

# What is Bioceramics?

- Ceramics are refractory polycrystalline compounds
- ✓ Inorganic
- ✓ Hard and brittle
- ✓ High compressive strength

- Applications
  - Orthopaedic load-bearing coatings
  - Dental implants
  - Bone graft substitutes
  - Bone cements

## Bio Ceramics

## Classification of Bio-ceramics

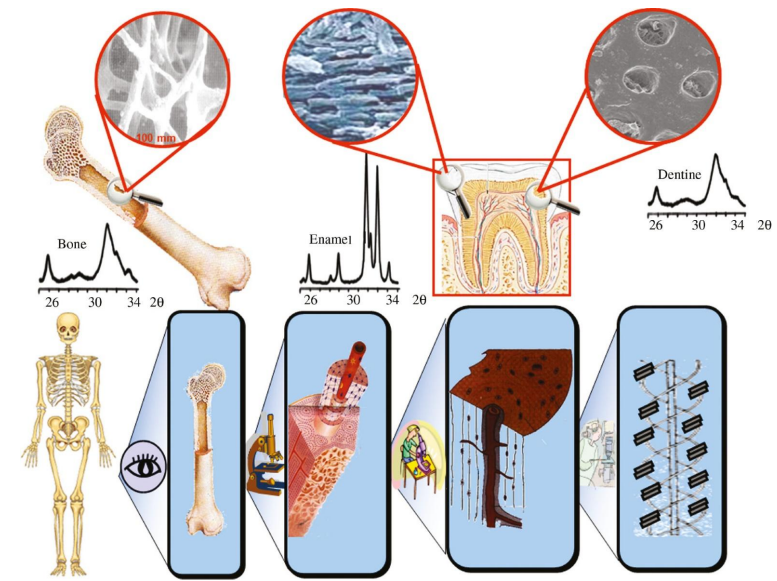
The development of bio-ceramics can be classified into three generations.

- The **first generation** would correspond to bio-inert bio-ceramics, such as alumina and zirconia, which are mostly used for inert orthopedic and dental implants.
- The **second generation** comprises bioactive and bioabsorbable ceramics, such as calcium phosphates or bioglasses.
- The **third generation** is scaffolds for tissue engineering which aim to drive the regeneration of living tissues.

In the meantime, many studies have demonstrated that better and unusual material properties can be achieved by manipulating **ceramic length scales in the nano range**. For that reason, during the last two decades, nanostructured materials have been widely studied and significant steps forward have been made in their understanding in recent years.

- Ceramics are broadly used in a large variety of technological applications requiring both structural and functional properties.
- They have received significant attention as candidate materials for use as structural materials under conditions of high loading rates, high temperature, wear and chemical etching too severe for metals.
- In this sense, bone-related biomedical applications are the most demanding of bioceramics.
- However, their inherent brittleness derived from their low fracture toughness has prevented their use in some applications.
- Moreover, the presence of flaws or defects in the material can lead to catastrophic failure during mechanical loading. Therefore, new kinds of materials have been studied for increasing the performance of ceramic matrix materials.
- For ceramics used in biomedical applications, which are extensively called bioceramics, this problem still remains.
- Nanophased ceramics are being investigated as a way of solving some of the structural and bio-related problems.

- For example, nanometric features in the surface of a prosthesis seem to reduce the risk of rejection and enhance the proliferation of osteoblasts (bone-forming cells).
- Nanophased or nanostructured ceramics can be obtained either by nanocrystalline materials or with nanocomposites.



**Bioceramics: from bone substitutes to nanoparticles for drug delivery**

## Properties and Application of nanocrystalline ceramics

- In the case of nanocrystalline ceramics, as the grain size is reduced, the grain volume at grain boundaries is increased (Meyers et al., 2006).
- Thus, due to the high density of interfaces, an important fraction of atoms will be at the interface.
- This fact allows nanocrystalline materials to offer unusual and improved properties when compared to microscale materials.
- There are studies (Webster et al., 1999) that provide evidence that nanophase ceramics could promote osseointegration, which is critical for the clinical success of orthopaedic/dental implants.
- Webster et al. (2000) synthesized dense nanophase alumina ( $\text{Al}_2\text{O}_3$ ) materials and showed a significant increase in protein absorption and osteoblast adhesion on the nano-sized ceramic materials compared to traditional micron-sized ceramic materials.
- Other studies (Du et al., 1999) have suggested that better osteoconductivity would be achieved if synthetic Hydroxyapatite (Hap) could more resemble bone minerals in composition, size and morphology.

## Advantages

The use of nanocrystalline materials can thus offer advantages for use in biomedical applications, such as:

- increased resistance/hardness
- improved toughness
- lower elastic modulus and lower ductility
- reduced risk of rejection
- enhanced proliferation of osteoblasts
- promotion of osseointegration

With ceramic nanocomposites, even greater improvements can be achieved and the use of new ceramic matrix nanocomposites has been suggested (Gleiter, 1995; Narayan et al., 2004;

# Nano-Composites

## Ceramic nanocomposites

□ Nanocomposites based on ceramic materials have been studied in order to improve mechanical properties and alter functional properties.

□ The ceramic nanocomposites reported until now are either a ceramic nanophase in a ceramic matrix, a carbonaceous nanophase in a ceramic matrix or a ceramic nanophase in a polymer matrix.

□ Enhancements in stability, hardness, strength, toughness and creep resistance compared to the unreinforced matrix material have been reported in nanocomposites (Narayan et al., 2004).

□ Moreover, the combination of properties can lead to a new generation of medical devices and implants combining mechanical properties with bioactive properties.

□ Zirconia/alumina nanocomposites: also known as alumina-toughened zirconia (ATZ), they consist of a zirconia matrix reinforced with alumina nanoparticles. They show exceptional resistance and extraordinary toughness.

□ Silicon nitride/silicon carbide nanocomposites: the obtained results are controversial.

□ Ceramic/carbon nanofibre composites: widely used, there is an improvement in properties (Pace et al., 2002).

□ Ceramic/carbon nanotube (CNT) composites: mechanical and electrical properties are enhanced, but biocompatibility issues are still controversial (Streicher et al., 2007; Garmendia et al., 2008, 2009, 2010, 2011).

□ Ceramic in polymer composites: especially relevant for tissue engineering applications.

Some examples of ceramic based nanocomposite materials are as follows.

- Alumina-based nanocomposites: with the addition of several nano-reinforcements, alumina matrix materials with improved mechanical properties (higher resistance, hardness, wear resistance and fracture toughness) have been obtained.
- Alumina/silicon carbide nanocomposites: the incorporation of SiC nanoparticles to an alumina matrix increases wear resistance.
- Alumina/zirconia nanocomposites: also known as zirconia-toughened alumina (ZTA) nanocomposites, they consist of a fine-grained alumina matrix reinforced with zirconia particles. The addition of the zirconia nanoparticles is intended to increase the toughness of the alumina matrix.
- Alumina/titania nanocomposites: increased hardness, fracture toughness and fracture resistance have been achieved.