Bending Strength of Zirconia-Bioglass Composites

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Introduction

An important application of ceramics is observed in the dentistry, especially in the development of prosthesis or parts in restorations, such as abutments [1]. All-ceramic dental restorations are attractive to the dental community because they provide higher strength, better biocompatibility and aesthetics, as compared with metal and resin restorations [2]. On the other hand, the applications of all-ceramic crowns and bridges have been limited by their brittle behavior, long processing time and poor machining performance [3].

Tetragonal zirconia polycrystals (TZP) are usually fabricated by solid-state sintering at temperatures around 1550-1600^{0}C [4], while it is an expensive fabrication method and will inevitably increase the production cost limiting their use. Sometimes, in order decreasing the sintering temperature, additives are deliberately introduced. The possibility of to unite the good mechanical and biological properties of the $3CaO.P_2O_5$-SiO_2-MgO bioglass [5] beyond its thermal compatibility with the TZP properties, reducing to the production costs and allows to glimpse an increase of the application field these materials, in special as parts of dental implantation.

The purpose of this study is to evaluate the modulus of rupture of the ZrO_2-bioglass ceramics sintered at low temperatures, correlating these properties with thermal residual stress generated after sintering, in the both phases ZrO_2-matrix and grain boundary.

Experimental procedure

Commercial ZrO_2-(3mol.%Y_2O_3) powder containing 15 vol.% of residual ZrO_2-Monoclinic phase (Tosoh 3YSB-Japan) and bioactive $3CaO.P_2O_5$-SiO_2-MgO bioglass (V4) powder [5] were used as starting powders. The Y-TZP and V4-bioglass powder were mixed by milling for 4h, using and high-purity ZrO_2 balls, then dried and sieved through 32μm screen. Powder mixtures were prepared using 0, 3, 5 and 10% of bioglass. The mixtures were compacted by cold uniaxial pressing at 80MPa, and sintered at 1300^{0}C, for 2h, with heating rate of 10^{0}C/min. Bulk density was measured by the Archimedes method. Crystalline phases were determined X-Ray diffractometry: the monoclinic-ZrO_2 content was calculated using the Garvie method [6]. Four-point bending test was used for determination of bending strength. Rectangular bars of 4x3x45mm were obtained according ASTM C 1116-94. The tests were conducted with outer and inner spans of 40 and 20 mm and crosshead speed of 0.5 mm/s at room temperature using an MTS 310 Universal Test Machine.

Results and discussions

X-Ray diffractogram indicates the presence of the high fraction of t-ZrO_2 phase and residual m-ZrO_2. A little increasing of the monoclinic content is observed as function of additive increasing, see Figure 1. It is observed that samples presented almost full density when bioglass is added.

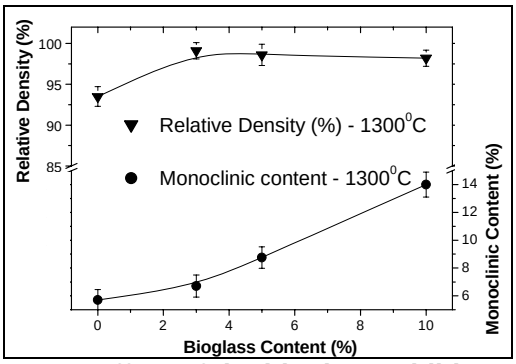

Figure 2 - Effect of the bioglass addition on the density and ZrO_2-monoclinic content.

The results of bending strength testing are presented in the Figure 2. These results are related to the increasing of transformed monoclinic phase, and its consequent effect into densification of the ZrO_2 samples, as function of bioglass content. Samples doped with 10% of bioglass presented a bigger

porosity level than sample with bioglass 3%, corroborating with presented bending strength results. Moreover, the minor densification in samples with 10% of bioglass implies that the pores size into this material, also is superior to pores size into the samples with bioglass 3%.

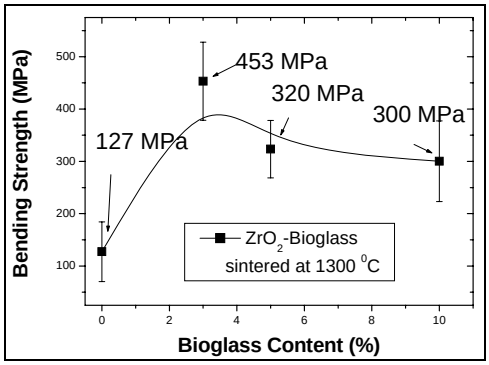

Figure 2 – Bending strength as function of bioglass content.

The residual stress in the zirconia matrix is calculated according to the theoretical model proposed by Taya *et al*. [7], considering E-modulus of 90 and 190MPa and coefficient of thermal expansion of $10.7x10^{-6}$ and $10.2x10^{-6}/^0C$, for bioglass and ZrO_2, respectively. The results of residual compressive stress in the grain boundary and tensile stress in the ZrO_2-matrix grains are presented in the Figure 3.

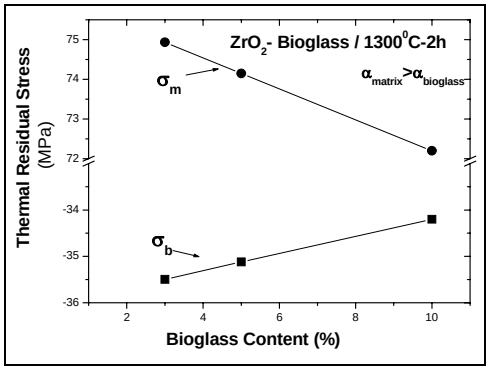

Figure 3– Residual stress as function of bioglass content (grain boundary).

The toughening of the ceramics developed in this work can be related to various phenomena, such as tetragonal-monoclinic transformation, crack deflection, transformation induced by thermal residual stress, and porosity of the sintered samples. It can be observed that the increasing of the intergranular phase (bioglass) leads to the increasing of % of monoclinic phase and increasing of the porosity associated to this phenomena. The increasing of bioglass content leads to greater accumulates of glass concentrations in triple junctions with consequent formation of stress concentration to crack propagation. The tensile thermal residual stresses in the ZrO_2 matrix show an effect each lesser time as function of bioglass addition in composition. Therefore, it has a reduction in the residual stress contribution in phase transformation induced by stress, which could improve the toughness. The high porosity presented for monolithic ZrO_2-ceramics (around of 10%), are due to low sintering temperature used in the solid state sintering and is considered to be the main factor for the low fracture toughness presented by ZrO_2 sintered without bioglass addition.

On the other hand, the presence of low amounts of bioglass facilitates the diffusional processes, reduces the possibility of *t-m* transformation during the cooling and increases the thermal residual stress favoring the phase transformation during the crack growth, thus increasing the fracture toughness.

Conclusions

The Y-TZP-bioglass ceramics sintered at 1300 ^{0}C with 3% of bioglass showed good mechanical properties, presenting strength of 453 MPa. These results are well established with the high relative density and low monoclinic-ZrO_2 phase presented in samples. An increasing of porosity and *t-m* transformation is observed in samples sintered with higher additive content, reducing the mechanical properties. The relatively-low sintering temperature used in this work, 1300^0C, associated with good mechanical properties, can be attractive for development of ZrO_2–bioglass components to be used in dental implant parts.

References

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