MSc Bio materials Lect 5

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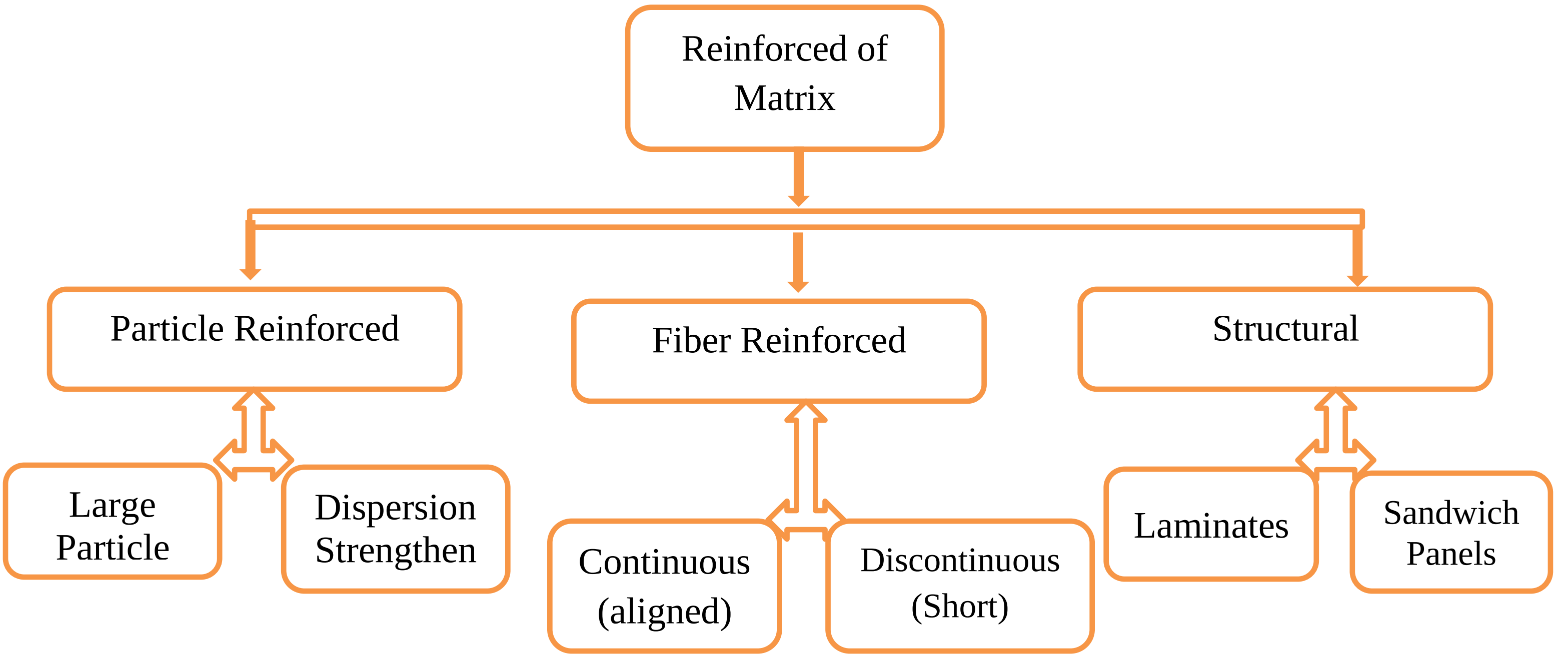
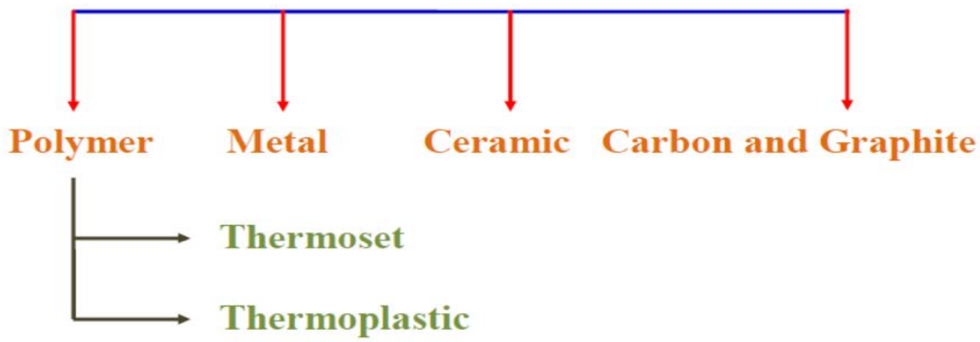
Composite Biomaterials

Composite materials

By definition, a composite is a combination of two materials in which one of the materials, called the reinforcing phase, is in the form of fibers, sheets, or particles, and is embedded in the other materials called the matrix phase. The reinforcing material and the matrix material can be metal, ceramic, or polymer. Composites typically have a fiber or particle phase that is stiffer and stronger than the continuous matrix phase and serve as the principal load carrying members.



Based on the type of matrix material:



Types of Fibres

1. Advanced Fibres: Fibres possessing high stiffness and strength

a) Glass b) Carbon c) Organic d) Ceramic

E glass: high strength S2 glass: high strength, modulus and stability under extreme temperature, corrosive environment R glass: enhanced mechanical properties C glass: resists corrosion in an acid environment D glass: dielectric properties

The composite materials is Enhanced desired properties :

• Strength • Stiffness • Toughness • Corrosion resistance • Wear resistance • Reduced weight • Fatigue life • Thermal/Electrical insulation and conductivity • Acoustic insulation • Energy dissipation • cost, ……………………..

2. Natural Fibres:

a) Animal fibres : Silk , Wool , Spider silk , Camel hair
b) Vegetable fibres : Cotton , Jute , Bamboo , Sisal , Banana , Flax
c) Mineral fibres i) Asbestos ii) Basalt iii) Mineral wool iv) Glass wool

What are the functions of a reinforcement?

1. Contribute desired properties

2. Load carrying

What are the functions of a matrix?

1. Holds the fibres together 2. Protects the fibres from environment 3. Protects the fibres from abrasion (with each other) 4. Helps to maintain the distribution of fibres 5. Distributes the loads evenly between fibres 6. Enhances some of the properties of the resulting material and structural component component (that fibre alone is not able to impart) impart).

Fabrication Processes of Fibrous Composites

• More than 50 processes depending upon the fiber and matrix type and nature

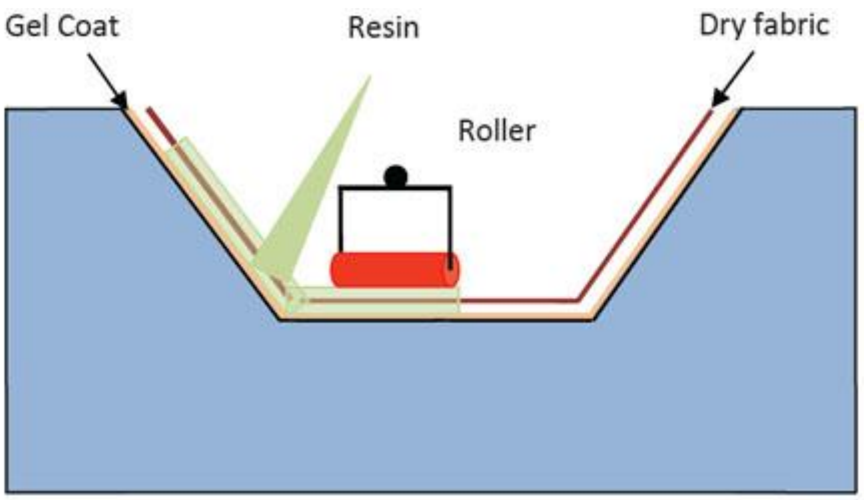
•Wet/Hand Lay-Up

• Spray Lay-Up

• Vacuum Bagging

Hand lay up

Hand lay-up is an open molding method suitable for making a wide variety of composites products from very small to very large. Production volume per mold is low; however, it is feasible to produce substantial production quantities using multiple molds. Hand lay-up is the simplest composites molding method, offering low cost tooling, simple processing, and a wide range of part sizes. Design changes are readily made. There is a minimum investment in equipment. With skilled operators, good production rates and consistent quality are obtainable.



Spray Lay Up

Fibre is chopped in a hand-held gun and fed into a spray of catalysed resin directed at the mould. The deposited materials are left to cure under standard atmospheric conditions.

Main Advantages:

i) Widely used for many years.

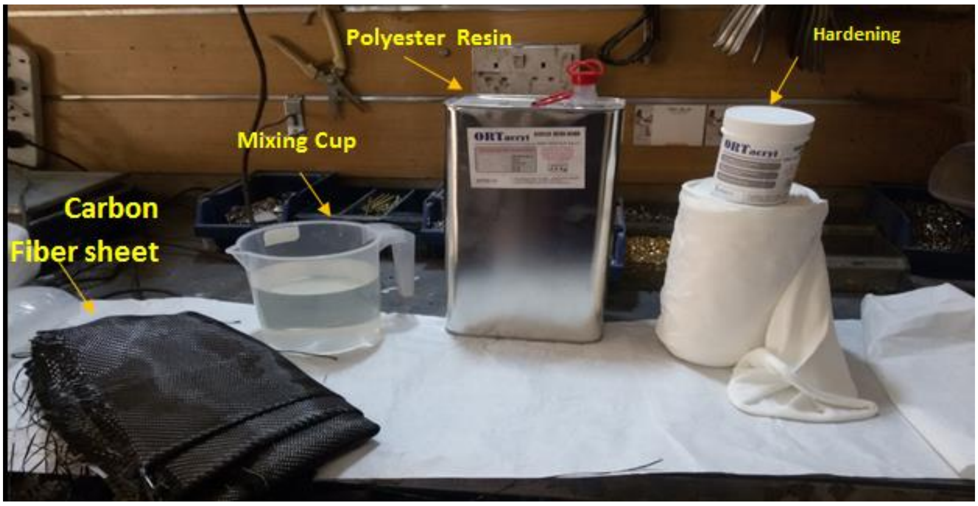
ii) Low cost way of quickly depositing fibre and resin.

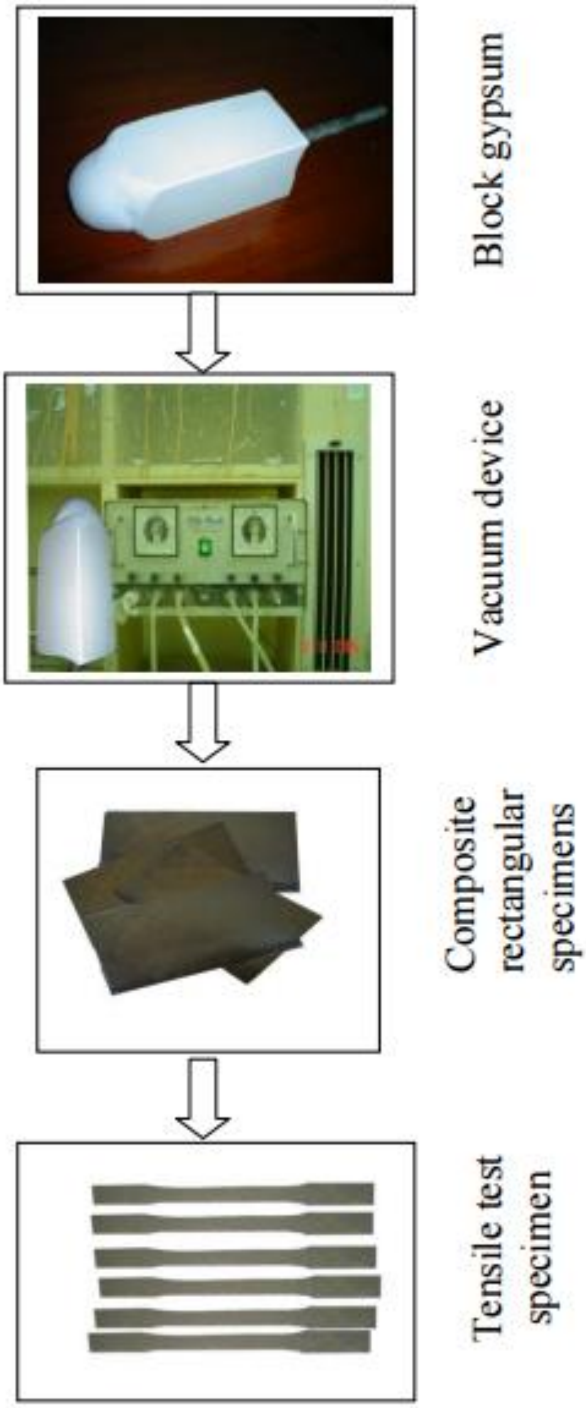
iii) Low cost tooling.

Main Disadvantages:

i) Laminates tend to be very resin-rich and therefore excessively heavy.
ii) Only short fibres are incorporated which severely limits the mechanical properties of the laminate.

Vacuum Bagging





The method of preparation of composite specimen is called vacuum method to prevent defects and cavities which follow by:

1-At first stage , the plate negative mold is mold ,in order to insure that surface of the final positive mold is smooth and the resulting specimens have no defect on their surface. The plate mold has dimensions of (30,20,10)cm .

2-Preparing the positive mold by pouring the plaster of Paris into the negative plate mold which contains steel beam and modified the block edges enhance the edge tear resistance.

3-Soaking the PVA (poly vinyl acetate) bag for 10 min and covering the positive block (poly vinyl acetate).

4-Addressing the required numbers of fibres .

5-Covering the block with a second PVA.

6-The resin with hardener are stirred slowly for (1-2) minutes. With using the vacuum device , polyester material is added and lets the composite to cure.

7-After the resin curing , a cubic composite material is obtained which it will be cut according to required dimensions of specimens.

Rule of Mixture:-

The properties of composites may be estimated by the application of simple rule of mixture theories .these rules can be used to estimate average composite mechanical and physical properties along different directions, which may depend on volume fraction or weight fraction. The density of the composite material can be calculated from the following rule.

Fibre Volume Fraction (Vf) = Volume of fibres/Volume of composite

Matrix Volume Fraction (Vm) = Volume of matrix/Volume of composite

$$\rho_c = \sum v_i \rho_i = v_1\rho_1 + v_2\rho_2 + \cdots \dots \dots \dots \dots v_n\rho_n \ \left(\frac{kg}{m3}\right)$$

Where:-

ρ_{c}: Density of the composite materials.

ρ_1, ρ_2, ρ_n: density of each element

v1, v2, vn: volume fraction of each element.

To calculate the volume fraction of each of fiber and matrix basis as follow:-

- In term of volume fraction:-

$v_f = \frac{vf}{vc} \times 100\%$

$V_m = \frac{vm}{vc} \times 100\%$

Where:-

V_f, V_m: *volume fraction of each of the fiber and matrix.*

vf, vm, vc: *the volume of each of the composite materials, matrix and fiber.*

- In term of weight fraction:-

Here it should be noted that:

$wf + wm = 1$

$V_f + V_m = 1$

Two mathematical expressions have been formulated for the dependence of the elastic modules on the volume fraction of the constituent phases for a two – phase composite .these rules of mixtures predict that the elastic modulus in the longitudinal direction is:-

$E_C = Ef\, Vf + Em\, Vm$

Also the modulus of elasticity in the lateral direction is:-

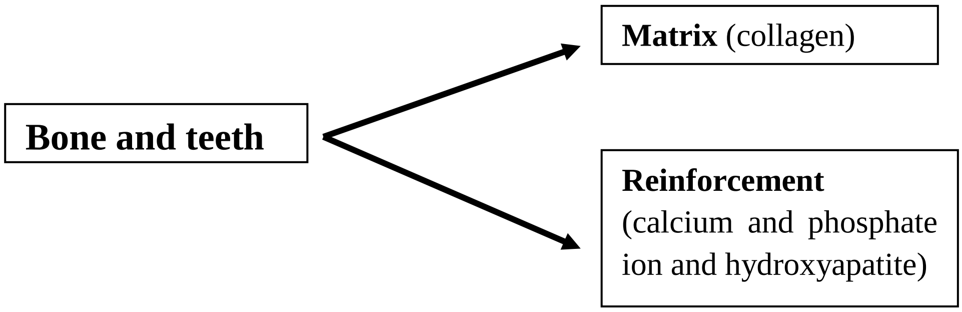
$E_C = \frac{Ef\, Em}{Ef\, Vm + Em Vf}$

Where *E*f is the fiber modulus, *V*f is the fiber volume percentage, *E*m is the matrix modulus, and *V*m is the matrix volume percentage .

Biocomposites

The term ‘Biocomposites’ refers to the composites that can be employed in bioengineering which are contain two or more distinct constituent materials or phases, on a scale larger than the atomic (macroscopic scale).

The bones, cartilage, tendons, skin, ligaments, teeth, etc. are natural composite structures in the human body.



These natural composite have anisotropic properties. The anisotropy of the elastic properties of the biological tissues has to be considered in the design criterion for implants made from composite biomaterials.

Natural composites have hierarchical structures particulate, porous and fibrous structural features which are seen on different micro-scales.

The amount, distribution, morphology and properties of structure components determine the final behaviour of resultant tissues or organs.

Some synthetic composites can be used to produce prosthesis able to simulate the tissues, to compromise with their mechanical behavior and to restore the functions of the damaged tissues.

The factors that are largely affected to the properties of biomedical composites represent by: shape, size, distribution, volume fraction, bioactivity properties of the reinforcement or matrix phases; in addition to molecular weight of matrix and interfacial situation between the reinforcement and matrix.

Applications of composite biomaterials:

1- Dental filling composites (like polymer matrix filled with barium glass or silica).
2- Joint prostheses fixation (like bone particles or carbon fibers reinforced methylmethacrylate bone cement and ultra-high molecular weight polyethylene.
3- Orthopedic implants with porous surface.
4- Rubber used in catheters, rubber gloves are usually filled with very fine particles of silica to improve the properties of rubber.

Advantages of bio-composite:

1- Good durability in small to moderate restorations.
2- High biocompatibility.
3- Moderate resistance to wear and corrosion.
4- Inert.
5- Provides high fracture toughness.
6- Resistance against fatigue failure.
7- These biocomposites are highly compatible with modern diagnostic methods, magnetic resonance imaging (MRI).
8- Their combinations of low density/weight that make them ideal materials for such applications.
9- Polymer composites offer low modulus but high strength, suitable for some orthopedic application.
10- For dentistry, composites offer better aesthetic characteristic & more economical than metal.

Disadvantages of bio- composite:

1- Each constituent of the composite be biocompatible.
2- Water absorption in case of polymer composite causes a reduction in stiffness and others mechanical properties.

3- The degradation of interface between components is also problem which must be avoided.

Particulate Ceramic Biocomposite

The ceramic particulate reinforcement has led to the choice of more materials for implant applications that include ***ceramic/metal, ceramic/polymer, ceramic/ceramic*** composites.

Metals face corrosion related problems and ceramic coatings on metallic implants degrade as the time progress during long time applications.

Biocompatible polymers have been mostly applied as matrix for composite materials associated with ceramic fillers in tissue engineering. Although ceramics are generally stiff and brittle materials, polymers are known to be flexible and exhibit low mechanical strength and stiffness. Composites aim to combine the properties of both materials for medical applications.

Ceramic/ceramic composites enjoy superiority due to similarity with bone materials, exhibiting biocompatibility and are able to be shaped into definite size.

The composites made of bioinert and bioactive ceramics are produced to achieve two important features, bioactivity and mechanical strength. Like composite of alumina ceramic can form composites with hydroxyapatite that are bioactive with high strength that it can form osteointegration with bone.

The stress in one of the components of a two phase composite can be calculated from the equation:

$$\boldsymbol{\sigma} = \frac{\mathbf{E_1 * P}}{\mathbf{E_1 * A_1 + E_2 * A_2}}$$

where *P* is the total load on the structure and *E* and *A* are the Young's modulus and cross-sectional area of each of the components. The applied load can be assumed to be the same before and after implantation, therefore the following equations for the stress in the bone in the two configurations:

$$\sigma_{bone} = \frac{E_{bone} * P}{E_{bone} * A_{bone}} = \frac{P}{A_{bone}}$$

Post implantation: $$\sigma = \frac{E_{bone} * P}{E_{bone} * A_{bone} + E_{implant} * A_{implant}}$$

Implants with a higher modulus and a larger cross-sectional area will shield the bone.

Fibrous Composites

The fibers incorporated in a polymer matrix is to increase stiffness, strength, fatigue life, and other properties.

Fibers are mechanically more effective in achieving of stiff, strong composite than are particles. For that reason, carbon fibers have been incorporated in the high-density polyethylene used in total knee replacements. Also the reason of the use of ultra high molecular weight polyethylene (UHMWPE) in these implants is due to providing adequate wear resistance.

Fibers have also been incorporated into polymethyl methacrylate (PMMA) bone cement on an experimental basis. Significant improvements in mechanical properties can be achieved. Metal wires have been used as macroscopic “fibers” to reinforce PMMA cement used in spinal stabilization surgery.

Biocomposites are used for:

hard tissue applications, including prosthetic socket, dental applications (tooth , archwire and denture), external fixator, bone plate, total hip replacement, artificial leg, composite screws and pins and cages for spinal.

Soft tissue applications including artificial tendon, ligament, and artificial arteries (vascular graft).

Bounds of properties of biocomposites

$$E_{II} = E_i * V_i + E_m * (1 - V_i)$$ In the longitudinal direction of fibers (upper bound)

$$\frac{1}{E_{\perp}} = \frac{V_i}{E_i} + \frac{(1-V_i)}{E_m}$$ In the lateral direction of fibers (lower bound)

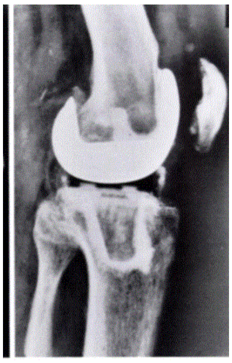
Porous materials

Porous materials have a high ratio of surface area to volume.

Porous materials, are used as implants in hard tissue, (like hydroxyapetite), and used in soft tissue applications include polyurethane, polyamide, and polyester.

Examples of composite biomaterials

Bone repair and joint



Dental filling composite

Artificial Legs