

Porous Ceramic Composite $\text{ZrO}_2(\text{MgO})\text{-MgO}$ for Osteoimplantology

A S Buyakov^{1,2}, S N Kulkov^{1,2}

¹Strength and Design Department, Physical-Technical Faculty, Tomsk State University, 634050 Tomsk, Russia.

²Laboratory of Physics of Nanostructured Functional Materials, Institute of Strength Physics and Materials Science SB RAS, 634055 Tomsk, Russia

E-mail: Alesbuyakov@gmail.com

Abstract. Pore and crystalline structure, biocompatibility of ceramic composite $\text{ZrO}_2(\text{MgO})\text{-MgO}$ were studied. The main mechanical characteristics were determined and it has been shown that compression strength directly depends on microstresses obtained from X-ray data. In-vitro studies of mesenchymal stromal stem cells (MMSC), cultivated on material surface are shown that cell proliferation and differentiation of MMSC goes through osteogenic type.

1. Introduction

Bone integrity regeneration in terms of postoperative recovery and aesthetic due to the cancer resection or injuries is one of very important issues. An application of ceramics for using as osteoreplacement material has a special interest now. The most actively developed studies in this area are investigations of zirconium ceramic (ZrO_2) included in ISO register as a material for bone replacement. Moreover, magnesium is involved in protein synthesis and stabilization of DNA molecules, which can improve regeneration processes. Using of such ceramics can provide bone tissue integration with an implant and prevents the risk of forming adverse biological response from the surrounding tissues.

However, successful osteo-integration depends not only on biocompatibility of the material, but also on the structure-phase state and mechanical parameters [1, 4]. Mechanical characteristics of osteoreplacement material should correspond to bone tissue properties [5]. Strength of the material is mostly determined by its microstructure that is why information about the fine crystalline structure parameters is very important for obtaining the necessary strength of osteoreplacement material. The aim of this work is to study influence of composition, micro- and fine crystal structure on mechanical properties of the porous ceramic composite $\text{ZrO}_2(\text{MgO})\text{-MgO}$ and to study biocompatibility of the material.

2. Materials and Methods

Ceramics with different MgO concentrations with a pore volume 50% sintered at 1600°C were studied. Porosity level was achieved by adding ultra-high-molecular-weight polyethylene particles. Material microstructures were studied by scanning electron microscope Tescan VEGA 3. Fine crystalline structure parameters were measured from X-ray diffraction data and compressive strength of were studied by using universal testing machine Devotrans DT.



Biocompatibility of ceramics was studied by in vitro definition of mesenchymal stromal stem cells (MMSC) response on the surface of ceramic samples. To determine the ability of MMSC to directed osteogenic differentiation during their cultivating on the surface of porous ceramic materials were made a detection alkaline phosphatase, which is the first marker of osteogenic differentiation, produced by cells.

3. Results and Discussion

Figure 1 represents distribution of pores inside of ceramic samples: with an average size 103 microns and 28 μ m.

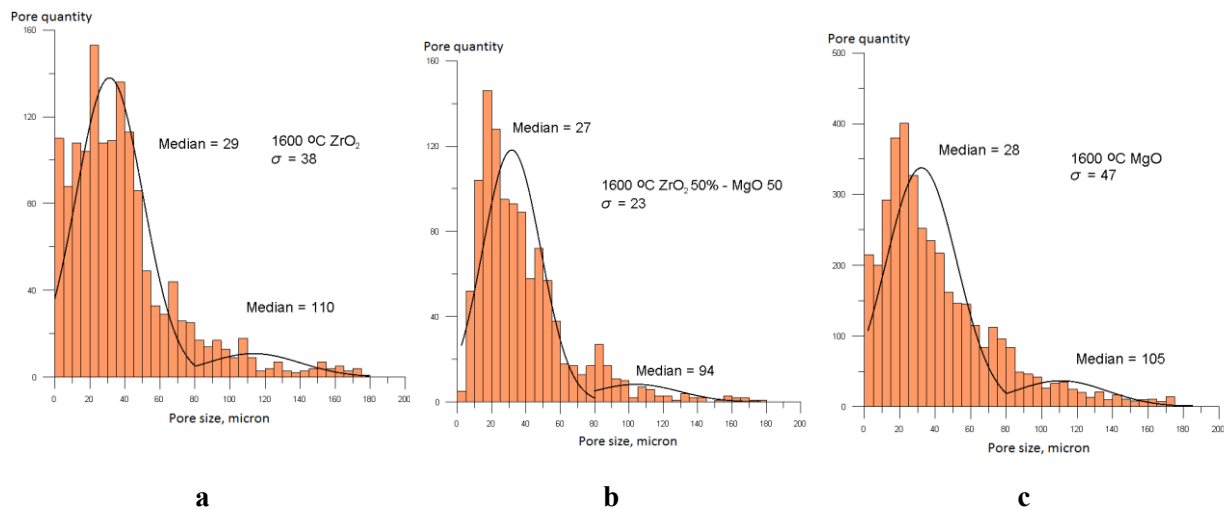


Figure 1. Pore size distribution according to the composition: **a.** $\text{ZrO}_2(\text{MgO})$; **b.** 50% $\text{ZrO}_2(\text{MgO})$ + 50% MgO; **c.** MgO

From X-ray data were determined the coherent diffraction domain sizes (CDD) and crystalline lattice microdistortions. This data was compared with the experimental results of ceramics compressive strength. Analyses of “stress-strain” diagrams are shows that the highest compressive strength corresponds to pure MgO ceramic – 33 MPa. ZrO_2 concentration increasing proceeds with decreasing of compressive strength to 18 MPa, which is correspond to the spongy bone ultimate strength [6].

On the Fig. 2 is shown the dependence of compressive strength vs. microstresses. As one can see strength directly depends on microstresses, this means that grain boundaries are very important in mechanical properties formation [7, 8].

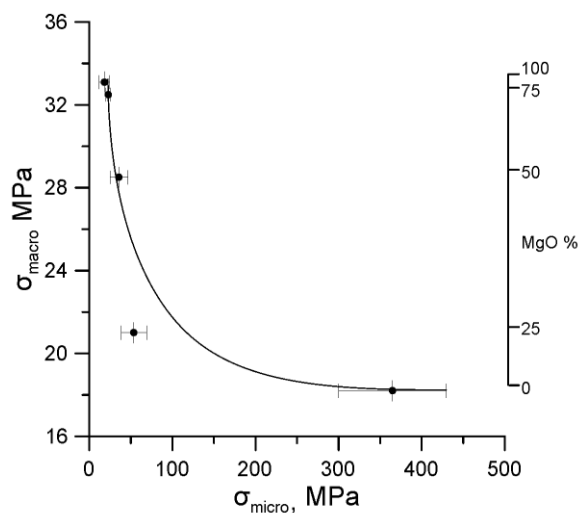


Figure 2. Compressive strength vs. microstresses

Strength, Fig. 3a, and elastic modulus, Fig. 3b, dependence on microstresses in MgO crystalline lattice can be determined as the linear. The dependence of strength vs. microstresses in ZrO_2 crystalline lattice is not obvious and was not found. It can be seen that elastic modulus and strength increasing mostly depends on microstresses in MgO crystal grains.

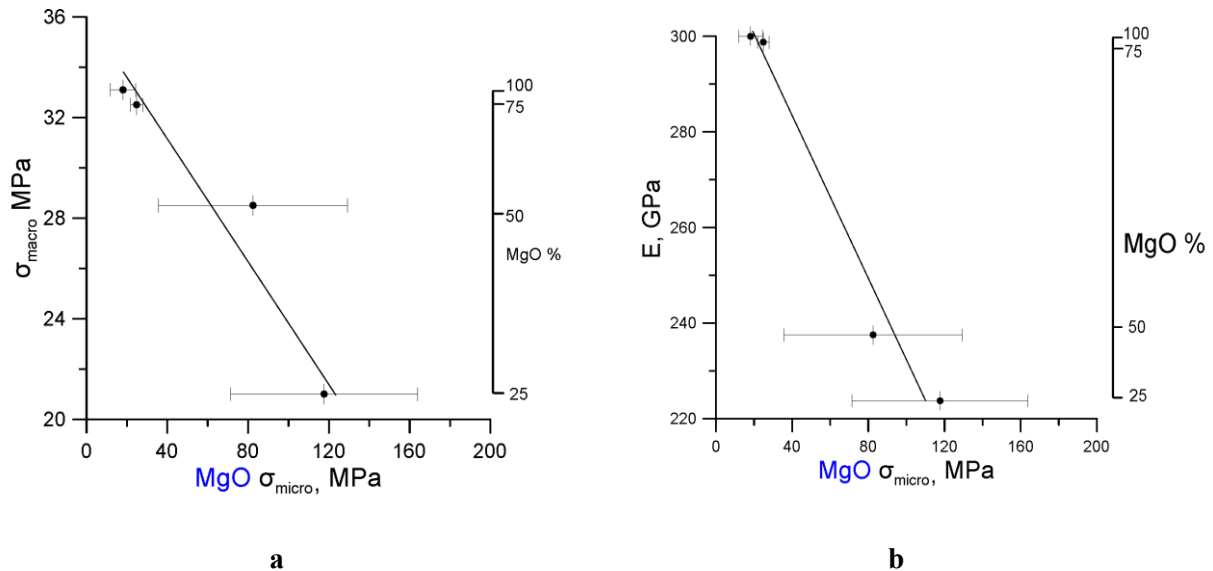


Figure 3. Linear dependences from MgO microstresses of: **a.** ceramics compressive strength; **b.** ceramics elastic modulus

Studying of MMSC vitality and osteogenic differentiationability during their cultivating on the porous ceramic samples in osteogenic media was carried out by analysis of material cytotoxicity and alkaline phosphatase detection, which is a first marker of osteogenic differentiation.

Figure 4 a. shows undifferentiated MMSC (dark areas on the picture) in marker-media, which do not express or weakly express alkaline phosphatase and give only background staining. After 7 days of culturing various degrees of cells propagation with the highest activity on the composition with 25% of MgO concentration were observed. Figure 4 b. shows the results after 14 days of cultivation in osteoinductive media: cells differentiate into osteogenic direction, grow, agglomerate and give saturated media staining with colorimetric detection of alkaline phosphatase. The mean cell viability on the ceramic surfaces was about 93%, which is comparable to cell viability in a control sample. In addition, the presence of cell clusters in the pores should be noted, which may be described by their proliferation.

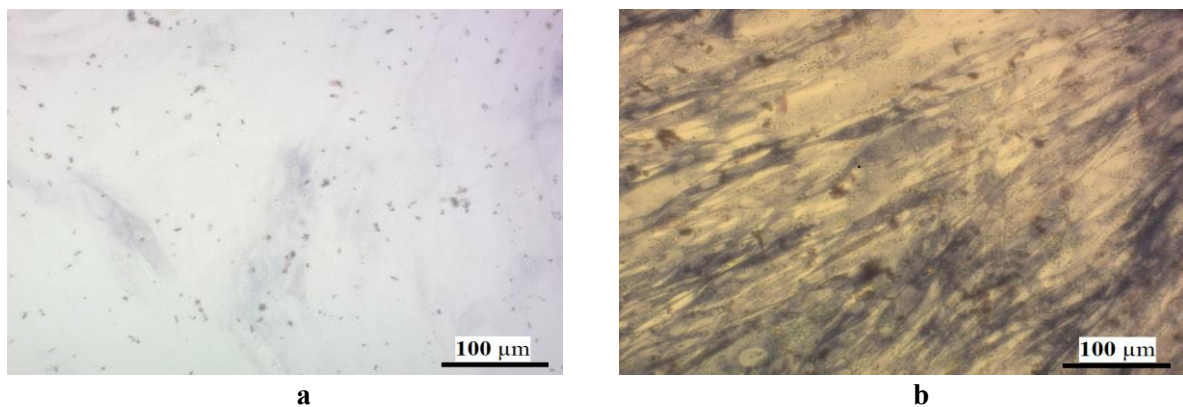


Figure 4. Alkaline phosphatase detection on: **a.** first day of experiment; **b.** 14th experiment day

4. Conclusions

It was shown that during sintering of porous ceramic the bimodal porosity structures with the mean size 28 and 103 μm were formed. Strength directly depends on microstresses and at high microstresses ceramic has a low strength. Ceramics strength dependence vs. microstresses in MgO can be determined as a linear. In vitro studies shown that the tested materials are not cytotoxic - cells vitality was 93%. MMS cells on the surface of ceramic samples also had osteogenic differentiation ability.

Acknowledgments

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References

- [1] Hulbert S F, Young F A, Mathews R S, Klawitter J J, Talbert C D, Stelling F H, 1970 *Journal of biomedical materials research* **4** (3) 433
- [2] Kulkov S N, Buyakova S P, Gömze L A, 2014 *Építőanyag-JSBCM* **66**, (1) 2
<http://dx.doi.org/10.14382/epitoanyag-jsbcm.2014.1>
- [3] Salerno A, Oliviero M, Di Maio E, Iannace S, Netti P A, 2007 *Journal of applied polymer science* 2007 **106** (5) 3335
- [4] Gömze L A 2016 APPLIED MATERIALS SCIENCE I. Compilation of Selected Scientific Papers, *Published by IGREX Ltd, ISBN 978-963-12-6600-9* pp 1-189
- [5] Currey J D, Butler G, 1975 *J Bone Joint Surg Am* **57** (6) 810
- [6] Carter D R, Hayes W C, 1976 *Science* **194** (1) 174
- [7] Kumar S, Kurtz S K, Agarwala V K, 1996 *Actamechanica* **114** (4) 203
- [8] Kulkov S N, Buyakova S P, Kalatur E S, Buyakov A S, 2016 *Építőanyag-JSBCM* **68** (3) 70
<http://dx.doi.org/10.14382/epitoanyag-jsbcm.2016.12>