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. Based on their excellent biocompatibility they are used as implants within bones, joints and teeth. They are used as coatings in conjunction with metallic core structures for prosthesis. Herein the ceramic provides the hardness and wear resistance while the metallic core provides toughness and high strength for load bearing applications. Ceramic structures can be designed with varying porosity for bonding with the natural bone. 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.

Porous
- Porous Hydroxyapatite

Bio resorb able (biodegradable)
- Tricalcium phosphate ceramics.

1- Bio inert high strength ceramics

Ceramics are fully oxidized materials and are therefore chemically very stable. Thus ceramics are less likely to elicit an adverse biological response than metals, which only oxidize at their surface. Three types of inert ceramics are of interest in musculoskeletal applications: carbon, alumina, and zirconia. 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.

2- 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.**

3- Porous ceramics

The processing techniques required for porous ceramics depend critically on the volume fraction and size of the required porosity. For example, ceramics with porosity levels greater than 70 vol.% can be produced with a (hollow) cellular structure. The processing of cellular ceramics often involves a foaming process and the pore size is typically greater than 100 µm. High-porosity ceramics can also be produced by the bonding or sintering of ceramic fibers. These are termed fibrous ceramics and such materials are commonly used as high-temperature thermal insulation.

The potential advantage offered by a porous ceramic implant , The mechanical requirements of prostheses, however, severely restrict the use of low-strength porous ceramics to nonloadbearing applications. Commercially available porous products originate from two sources: hydroxyapatite converted from coral or animal bone. The optimal type of porosity is still uncertain. The main purpose of reaching third-generation bioceramics is to obtain porous ceramics that act as scaffolds for cells and inducting molecules able to drive self-regeneration of tissues. With these requirements, second-generation bioceramics with added porosity are being studied, although the design of new advanced ceramics is also explored with added porosity. This porosity should be in agreement with biological requirements. As starting material, nanometric apatites, shaped as pieces with interconnected and hierarchical porosity within the micrometer range, would be a good starting point to fabricate these scaffolds.

4-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**

Aluminum oxide is produced by heating its hydrates. At least seven forms of alumina have been reported, but six of these forms have traditionally been designated 'gamma alumina'. When heated above 12000C, all other structures are irreversibly transformed to the hexagonal alpha-alumina, corundum, a close-packed arrangement of oxygen ions.

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

Arising from the chemical stability and high surface finish and accurate dimensions, there is a very low friction torque between the alumina femoral heads and the acetabular cup, leading to a low wear rate.

Combinations of ceramic head/UHMWPE cup and ceramic head/ceramic cup were tested and compared to the metal head/UHMWPE cup. The wear resistance of the ceramic head/UHMWPE cup combination over metal/UHMWPE has improved from 1.3 to 34 times in the laboratory and from three to four times clinically. High-density, high-purity polycrystalline alumina is used for femoral stems, femoral heads, acetabular components, and dental implants

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.

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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.

Zirconia (ZrO2) is a white amorphous powder and dioxide of zirconium. Zirconia is bioinert and thus does not interact with the human body. With an increase in temperature Zirconia changes its monoclinic crystalline state and morphs into tetragonal crystalline and subsequent cubic crystalline. Zirconium Oxide ceramic has several advantages over other ceramic materials, due to its transformation toughening mechanisms, low thermal conductivity, abrasion resistance, desirable biocompatibility, diminished plaque accumulation and excellent light dynamics

It can be used in bulk form or as a coating.Partially stabilized zirconia is commonly used in prosthetic devices because it is stronger and has high resistance to wear. The flexural strength and fracture toughness of zirconia is higher as compared to other ceramics which makes it resistant to masticatory forces when used as crows with exact precision of fit . Also, zirconia implants have shown to accumulate less bacteria in vivo and undergo a lower rate of inflammation - associated processes compared to titanium . Zirconia has also been used in shoulder reconstruction surgery and as a coating over titanium in dental implants.

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

The benign biological reaction elicited by carbon-based materials, along with the similarity in stiffness and strength between carbon and bone, made carbon a candidate material for musculoskeletal reconstruction . Isotropic carbon, on the other hand, has no preferred crystal orientation and hence possesses isotropic material properties. There are three types of isotropic carbon: pyrolytic, vitreous, and vapordeposited carbon. Pyrolytic carbons are formed by the deposition of carbon from a fluidized bed onto a substrate. The fluidized bed is formed from pyrolysis of hydrocarbon gas at between 1000 and 2500°C .

Carbon is a versatile element and exists in different forms.

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

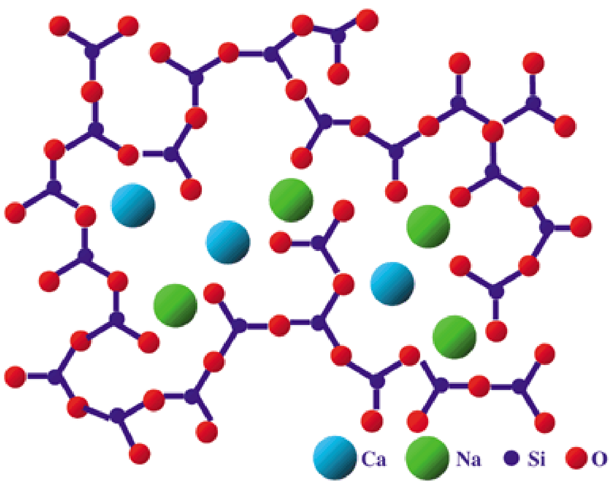
However, their brittleness and low tensile strength limits their use in major load bearing applications. It is used as biomaterial particularly in contact with blood due to blood compatibility, no tissue reaction and nontoxicity to cells; therefore it is used for repairing diseased heart valves and blood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

Hydroxyapatite ceramics are bioactive, such that they promote hard tissue ingrowth and osseointegration when implanted within the human body. The porous structure of this material can be tailored to suit the interfacial surfaces of the implant. However they lack mechanical strength for load bearing applications as standalone structural members.

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.

The porosity of the hydroxypatitie structure can be controlled similar to the human bone. Thus it is ideal to be used in implants for artificial tooth, hip and knee replacements. Typically most high-bearing implants contain hydroxyapatite coating. The hydroxypatite coating is applied to the core metallic implant using plasma spray technology. This minimizes the delamination of the hydroxypatite coating from the metal implant and prolongs the working life of the prosthesis.

Typical properties of hydroxyapatite are:

- Biocompatibility.
- Bioactivity.
- Noninflammatory.
- Nontoxicity

Applications:

- Artificial bone substitutes in orthopedic.
- Dental applications.

Type of Attachment	Type of Bio ceramic
Dense, nonporous, almost inert ceramics attach by bone ingrowth into the surface irregularities, by cementing the device into the tissue, or by press fitting into a defect (morphological fixation)	Alumina, Zirconia
For porous implant bone ingrowth occurs, which mechanically attaches the bone to the material (biological fixation)	Porous Hydroxyapetite, Hydroxyapatite coated porous metals.
Surface-reactive ceramics, glasses, and glass-ceramics attach directly by chemical bonding with the bone (bioactive fixation)	Bio-active glass, Bio-active Glass-ceramics, Dense Hydroxyapatite
Resorbable ceramics and glasses in bulk or powder form designed to be slowly replaced by bone	Calcium Sulfate, Tricalcium Phosphate, Calcium phosphate salts, Bioactive glasses

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

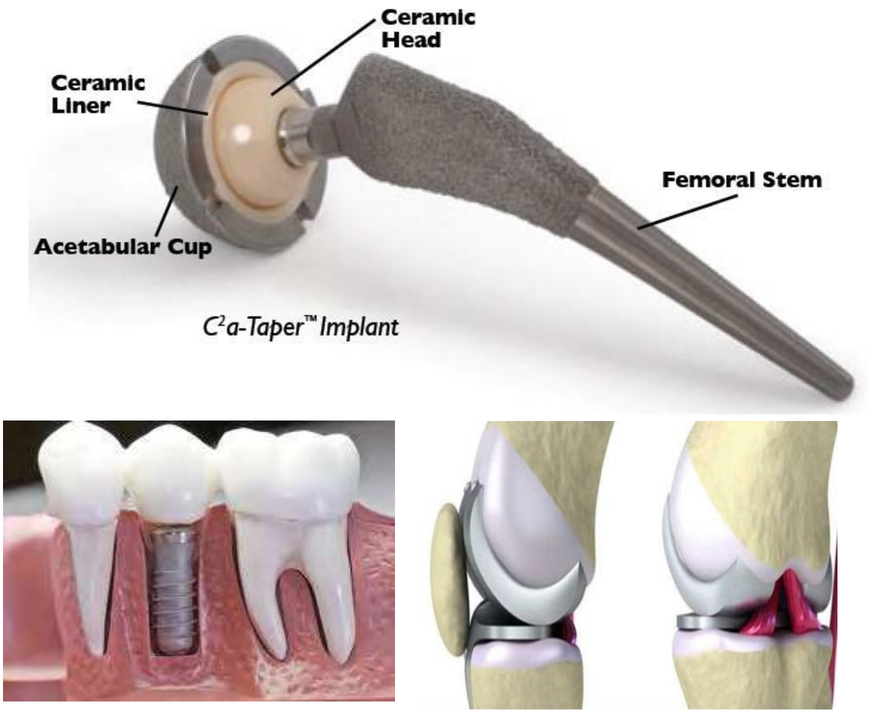


Figure (1): Ceramic products for medical applications.

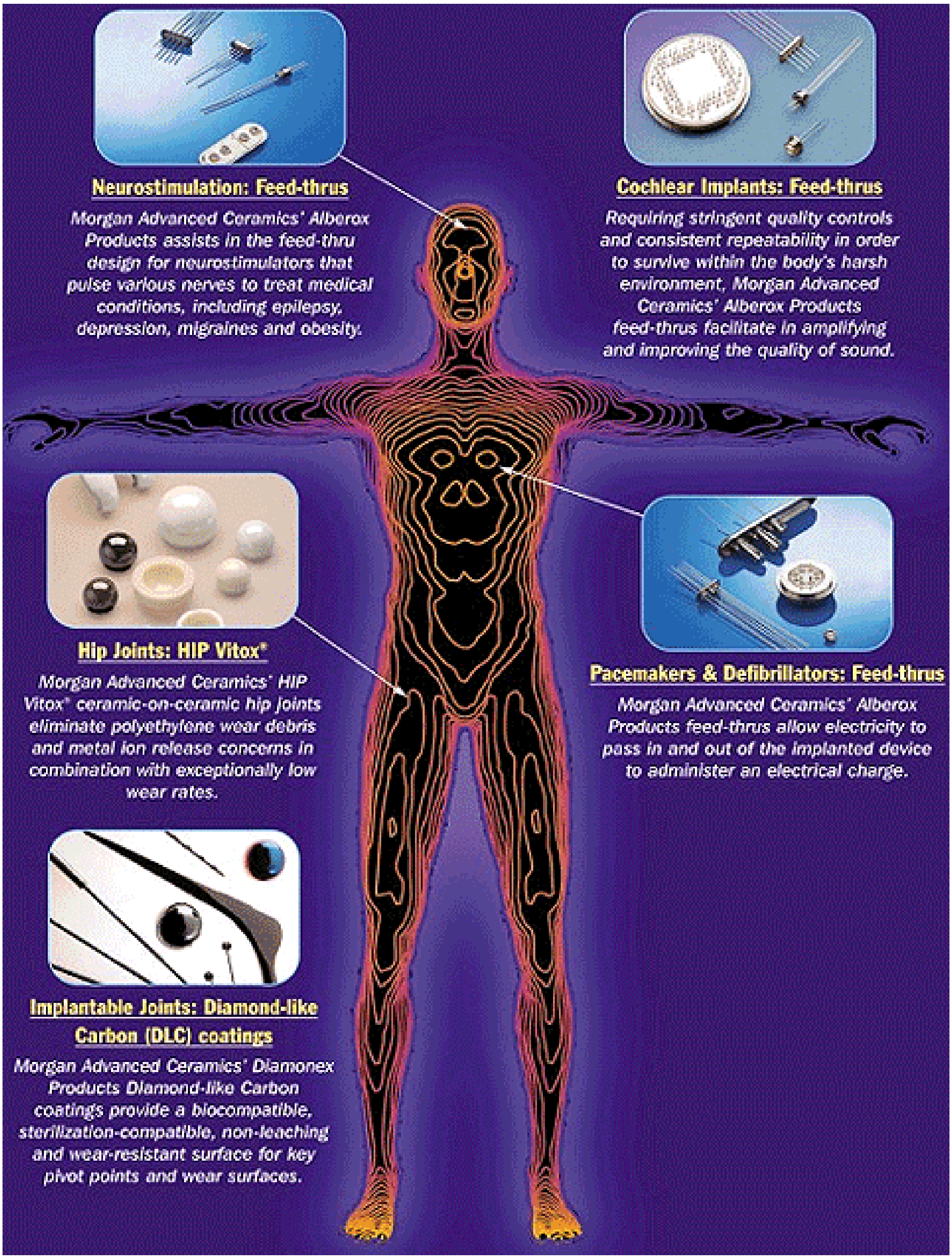


Figure (2): medical applications of ceramics

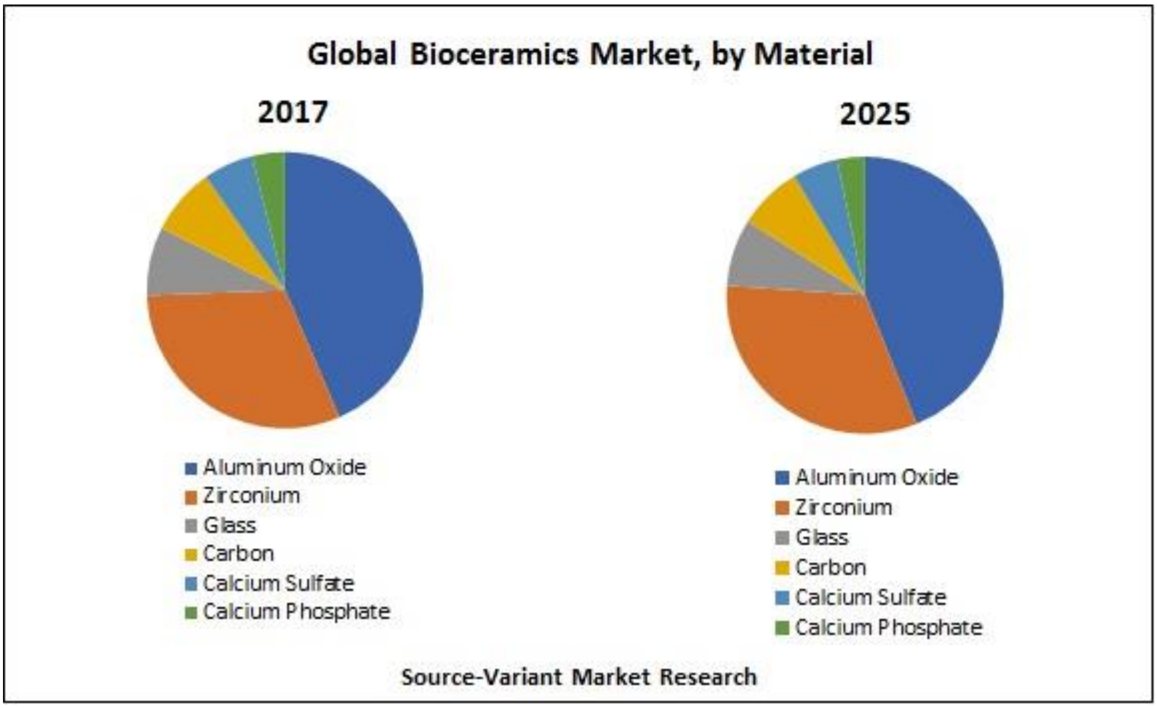


Figure (3): global bio ceramics market