University of Al-Mustaqbal
College of Science
Department of Medical Physics

Biomaterials

Stage : fourth

LEC (3)

Properties of Biomaterials(Physical & Chemical)

BY

M.SC. Mariam Hassan Abd Muslim

1.1 Introduction:

A biomaterial is any natural or synthetic material used in or on the body for diagnosis, repair, replacement, or support (e.g., hip implants, stents, sutures, contact lenses, bone coatings).

1.1 Physical Properties of Biomaterials

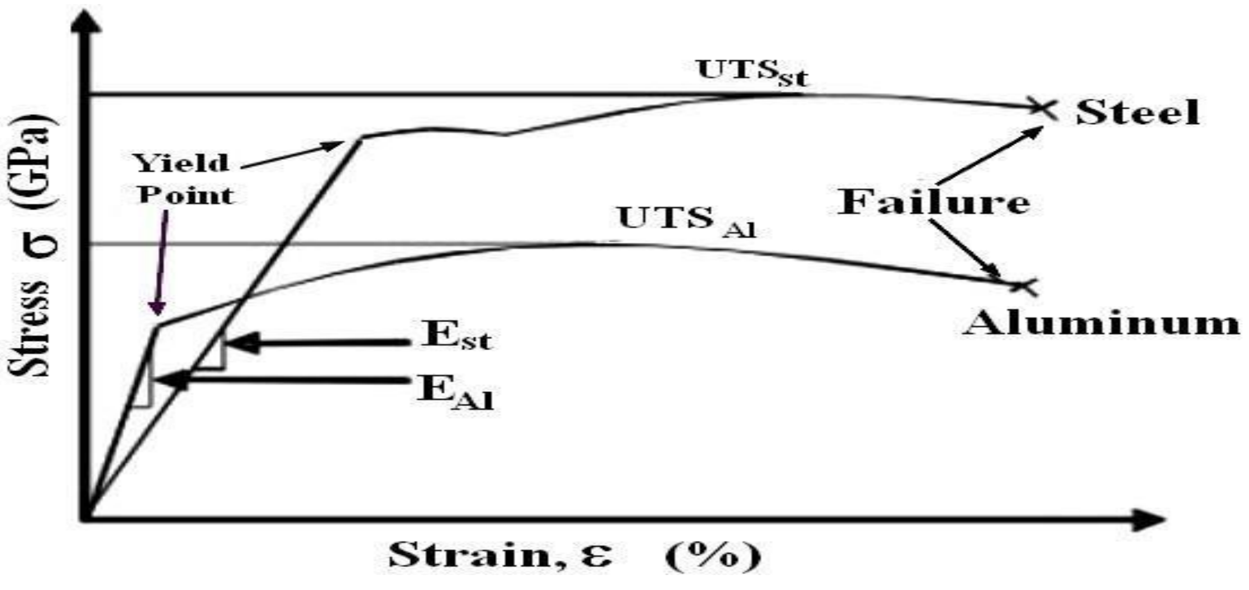
In biomedical design, “physical” behavior typically includes mechanical properties, because they directly control service performance.

1.1.1 Density

Influences implant weight and patient comfort.
Titanium is relatively light compared with Co–Cr and stainless steel.

1.1.2 Mechanical Properties (Performance-Critical)

(a) Elastic Modulus (E) and Stress Shielding



If an implant is much stiffer than bone, it may carry most of the load, reducing stress in bone and potentially causing bone resorption (stress shielding).Modern strategies reduce effective stiffness using porous/lattice titanium structures (3D-printed) or lower-modulus polymers like PEEK.

(b) Toughness and Fracture Resistance

Metals are generally tougher (more energy absorbed before fracture).
Ceramics can be strong but typically brittle, requiring tight defect control and stress-reducing design.

(c) Fatigue Resistance

Physiological loads are cyclic and may reach millions of cycles. Fatigue failure is promoted by surface roughness, porosity, sharp corners (stress concentration), and corrosive body fluids, leading to corrosion-fatigue or tribocorrosion.

(d) Creep and Stress Relaxation

These time-dependent deformation mechanisms are especially important in polymers such as UHMWPE, which may deform under long-term loading conditions.

Term	Definition	Formula	Unit
Stress	Force per unit area	$\sigma = F/A$	Pa
Strain	Deformation ratio	$\varepsilon = \Delta L/L_0$	dimensionless
Young's Modulus	Stiffness of material	$E = \sigma/\varepsilon$	GPa
Poisson's Ratio	Lateral to axial strain ratio	$\nu = -\varepsilon_t/\varepsilon_l$	dimensionless

1.1.3 Surface Properties

Surface roughness and porosity influence friction, wear, and osseointegration. While porosity promotes bone ingrowth and fixation, it also reduces mechanical strength, representing an important design trade-off.

1.1.4 Wear and Tribology

Wear is critical in joint replacements such as hips and knees. Common wear mechanisms include abrasive, adhesive, fretting, and third-body wear. Wear debris can trigger inflammatory reactions and osteolysis, ultimately leading to implant loosening.

1.1.5 Thermal Properties

Thermal behavior is important during processing and sterilization. In polymers, the glass transition temperature (Tg) governs the transition between rigid and rubbery behavior. Increased crystallinity often reduces water uptake and slows hydrolytic degradation.

Material	Thermal Conductivity
Enamel	0.92 $W.m^{-1}.^{o}C^{-1}$
Dentine	0 .63 $W.m^{-1}.^{o}C^{-1}$
Acrylic Resin	0.21 $W.m^{-1}.^{o}C^{-1}$
Dental Amalgam	23.02 $W.m^{-1}.^{o}C^{-1}$
Zinc Phosphate Cement	1.17 $W.m^{-1}.^{o}C^{-1}$
Zinc Oxide Cement	0.46 $W.m^{-1}.^{o}C^{-1}$
Silicate Materials	0.75 $W.m^{-1}.^{o}C^{-1}$
Porcelain	1.05 $W.m^{-1}.^{o}C^{-1}$
Gold	291.70 $W.m^{-1}.^{o}C^{-1}$

1.1.6 Electrical Properties

Electrical conductivity is important for biomedical electrodes, sensors, and neural interfaces. Metals conduct well, whereas most ceramics are electrical insulators.

1.1.7 Optical Properties

Optical properties such as transparency, refractive index, and resistance to haze are essential for ophthalmic devices including contact lenses and intraocular lenses.

1.1.8 Transport and Diffusion

Diffusion of water, ions, and small molecules in polymers controls swelling, hydrolytic degradation, and drug-release behavior in controlled delivery systems.

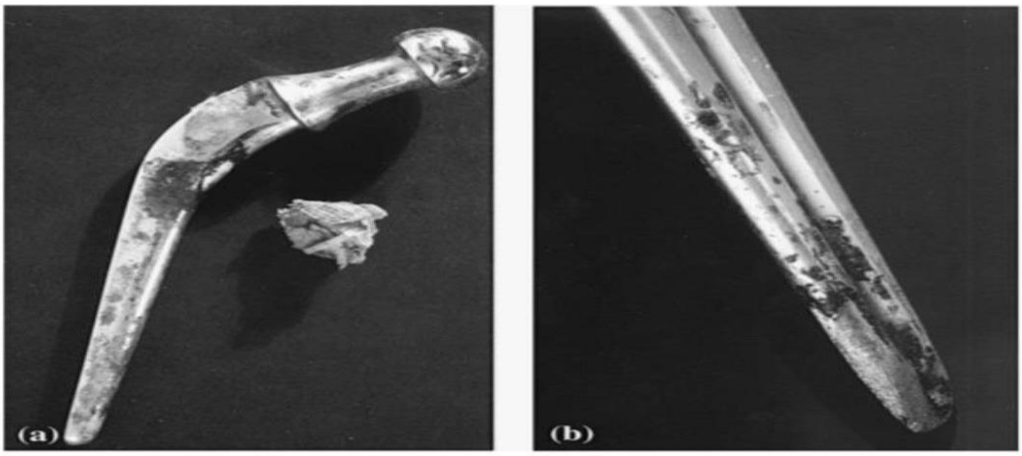
1.2 Chemical Properties of Biomaterials

1.3.1 Chemical Stability and Biocompatibility

Biocompatibility is not a single material property; it results from the interaction between degradation products, surface chemistry, protein adsorption, and the body's immune and inflammatory responses.

1.3.2 Corrosion of Metals

Metal corrosion is an electrochemical oxidation–reduction process occurring in body fluids. Clinically important forms include uniform corrosion, pitting corrosion (often promoted by chloride ions), crevice corrosion, galvanic corrosion, fretting and tribocorrosion, and stress corrosion or corrosion-fatigue.
Passivation: Protective oxide films greatly enhance corrosion resistance, such as TiO_2 on titanium and Cr_2O_3 on stainless steel. Mechanical wear can disrupt these films and enable localized attack.



1.3.3 Polymer Degradation

(a) Hydrolysis

Ester-based polymers such as PLA, PLGA, PGA, and PCL degrade by hydrolysis, leading to reduced molecular weight and mechanical strength. The degradation rate depends on crystallinity, geometry, temperature, pH, and additives.

(b) Oxidation

Oxidative degradation may occur in long-term polymer implants, causing embrittlement and cracking.

(c) Degradation Products

Degradation products must be non-toxic and safely metabolized or excreted

1.3.4 Ceramic Chemistry

1. Bioinert ceramics (alumina, zirconia) show minimal chemical interaction and excellent wear resistance.

2. Bioactive ceramics (hydroxyapatite, bioactive glass) form a chemical bond with bone through an apatite-like surface layer**.**

3. Resorbable ceramics (tricalcium phosphate, calcium phosphates) gradually dissolve and are replaced by natural bone. Solubility depends on pH, fluid composition, and microstructure.

Applications include: Replacement for hips, knees, teeth, tendons and ligaments, and repair for periodontal disease, maxillofacial reconstruction, augmentation and stabilization, spinal fusion and bone fillers after tumor surgery. Carbon coatings are thrombo-resistant and are used for prosthetic heart valves.

(I) Types of Bio-ceramics – Tissue Attachment

The mechanism of tissue attachment is directly related to the type of tissue response at the implant interface. No material implanted in living tissues is inert; all materials elicit a response from living tissues.

Four types of response allow different means of achieving attachment of prostheses to the musculo-skeletal system.

The types of implant-tissue response are:

a- If the material is toxic, the surrounding tissue dies;

b- the material is nontoxic and biologically inactive (nearly inert), a fibrous tissue of variable thickness forms;

c- If the material is nontoxic and biologically active (bioactive), an interfacial bond forms;

d- If the material is nontoxic and dissolves, the surrounding tissue replaces .

The attachment mechanisms with examples are summarized below:

Type of Bioceramic	Type of Attachment	Example
1	Dense, nonporous, nearly inert ceramics attach to bone-growth into surface irregularities by cementing the device into the tissues, or by pressing fitting into a defect (termed **Morphology Fixation**).	Al_2O_3 (single crystal and polycrystalline)
2	For porous inert implants bone ingrowth occurs, which mechanically attaches the bone to the material (termed **Biological Fixation**)	Al_2O_3 (porous polycrystalline) hydroxyapetite-coated porous metals
3	Dense, nonporous, surface-reactive ceramics and glass-ceramics attach directly by chemical bonding with the bone (termed **Bioactive Fixation)**	Bioactive glasses Bioactive glass-ceramics Hysdroxyapetite
4	Dense, nonporous (or porous), resorbable ceramics are designed to be slowly replaced by bone.	Calcium sulphate (Plaster of Paris) Tricalcium phosphate, Calcium phosphate salts

1.3.5 Surface Chemistry (Most Biologically Sensitive Factor)

Immediately after implantation, proteins adsorb onto the material surface, altering their conformation and influencing subsequent cell attachment. Key surface parameters include surface energy, wettability, surface charge, and functional groups.

Common surface modification techniques include acid etching, grit blasting, plasma treatment, hydroxyapatite coatings, and antimicrobial or anti-fouling coatings.

1.3.6 Sterilization Compatibility

Sterilization methods must be compatible with the material. Steam autoclaving is suitable for metals but may damage polymers. Gamma or electron-beam irradiation can cause polymer chain scission or crosslinking, while ethylene oxide is effective at low temperature but requires careful removal of residues.