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COMPRESSIVE MECHANICAL PROPERTIES OF POROUS TI-6AL-4V WITH PALM STEARIN BINDER SYSTEM

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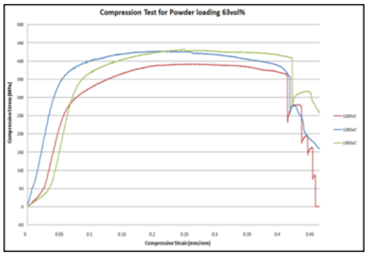
Graphical abstract



Abstract

Most Ti-6Al-4V implant used today are often much stiffer than human bone. However, the young modulus of those Ti-6Al-4V implants can be reduced through the formation of porous structure. Palm stearin binder system with an addition of sodium chloride as space holder has been established in the fabrication of porous Ti-6Al-4V. Thus, this paper focuses on the compressive mechanical properties of porous Ti-6Al-4V with utilization of palm stearin binder system along with sodium chloride (NaCl) as the space holder. The evaluated compositions consist of the powder volume fraction of 63vol% and 65vol%. The samples were compacted by thermal compacting machine at temperature of 160^{o}C. Two different debinding processes involved, which are heptane solvent and water leaching. Then the samples were sintered up to three different temperatures, which are 1200^{o}C, 1250^{o}C and 1300^{o}C. Mechanical properties of the porous Ti-6Al-4V were characterized by axial compression testing. The maximum compressive stress and Young's modulus of the samples were determined to be 403.87MPa and 9.92GPa.

Keywords: Metal injection molding (MIM), Ti-6Al-4V, palm stearin, compression test, Young's Modulus.

1.0 INTRODUCTION

Titanium alloy, Ti-6Al-4V is one of the most attractive metallic materials for biomedical applications. It is widely used in the biomedical field since it is biocompatibility and corrosion resistance. The properties of an existing solid Ti-6Al-4V implant are significantly higher than the cortical bone[1,2]. The major concerned is the mismatch of Young's modulus between natural bone and the solid implant. Those implant materials are much stiffer and the bone will become stress shielding. These may lead to bone resorption and eventual loosening of the implant. In order to minimize the negative impact of this stiffness incompatibility, substitution with porous Ti-6Al-4V implant that mimic the bone structure is the suitable solution[3,4]. Porous metallic materials attract the interest of researchers as a method to reduce mechanical mismatches and achieving stable long-term fixation for full bone ingrowth.

A porous Ti-6Al-4V boasts its advantages which are low density, high specific strength, light weight, and good permeability. The porous Ti-6Al-4V implant with an adequate pore structure and strength has been sought as the ideal bone substitute. Eventually, a porous Ti-6Al-4V implant should have sufficient strength to resist stresses and physiological loadings that are imposed on it while maintaining its original size and shape [5]. The porous structure should provide sufficient mechanical strength to support itself until the new bone tissue is completely formed into the pores. Thus, this study will focus on the compressive mechanical properties of porous Ti-6Al-4V. Palm stearin binder system and space holder method were used in the fabrication of the porous structure of Ti-6Al-4V. Existing binder systems used are thermoplastic compounds, thermosetting compounds, water based systems, gelatin system and inorganic. A palm stearin will be used as the main binder with a second binder which is polyethylene [6]. The palm stearin is a waste of the palm refining oil process. The advantages of the using an organic binder like palm stearin it is natural resources and availability in Malaysia. Moreover, palm stearin binder system is that their chemistry and rheological properties can be modified to meet the specific requirements. Then, sodium chloride as the space holder material was purposely used due to it has short debinding process as it is fast dissolution in water.

2.0 EXPERIMENTAL

2.1 Preparation of Sample

Titanium alloy powders of Ti-6Al-4V with grain size of 50µm and the space holder material, sodium chloride (NaCl) were used. The desired grain size of the space holder particles (<100µm) was obtained by sieving. The powder volume fractions used were 63vol% and 65vol%. Two types of binder were used which are palm stearin (PS) as an organic binder (60wt%) and polyethylene (PE) as a thermoplastic binder (40wt%). All materials were mixed together by using Sigma Blade Mixer Winkworth 2Z UK769 with a rotation frequency of 50rpm at temperature of 150°C. Once obtained homogenized granules of feedstock, the feedstock were compact into rectangular shape with warm compacting machines at temperature of 160°C. Then, the palm stearin binder and NaCl in the compact samples were removed through solvent extraction step and water leaching. The compacted samples were immersed into the heptane for 6 hours at the temperature of 60°C to remove palm stearin. Subsequently, the compacted samples were immersed in distilled water for water leaching at a temperature of 40°C to remove NaCl. Next, the samples were sintered up to temperature 500°C and maintain for two hours to decompose the polyethylene. Then, the temperature was raised up to three different sintering temperatures which are 1200°C, 1250°C and 1300°C to continue sintered the titanium alloy.

2.2 Compression Testing

The static compression tests are carried out by INSTRON mechanical testing machine. The strain rate is 0.5 mm/minutes. The compression behavior was analyzed for the sintered Ti-6Al-4V specimens for both composition of powder volume fraction (63vol% and 65vol %). The dimension of the specimen was 10 ± 0.5 mm of length, 5 mm ± 0.5 mm of width and height of 16 mm ± 0.5mm.

3.0 RESULTS AND DISCUSSION

3.1 SEM Analysis

The porous characteristics of the sintered porous Ti-6Al-4V were observed using Scanning Electron Microscopy (SEM). Figure 1 shows the SEM micrograph of the porous Ti-6Al-4V for both composition 63vol% and 35vol% with a porosity of ~24% and ~22% respectively. It can be seen that the porous Ti-6Al-4V exhibited an interconnected porous structure with open-cellular pores. The pore size of the porous Ti-6Al-4V ranged from 5 to 50 µm. The interconnected porous structure with appropriate pore sizes was an essential feature. It allows new bone tissue ingrowth and body fluid transportation, providing the prerequisite of vascularization in the body. This pore size range was tailored to endow the porous Ti-6Al-4V with new bone tissue ingrowth ability.

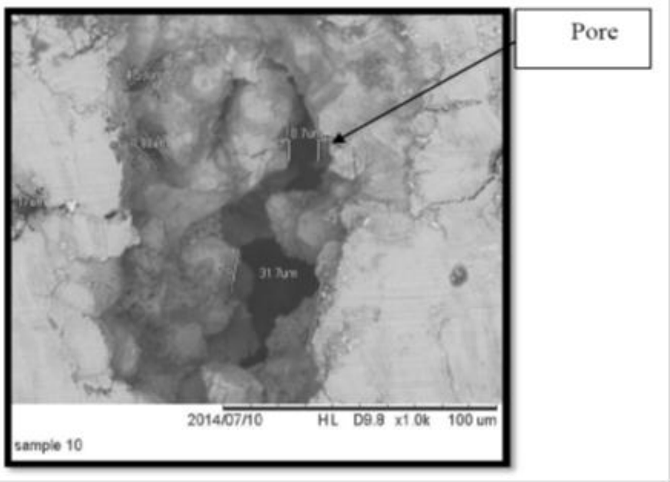


Figure 1 SEM micrograph showed the interconnected pores of as-sintered Ti-6Al-4V

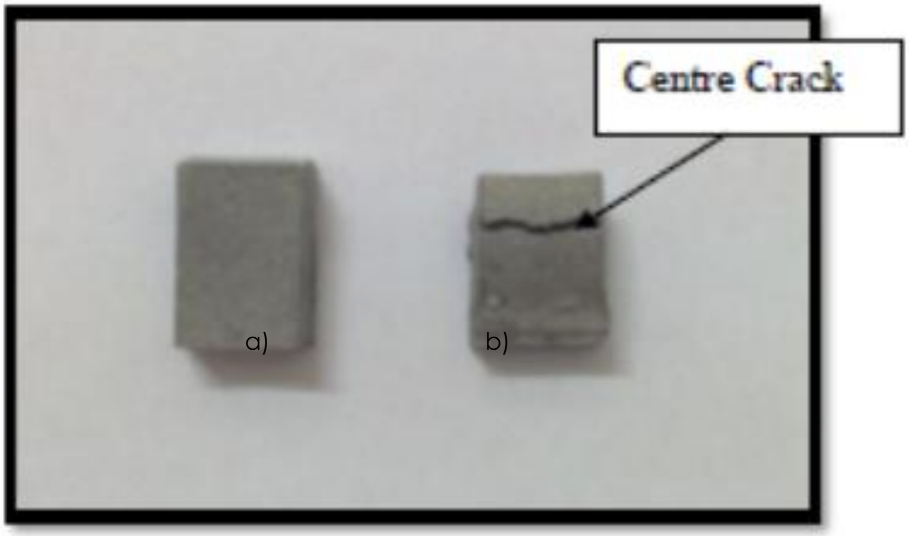


Figure 2 Specimen of the compression testing (a) before testing (b) after testing

3.2 Compression Testing

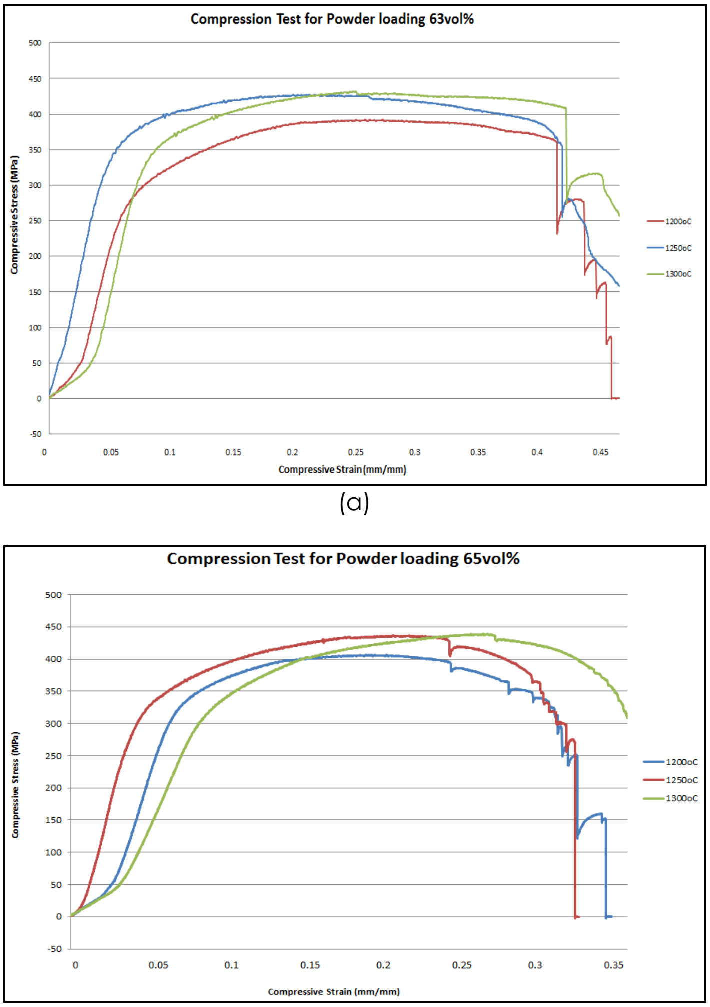
The mechanical properties of the porous Ti-6Al-4V were measured by compressive tests. The picture of the deformed or fractured specimen is shown in Figure 2, as can be seen the specimen was cracked at the center of the specimen.

Compressive test result comparison between both powder loading 63vol% and 65vol% was shown in Table 1. Based on the result, the maximum compressive stress of the samples was 423.64 ± 20.85MPa and 401.1 ± 37.84MPa for 63vol% and 65vol% respectively. There are no significant differences between those two compositions. While the Young's modulus was 13.119 ± 2.08 GPa and 6.13 ± 1.56GPa respectively. Powder loading of 63vol% obtained higher Young's modulus compare to powder loading 65vol%. It showed that high porosity will obtained high values of Young's modulus [7,8,9,10].

The relationship between sintering temperature and stress in the sintered specimens subjected to compression is presented in Figure 3. The plotted graph showed that high sintering temperature of 1300°C obtained higher ultimate stress than other two lower sintering temperature, 1200°C and 1250°C which were 444.48MPa and 438.94MPa for powder loading 63vol% and 65vol% respectively [11,12].

Table 1 Compression test for powder loading 63vol% and 65vol% at three different sintering temperatures.

Powder loading	63 vol %			65 vol %		
Sintering temperature (°C)	1200	1250	1300	1200	1250	1300
Maximum compressive load (kN)	21.82	23.94	25.25	20.72	23.83	25.90
Maximum compressive stress (MPa)	402.79	432.17	444.48	363.26	406.27	438.94
Young modulus (GPa)	11.11	12.99	15.27	4.57	7.68	5.32



(a)

(b)

Figure 3 Graph of compressive stress against compressive strain for powder loading (a) 63vol% (b) 65vol%

4.0 CONCLUSION

Young's modulus of the porous Ti-6Al-4V was influenced by the porosity of the samples. Powder loading of 63vol% contained ~24% of porosity obtained higher Young's modulus which are 13.119 ± 2.08 GPa. While, powder loading of 65vol% with porosity of ~22% only obtained Young's modulus of 6.13 ± 1.56GPa. High sintering temperature of 1300°C obtained the highest ultimate stress of 444.48MPa (63vol%) than sintering temperature of 1200°C and 1250°C.

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