MODULE - V

Plastic-: Thermosetting and thermoplastics. Ceramics: Types, structure, Mechanical properties, application Composite Materials: Agglomerated Materials: Cermets .Reinforced Materials: Reinforced Concrete. Fibre reinforced plastics, Properties of composites, Metal matrix composites, manufacturing procedure for fiber reinforced composite.

MODULE – V

Composite is a mixture of two or more distinct constituents or phases. However this definition is not sufficient, and three other criterias have to be satisfied to say a material is a composite.

1. Both constituents have to be present in reasonable proportion, say greater than 5%.
2. It is only when the constituent phases have different properties than the produced material.
3. A man made composite is usually produced by intimate mixing and combining constituents by various means. This will not classified as composite.

Composite can be classified on the basis of types of matrix and reinforcement used.

Matrix: The constituent that is continuous and is often but not always, present in greater quantity is known as matrix.

Reinforcement: This is the reinforcing phase as it enhances or reinforces the mechanical properties of matrix. In most cases reinforcement are stronger, harder and stiffer than matrix although there are some exceptions.

Based up on matrix, composite can be classified in to three types.

i. Polymer matrix composite (PMCs)
ii. Metal matrix composite (MMCs)
iii. Ceramic matrix composite (CMCs)

Based up on reinforcement, composite is of two types.

1. Fibre reinforced composite
2. Particulate reinfored composite.

Polymer Matrix Composite (PMCs)

Plastic : Thermosetting and Thermoplastic

Here most common matrix materials for composites are polymer. In general mechanical properties of polymers are inadequate for many structural purposes, particularly strength & stiffness. Therefore it need for proper reinforcement. Processing of PMCs need not involve high temp. & Pressure.

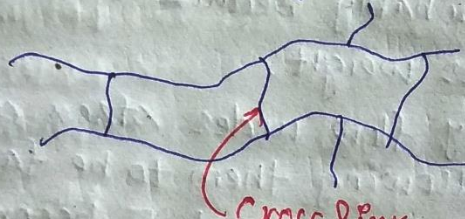
Polymers are of 3 types.

Polymers
- Thermosets
- Thermoplastics
- Rubber

Thermosettings

↳ Thermosetting polymers or thermosets are resins which readily cross-link during curing. Curing involves applications of heat and pressure or the addition of a catalyst known as Curing agent or hardener.

↳ Bonding in polymer chain is covalent type. These strong bonds of cross links have the effect of pulling the chains together. Thermosets cannot be reshaped by reheating; they just degrade. In some cases they just burn, but do not soften sufficiently for reshaping.



↳ Thermosets have various advantages because of crosslink, such as it can be used as higher temp., better creep properties, more resistant to chemical attack.

↳ Some examples of thermosets are epoxy, polyester, phenolics, polyimides etc.

↳ **Epoxy**

This is more expensive and viscous than polyesters. Curing temp. required 180°C. Shrinkage is low.

↳ **Polyester**

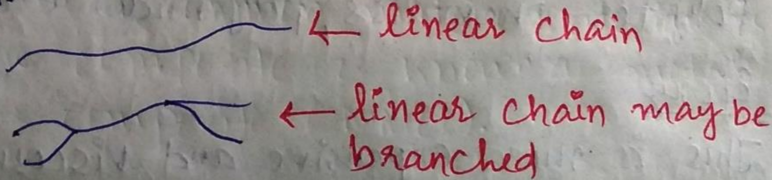
This start with low molecular wt. polymers. Polyesters are less brittle. It has high shrinkage.

↳ **Phenolics**

This is the oldest thermoset with low cost and good balance in properties. Good fire resistance is it's important property. It can be produced by reacting phenol and formaldehyde.

Thermoplastics

- Thermoplastics are the polymers which can be repeatedly heated, fabricated, cooled and consequently scrap may be recycled, though there is evidence that this slightly degrades properties probably because of a reduction in molecular weight.
- These readily flow under stress at elevated temp., so allowing them to be fabricated into required component & become solid, retain their shape wheon cooled to room temp.
- Example: Acrylic, nylon, polystyrene, poly ethylene, poly etheretherketone (PEEK), PTFE.
- These are linear polymers, they donot cross link.



- **Acrylics**

  These have good light transmission and resistance to weathering property. It can be used in lenses, transparent aircraft enclosures, drafting equipments etc.

- **Polyethylene**

  It has properties like chemically resistant, electrically insulating, tough & relatively low co-efficient of friction, low strength. so it can used in flexible bottles, toys, tumblers, battery partes, wrapping materials

Q: Write down some differences betn thermoplastics and thermosets. (2 or 6 marks)

Thermoplastics	Thermosets
1. These type of polymers can be repeatedly softened by heat and hardened by cooling.	1. These type of polymers once hardened and set, cannot be softened with high heat & pressure.
2. These are linear chained and some-times can be branched.	2. These are cross linked polymers.
3. It cannot be used at higher temp.	3. It can be used at high temp. without any damage.
4. It have less mechanical strength, soft, tough one.	4. It have good mechanical properties, creep, high strength etc.
5. It have intermolecular bond.	5. It have covalent bond.
6. These are less resistant to chemical attack.	6. These are high resistant to chemical attack.
7. These can be reshaped.	7. It cannot be reshaped.
8. Example: PEEK, PTFE, polyethylene, acrylics, nylon etc.	8. Example: Epoxy, Phenolics, polyimides etc.
9. Applications: Bearing, toys, photographic films, insulating coating, bottles, wrapping materials etc.	9. Applications: Electrical circuit, automobile body, helmets, etc.

Q: What do you mean by "Degree of Polymerization"? (2marks)

A: Degree of polymerization can be defined as the ratio of molecular weight of polymer to the molecular wt. of repeated 'mer' unit.

$$\text{Degree of polymerization} = \frac{\text{Molecular wt. of Polymer}}{\text{Molecular wt. of mer}}$$

$$= \frac{M_n}{M_o}$$

M_n = Avg. molecular wt. of polymer

M_o = Avg. molecular wt. of 'mer' unit

Metal Matrix Composites

- When most common matrix materials is metal then the composite is known as metal matrix composite (MMCs).
- In comparison with PMCs, MMCs have certain superior mechanical properties such as high strength, stiffness, greater shear and compressive strength, better temp. capabilities.
- There are some advantages of physical attributes of MMCs such as no significant moisture absorption properties, non-inflammability, high electrical and thermal conductivities, resistance to most radiation.

↳ Metal matrix composites can be prepared by solid state, liquid state processing, deposition, in-situ process.

↳ Most commercial application of MMCs are multifilamentary superconductors and aluminium reinforced with silicon carbide particles.

↳ The reinforcements used are may be fibre, particulate or whisker type.

↳ Other applications in aerospace such as blades, discs, combustion chamber, nozzle, heat exchangers, shafts, wings, structural blades, superconductor filaments, electrodes

Manufacturing Procedure for fiber reinforced Composite:-

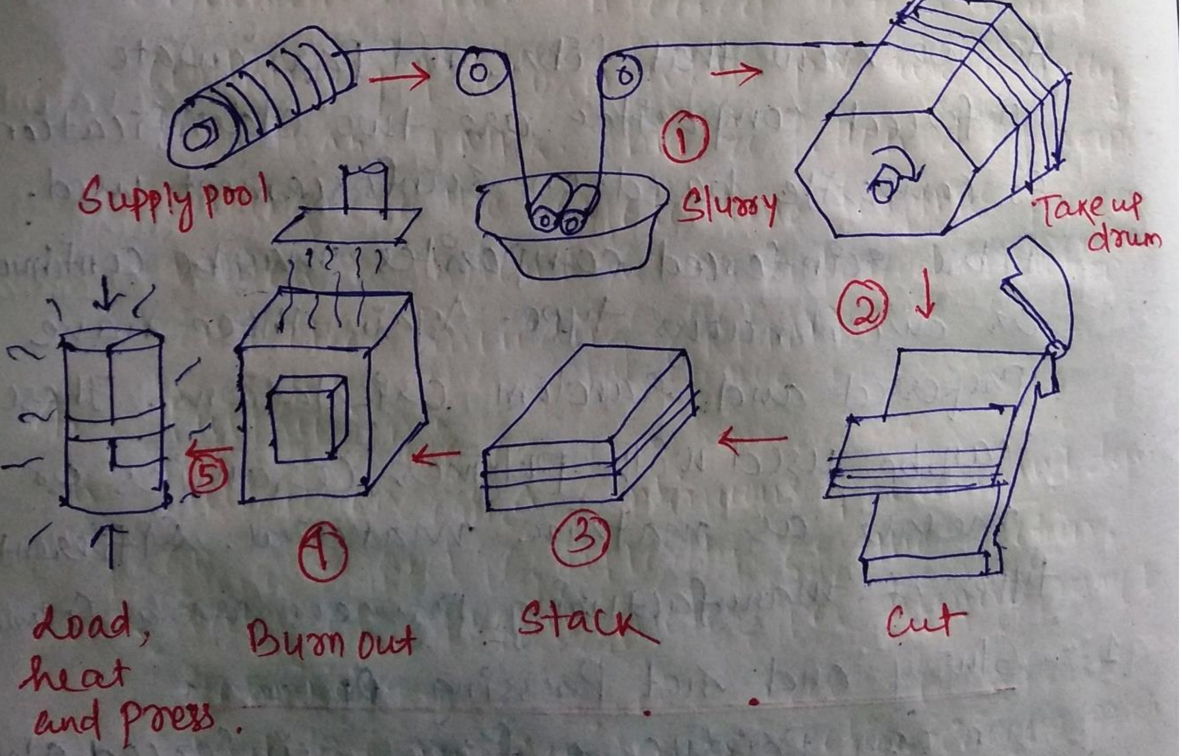
As we know that fibre and particulate reinforced composites are two classification of composite based on reinforcement used. Fibre reinforced composites may be continuous or discontinuous type. Again those have preferred and random orientations. These can be used with polymer, ceramics or metals as matrix material. Different types of manufacturing process are as follows.

1. Slurry and hot Pressing Process:

We can produce a fibre reinforced glass matrix composite. Here continuous fibre will be used and matrix is glass. Therefore it is one type of CMC.

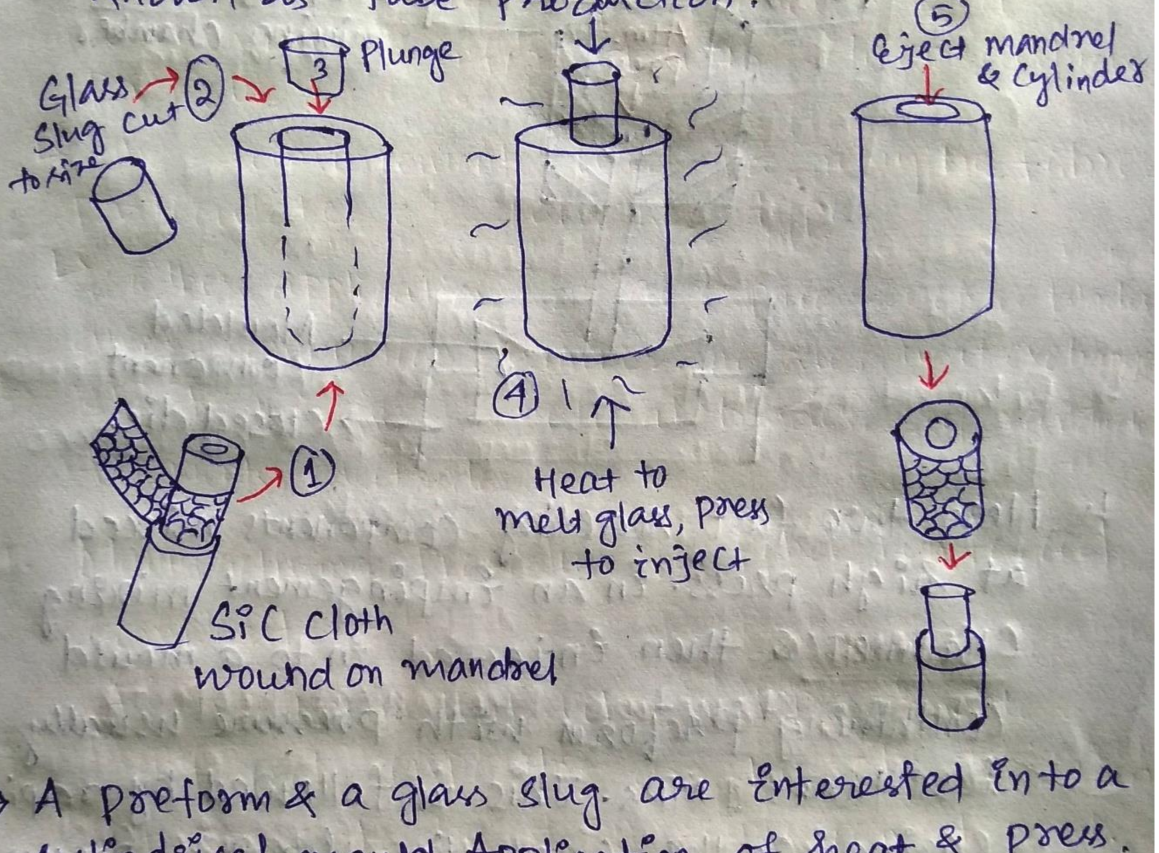
↳ Intimate mixing of continuous fibres and the glass is achieved by drawing bundles of fibres called tows, through a slurry of powdered glass in water and a water soluble resin binder. The tows impregnated with slurry, are wound on to a mandrel to form a monolayer tape. This tape is cut into plies which are stacked into required stacking sequence e.g. unidirectional or cross plied etc. prior to burnout of binder. This is hot pressed to consolidate the matrix.

↳ In glass ceramic composite production some crystallization occurs during the hot pressing stage but an additional treatment may be required to complete devitrification.



2. Matrix Transfer Moulding :

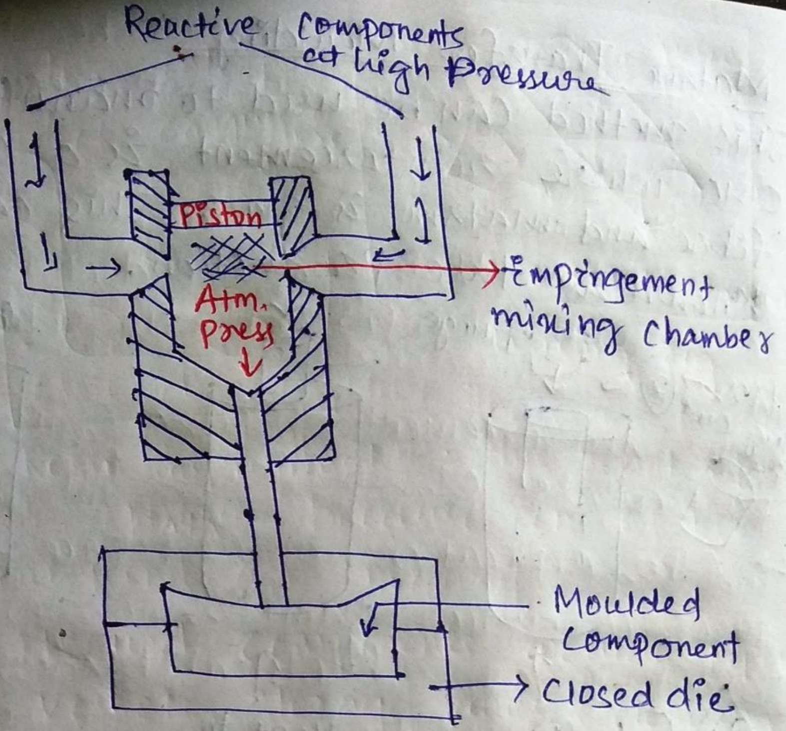
↳ This method can be used to manufacture a CMC where reinforcement is a continuous fibre and matrix is glass. This can also be known as tube production.



↳ A preform & a glass slug are interested into a cylindrical mould. Application of heat & press. forces the fluid glass into the pores in the prefo and after cooling the composite tube is ejecte from the mould.

3. Resin Transfer Moulding (RTM):

↳ In RTM low viscous resin is injected in to the closed mouldwing low press in the mould and that will be cured. In some cases rapid curing also occur. Those are known as reinforced reaction injection moulding (RRIM)

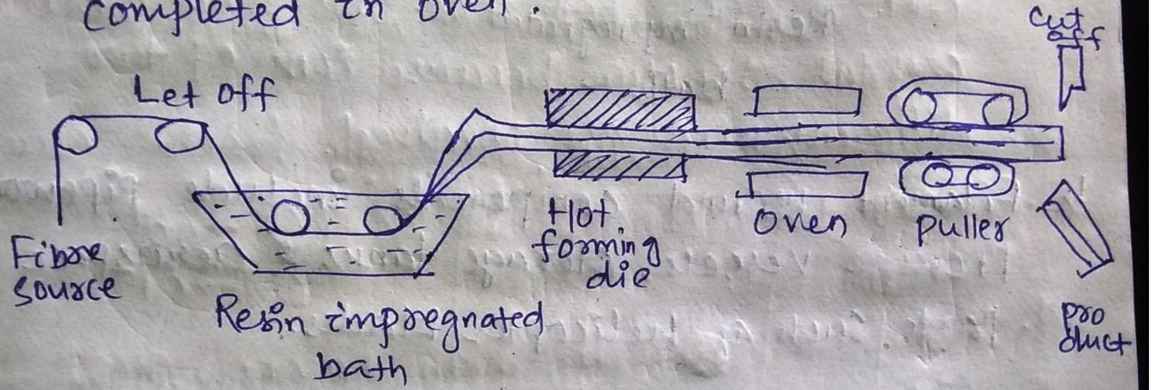


↳ Here two fast reacting components mixed at high press. in an impingement mixing chamber & then injected in to a mould containing preform with pressure usually less than 1 MPa. This is followed by rapid curing so the cycle time for this process which is known as reinforced reaction injection moulding (RRIM)

4. Pultrusion :

↳ Pultrusion is a continuous process and depending on size and complexity of the section, rates of several meters per minute may be achieved.

↳ Rods of uniform cross-section can be produced in long lengths by pultrusion. Continuous rovings of the reinforcement are impregnated with resin by being passed through a bath of resin. The impregnated ~~bath~~ fibres are then pulled through a heated die which compacts & shapes to the required profile in a manner reminiscent of extrusion. Since the process relies on a pulling action the name has been devised as pultrusion. Curing takes place in the heated die but is sometimes completed in oven.

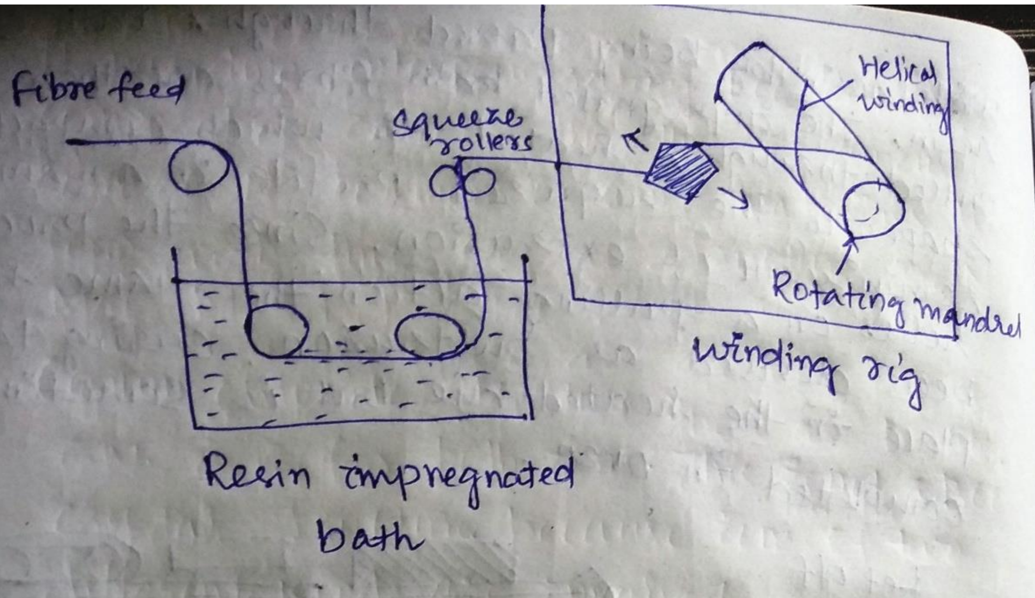


5. <u>Filament winding</u>

↳ In filament winding a continuous strand of impregnated fibres or tape, is wound on to a a mandrel. With computer controlled systems the impregnated fibres may be precisely laid down in a predetermined manner such that the fibres are oriented to obtain the desired mechanical performance from the finished component.

↳ A major advantage of filament winding process is that the rate of lay down of the impregnated reinforcement is high, typically in the range of 50-350kg/h.

↳ After the resin has cured, the mandrel is withdrawn & this imposes some limit on shape of the component.



↳ Filament wound components include pipework, Pressure vessels, storage tanks & aerospace parts such as helicopter blades.

CERAMICS

Types, Structure, Mechanical Property, Applications :-

↳ Ceramics materials are inorganic and nonmetallics. Most ceramics are compounds between metallic and nonmetallic elements for which the interatomic bonds are either totally ionic or predominantly ionic but having some covalent character.

↳ Hence the degree of ionic character is dependent up on electronegativities of the atoms. So we have to know about the co-ordination no. and cation-anion radius ratio.

Co-ordination no.	Cation-anion Radius ratio
2	< 0.155
3	0.155 - 0.225
4	0.225 - 0.414
6	0.414 - 0.732
8	0.732 - 1.0

Type and Crystal structure:

Some of the type and crystal structure of ceramics are as follows.

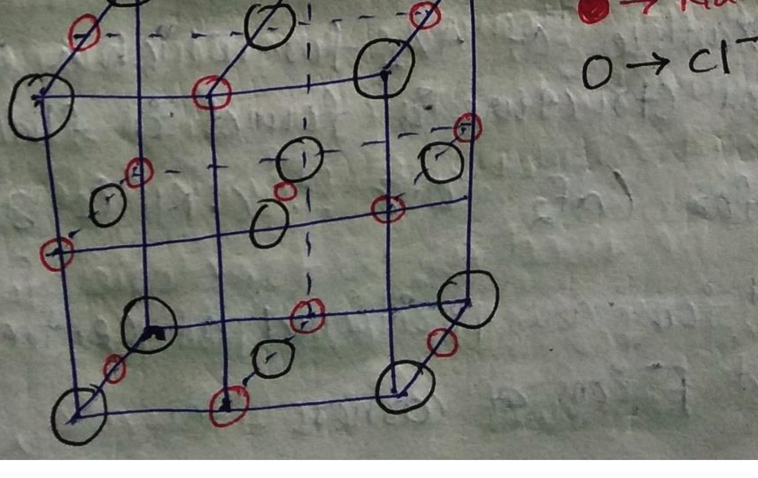
1. AX - type

Some common ceramic materials are those in which there are equal no. of cations and anions. These are often referred to as AX compounds, where A denotes cation and X as anion.

Rock Salt Structure :-

AX crystal structure is sodium chloride (NaCl). Co-ordination no. for both cations & anions is 6, $\therefore \frac{r_C}{r_A} = 0.414 - 0.732$

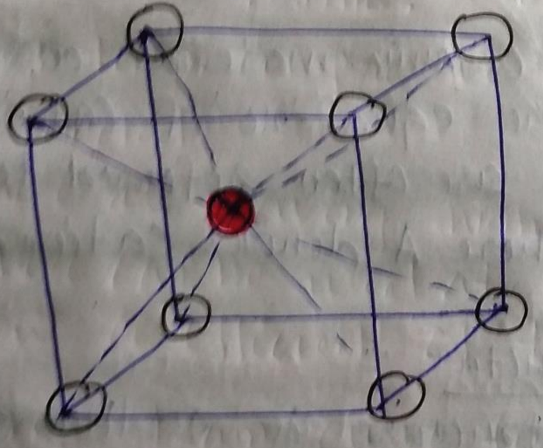
A unit cell of this structure is generated from an FCC.



...lattices, one composed of cations, the other of anions. Some of the common Ceramic materials that form with this crystal structures are NaCl, MgO, MnS, LiF & FeO.

Cesium chloride structure:

C.N. is 8 for both ions. This is not a BCC crystal structure because ions of two different kinds are involved.



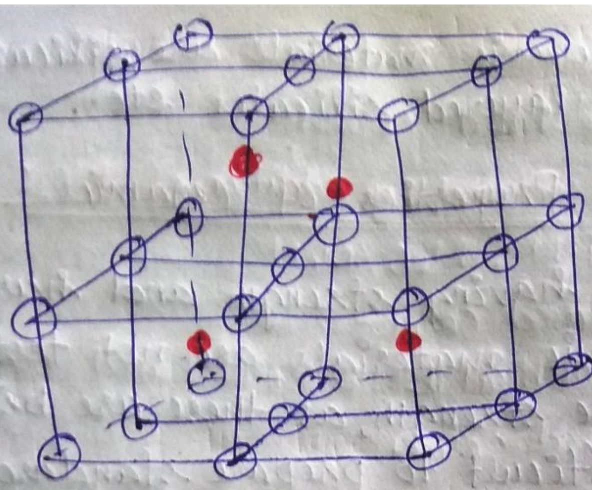
2. **AmXp - Type Crystal Structure:**

If the charges on the cations and anions are not the same, a compound can exist with the chemical formula AmXp where m and/or $p \neq 1$.

An example of AX_2 for which a common crystal structure is found in fluorite (CaF_2)

$\frac{r_C}{r_A}$ for $CaF_2 = 0.8$ ∴ C.N. is 8.

Ca^{2+} ions are positioned at centres of cube and F^- ions at corners.



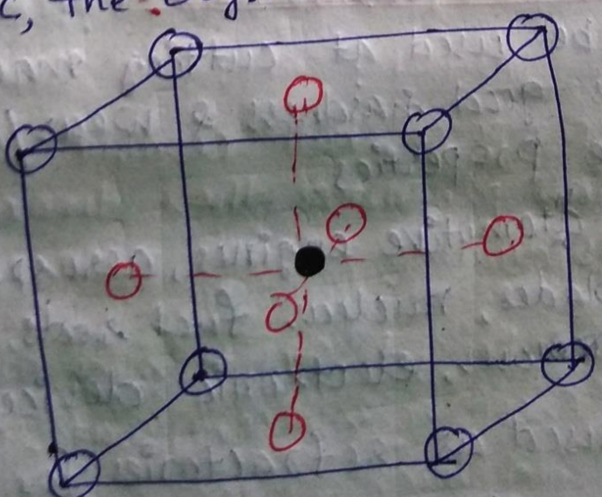
● → Ca^{2+}

○ → F^-

3. **$A_mB_nX_p$ - type Crystal Structure.**

It is also possible for ceramic compounds to have more than one type of cation; for two types of cation (Represented by A & B), their chemical formula may be designated as $A_mB_nX_p$.

2marks Example is Barium titanate ($BaTiO_3$) having Ba^{2+}, Ti^{4+} cations & O^{2-} anions. At temp. above 120°C, the crystal structure is cubic.



○ → Ba^{2+} ions situated at all corners.

○ → O^{2-} located at centre of each six faces.

Ti^{4+} → Cube centre

Some other ceramic materials are silicate, silica glass, layered silicates etc.

Mechanical Properties of ceramics

1. These are having strength and hardness. But ceramic materials are not tested for tensile strength, as these are brittle, it is difficult to prepare standard specimen.
2. These are brittle. So brittle fracture occur.
3. High temp. compressive creep tests are conducted.
4. These are having high hardness, good wear resistance.
5. These can be used at high temp. It have low co-efficient of thermal expansion.
6. Stress-strain curve for ceramics show a linear relationship.

Applications of ceramics:

1. These can be used at cutting machines, as it has good hardness & wear/abrasion resistance properties.
2. Used at automotive engines, aerospace turbine blades, nuclear fuel rods, light weight armour, electronic devices.
3. Can be used as refractories for furnaces.
4. Used for structural purposes.
5. Can be used as whitewares, basins, tiles etc.

Composite Materials:-

Agglomerated Materials: Cermet

- As composite is a combination of matrix and reinforcement, it can be produced using metal, nonmetals, ceramics and polymers. So, some are agglomerated materials and some are reinforced materials.

Agglomerated materials:

- Agglomeration is a process that bind macro-scopic particles binds together to form an integrated mass to serve a useful purpose.
- In industries fine particles present, that cause material loss along with some health hazardous issues. So, they are agglomerated using some binder and produce brick, sinter product.
- In composite, agglomerated materials bind macroscopic particles in to a solid mass, so that load can transferred between matrix and reinforcement. It enhances mechanical properties also.
- Example: Some carbides, nitrides etc.

Cermets

- Cermets are composite materials composed of ceramics (cer) and metals (met). It consists of both properties of ceramics and metals, which can be obtained from either one material.

Types of Cermets:

1. Carbonitride based Cermets
   Generally produced by addition of Mo_2C
   Ex: TiC/TiN; MoC/MoN
2. Nitride based Cermet
   Ex: TiN, cubical BN & ZrN based cermets
3. Boride based cermet
   Ex: CrB-Mo, CrB-Cr, CrB-Ni, combination of ZrB_2/SiC excellent corrosion resistant

General Methods of Cermet Fabrication:

Various methods can be adopted for cermet fabrication.

1. Static cold pressing
2. Hydrostatic cold pressing
3. Powder metallurgy route (Powder rolling)
4. Warm extrusion (Long piece with uniform cross-section)
5. Hot isostatic pressing (Simple/complex shap

Advantages Of Cermets:

As Cermets composed of both ceramic and metal it delivers all properties these two constituent have individually.

- Ceramics give benefits such as high abrasion resistance, creep resistance, greater chemical stability and high refractoriness.
- Main disadvantage of ceramic part is brittleness.

↳ Metal part delivers ductility, high thermal conductivity, mechanical shock resistance but less resistant to higher temp.

Reinforced Materials

↳ Reinforcement plays a role in increasing the mechanical properties of a pure resin system, after reinforcing that material become composite material. The material that strengthen the existing material when added to it are called reinforced material.

↳ Ex: Concrete tends to fail in tension thats why we provide steel in it and then it is called reinforced cement concrete.
Reinforcing polymer matrix with fibres is called fibre reinforced Plastic, it is mainly used in marine, automotive, construction industry.

Reinforced Concrete

↳ Concrete comes from the Latin word 'Concretus' which means compact or condensed. Concrete is used in nearly every type of construction.
Traditionally, a concrete has been primarily composed of cement, water and aggregates (coarse / fine). Although aggregates make up the bulk of the mix, it is hardened cement paste that binds the aggregate together and contributes to strength of concrete.

↳ Concrete is not a homogeneous material, & it's strength & structural properties may vary greately depending up on it's ingredients & method of manufacture. However, concrete is normally treated in design as a homogeneous material. Steel reinforcements are often included to increase the tensile strength of concrete. Such concrete is known as reinforced cement concrete (RCC) or simply reinforced concrete (RC).

How to prepare Reinforced concrete (RC)??

RC can be prepared by using

i) Cement

It can be portland cement or normal cement that have limestone, silica, clay content. Sometimes blast furnace slag also used.

ii) Sand

iii) Aggregates

This may be coarse or fine. Chips, gravels, coarse or granular sand, fine sand may be used.

iv) Water

Excess water reduces strength whereas less water make the concrete nonworkable. So all elements should be added with accurate proportions. Water should not contain oil, acidic or alkaline elements with it.

v) Admixtures

These are added to enhance properties of RC. It may be chemical admixtures such as compounds of sodium and calcium nitrites, sulphites or carbides, or it may be mineral admixtures such as flyash and blast furnace slag.

Advantages and Disadvantages of RC:

1. It can be poured, moulded in to any shape varying from simple slabs, beams & columns to complicated shells & domes by using formwork.
2. The materials required for concrete (sand, gravel and water) are often locally available and are relatively inexpensive.
3. Low maintenance
4. Water and fire resistance
5. Good rigidity
6. Considerable compressive strength than other materials.
7. It is economical.
8. Low skilled labour required.

Disadvantages

1. Low tensile strength.

It has low t.s. which is about $1/10^{th}$ of it's compressive strength & hence cracks when subjected to tensile stresses. Reinforcements are therefore often provided in tension zones to carry tensile forces & to limit crack widths.

2. Requires forms & Shorings

3. Time dependent volume changes

Concrete undergoes drying shrinkage & if restrained, will result in cracking or deflection.

4. Variable properties

The properties of RC may widely vary due to variation in it's proportioning, mixing, pacing & curing.

5. CO_2 emission

Cement, commonly composed of calcium silicates, is produced by heating limestone & other ingredients to about 1480°C by burning fossil fuels & it accounds for about 5-7% of CO_2 emission globally.

Applications

RC has been used in a variety of applications such as building, bridges, roads & pavments dams, retaining walls, tunnels, arches, domes, shells, tanks, pipes, ~~[illegible]~~ chimneys, cooling tower, poles, etc.

Fibre Reinforced Plastics

↳ Polymer matrix composites are not have high amount of strength, stiffness, not used at high temp. and have malleable properties. Hence to enhance it's mechanical properties, these are reinforced with other materials.
Reinforcing polymer matrix with fibres is known as fibre reinforced Plastics (FRP).

↳ The fibres are usually glass, carbon, aramid, etc. Glass fiber reinforced plastics (GRP) are a composite material made of a polymer matrix reinforced with fibers.

↳ FRP composites are anisotropic whereas steel and aluminium are isotropic. Therefore their properties are directional, meaning the best mechanical properties are in the dirn of fibre replacement. These materials have a high ratio of strength to density, exceptional corrosion resistance & convenient electrical, magnetic & thermal properties.

↳ The primary function of fibre reinforcement is to carry the load along the length of fibre & to provide strength & stiffness in one direction. It replaces metallic materials in many structural applications where load carrying capacity is important.

↳ FRP are produced by match moulding, resin transfer moulding (RTM), filament winding, pultrusion, vacuum assisted resin injection etc.

↳ FRP are composites used in almost every type of advanced engineering structures with their ranging from aircraft, heli-copters and spacecraft through boats, Ships and offshore platforms & to automobiles, sports goods, Chemical processing equipment etc.

Properties of Composites

1. High Strength to weight ratio
2. Resistance to chemicals
3. electrical insulating properties
4. Thermal insulating properties (not for PMCs)
5. High fatigue resistance
6. High impact strength
7. corrosion resistance
8. High tensile and compressive strength