



Inhomogeneous Materials Perform Better: Functionally Graded Materials for Biomedical Applications

Bruno Henriques*

Mechanical Engineering Department, School of Engineering, University of Minho, Portugal

When introducing the theme of functionally Graded Materials (FGMs) first is necessary to define this class of materials. Conversely to conventional homogeneous materials, in which the composition tend to be uniform over its volume, in FGMs the composition and the structure gradually change over its volume, thus resulting in changes in the properties of the material. Variations in FGMs can include variations in chemical composition, physical state and geometrical configurations. Learning from nature, one can see that biological structures, particularly those that are load carriers (e.g. stems of plants and trunks trees, animal bones, etc.), are not uniform and that its geometry changes according to the boundary and loading conditions defined by their environment. A good example of this is the architecture of a bone, which displays a change from a dense stiff external structure (the cortical bone) to a porous internal one (the cancellous bone). This configuration corresponds to an optimized configuration in respect to the direction of principle stresses and magnitude of the shear stress, thus resulting in an optimized mechanical design that produces uniform stress distribution with no localized stress peaks. The structure of bones and other biological tissues result from a continuous process of intelligent optimization, which is based on the ability of modeling its shape according to external mechanical stimuli. Therefore, the design of the optimal structures to be used in certain components can be inspired in these optimized biological structures.

FGMs were first applied to increase the adhesion strength and reduce the thermal stresses in metal-ceramic joints to be used in rocket engines. However, the concept has evolved from the initial limited objective of relieving stress when combining two dissimilar materials like metal and ceramic to many other fields of application such as optics, nuclear energy, engineering, electronics, biomaterials, just to cite a few. I will focus particularly on the application of FGMs to biomaterials as its importance has been growing remarkably. Therefore, special attention will be given ahead to Functionally Graded Biomaterials for the following applications: scaffolds, artificial joints, dental implants and dental restorations.

The functional gradation has been applied to the manufacturing of scaffolds for tissue engineering with success. Porosity gradients in hydroxyapatite ceramics for bone implants showed to improve osteoconduction and demonstrated excellent bioactivity. The macropores in the outer layer provide access for cells and blood vessels and enhance new bone formation, whereas the inner denser structure improve the strength of the implant. The addition of collagen to Hydroxyapatite (HAP, $\text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2$) to develop functionally graded porous structures for the fabrication of scaffolds have also been tested with good results. The advantage of these scaffolds is the possibility of controlled and accelerated remodeling and incorporations of the new formed materials as living hard tissue.

The application of functionally graded features has also shown to enhance the adhesion between bones and orthopedic implants. Several approaches have been tested and revealed enhanced results as

compared to conventional fixation methods. The FGMs approaches are the following: prostheses coated with a porous metal; metallic or ceramic prostheses coated with calcium phosphate ceramics (e.g. bioactive ceramic and hydroxyapatite); and surface porous prostheses coated with HAP. The latter alternative has been shown to promote the best fixation to the bone as the presence of hydroxyapatite accelerates the bone ingrowth into the implant and allows the bone to bond to HAP physicochemically. This phenomenon prevents pain while walking caused by micromotion or loosening of the prosthesis, and allow weight bearing earlier after implantation. Another possibility of creating a functionally graded interface for bone fixation to a prosthesis is to place HAP granules between the bone and the polymethylmethacrylate (PMMA) bone cement. This allows an effective bonding of the bone cement to the prosthesis; a mechanical bonding between the bone cement and the HPA granules; and finally the chemical bonding between the granules and the bone. This technique inhibits the formation of a connective tissue membrane between the bone and the bone cement that often occurs several weeks after implantation (in surgeries when no HAP granules are used) and that can cause the prosthesis to loosen at the interface between the bone cement and the bone.

Similar behaviour can be expected from functionally graded dental implants composed of metal (usually titanium and titanium alloys) and HAP. They exhibit good biocompatibility and toughness. Furthermore, animal implant test showed that the presence of HAP favors the growth of new bone, which is mostly in contact with Ti/HAP FGMs and only partially in contact with the titanium implant.

Dental restorations have also received some attention in respect to their damage resistance and aesthetic improvement by applying the concept of functionally graded structures in their fabrication. The performance deficiencies reported by clinical studies with alumina- and zirconia-based restorations all-ceramic restorations, such as fracture, poor aesthetic properties of ceramic cores and the difficulty in achieving strong ceramic-resin-based cement bond have been successfully addressed by FGMs system. A functionally graded glass/zirconia/glass (G/Z/G) structure was demonstrated to improve the damage resistance, the aesthetics and the potentially cementation properties as compared to conventional homogeneous monolithic yttria-stabilized tetragonal zirconia polycrystal (Y-TZP) restorations. The same G/Z/G system,

***Corresponding author:** Bruno Henriques, Mechanical Engineering Department, School of Engineering, University of Minho, Portugal, Tel: 00-351-934273676; E-mail: brunohenriques@dem.uminho.pt

Received July 10, 2013; Accepted July 11, 2013; Published July 12, 2013

Citation: Henriques B (2013) Inhomogeneous Materials Perform Better: Functionally Graded Materials for Biomedical Applications. J Powder Metall Min 2: e112. doi:10.4172/2168-9806.1000e112

Copyright: © 2013 Henriques B. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

displaying a controlled modulus gradient at the surface, has also shown to exhibit significantly higher load bearing capacity and slide contact resistance than homogeneous zirconia counterparts.

Additionally, the application of a metal-ceramic composite interlayer between the metallic substrate and the veneering porcelain in a metal-ceramic dental restoration has been shown to produce a

significant improvement on the adhesion between the two dissimilar materials.

With this brief review of the applications and benefits of FGMs to the biomedical field I intended to underline the importance, but foremost, the potential that this useful concept can bring to the design and manufacture of various types of biomedical components.

Citation: Henriques B (2013) Inhomogeneous Materials Perform Better: Functionally Graded Materials for Biomedical Applications. J Powder Metall Min 2: e112. doi:10.4172/2168-9806.1000e112

Submit your next manuscript and get advantages of OMICS Group submissions

Unique features:

- User friendly/feasible website-translation of your paper to 50 world's leading languages
- Audio Version of published paper
- Digital articles to share and explore

Special features:

- 250 Open Access Journals
- 20,000 editorial team
- 21 days rapid review process
- Quality and quick editorial, review and publication processing
- Indexing at PubMed (partial), Scopus, EBSCO, Index Copernicus and Google Scholar etc
- Sharing Option: Social Networking Enabled
- Authors, Reviewers and Editors rewarded with online Scientific Credits
- Better discount for your subsequent articles

Submit your manuscript at: <http://omicsgroup.info/editorialtracking/primatology>