THE EFFECT OF NANO BIOGLASS ON THE FABRICATION OF POROUS TITANIUM SCAFFOLDS

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Abstract: *In this study, porous titanium composites containing 5, 10 and 15 wt. % nanobioglass were fabricated by space holder sintering process. The pore morphology and phase constituents of the porous samples were characterized by X-ray diffractometry (XRD) and scanning electron microscopy (SEM). The mechanical properties were determined by compression test. The porosity of the sintered samples showed an upward trend with an increase in bioglass content. As the bioglass content was increased, the compressive strength was first increased and then decreased. The results obtained in this work suggest that the fabricated porous compact with 10 wt. % bioglass with compressive strength value of about 76.7 MPa, high porosity and good biocompatibility has the potential application for bone tissue engineering.*

Keywords: *Titanium, Bioglass, Mechanical properties, Porosity.*

1. INTRODUCTION

Titanium alloys have been widely employed in orthopedic applications due to their good biocompatibility, excellent corrosion resistance and specific strength, compared to other metallic biomaterials [1]. Synthesis of metal matrix composites reinforced by bioactive ceramics is a suitable choice for improving the biomechanical compatibility [2]. The most common bioactive materials, used in medicine, are hydroxyapatite (HA), 45S5 Bioglass and Al_2O_3 [3-5].

Among various techniques for producing Ti-based composites, solid-state processing methods are more convenient than liquid methods [6].

Fabrication of porous materials is known as desirable candidate for reducing the mechanical mismatch between the bone and implant [7]. Both the strength and elastic modulus are crucial variables in characterization of porous Ti-based materials. It is well documented that the biomechanical properties and biocompatibility are influenced by the pore morphology, pore size and porosity [8].

In this work, porous Ti-(5, 10 and 15%) bioglass composites were fabricated by powder metallurgy process with the TiH_2 particles as space holder. The effect of bioglass content on structural characteristics and the mechanical properties of porous compacts were investigated in details.

2. EXPERIMENTAL PROCEDURE

The elemental powders were Ti (<325 μm, Merck) and bioglass based on SiO_2-CaO-P_2O_5 system. The bioglass was synthesized by sol-gel technique with nominal composition of 58% SiO_2, 33% CaO and 9% P_2O_5 (based on mol %) [9]. The titanium-nanobioglass scaffolds were fabricated using powder metallurgy route and a space holder sintering process. Ti powders with 40 wt. % TiH_2 as space holder were mixed with 5, 10 and 15 wt. % bioglass. The mixed powders were uniaxially pressed in a steel die (internal diameter of 17 mm) under applied pressure of 450 MPa. Finally, the green compacts were sintered in two steps. First, the samples were kept at 700°C for 3h to ensure the completely decomposition of space holder particles. Second, the compacts were sintered at 1000°C for 3h.

For convenience, the compacts were denoted with bioglass content as T_0, T_5, T_{10} and T_{15}, respectively.

The phase constituents of the sintered compacts were analyzed by X-ray diffraction (Philips Xpert-MPD diffractometer) with CuK_α radiation. The pore morphology, pore size and distribution of bioglass in matrix were characterized using scanning electron microscopy equipped with energy dispersive spectrometer (EDAX).

The porosity of porous compacts was

estimated by measuring their dimension and weight according to the equation (1):

$$P = (1-\rho/\rho s) \times 100 \quad (1)$$

where P is total porosity, ρ and ρ_s are the density of the sintered porous and bulk material, respectively.

The mechanical characteristics of the sintered compacts were examined by compression test at room temperature. During the test, a crosshead speed of 2 mm/min was applied.

3. RESULTS AND DISCUSSION

Fig. 1 shows the XRD pattern of synthesized bioglass. No evidence of any peak in the XRD pattern confirms amorphous structure of prepared bioglass.

The size distribution of the synthesized bioglass is observed in Fig. 2. The particle size varies from 30 to 75 nm. This indicated that nano-size bioglass has been fabricated by sole-gel method.

The XRD patterns of the consolidated samples are observed in Fig. 3. No significant difference is observed in the phase constituents at different bioglass contents. The peaks corresponding to Ti and TiO_2 are seen after sintering.

The presence of TiO_2 phase can improve the corrosion resistance of compacts. Observation of TiH_2 peaks in XRD patterns show that space holder has not been completely removed.

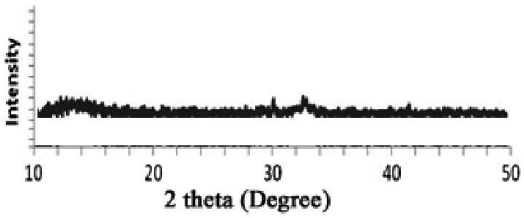

Fig. 1. XRD pattern of synthesized bioglass.

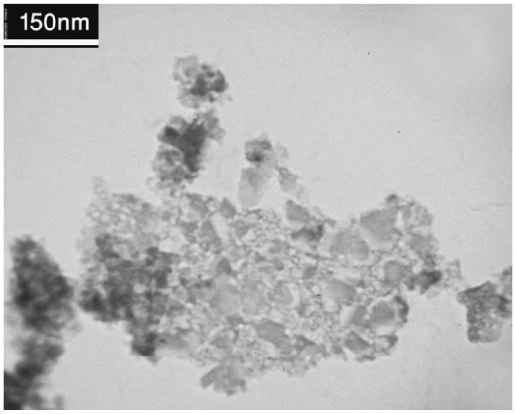

Fig. 2. Nano-size bioglass fabricated by sole-gel method.

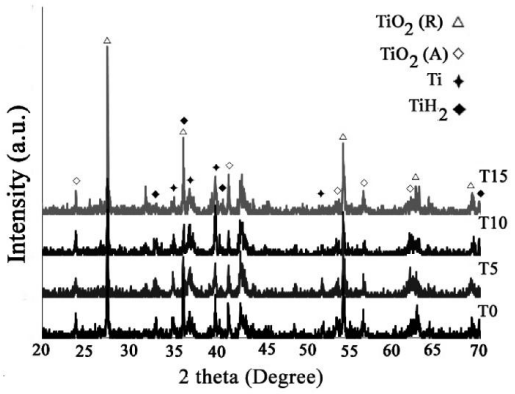

Fig. 3. XRD patterns of sintered samples with different bioglass contents.

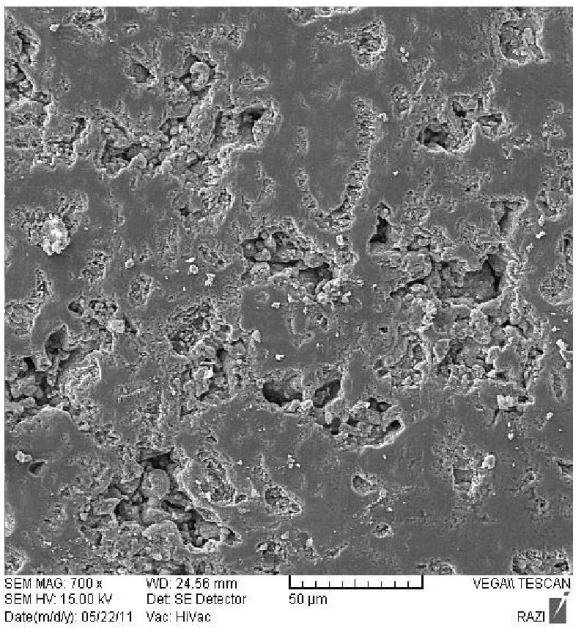

Fig. 4. SEM micrograph of porous sample with 5 wt. % bioglass.

Figs. 4 and 5 show the morphology of pores from the porous T_5 and T_{10} compacts, respectively.

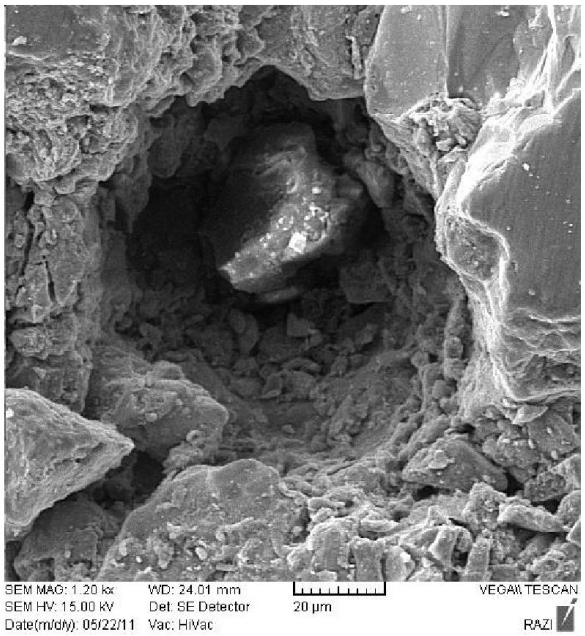

Fig. 5. Pore morphology of porous sample with 10 wt. % bioglass.

It is reported that the morphology of pores can be influenced by the morphology of its constituent powders. Two types of pores, macropores and micropores, were observed. The macropores size ranges from 50-100 µm. The macropores are formed due to TiH_2 decomposition, while the micropores are resulted from partial sintering. It has been reported that the interconnectivity of the pores, which enhance the circulation and increase the distribution of osteogenesis around the implant [10], can be increased by an increase in pore size and/or porosity.

Generally, the pore size is determined by the size of the space holder and the sintering temperature [7]. The porosity as a function of bioglass content is measured. It can be found that the porosity increase with increasing bioglass content. The maximum porosity was obtained for the porous samples synthesized from 15 wt.% bioglass, showed a porosity value of 36 %.

Distribution of bioglass particles in Ti matrix is shown in Fig 6 for T_5 and T_{15} samples, respectively. As can be seen, the bioglass particles were dispersed uniformly at overall matrix. Gradual agglomeration was observed in sample contain 15 wt.% bioglass. For further

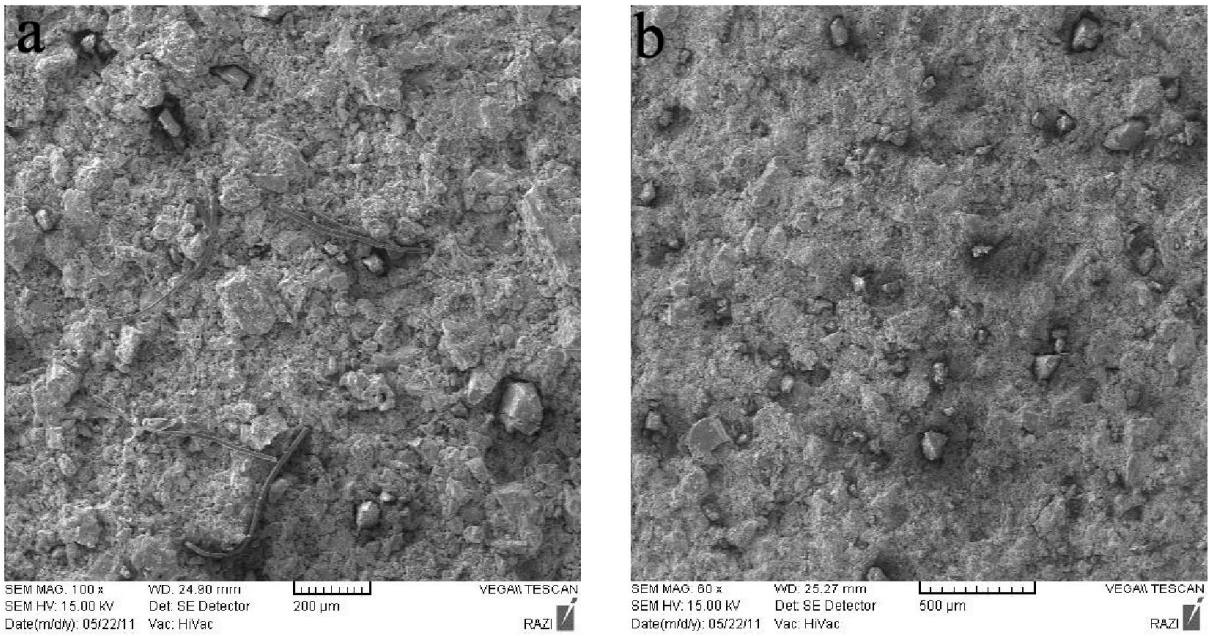

Fig. 6. Thc bioglass distribution in Ti matrix: (a) T5 and (b) T15 compacts.

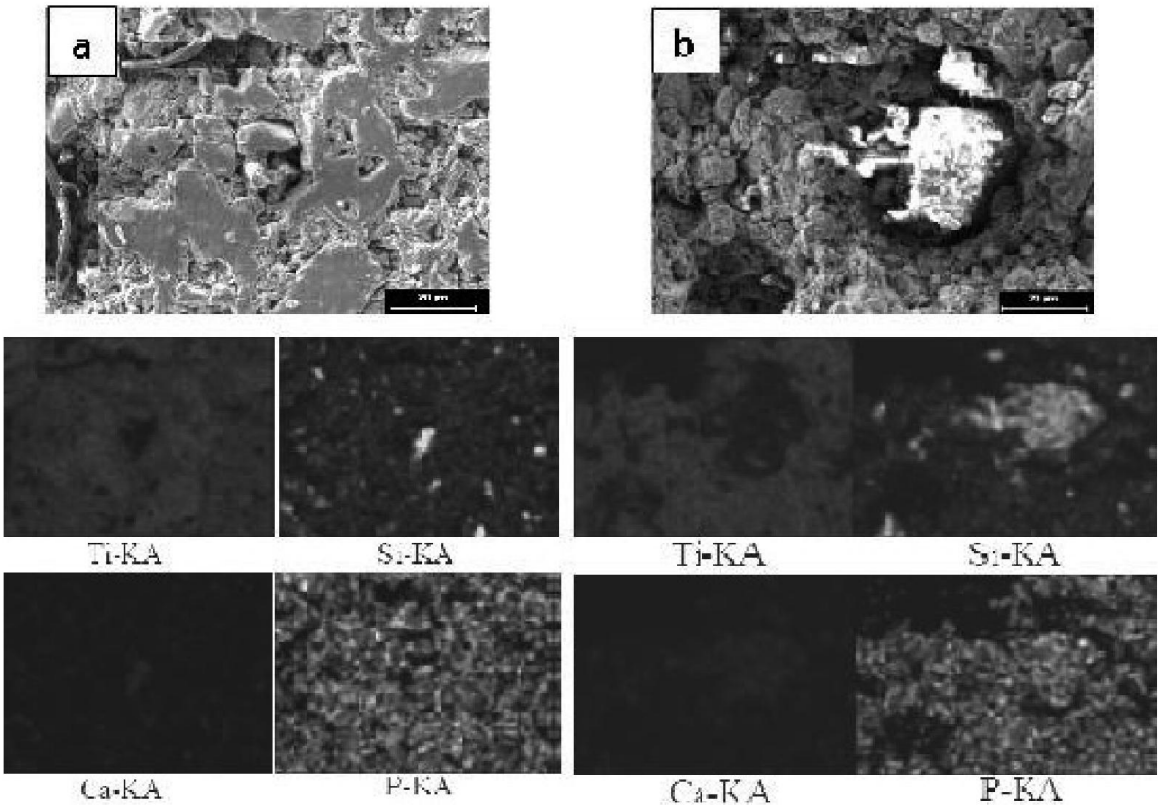

Fig. 7.

investigation, elemental map was used (Fig. 7). Diffusion of soluble ions such as Ca and P from bioglass to titanium matrix was also observed, which increased by bioglass content. Such elements can be played an important role in bone-like apatite formation.

The mechanical properties of porous samples were studied by the compression test. The effect of bioglass content on the compressive strength and elastic modulus (the slope of elastic deformation region) of sintered samples is shown in Table 1.

As the bioglass content was increased, the compressive strength was increased up to 10 wt. % bioglass and then decreased. Moreover, the elastic modulus has the same trend which first increased with bioglass content and then decreased. Based on Gibson-Ashby model, relative density is the most important variable affecting the peak stress and elastic modulus of a porous sample. It has been reported that the strength of the cancellous bones are in the range of 3-20 MPa [11]. Also, the elastic modulus of the nature bone is reported in the range of 10-40 GPa [11]. In fact, the Young's modulus of sintered sample is lower than the requirement of porous bone substitute.

Table 1. The effect of bioglass content on the compressive strengths and elastic modulus of porous samples

Material	Compressive Strength (MPa)	Elastic Modulus (GPa)
T_0	45.6	6.6
T_5	68.8	8.6
T_{10}	76.7	8.9
T_{15}	73.5	8.8

With considering of future application for hard tissue replacement implants, a biomaterial with low elastic modulus can be profitable. According to the results obtained in the present study, porous Ti-based nanocomposite with enough strength and reasonable interconnected pore structure is a promising biomaterial for bone tissue engineering.

4. CONCLUSIONS

In the present work, porous Ti-(5, 10 and 15 wt. %) bioglass compacts were successfully synthesized using powder metallurgy and a space holder sintering process. The porosity of the sintered samples showed a upward trend with an increase in bioglass content. With increasing the bioglass content up to 10 wt. %, the compressive strength and elastic modulus of porous compacts increase. According to the results obtained in the present study, porous Ti-10% bioglass with enough strength and open-cellular structure are a promising biomaterial for bone tissue engineering.

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