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Bio Ceramics MSc Lect. 4

Presentation · January 2018

DOI: 10.13140/RG.2.2.18713.88163

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A ceramic material is an inorganic, non-metallic, often crystalline oxide, nitride or carbide material. Some elements, such as carbon or silicon, may be considered ceramics. Ceramic materials are brittle, hard, strong in compression, weak in shearing and tension. They withstand chemical erosion that occurs in other materials subjected to acidic or caustic environments. Ceramics generally can withstand very high temperatures, such as temperatures that **range from 1,000 °C to 1,600 °C** (1,800 °F to 3,000 °F). Glass is often not considered a ceramic because of its amorphous (noncrystalline) character. However, glassmaking involves several steps of the ceramic process and its mechanical properties are similar to ceramic materials.

Traditional ceramic raw materials include clay minerals such as kaolinite, whereas more recent materials include aluminium oxide, more commonly known as alumina. The modern ceramic materials, which are classified as advanced ceramics, include silicon carbide and tungsten carbide. Both are valued for their abrasion resistance, and hence find use in applications such as the wear plates of crushing equipment in mining operations. Advanced ceramics are also used in the medicine, electrical, electronics industries and body armor.

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

Bio ceramics are made in many different phases. They can be single crystals (sapphire), polycrystalline (alumina or hydroxyapatite), glass (Bioglass, glass ceramics) or composites (polyethylene-hydroxyapatite).

Introduction of Ceramic Materials for Artificial Joints

Ceramic materials have been used for artificial joints since the 1970s when the first generation of alumina products demonstrated superior resistance to wear, compared to the traditional metal and polyethylene materials. Advances in material quality and processing techniques and a better understanding of ceramic design led to the introduction of second generation alumina components in the 1980s that offered even better wear performance.

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 Bio ceramics:

- 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:

Bioceramics

Bioinert
- Alumina.
- Zirconia.
- Carbon.

Bioactive
- Bioglass.
- Hydroxyapatite.

Bio resorb able (biodegradable)
- Tricalcium phosphate ceramics.

Bio inert 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*.

Applications:

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.**

Properties:

- **Excellent biocompatibility.**
- **High bone bonding ability.**
- **Low mechanical strength.**

Biodegradable (bioresorbable) ceramics, as the name implies, degrade to implants in the host, bio resorbable refers to a material that placement within the human body which start to dissolve and slowly replaced by advanced tissue (such as bone), examples of these are *tricalcium phosphate ceramics*, *coralline*.

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.**

Properties:

- High compatabilty.
- Low chemical resistance.
- Poor mechanical strength.

The rate of degradation varies from material to another.

Generally, degradation rate of materials depends on *material composition*, *their functions* and *components of biological medium*.

Bio Ceramic materials and application

- **Alumina**

ASTM specifies that alumina for implant uses should be contain (99.5 %) of Al_2O_3 and less than (0.1 %) of SiO_2.

Typical properties of alumina are:

High hardness
High mechanical strength.
Minimal or no tissue reaction.
Good biocompatibility.
Blood compatibility.
Nontoxic to tissues.
Good corrosion resistance.
Excellent wear and friction behaviour.

.

The strength of alumina depends on its grain size and porosity. Generally, the smaller the grains, the lower the porosity and the higher the strength.

- Applications of **Alumina**
  - Orthopedics:
    Hip prosthesis ball.
    Bone screws.
    Knee prosthesis.
    Middle ear implants.
  - Dental implants: crowns and bridges.
  - Maxillofacial reconstruction.

- **Zirconia**

Pure zirconia can be obtained from chemical conversion of zircon. Zirconium dioxide is a white crystalline oxide of zirconium. Its most naturally occurring form, with a monoclinic crystalline structure .

Zirconia has some mechanical properties and biocompatibility better than alumina ceramics; therefore it's represented as an alternative to alumina.

It can be used in bulk form or as a coating.

Typical properties of zirconia are:

- High strength.
- High fracture toughness.
- Excellent wear resistance.
- High hardness.
- Excellent chemical resistance.

Applications:

- Femoral head in total hip joint replacement.
- Acetabular cup in total hip joint replacement.

One reason for the excellent wear and friction characteristics of zirconia are attributed to the fact that zirconia has less porosity.

➤ Carbon

Carbon is a versatile element and exists in different forms.

- Crystalline diamond.
- Graphite.
- Noncrystalline glassy carbon.
- Quasicrystalline carbon.

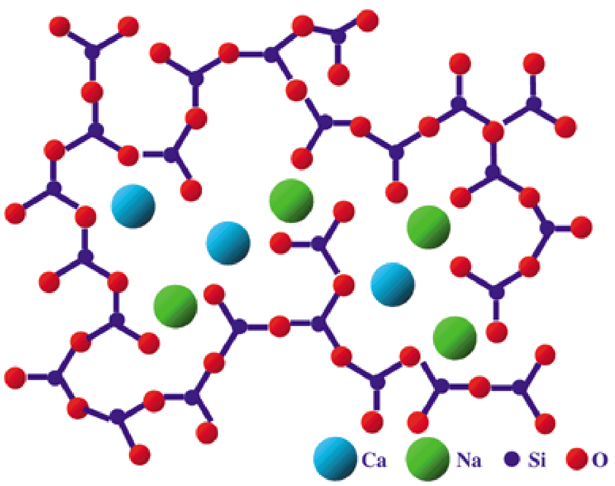
However, their brittleness and low tensile strength limits their use in major load bearing applications. It is used as biomaterial particularly in contact with blood due to blood compatibility, no tissue reaction and nontoxicity to cells; therefore it is used for repairing diseased heart valves and blood vessels.

Due to their good compatibility of carbon materials with bone and other tissue that carbon is an exciting candidate for orthopedic implants and used as a surface coating.

None of the three-bioinert ceramics (Alumina, Zirconia and Carbon) exhibited bonding with the bone. However, the bioactivity of the bioinert ceramics can be achieved by forming composites with bioactive ceramics.

Bioglass & Glass Ceramic

Bioglasses is a glass specifically composed of 45 wt% SiO_2, 24.5 wt% CaO, 24.5 wt% Na_2O, and 6.0 wt% P_2O_5.[1] Glasses are non-crystalline amorphous solids that are commonly composed of silica-based materials with other minor additives.



Typical properties of Bioglass & Glass Ceramic are:

- **Nontoxic.**
- **Chemically bond to bone.**

Applications

- **Orthopaedics.**
  Filling bone defects.
- **Dental prosthesis.**
  Teeth filling.

Hydroxyapatite

The hydroxyapatite (HAp) $Ca_{10}(PO_4)_6(OH)_2$ is a well-known as a valuable material for bone substitution. It is one of a few bioactive implantation materials capable of creating a direct bond with bone tissue.

The crucial question in the use of calcium phosphates for bone grafting is what kind of porosity of the implant is the most effective to promote ingrowth and yet strong enough to resist compressive stresses found in the place to be grafted. It is known that the ability for bone ingrowth increases and the compressive strength decreases when the porosity of the ceramic is increased. Porous ceramic has good ingrowth properties but may fracture. Dense implants remain intact but may be surrounded by fibrous tissue.

Typical properties of hydroxyapatite are:

- Biocompatibility.
- Bioactivity.
- Noninflammatory.
- Nontoxicity

Applications:

- Artificial bone substitutes in orthopedic.
- Dental applications.

The following figure represents some of ceramic products for medical applications.

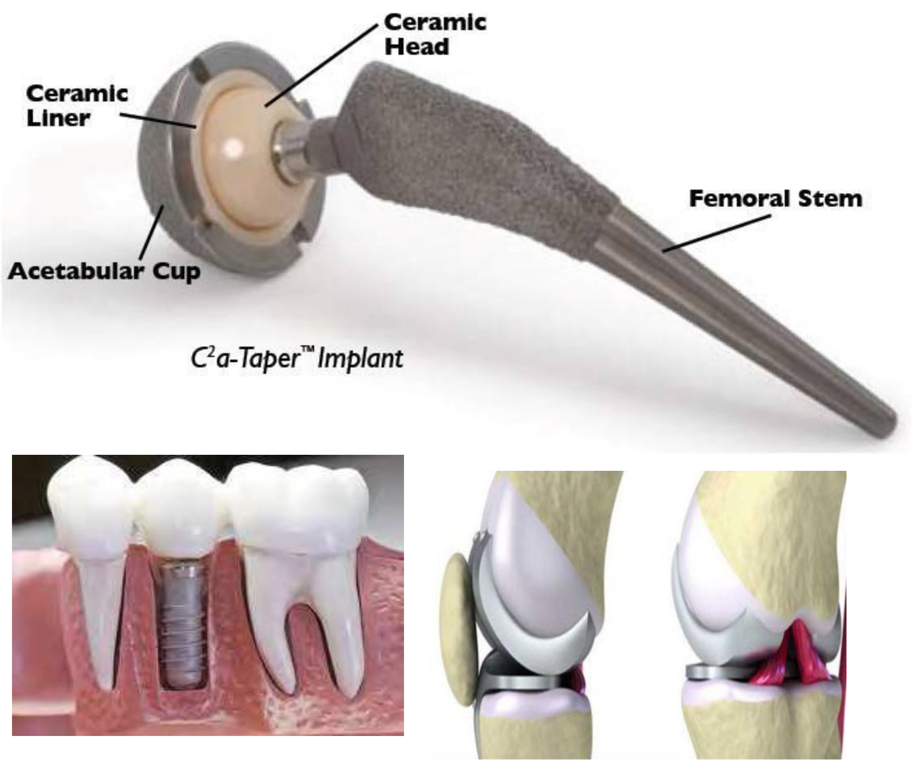


Figure (1): Ceramic products for medical applications.

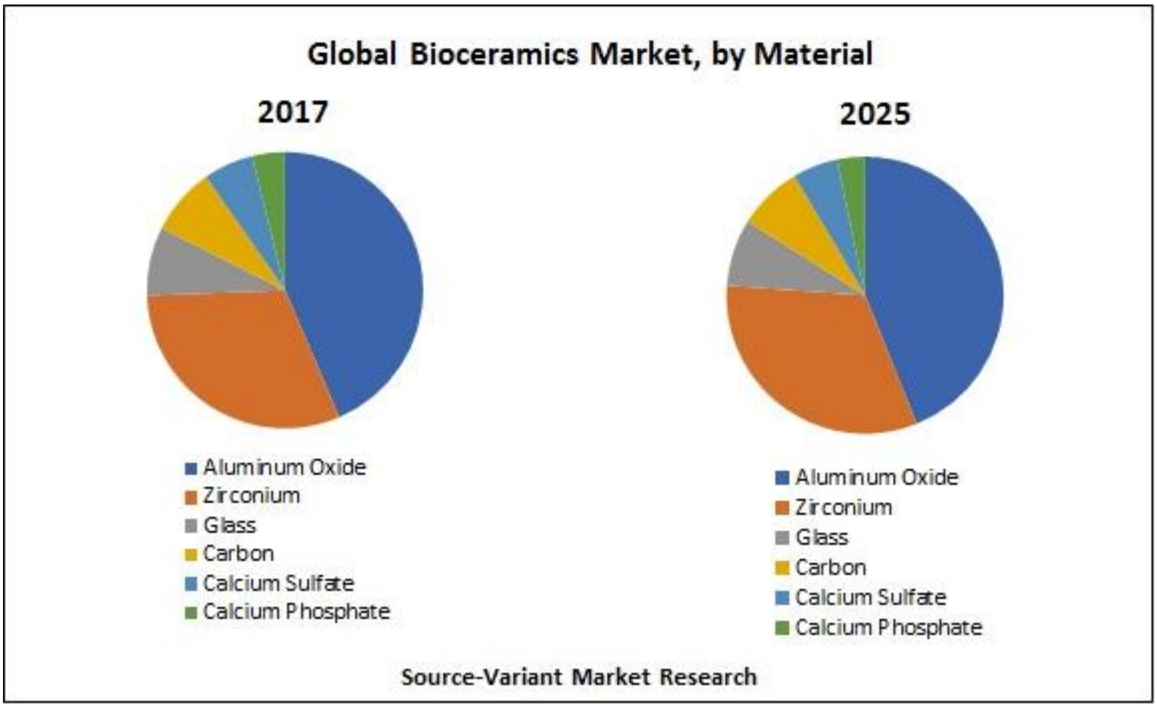


Figure (2): global bio ceramics market

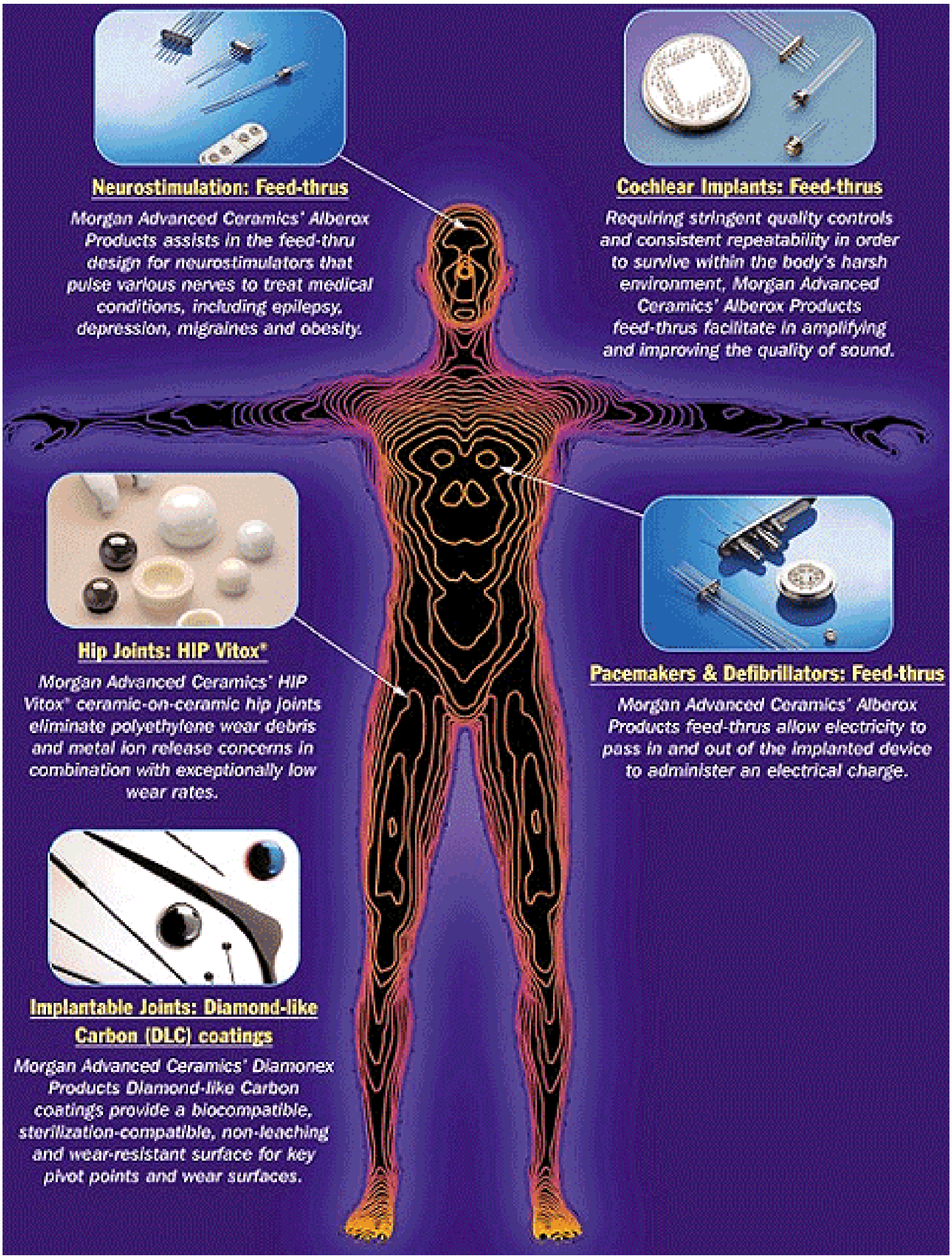


Figure (3): medical applications of ceramics

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