

Functionally Graded High Strength Ceramics Obtained by Selective Laser Melting

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Editorial

Due to its excellent mechanical properties, good biocompatibility, corrosion resistance and excellent chemical stability oxide ceramics (alumina and zirconia) have been qualified as a material for a growing range of medical applications such as prostheses, dental materials, femoral heads, among others [1,2]. It is often used in its dense form, despite there are some applications where the use of porosity has proven to be beneficial [3-5]. The use of dense ceramic prostheses can pose the problem of stress shielding (reduction in bone density as a result of removal of normal stress from the bone by an implant) due to the mismatch in Young's modulus (YM) relative to the bone, which is significantly lower [6,7]. Porosity have the ability to reduce the YM of the ceramic, reducing the mismatch to that of the bone, and at the same time, exhibits the potential of bone ingrowth in implants, depending on porous parameters such as pore size interconnectivity and porosity [5]. Four levels of pore sizes was described by Smiske et al. [8] as heaving specific features: 1) the range between 1-100 microns are similar to porous bone structure and must be present in biomaterials for biomimetic principles; 2) the range between 100-350 microns is optimum for bone ingrowth; 3) the range between 350-1000 microns is useful to decrease the ceramic YM and to reduce the stress shielding; 4) the range of 350 to 3500 microns is usefull for mechanical attachment of a porous implant during the medical surgery. The implant should therefore include these types all these types of porosity ranges rather than being dense or having homogeneous porosity. Together with the type of porosity, the pore connectivity also impacts the mechanical properties and cell/tissue ingrowth in an implant [9]. The gradation in porosity size and shape across the implant volume follows the philosophy of the functionally graded materials (FGMs). FGMs offer the advantage of tailoring materials with specific structural, compositional, morphological, and mechanical properties. The early research and development of FGMs was driven by the need of reducing the thermal stresses developed in thermal barrier coatings on high temperature alloys. Now FGMs can be found in various material/phase combinations. FGMs have also been used as biomaterials for dental and orthopedic applications [10-12]. FGMs have been reviewed by some researchers.

The traditional processing methods for porous biomaterials cannot meet all the above-mentioned specifications simultaneously. The Selective Laser Melting is a powerful technology that can address them based on its capacity to create parts with complex shapes from a 3D CAD file, built layer by layer [8]. Therefore, selective laser sintering/melting (SLS) technology can be used to produce components with the desired size, shape and distribution of the porosity within the ceramic component. Only limited references can be found in literature on the laser sintering of oxide ceramic components, and no references could

be found where the control of the morphology and distribution of porosity of oxide ceramics had been tried from 3D complex geometries. Selective laser melting of oxide ceramics such as alumina (Al₂O₃) and zirconia (ZrO₂) has previously been investigated for use in biomedical applications by Hagedorn et al. [13]. The production of other ceramic and polymeric components (e.g. HAP, apatite-mulite and PMMA) has also been investigated. [14].

While porosity is convenient for the osseo integration reasons and YM adaption, it brings also undesired issues such as the weakening of the ceramic structure. On the other hand, porosity offers the opportunity to introduce additional materials into the object that accounts for improvements in the mechanical properties. The infiltration of bioactive glassy or polymeric materials in implants and porcelain dental prostheses, for instance, can overcome the lack of mechanical properties of the porous zirconia. It has been shown elsewhere that the infiltration of a glass with low coefficient of thermal expansion on an alumina-zirconia matrix produced compressive stresses in the matrix, enhancing the strength of the ceramic by 25-50% [15]. This fact would be of extreme importance at the early stage of implantation of an implant, where both higher mechanical strength and good bonding to human bone as well as to soft tissues are needed. At a second stage, these materials are expected to be resorbed inside body, allowing the bone to grow inside the porous implant.

In the case of dental prostheses, the positive effect of the infiltration of a glass on the surface of a zirconia dental substructure, creating a graded structure, has also been demonstrated [10-12]. The infiltrated zirconia displayed increased resistance to flexural fracture relative to monolithic Y-TZP. This was attributed to the graded structure that spread the maximum tensile stresses from the surface into the interior. A twice load-bearing capacity of the graded substructure (glass infiltrated) was obtained compared to homogeneous zirconia structure [10-12].

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