study the fibre glass surfaces.
5. It is used to study the thin film oxide thickness measurements.
6. It is an important analytical tool in wood adhesive research area.
7. It is an unique approach in probing electronic structures.

Investigation of internal structure of a solid  
By X-ray diffraction - Bragg's law

William Hendry Bragg and Sir William Lawrence Bragg, English Physicists, Father and Son both worked in X-ray crystallography. The son Bragg formulated the fundamental equation for X-ray diffraction. They were jointly awarded Nobel prize in Physics in 1915.

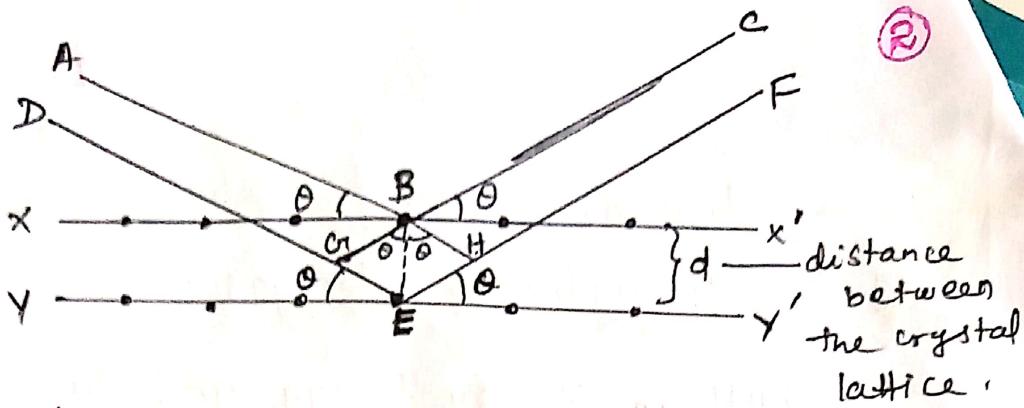
When a beam of X-ray is passed through a crystal, the impression is taken on a photographic plate, a pattern called Diffraction pattern is obtained.

By using Pattern, Bragg investigated the structure of the crystals of NaCl, KCl, etc..

Bragg devised a spectrometer for the measurement of intensity of X-ray beams.

The diffraction pattern thus obtained is used to study the crystal structure.

The Bragg's method for the study of the internal structure of crystals is based upon the Braggs equation, which may be derived as follows.



A crystal may be considered to be made up of a parallel equidistant atomic planes as represented by the line,  $xx'$ ,  $yy'$  etc.

Suppose a beam of X-rays is incident on the crystal at an angle  $\theta$ , a part of the beam, say for example, the ray  $AB$  is reflected at the point  $B'$  along the path  $BC$ . and the ray  $DE$  is reflected by the atom  $E$  along the path  $EF$  as shown in the figure.

Obviously, as compared to the ray  $AB$ , a ray like  $DE$  has to travel a longer distance equal to  $CREH$  in order to emerge out of the crystal where  $BC$  and  $BH$  are the perpendiculars drawn on the lines  $DE$  and  $EF$  respectively.

The reflected beams like  $BC$ ,  $EF$ , etc. then undergo interference with each other. If these reflected rays are in phase, they reinforce each other and the intensity of the reflected rays is maximum.

On the other hand, if the reflected rays are out of phase, the intensity of the reflected beam is very low.

(3)

(2)

If a photographic plate is placed to receive the reflected rays, a diffraction pattern is obtained.

Since the reflected rays BC and EF are in the phase, the extra distance GEH traversed by the ray DE, should be an integral multiple of the wavelength ( $\lambda$ ) of the X-rays.

$$\text{i.e. Distance } GEH = n\lambda \quad \text{--- (1)}$$

where 'n' is an integer i.e. 1, 2, 3, 4 etc ...

If 'd' is the distance between the successive atomic planes, it is obvious from the figure that

$$\Delta GBE, \sin \theta = \frac{GE}{BE}$$

$$GE = BE \sin \theta$$

$$\therefore [GE = d \sin \theta]$$

$$\text{and } \Delta EBH, \sin \theta = \frac{EH}{BE}$$

$$EH = BE \sin \theta$$

$$\therefore [EH = d \sin \theta]$$

$$\begin{aligned} \therefore \text{path difference} &= GE + EH \\ &= d \sin \theta + d \sin \theta \\ &= 2d \sin \theta \end{aligned}$$

$$\text{i.e. } GEH = 2d \sin \theta.$$

$$\therefore [2d \sin \theta = n\lambda] \text{ this is known as Bragg's law.}$$

## Miller indices:

Various planes of a crystal are to be characterized and indexed for a better understanding of the crystal.

Miller introduced a set of integers ( $hkl$ ) to specify a plane of the crystal. This set of three members ( $hkl$ ), is known as Miller's indices of a particular plane of a crystal.

"The Miller indices ( $hkl$ ) of a plane of a crystal are inversely proportional to the intercepts of that plane, on the three crystallographic axes".

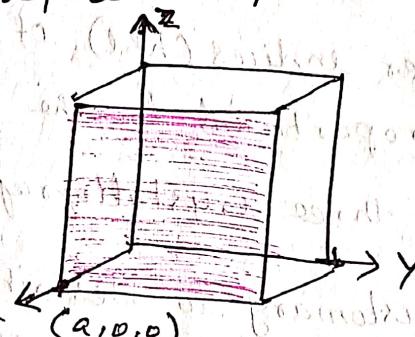
It is customary to describe crystal planes by a set of Miller indices. Miller indices of a plane of crystal can be obtained as follows:

- ① Find the intercepts on the crystal axes as multiples of the lattice constants  $a_1, b_2, c_3$ .
- ② Take reciprocals of these numbers and
- ③ Using an appropriate multiplier, convert the 1/intercept set to the smallest possible set of whole numbers.
- ④ Represent the above as a set of integers ( $hkl$ ) for a given plane of a crystal.

Miller Indices due of a plane of a crystal:

The following treatment of the procedure used to assign the Miller Indices is a simplified one and applied only to a Cubic Crystal System.

The procedure is most easily illustrated using an example so we will first consider the following surface or plane.



Step (i): Identify the intercepts on the x, y and z axes:

In this case, the intercept on the x-axis is at  $x = a$ , but the surface is parallel to the y and z-axes. Therefore, there is no intercept on these two axes but we shall consider the intercept to be at infinity ( $\infty$ ) for the special case where the plane is parallel to an axis.

The intercepts on the x, y and z axes are thus,

Intercepts:  $a, \infty$  and  $\infty$ .

Step 2: Specify the intercepts in fractional coordinates.

The coordinates are converted to fractional coordinates by dividing the respective cell dimensions, for example, a point  $(x, y, z)$  in a unit cell of dimensions  $a \times b \times c$  has fractional coordinates of  $(x/a, y/b, z/c)$ .

In the case of a cubic unit cell, each coordinate will simply be divided by the cubic cell constant,  $a$ . This gives fractional intercepts

$$\text{as } \left[ \frac{a}{a}, \frac{\infty}{a}, \frac{\infty}{a} \right] \text{ i.e. } [1, \infty, \infty]$$

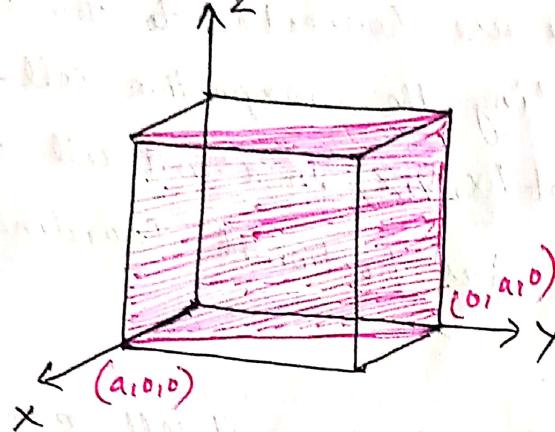
Step 3: Take the reciprocals of the fractional intercepts.

This final manipulation generates the Miller Indices which should then be specified without being separated by any commas or other symbols.

The Miller Indices are also enclosed within the standard brackets (...) when one is specifying a unique surface which is being considered here.

The reciprocals of 1 and  $\infty$  are 1 and 0, respectively, thus yielding Miller Indices: (100).

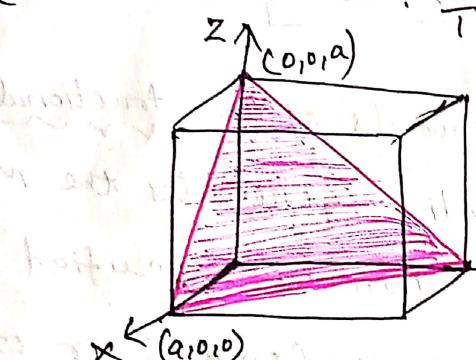
(1) Miller Indices for the following crystals:



- (1) Intercepts:  $a, a, \infty$

- (2) Fractional Intercepts:  $\alpha_a, \gamma_a, \beta_a$

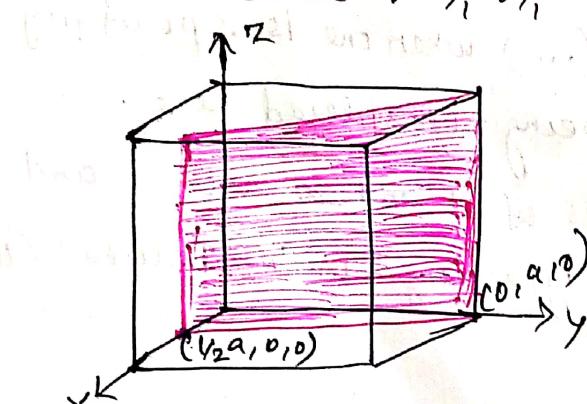
- $$(3) \text{ Miller indices: } \frac{1}{1}, \frac{1}{1}, \frac{1}{\infty} = (110)$$



- (1) Intercepts: a, a, a

- (2) Fractional Intercepts:  $g_a^a, g_a^a, g_a^a =$  ~~\_\_\_\_\_~~

- (8) Miller indices:  $\frac{1}{h_1} \frac{1}{h_2} \frac{1}{h_3} = (111)$



- (ii) Intercepts :  $y_2^a, a, \infty$

- ② Fractional intercepts:  $y_2 \frac{q}{a}, \frac{q}{a}, \frac{\infty}{a}$

- $$\textcircled{B} \quad \text{Miller Indices} = \frac{2}{1}, \frac{1}{1}, \frac{1}{2}$$

$$= (2 \mid 0)$$