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2. Biomaterials

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2.1 Introduction to Biomaterials:

A material intented to interface with biological systems to evaluate, treat, augment or replace any tissue, organ or function of the body. **Metals, ceramics, plastic, glass, and even living cells and tissue** all can be used in creating a biomaterial. They can be reengineered into molded or machined parts, coatings, fibers, films, foams, and fabrics for use in biomedical products and devices.

A. Biomaterials:

- Polymeric biomaterials, Bioceramics, Metallic biomaterials, Hydrogels
- Biocomposite thin films,grafts,coatings, Biologically based (derived) biomaterials, Pyrolytic Carbon for long term medical implants
- Textured and Porous materials

B. Biocompatibility:

- Biocompatibility: The ability of a material to perform with an appropriate host response in a specific application.
- Host response: the reaction of a living system to the presence of a material eg. Resistance to blood clotting

Resistance to bacterial colonization

Normal uncomplicated healing

- Biocompatibility→ Tissue Engineering

2.2 Some Application of Biomaterials:

Application	Types of Materials
• **Skeletel system**	
• Joint replacement(Hip, knee)	Titanium , Stainless steel, PE
• Bone plate	Stainless steel, Co-Cr alloy
• Bone cement	PMMA (Polymethyl Methacrylate)
• Artificial tendon and ligament	Hydroxylapatie Teflon, Dacron
• Dental implant	Titanium, alumina, calcium phosphate

- **Cardiovascalar sysem**
- Blood vessel prosthesis — Dacron, Teflon, Polyurethane
- Heart valve — Reprocessed tissue, Stainless steel, Carbon
- Catheter — Silicone rubber, teflon, polyurethane
- **Organs**
- Artificial heart — Polyurethane
- Skin repair template — Silicone-collage composite
- Artificial kidney — Cellulose, polyacrylonitrile
- Heart-lung machine — Silicone rubber
- **Senses**
- Cochlear replacement — Platium electrodes
- Intraocular lens — PMMA, Silicone rubber, hydrogel
- Contact lens — Silicone-acrylate. Hydrogel
- Corneal bandage — Collagen, hydrogel

2.3 Leading Medical Device Company:

- Johnson & Johnson (www.jnj.com)
- Biomet INC (www.biomed.com)
- Strycker Howmedica Osteonics (www.osteonis.com)
- Sulzer Orthopedics Ltd (www.sulzerotho.com)
- Zimmer (www.zimmer.com)
- Merck & Co Inc (www.merck.com)
- Nobel biocare/AstraZeneca/Pacesetter AB/Q-med/Artimplant/Doxa

2.4 Properties of Materials:

- Solids are distinguished from the other states of matter such as liquids and gases
- Atoms are held together by interatomic forces mainly
  - Ionic bonding
  - Covalent bonding
  - Metallic bonding

A. Ionic Bonding:

- Attraction of anions and cations constitutes ionic bonding
- In ionic bond (metallic atoms) electron donors transfer one or more electrons to electron acceptors (nonmetallic)
- Anions (Nonmetals)are strongly attracted by electrostatic force
- Ionic bonds result into packing which reduces surface energy and leads to a highly ordered arrangement called crystal structure
- Bound electrons cannot be served as a carrier further
- So ionic solids are poor electrical conductors, chemically less reactive and poor overall energy content

eg. Sodium chloride, Magnesium oxide

B. Covalent Bonding:

- Elements between metals and nonmetals having equal valence electrons and equal tendency to donate and accept electrons
- eg. Carbon and Silicon, C-C
- Tendency of sharing valence electrons
- Stable electron structure
- Nearest neighbors form tetrahedron crystal
- Strong bonds – Diamond (Hardest material)
- Due to localization of the valence electrons these materials are poor electrical conductors.

C. Metallic Bonding:

- Many metals are very strong (e.g. Cobalt) and have high melting points (e.g. Tungsten)
- Very strong interatomic bonds
- Atoms are arranged in an orderly, repeating, three dimensional pattern with migration of valence electrons
- Metal crystal composed of positive ion cores and negetive electrons circulate about atoms lacking valence electrons
- Bonding arise because the negative electrons act like glue between the positive ion cores
- High electrical and thermal conductivity

2.5 Mechanical Properties of Materials:

- Elastic Behavior, Stress and strain, Tension and compression, Shear, Isotropy, Fatigue, Toughness

A. Elastic Behavior

- Hook's Law
- Initial extension is proportional to the load applied
- Most of the solids behave in an elastic manner (like Spring)

B. Stress and Strain:

- Extension for a given load varies with the geometry of the specimen
- Hook's law is not sufficient to compare relative stiffness of different materials
- To resolve this problem load and deformation is normalized
- Load per unit cross sectional area
- Elongation per unit of the original length
- Normalized Load= Stress (σ) (F/A)
- Normalized deformation = Strain (ε) (dL/L)

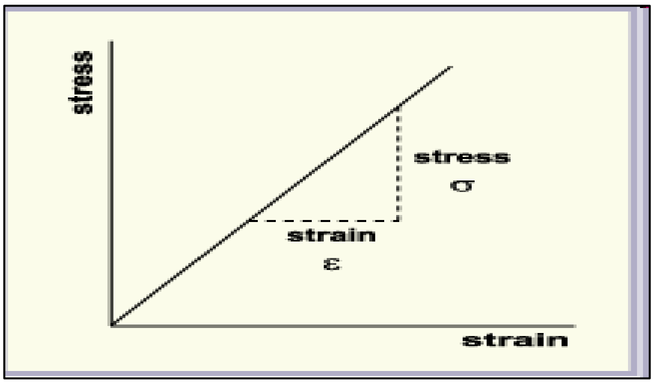

Figure 2.1: Stress and Strain

C. Tension and Compression:

- Technique for flexible materials like rubbers, polymers and soft tissues
- In tension and compression area supporting the load is perpendicular to the loading direction (Tensile stress)
- The change in length is parallel to the original length (Tensile strain)
- Unit for stress pascal (Pa) or N/mm^2

D. Shear:

- Shear stress (τ): Applied load is parallel to the area supporting it
- Shear Strain (γ): Dimensional change is perpendicular to the reference dimension
- Elastic constants
- $\sigma = E\ \varepsilon$, Tension or compression E=Young's Modulus
- $T = G\ \gamma$, Shear
- G = shear modulus
- Stronger bonds= higher values

E. Isotropy:

- Isotropic Materials: A material whose properties are same in all directions
- e.g. metals, alloy and ceramic
- Great magnitude of grains which forms aggregated crystals
- High values of E and G
- Polymeric materials such as bones, ligaments and sutures are anisotropic materials
- Need more than two elastic constants to relate stress and strain properties

F. Fatigue:

- Due to fatigue fracture occurs when the loads are applied and removed for a great no. of cycles

- Fatigue occurs even in tough and ductile materials
- e.g. Prosthetic heart valves and prosthetic joints
- Repetitive loading produce microscopic cracks which then propagate by small steps at each load cycle
- Failure occurs with stepwise propagation
- For design purpose, Endurance limit or fatigue strength= 10^6 to 10^8
- Factors affecting Fatigue strength: Environment, temp, corrosion, deterioration and cycle rate

G. Toughness:

- Ability of material to plastically deform under the influence of stress field that exist at the tip of a crack is a measure of its toughness
- Fracture toughness= f(crack propagation stress, crack depth ,shape)
- Critical stress intensity factor K_{IC}
- Unit of K_{IC} is Pa $m^{0.5}$ or $N.m^{3/2}$

2.6 Surface Properties of Materials:

- Roughness- Rough, stepped or smooth
- Wettability- hydrophilic or hydrophobic
- Surface mobility- inhomogeneous with depth or overlayered
- Chemical Composition- atomic, supramolecular or macromolecular
- Electrical charge
- Crystallinity- different combination and organizations such as a silicon 100 unreconstructed surface or a silicon 111 reconstructed
- Heterogeneity to biological reaction

2.7 Characterization of Surface Properties:

A. Contact Angle Method:

- Principle: Liquid wetting of surfaces is used to estimate the energy of surfaces
- The force balance between the liquid-vapour surface tension(γ_{lv}) of a liquid drop and the interfacial tension between solid and the drop (γ_{sl}), manifested through the contact angle (Θ) of the drop with the surface
- Depth Analyzed: 3-20 A°
- Spatial resolution: 1mm
- Analytical sensitivity: Low or high depending on chemistry
- Cost effective

B. Electron spectroscopy for chemical Analysis (ESCA):

- Principle: X-rays induce the emission of electrons of characteristic energy

- Energy of electrons provide information about the nature and environment of the atom from which it came.
- Depth Analyzed: 10-250 A°
- Spatial resolution: 10-150 μm
- Analytical sensitivity: 0.1% atom
- Expensive technique

C. Secondary Ion Mass Spectroscopy (SIMS):

- Complex instrumentation and ultrahigh vacuum chamber
- Principle: A surface is bombarded with a beam of accelerated ions. Collision of these ions with atoms and molecules on the surface transfer enough energy to them so that they can sputter from the surface into the vacuum.
- Depth Analyzed: 10 A° -1 μm
- Spatial resolution: 100 A°
- Analytical sensitivity: very high
- Expensive technique

D. Scanning Electron Microscopy (SEM):

- Based on the images
- Principle: High energy electron beam is focused on the specimen and low energy secondary electrons are emitted from each spot where the focused electron beam impacts.
- Valuable for observing defects in thin films or analyzing the chemistry of fine particulates or assessing causes of implant failure
- Depth Analyzed: 5 A°
- Spatial resolution: 40 A°
- Analytical sensitivity: high, not quantitative
- Less Expensive technique

2.8 Classes of Materials:

- Polymers, Hydrogels, Bioresorbable and Biodegradable materials, Ceramics, Natural materials, Composite thin films, grafts, Coatings medical fibers, Biological functional materials, Smart materials
- Pyrolytic carbon for long term medical implants, Textured and porous materials, Non-fouling surfaces, Metals

2.8.1 Polymers:

- Polymers represent the largest class of biomaterials
- Polymers are used in the biomedical devices which include orthopedic, Dental, soft tissue and cardiovascular implants
- Mainly two types of polymers

A. Natural Polymers: Plant and Animal Sources:

- e.g. Cellulose, sodium alginate, natural rubber, Tissue based heart valves and sutures, heparin, glycosaminoglycans

B. Synthetic Polymers:

- Hydrophobic (non water absorbing)
- e.g.PMMA- Poly Methyl Methacrylate,PVC- Poly Vinyl Chloride, PE-Poly Ethylene,PP-Poly Propylene, PTFE-Polytetra Fluoro Ethylene, PET-Polyethylene Terepthalate, PUR-Polyurathane, Silicone rubber
- Hydrophilic,water swelling or water soluble
- e.g.PLA/PGA-Poly Lactic / Glycolic Acid,PA- Poly Amide,polyethylene glycol

2.8.2 Molecular Weight:

- In polymer synthesis molecular weight plays an important role.
- Polymer is produced with the distribution of molecular weights.
- To compare two different batches of polymer Average Molecular weight is introduced.

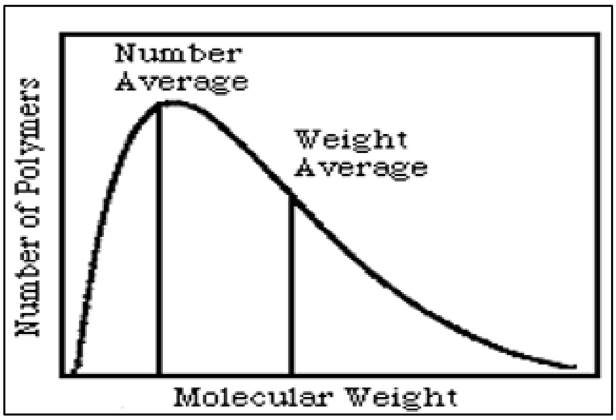

Figure 2.2.: Molecular Weight

2.8.3 Polydispersity Index (PI):

- Ratio of M_w to M_n is known as Polydispersity index.
- Measure of the breadth of the molecular weight distribution.
- For Commercial polymers PI ranges from 1.5-50
- For Biomedical applications linear polymers are used in the range of M_n(25,000 to 1,00,000) and M_w (50,000 to 3,00,000)
- For hip joint M_w ranges up to million
- Increase in molecular weight corresponds to increasing physical properties
- But melt viscosity increases with MW so process ability will decrease.

2.8.4 Polymerization (Synthesis):

- Polymer prepration fall into following catagories:

A. Addition: A reaction occurs between two molecules to form a larger molecule without the elimination of a smaller molecule.

- In addition, Polymerization, unsaturated monomers react through the stages of initiation, propagation and termination to give final polymer product.
- e.g. PVC, PE and PMMA
- Initiation → Propagation → Termination

Free radicals, cations, anions or stereospecific catalysts	Rapid chain Growth	radical, Solvent molecule, polymer molecule, initiator, an added chain transfer **agent**

Polymerization (Synthesis):

B. Condensation: A reaction occurs between two molecules to form a larger molecule with the elimination of a smaller molecule.

- Two monomers react to form a covalent bond,usually with elimination of a water,hydrochloric acid,methanol, or carbon dioxide.
- e.g. Nylon,PET

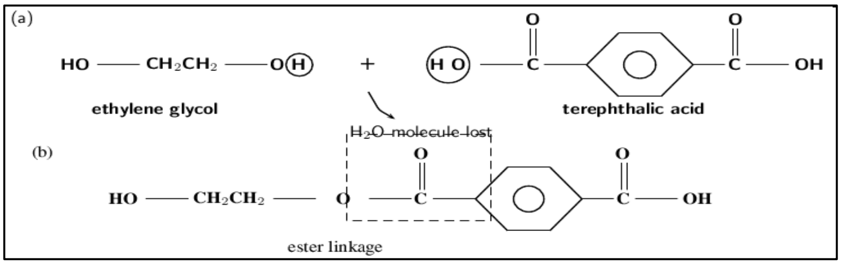

Figure 2.3.: Polymerization (Synthesis)

2.8 References:

A. Text books:

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2. Biomaterials – An Interfacial Approach
   Hench L.L. and Ethridg E.C.

B. Reference book:

3. The Biomedical Engineering handbook Bronzino J.D.