BIOMATERIAL

[Bio-ceramic]

Nur Istianah, ST.,MT.,M.Eng
## Glasses

<table>
<thead>
<tr>
<th>Glass Type</th>
<th>SiO₂</th>
<th>Na₂O</th>
<th>CaO</th>
<th>Al₂O₃</th>
<th>B₂O₃</th>
<th>Other</th>
<th>Characteristics and Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fused silica</td>
<td>&gt;99.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>High melting temperature, very low coefficient of expansion (thermally shock resistant)</td>
</tr>
<tr>
<td>96% Silica (Vycor™)</td>
<td>96</td>
<td></td>
<td></td>
<td></td>
<td>4</td>
<td></td>
<td>Thermally shock and chemically resistant—laboratory ware</td>
</tr>
<tr>
<td>Borosilicate (Pyrex™)</td>
<td>81</td>
<td>3.5</td>
<td>2.5</td>
<td>13</td>
<td></td>
<td></td>
<td>Thermally shock and chemically resistant—ovenware</td>
</tr>
<tr>
<td>Container (soda–lime)</td>
<td>74</td>
<td>16</td>
<td>5</td>
<td>1</td>
<td>4MgO</td>
<td></td>
<td>Low melting temperature, easily worked, also durable</td>
</tr>
<tr>
<td>Fiberglass</td>
<td>55</td>
<td>16</td>
<td>15</td>
<td>10</td>
<td>4MgO</td>
<td></td>
<td>Easily drawn into fibers—glass–resin composites</td>
</tr>
<tr>
<td>Optical flint</td>
<td>54</td>
<td>1</td>
<td></td>
<td></td>
<td>37PbO, 8K₂O</td>
<td></td>
<td>High density and high index of refraction—optical lenses</td>
</tr>
<tr>
<td>Glass–ceramic (Pyroceram™)</td>
<td>43.5</td>
<td>14</td>
<td>30</td>
<td>5.5</td>
<td>6.5TiO₂, 0.5As₂O₃</td>
<td></td>
<td>Easily fabricated; strong; resists thermal shock—ovenware</td>
</tr>
</tbody>
</table>
Glass ceramic

• Most inorganic glasses can be made to transform from a noncrystalline state to one that is crystalline by the proper high-temperature heat treatment.

• This process is called crystallization, and the product is a fine-grained polycrystalline material which is often called a glass–ceramic.

• The formation of these small glass-ceramic grains is, in a sense, a phase transformation, which involves nucleation and growth stages.
Cooling in crystallization
Glass-ceramic properties

- Glass-ceramic materials have been designed to have the following characteristics:
- relatively high mechanical strengths; low coefficients of thermal expansion (to avoid thermal shock);
- relatively high temperature capabilities; good dielectric properties (for electronic packaging applications); and
- good biological compatibility.
Ceramic fabrication techniques

- Glass forming processes
  - Pressing
  - Blowing
  - Drawing
  - Fiber forming

- Particulate forming processes
  - Powder pressing
  - Hydroplastic forming
  - Slip casting
  - Tape casting

- Cementation

- Drying
- Firing
Steps

1. The **melting point** corresponds to the temperature at which the viscosity is 10 Pa-s (100 P); the glass is fluid enough to be considered a liquid.

2. The **working point** represents the temperature at which the viscosity is $10^3$ Pa-s ($10^4$ P); the glass is easily deformed at this viscosity.

3. The **softening point**, the temperature at which the viscosity is $4 \times 10^6$ Pa-s ($4 \times 10^7$ P), is the maximum temperature at which a glass piece may be handled without causing significant dimensional alterations.

4. The **annealing point** is the temperature at which the viscosity is $10^{12}$ Pa-s ($10^{13}$ P); at this temperature, atomic diffusion is sufficiently rapid that any residual stresses may be removed within about 15 min.

5. The **strain point** corresponds to the temperature at which the viscosity becomes $3 \times 10^{13}$ Pa-s ($3 \times 10^{14}$ P); for temperatures below the strain point, fracture will occur before the onset of plastic deformation. The glass transition temperature will be above the strain point.
Forming

Figure 13.8 The press-and-blow technique for producing a glass bottle. (Adapted from C. J. Phillips, Glass: The Miracle Maker. Reproduced by permission of Pitman Publishing Ltd., London.)
Figure 13.9  A process for the continuous drawing of sheet glass. (From W. D. Kingery, *Introduction to Ceramics*. Copyright © 1960 by John Wiley & Sons, New York. Reprinted by permission of John Wiley & Sons, Inc.)
**Tempering**

**Figure 13.11** Typical time-versus-temperature processing cycle for a Li$_2$O–Al$_2$O$_3$–SiO$_2$ glass-ceramic. (Adapted from Y. M. Chiang, D. P. Birnie, III, and W. D. Kingery, *Physical Ceramics—Principles for Ceramic Science and Engineering*. Copyright © 1997 by John Wiley & Sons, New York. Reprinted by permission of John Wiley & Sons, Inc.)
Figure 13.15  Schematic representation of the steps in uniaxial powder pressing.
(a) The die cavity is filled with powder.  
(b) The powder is compacted by means of pressure applied to the top die.  
(c) The compacted piece is ejected by rising action of the bottom punch.  
(d) The fill shoe pushes away the compacted piece, and the fill step is repeated.  
(From W. D. Kingery, Editor, Ceramic Fabrication Processes, MIT Press. Copyright © 1958 by the Massachusetts Institute of Technology.)
Figure 13.17  Scanning electron micrograph of an aluminum oxide powder compact that was sintered at 1700°C for 6 min. 5000×. (From W. D. Kingery, H. K. Bowen, and D. R. Uhlmann, Introduction to Ceramics, 2nd edition, p. 483. Copyright © 1976 by John Wiley & Sons, New York. Reprinted by permission of John Wiley & Sons, Inc.)
Ceramics are refractory polycrystalline compounds;

- Inorganic
- Hard and brittle
- High compressive strength

**Applications:**

- Orthopaedic load-bearing coatings
- Dental implants
- Bone graft substitutes
- Bone cements
The class of ceramics used for repair and replacement of diseased and damaged parts of the musculoskeletal system are referred to as bioceramics.

Ceramics are refractory polycrystalline compounds;

- Usually inorganic
- Highly inert
- Hard and brittle
- High compressive strength
- Generally good electric and thermal insulators
- Good aesthetic appearance
Types of Bioceramics

- Bioinert
- Bioactive
- Bioresorbable
Bioinert

- Maintain their physical and mechanical properties while in host.
- Resist corrosion and wear.
- Have a reasonable fracture toughness.
- Typically used as structural-support implant such as bone plates, bone screw and femoral heads.
Bioactive

• Direct and strong chemical bond with tissue.
• Fixation of implants in the skeletal system.
• Low mechanical strength and fracture toughness.
• Examples: Glass ceramic, Dense nonporous glasses
Bioresorbable (Biodegradable)

- Chemically broken down by the body and degrade.
- The resorbed material is replaced by endogenous tissue.
- Chemicals produced as the ceramic is resorbed must be able to be processed through the normal metabolic pathways of the body without evoking any deleterious effect.
- Synthesized from chemical (synthetic ceramic) or natural sources (natural ceramic).
Bioceramics

- The class of ceramics used for repair and replacement of diseased and damaged parts of the musculoskeletal system are referred to as bioceramics.
Neurostimulation: Feed-thrus

Morgan Advanced Ceramics’ Alberox Products assist in the feed-thru design for neurostimulators that pulse various nerves to treat medical conditions, including epilepsy, depression, migraines and obesity.

Cochlear Implants: Feed-thrus

Requiring stringent quality controls and consistent repeatability in order to survive within the body’s harsh environment, Morgan Advanced Ceramics’ Alberox Products feed-thrus facilitate in amplifying and improving the quality of sound.

Hip Joints: HIP Vitox*

Morgan Advanced Ceramics’ HIP Vitox* ceramic-on-ceramic hip joints eliminate polyethylene wear debris and metal ion release concerns in combination with exceptionally low wear rates.

Pacemakers & Defibrillators: Feed-thrus

Morgan Advanced Ceramics’ Alberox Products feed-thrus allow electricity to pass in and out of the implanted device to administer an electrical charge.

Implantable Joints: Diamond-like Carbon (DLC) coatings

Morgan Advanced Ceramics’ Diamonex Products Diamond-like Carbon coatings provide a biocompatible, sterilization-compatible, non-leaching and wear-resistant surface for key pivot points and wear surfaces.
Bioceramics and bioglasses are ceramic materials that are biocompatible. Bioceramics are an important subset of biomaterials. Bioceramics range in biocompatibility from the ceramic oxides, which are inert in the body, to the other extreme of resorbable materials, which are eventually replaced by the body after they have assisted repair. Bioceramics are used in many types of medical procedures. Bioceramics are typically used as rigid materials in surgical implants, though some bioceramics are flexible. The ceramic materials used are not the same as porcelain type ceramic materials. Rather, bioceramics are closely related to either the body's own materials or are extremely durable metal oxides.
Biocompatibility

- Bioceramics' properties of being anticorrosive, biocompatible, and aesthetic make them quite suitable for medical usage. **Zirconia** ceramic has bioinertness and noncytotoxicity. Carbon is another alternative with similar mechanical properties to bone, and it also features blood compatibility, no tissue reaction, and non-toxicity to cells. None of the three bioinert ceramics exhibit bonding with the bone. However, bioactivity of bioinert ceramics can be achieved by forming composites with bioactive ceramics. Bioglass and glass ceramics are nontoxic and chemically bond to bone. Glass ceramics elicit osteoinductive properties, while calcium phosphate ceramics also exhibit non-toxicity to tissues and bioresorption.
<table>
<thead>
<tr>
<th>Material</th>
<th>Young’s Modulus, E (GPa)</th>
<th>Compressive Strength, $\sigma_{\text{UCS}}$ (MPa)</th>
<th>Tensile Strength, $\sigma_{\text{UTS}}$ (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alumina</td>
<td>380</td>
<td>4500</td>
<td>350</td>
</tr>
<tr>
<td>Bioglass-ceramics</td>
<td>22</td>
<td>500</td>
<td>56–83</td>
</tr>
<tr>
<td>Calcium phosphates</td>
<td>40–117</td>
<td>510–896</td>
<td>69–193</td>
</tr>
<tr>
<td>Pyrolytic carbon</td>
<td>18–28</td>
<td>517</td>
<td>280–560</td>
</tr>
</tbody>
</table>

Advantages and Disadvantages of Bioceramics

**Advantages**
- Biocompatible
- Wear Resistant
- Light Weight

**Disadvantages**
- Low Tensile Strength
- Difficult to Fabricate
- Low Toughness
- Not Resilient
Applications

- Ceramics are now commonly used in the medical fields as dental and bone implants. Surgical cermets are used regularly. Joint replacements are commonly coated with bioceramic materials to reduce wear and inflammatory response. Other examples of medical uses for bioceramics are in pacemakers, kidney dialysis machines, and respirators. The global demand on medical ceramics and ceramic components was about U.S. $9.8 billion in 2010. It was forecast to have an annual growth of 6 to 7 percent in the following years, with world market value predicted to increase to U.S. $15.3 billion by 2015 and reach U.S. $18.5 billion by 2018.
<table>
<thead>
<tr>
<th>Devices</th>
<th>Function</th>
<th>Biomaterial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Artificial total hip, knee, shoulder, elbow, wrist</td>
<td>Reconstruct arthritic or fractured joints</td>
<td>High-density alumina, metal bioglass coatings</td>
</tr>
<tr>
<td>Bone plates, screws, wires</td>
<td>Repair fractures</td>
<td>Bioglass-metal fibre composite, Polysulphone-carbon fibre composite</td>
</tr>
<tr>
<td>Intramedullary nails</td>
<td>Align fractures</td>
<td>Bioglass-metal fibre composite, Polysulphone-carbon fibre composite</td>
</tr>
<tr>
<td>Harrington rods</td>
<td>Correct chronic spinal curvature</td>
<td>Bioglass-metal fibre composite, Polysulphone-carbon fibre composite</td>
</tr>
<tr>
<td>Permanently implanted artificial limbs</td>
<td>Replace missing extremities</td>
<td>Bioglass-metal fibre composite, Polysulphone-carbon fibre composite</td>
</tr>
<tr>
<td>Vertebrae Spacers and extensors</td>
<td>Correct congenital deformity</td>
<td>$\text{Al}_2\text{O}_3$</td>
</tr>
<tr>
<td>Spinal fusion</td>
<td>Immobilise vertebrae to protect spinal cord</td>
<td>Bioglass</td>
</tr>
<tr>
<td>Alveolar bone replacements, mandibular reconstruction</td>
<td>Restore the alveolar ridge to improve denture fit</td>
<td>Polytetra fluoro ethylene (PTFE) - carbon composite, Porous $\text{Al}_2\text{O}_3$, Bioglass, dense-apatite</td>
</tr>
<tr>
<td>End osseous tooth replacement implants</td>
<td>Replace diseased, damaged or loosened teeth</td>
<td>$\text{Al}_2\text{O}_3$, Bioglass, dense hydroxyapatite, vitreous carbon</td>
</tr>
<tr>
<td>Orthodontic anchors</td>
<td>Provide posts for stress application required to change deformities</td>
<td>Bioglass-coated $\text{Al}_2\text{O}_3$, Bioglass coated vitallium</td>
</tr>
</tbody>
</table>
TABLE 1.3. Ceramics Used in Biomedical Applications

<table>
<thead>
<tr>
<th>Ceramic</th>
<th>Chemical Formula</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alumina</td>
<td>Al₂O₃</td>
<td>Bioinert</td>
</tr>
<tr>
<td>Zirconia</td>
<td>ZrO₂</td>
<td></td>
</tr>
<tr>
<td>Pyrolytic carbon</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bioglass</td>
<td>Na₂OCaOP₂O₃−SiO</td>
<td>Bioactive</td>
</tr>
<tr>
<td>Hydroxyapatite (sintered at high temperature)</td>
<td>Ca₁₀(PO₄)₆(OH)₂</td>
<td></td>
</tr>
<tr>
<td>Hydroxyapatite (sintered at low temperature)</td>
<td>Ca₁₀(PO₄)₆(OH)₂</td>
<td>Biodegradable</td>
</tr>
<tr>
<td>Tricalcium phosphate</td>
<td>Ca₃(PO₄)₂</td>
<td></td>
</tr>
</tbody>
</table>
Inert Ceramics: Aluminum Oxides (Alumina)

Applications

In orthopedics:

✓ femoral head
✓ bone screws and plates
✓ porous coatings for femoral stems
✓ porous spacers (specifically in revision surgery)
✓ knee prosthesis
✓ dental: crowns and bridges
Inert Ceramics: Zirconia, ZrO2

• Zirconia is a biomaterial that has a bright future because of its high mechanical strength and fracture toughness. Zirconia ceramics have several advantages over other ceramic materials due to the transformation toughening mechanisms operating in their microstructure that can be manifested in components made out of them. The research on the use of zirconia ceramics as biomaterials commenced about twenty years ago and now zirconia is in clinical use in total hip replacement (THR) but developments are in progress for application in other medical devices.
Fabrication:

- Obtained from the mineral zircon
- Addition of MgO, CaO, CeO, or Y2O3 stabilize tetragonal crystal structure (e.g. 97 mol%ZrO2 and 3 mol%Y2O3)
- Usually hot-pressed or hot isostatically pressed

Applications:

- Orthopaedics: femoral head, artificial knee, bone screws and plates, favored over UHMWPE due to superior wear resistance
- Dental: crowns and bridges
Zirconia Dental Application
Biodegradable Ceramics; Calcium Phosphates
The inorganic phase of the bone tissue is primarily composed of calcium phosphates. A significant influence in bone tissue regeneration is given to phosphate salts because their physical, chemical and structural properties are very similar to those of bone tissue. During the 1920’s these materials were available only as powders and they were used purely as filling materials. It was soon found, however, that they promote the formation of new bone tissue, particularly when the atomic ratio for these salts. Success of calcium phosphates in vivo implants depends on several factors, but very important ones are the Ca/P atomic ratio, the porosity and the crystalline structure.
Uses:

- repair material for bone damaged trauma or disease
- void filling after resection of bone tumours
- repair and fusion of vertebrae
- repair of herniated disks
- repair of maxillofacial and dental defects
- ocular implants
- drug-delivery
Bioactive Ceramics: Glass Ceramics

**Bioactive:** capable of direct chemical bonding with the host biological tissue

**Glass:**
- an inorganic melt cooled to solid form without crystallization
- an amorphous solid
- possesses short range atomic order ... BRITTLE!
Bioglasses are interesting versatile class of materials and structurally all silica-based glasses have the same basic building block - SiO4. Glasses of various compositions can be obtained and they show very different properties. Bioglasses have also found a place in prosthetics. These bioglasses are embedded in a biomaterial support to form prosthetics for hard tissues. Such prosthetics are biocompatible, show excellent mechanical properties and are useful for orthopedic and dental prosthetics.
Tests

- **IN VIVO;**

Studies that are in vivo are those in which the effects of various biological entities are tested on whole, living organisms usually animals including humans, and plants as opposed to a partial or dead organism, or those done in vitro ("within the glass"), i.e., in a laboratory environment using test tubes, petri dishes etc. Examples of investigations in vivo include: the pathogenesis of disease by comparing the effects of bacterial infection with the effects of purified bacterial toxins; the development of antibiotics, antiviral drugs, and new drugs generally; and new surgical procedures.
Consequently, animal testing and clinical trials are major elements of in vivo research. In vivo testing is often employed over in vitro because it is better suited for observing the overall effects of an experiment on a living subject. In drug discovery, for example, verification of efficacy in vivo is crucial, because in vitro assays can sometimes yield misleading results with drug candidate molecules that are irrelevant in vivo (e.g., because such molecules cannot reach their site of in vivo action, for example as a result of rapid catabolism in the liver).
In Vitro;

- **In vitro** studies are performed with microorganisms, cells or biological molecules outside their normal biological context. Colloquially called "test tube experiments", these studies in biology and its sub-disciplines have traditionally been done in test-tubes, flasks, petri dishes etc and since the onset of molecular biology involve techniques such as the so-called omics. Studies that are conducted using components of an organism that have been isolated from their usual biological surroundings permit a more detailed or more convenient analysis than can be done with whole organisms. In contrast, **in vivo** studies are those conducted in animals including humans, and whole plants.
• **In vitro** studies are conducted using components of an organism that have been isolated from their usual biological surroundings, such as microorganisms, cells or biological molecules. For example, microorganisms or cells can be studied in artificial culture medium, proteins can be examined in solutions. Colloquially called "test tube experiments", these studies in biology, medicine and its sub-disciplines are traditionally done in test-tubes, flasks, petri dishes *etc*. They now involve the full range of techniques used in molecular biology such as the so-called omics.

• In contrast, studies conducted in living beings (microorganisms, animals, humans, or whole plants) are called *in vivo*. 

Future trends

• Bioceramics have been proposed as a possible treatment for cancer. Two methods of treatment have been proposed: hyperthermia and radiotherapy. Hyperthermia treatment involves implanting a bioceramic material that contains a ferrite or other magnetic material. The area is then exposed to an alternating magnetic field, which causes the implant and surrounding area to heat up. Alternatively, the bioceramic materials can be doped with β-emitting materials and implanted into the cancerous area.

• Other trends include engineering bioceramics for specific tasks. Ongoing research involves the chemistry, composition, and micro- and nanostructures of the materials to improve their biocompatibility.
Conclusion

• Bioceramics has evolved to become an integral and vital segment of our modern health-care delivery system.

• In the years to come the composition, microstructure, and molecular surface chemistry of various types of bioceramics will be tailored to match the specific biological and metabolic requirements of tissues or disease states.

• “Molecular-based pharmaceutical" approach should be coupled with the growth of genetic engineering and information processing, resulting in a range of products and applications.

2. J. F. Shackelford (editor) (1999) *MSF bioceramics applications of ceramic and glass materials in medicine*


THANK YOU