MATERIALS & APPLICATIONS:

Applications :is one of important factors to selection materials :

1- Medical application (Biomaterials)

Biomaterial is a material intended to interface with biological systems to evaluate, treat, augment or replace any tissue, organ or function of the body. **Also biomaterial** is a nonviable material used in a (medical) device, intended to interact with biological systems (bio functionality).

Biocompatibility: is acceptance of an artificial implant by the surrounding tissues and by the body as a whole.

The following table represents the time scale over which the host is exposed to materials and devices:

material	Contact time
Syringe needle	1-2 s
Tongue depressor	10 s
Contact lens	12 hr- 30 days
Bone screw/plate	3-12 months
Total hip replacement	10-15 yrs
Intraocular lens	30 + yrs

The goal of using biomaterials:

Assisting in

1- Regenerating

2- Repairing

3- Supporting

4- Replacing

Selection parameters for biomaterials:

A biomaterial used for implant should possess some important properties in order to long-term usage in the body without rejection. The design and selection of biomaterials depend on different properties which are:

1- **Host Response:** is defined as the response of the host organism (local or systemic) to the implanted material or device.
2- **Toxicology :** A biomaterial should not be toxic, unless it is specifically engineered for such requirements .
3- **Biodegradability**: It is simply a phenomenon that natural and synthetic biomaterials are capable of decomposing in the body conditions without leaving any harmful substances behind.
4- **Bio functionality:** the bio functionality is playing a specific function in physical and mechanical terms. The material must satisfy its design requirements in service:
   - *Load transmission and stress distribution (e.g. bone replacement).*
   - *Articulation to allow movement (e.g. artificial knee joint).*
   - *Control of blood and fluid flow (e.g. artificial heart).*
   - *Space filling (e.g. cosmetic surgery).*
   - *Electrical stimuli (e.g. pacemaker).*
   - *Light transmission (e.g. implanted lenses).*
   - *Sound transmission (e.g. cochlear implant).*
5- **Healing**
6- **High corrosion resistance:** corrosion can reduce the life of implant device.
7- **High wear resistance:**

8- **Long fatigue life:**

9- **Mechanical, Physical and Performance Requirements**

10- **Ethics**

The classes of Bio materials

A- Bio metals

B- Bio Polymers

C- Bio ceramics

D- Composite biomaterials

C- Smart biomaterials

A- Metallic Biomaterials

Advantages and disadvantages of metallic Biomaterials:

Advantages

- High strength.
- High hardness.
- Fatigue and impact resistance.
- Wear resistance.
- Easy fabrication.
- Easy to sterilize.
- Shape memory.
- inert

Disadvantages

- High modulus.
- High corrosion.
- Metal ion sensitivity and toxicity.
- High density

In general metallic biomaterials can be grouped in the following categories:

- Stainless steels.
- Co-based alloys.
- Titanium-based alloys.
- Specialty metallic alloys.

STAINLESS STEELS

Stainless steel (type **316** or **316L)** is stronger and more resistant to corrosion than the vanadium steel.

(Co Cr) ALLOYS

The corrosion products of CoCrMo are more toxic than those of stainless steel 316L , but it has the highest strength/wear resistance .

Ti ALLOYS

Ti-based alloys such as (Ti_6Al_4V) are finding ever-increasing applications in biomaterials due to their excellent mechanical, physical and biological performance.

The Ti6Al4V alloy has some **disadvantages**: its elastic modulus, although low, is 4 to 6 times greater than that of cortical bone and has low wear resistance that is a problem in articulations surfaces. Also, (V) can cause toxicity, neuropathy and adverse tissue reactions, and (Al) ions from the alloy might cause long-term Alzheimer diseases.

Bio metals applications

Table : Implants division and type of metals used

Division	Example of implants	Type of metal
Cardiovascular	Stent Artificial valve	316L SS; CoCrMo; Ti Ti6Al4V
Orthopedics	Bone fixation (plate, screw, pin) Artificial joints	316L SS; Ti; Ti6Al4V CoCrMo; Ti6Al4V; Ti6Al7Nb
Dentistry	Orthodontic wire Filling	316L SS; CoCrMo; TiNi; TiMo AgSn(Cu) amalgam, Au
Craniofacial	Plate and screw	316L SS; CoCrMo; Ti; Ti6Al4V
Otorhinology	Artificial eardrum	316L SS

B- Polymeric Biomaterials

Polymeric biomaterials are chosen for different applications depending on their properties and are widely used in clinical applications such as dentistry, ophthalmology, orthopedics, cardiology, drug delivery, sutures, plastic and reconstructive surgery, extracorporeal devices, encapsulates and tissue engineering.

What is the mean of polymer degradation?

Polymer degradation is a change in the properties—tensile strength, color, shape, etc.of a polymer or polymer-based product under the influence of one or more environmental factors such as heat, light or chemicals such as acids, alkalis and some salts.

Biodegradation is the disintegration of materials by bacteria, fungi, or other biological means. Although often conflated, biodegradable is distinct in meaning from compostable. While biodegradable simply means to be consumed by microorganisms,

Advantages of biopolymers

- Not expensive.
- Easy to fabricate.
- Resistance to corrosion.
- Wide range of physical, chemical and mechanical properties.
- Low density (low weight).
- May be biodegradable.
- Good biocompatibility.
- Low coefficients of friction.

Disadvantages of Polymers

- Low mechanical strength.
- Thermo sensitive.
- Easily degradable.
- Absorb water & proteins etc.
- Wear & breakdown.
- Bacterial colonization because of their organic structure.

In general the biopolymer may be:

Thermoplastic biopolymer: materials that can be shaped more than once.

(Used as replacements for blood vessels).

Thermosetting biopolymer: materials that can only be shaped once

(Used in dental devices, and orthopedics such as hip replacements.).

Elastomer biopolymer: material that is elastic. If moderately deformed, the elastomer will return to its original shape. Used as catheters.

1-Polyvinylchloride (PVC)

The PVC is an amorphous. PVC sheets are used in blood and solution storage bags. PVC tubing is commonly used in intravenous (IV), dialysis devices, catheters, and cannulae (i.e. mostly for external use).

2- Polyethylene (PE)

a- HDPE is used in pharmaceutical bottles.

b- LDPE is used for flexible container applications, disposable for packaging.

c- LLDPE(linear low density) is employed in bags due to its excellent puncture resistance.

d- UHMWPE(**Ultra-high-molecular-weight polyethylene)**Also known as **high-modulus polyethylene**, (**HMPE**), or **high-performance polyethylene** (**HPPE**),

3- Polypropylene (PP)

PP is used to make disposable syringes, packaging for devices, solutions, and drugs, suture, artificial vascular grafts, etc.

4- Polymethylmetacrylate (PMMA)

PMMA is used broadly in medical applications such as a blood pump and reservoir, membranes for blood dialyzer, and in vitro diagnostics. It is also found in contact lenses and implantable ocular lenses due to excellent optical properties, dentures, and maxillofacial prostheses due to good physical and coloring properties, and bone cement for joint prostheses fixation.

5- Polystyrene (PS)

PS is commonly used in roller bottles.

6- Polyesters

It's used for artificial vascular graft, sutures as a soft matrix or coating.

7- Polyurethanes

They are widely used to coat implants and arteries, cardiovascular prostheses, catheters and pacemakers (as insulator).

8- polycarbonates

Polycarbonates have found their applications in the heart/lung assist devices, food packaging**.**

9- Polyethylene terephthalate, called Dacron,

Is used in the artificial heart valves. Dacron is used because tissue will grow through a polymer mesh. Dacron is used for large arteries.

Polymers In Specific Applications

Application	Properties and design requirements	Polymers used
Dental	• stability and corrosion resistance. • strength and fatigue resistance. • good adhesion/integration with tissue. • low allergenicity.	PMMA polyamides
Ophthalmic	• gel or film forming ability • oxygen permeability	polyacrylamide PHEMA (polyhydroxyethylmethacrylate)
Orthopedic	• strength and fatigue resistance. • good integration with bones and muscles	PE, PMMA
Cardiovascular	• fatigue resistance, lubricity, • sterilizability	silicones, Teflon, poly(urethanes)
Drug delivery	• compatibility with drug, biodegradability	silicones, HEMA
Sutures	• good tensile strength, strength retention • flexibility, knot retention.	PP, nylon

C- Ceramic Biomaterials

Ceramics used for repair and replacement of diseased and damaged parts of skeletal systems are named as bio ceramics.

Ceramics are used as parts of the musculoskeletal system, dental and orthopedic implants, orbital and middle ear implants, cardiac valves, coatings to improve the biocompatibility of metallic implants.

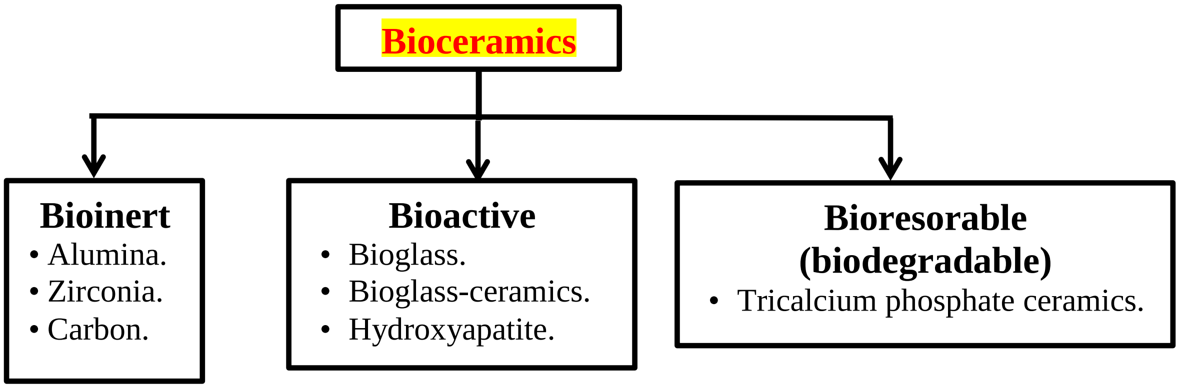
Advantages to Bioceramics:

- High biocompatibility.
- Less stress shielding.
- No disease transmission.
- High compression strength.
- Wear & corrosion resistance.
- Low thermal and electrical conductivity.
- Can be highly polished.
- Unlimited material supply.
- Inert.

Disadvantage of Bioceramics:

- Brittleness.
- Low strength in tension.
- Low fracture toughness.
- High modulus (mismatched with bone).
- Difficult to fabricate.
- Susceptibility to microcracks.
- Not resilient.

The three basic types of bioceramics are:



Bioinert high strength ceramics maintain their physical and mechanical properties while it is in the host. The term bioinert refers to any material that once placed in the human body has minimal interaction with its surrounding tissue. Examples of these are *Alumina* (Al_2O_3), *zirconia* (ZrO_2) and *carbon*. It is used for knee prostheses and dental implants …..etc.

Bioactive, ceramics which form direct chemical bonding with bone or even with soft tissues in biological medium (i.e. forms a very strong biological bond after a small amount of dissolution), examples of these are *bioglass*, *glass ceramics*, *calcium phosphates* and *hydroxyapatite*.

Applications:

- Bone void filler.
- Middle ear implants.
- Dental implants.

Biodegradable (bioresorbable) ceramics, as the name implies, degrade to implants in the host, bioresorbable refers to a material that placement within the human body which start to dissolve and slowly replaced by advanced tissue (such as bone)

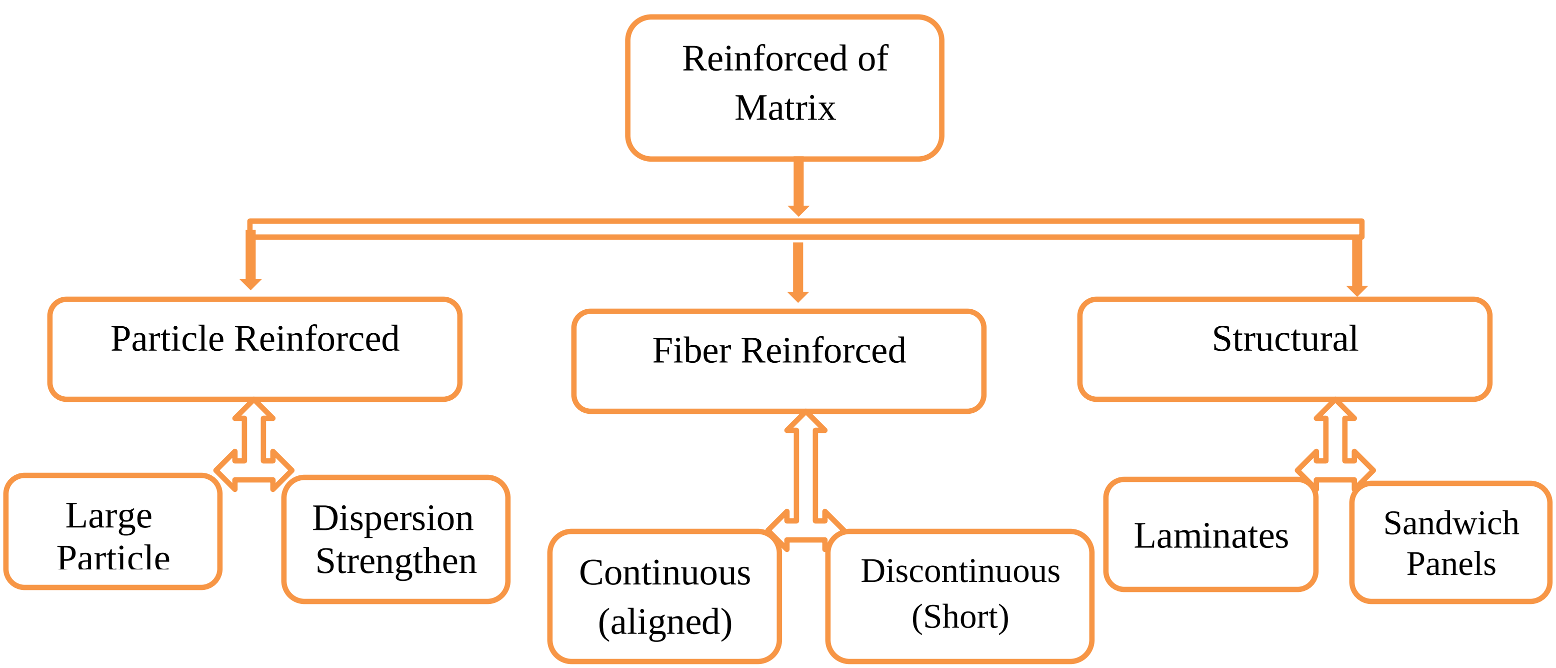
The biodegradable (resorbable) ceramics are used for applications such as

- Drug delivery systems.
- Repairing of damaged or diseased bone, bone loss,
- Filling spaced vacated by bone screws.
- Repairing herniated discs.
- Repairing of maxillofacial and dental defects.

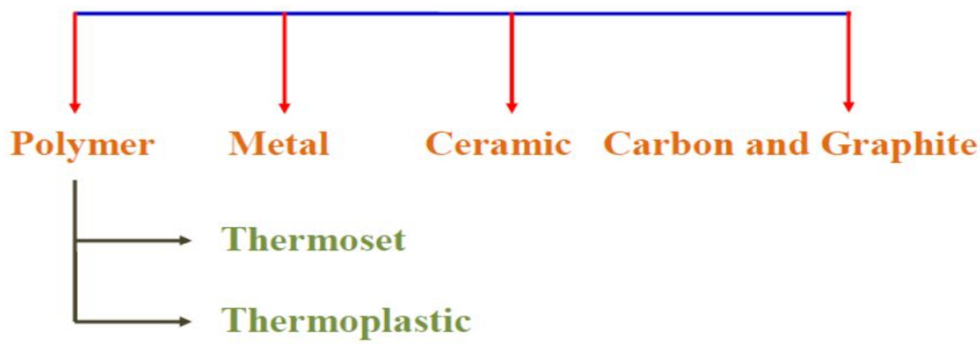
Composite Biomaterials

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

2. Natural Fibres:

a) Animal fibres i) Silk ii) Wool iii) Spider silk iv) Camel hair
b) Vegetable fibres a) Cotton b) Jute c) Bamboo d) Sisal e) Banana f) Hemp g) Sugarcane h) Coir i) Kenaf j) 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

3. Transfer the strength to matrix

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 fibre and matrix type and nature**
- **Wet/Hand Lay-Up**
- **Spray Lay-Up**
- **Vacuum Bagging**

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

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:-

$v_f = \frac{\rho c}{\rho f} Wf$

$V_m = \frac{\rho c}{\rho m} Wm$

Where:-

$\rho c, \rho f, \rho m =$ *The density of composite, fiber and matrix respectively.*

$wf, wm : the\ weight\ fraction\ of\ fiber \& matrix.$

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:-

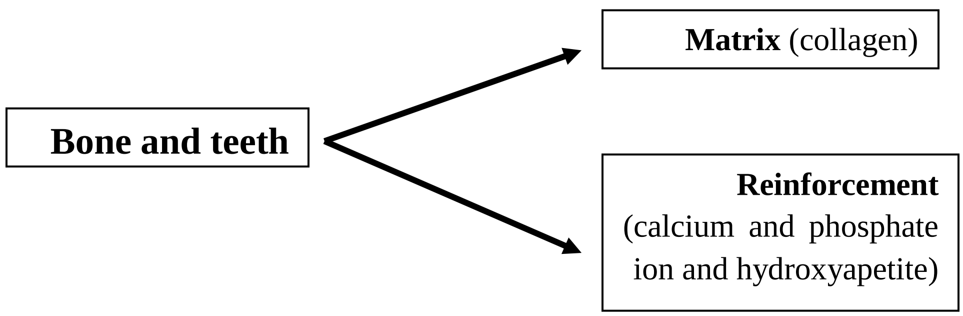
$E_C = \frac{Ef\,Em}{Ef\,Vm + Em\,Vf}$

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- Moderate resistance to wear and corrosion.
3- Inert.
4- Provides high fracture toughness.
5- Resistance against fatigue failure.
6- Their combinations of low density/weight that make them ideal materials for such applications.
7- Polymer composites offer low modulus but high strength, suitable for some orthopedic application.

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.

Examples of composite biomaterials