EFFECT OF PORE SIZE ON MECHANICAL PROPERTIES OF TI-6AL-4V METAL FOAMS

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ABSTRACT

Bulk Ti-6Al-4V is used for biomedical applications, such as prosthetic hip and knee joints due to some momentous characteristics, i.e., excellent strength to weight ratio, corrosion resistance and moderate Young's modulus. The objective of the study was to investigate the effect of varying pore size on the mechanical properties of Ti-6Al-4V metallic foam. NaCl was used in order to introduce porosity within the matrix. Final sintered products had porosity in the range of 62 % to 74 %. Compressive strength and Young's modulus of sintered pellets were found to be in the range of 23 MPa to 3 MPa and 2 GPa to 0.84 GPa, respectively. In this research fabricated metal foams have comparable mechanical properties to that of cancellous bones.

KEYWORDS

Porous material, Pore size, Titanium alloys, Bio-material, Space holder

1. INTRODUCTION

Ti alloys e.g. Ti-6Al-4V and NiTi have various bio- medical applications such as in synthetic knee and hip joint, because of its striking biocompatible nature, high strength to weight ratio and moderate Young's modulus [1]. Bulk materials such as stainless steel, Co-Cr alloys, and Ti and its alloys have high Young's modulus as compared to the natural bones such as crotical and cancellous bones [2, 3], triggering off stress shielding effect due to the hindrance in transfer of load between implant and the bone [4, 5].

In recent times extensive research is pursuing on porous Ti alloys due to their splendid mechanical properties and biocompatible nature Young's modulus of porous Ti-6Al-4V implant material is quiet equipollent to that of bone which could in fact preclude loosening of the implant. On the other hand porous material also facilitates fluid transmission and tissue growth which promote a tremendous level of integration between implant and bone [6]. Multiple methods such as powder sintering, electro chemical dissolution of steel wires [7], superelastic expansion of argon filled pores [8], hot isostatic pressing (HIP) using argon gas, spark plasma sintering [9, 10] and fabrication of metallic foam through space holder [8] are employed for the fabrication of metallic foams. None of the methods are as reliable as fabrication through space holder technique in order to get desired and explicit range of porosity which has monumental influential effect on the mechanical properties [12]. Innumerable types of space holder are being used for the fabrication of metal foams such as ammonium bicarbonate [8], sodium chloride [12], sodium fluoride [13], and magnesium [16].

Basic aim of this research was to study the effect of pore size on mechanical properties, in addition to that final porosity, pore shape and different phases present in Ti-6Al-4V were also part of the study. NaCl was used to generate porosity within the matrix, reason for choosing NaCl is due to its non-reactive nature, thus it would not undergo into any sort of chemical reaction with the base material which could affect the desired results.

2. EXPERIMENTAL

Ti-6Al-4V powder in pre-alloyed form having particle size less than 50 µm was used in this study. Sodium chloride powder (purity~99.5%) was used as space holder with three distinct particle sizes i.e. 100-180 µm, 350-500 µm and 500-700 µm. Desired volume percentage of space holder, i.e., 60 volume %, 70 volume % and 80 volume % and Ti-6Al-4V were mixed in V-blender for 3 h at a rotational speed of 28 rpm to ensure homogeneous mixing of the two powders. The powder mixture was dried in an oven at 85 ^{o}C for 24 hours to ensure complete removal of water vapors traces from the mixed powders. Mixed powders were cold compacted at room temperature using Tungsten Carbide die having diameter of 12 mm at 445 MPa in uniaxial pressing machine. Sintering of pallets was carried out in carbolite tube furnace at 1200 ^{o}C for 2 hours in argon atmosphere with heating and cooling rate at 5 ^{o}C/min. Sintering cycle for the fabrication metal foams. First dwell was at 150 ^{o}C for 15 minutes with the intention of removal of remaining moisture from the pellets which might have left during drying of the powder. Second dwell was set at 805 ^{o}C for the eradication of sodium chloride from the pellets and then temperature was hauled up to1200 ^{o}C for 2 h. However it was observed during study that ample amount of salt was eliminated at 1200 ^{o}C in the form of vapors. Samples were cooled down in argon atmosphere. Sintered pellets were placed in distilled water at 80 ^{o}C for 1 h, in order to root off the remnants of space holder which might be retained during sintering process, and then dried at 100 ^{o}C for 2 hours in an oven.

Porosity was determines by Archimedes' principle. Olympus optical microscope was used to observe shape of the pores formed and their distribution in the Ti-6Al-4V matrix. In order to observe the micro structure, characterize the interconnectivity, and to determine pore size Philips XL 30 and Hitachi SU-1500 scanning electron microscopes were utilized. Compressive strength was determined by uniaxial compression test at room temperature on Instron-8501 100kN testing machine with the cross head speed of 0.1 mm/minute. XRD was carried out for the phase identification using Panalytical X'pert Pro.

3. RESULT AND DISCUSSION

SEM images, of as received Ti-6Al-4V powder and salt used as space holder are shown in Figure 2 (a), (b) respectively. Ti-6Al-4V powder is of irregular shape. Overall average porosities of samples achieved during experimentation were found to be 62 %, 63 % and 64 % by using salt size of 100180 µm, 350-500 µm and 500-700 µm, respectively, whereas the 60 volume % of the salt used was kept constant.

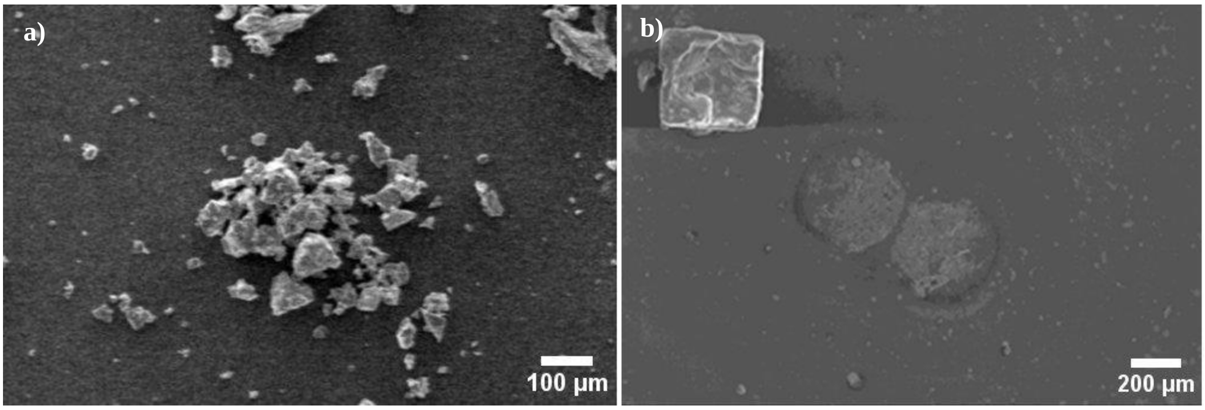

Figure 1: SEM image of (a) as received Ti-6Al-4V powder (b) as received salt.

Optical micrographs of the samples in which 350-500 µm particle size salt, whereas the volume % of the salt used was kept 60%,70% and 80% in Figure 2 (a), Figure 2 (b) and Figure 2 (c), respectively. By observing optical micrographs, two very significant features were spotted out, namely micro and macro porosity; macro porosity was due to evaporation of NaCl during sintering, indicated by the big large dark regions. Micro porosity was specified by dark small spots in the white matrix and often seen during pressureless sintering. It was also observed in the previous literature during fabrication of NiTi metallic foams [19, 20].

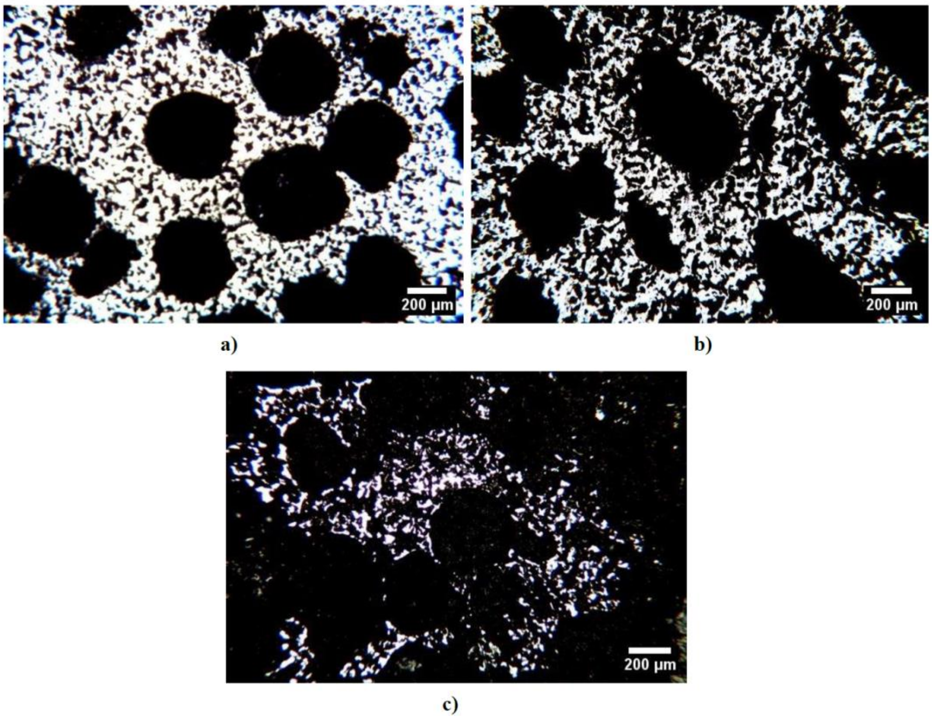

Figure 2: Optical images of sintered Ti-6Al-4V metal foams fabricated with (a) 60 volume % salt (b) 70 volume % salt (c) 80 volume % salt. The particle size of the salt used was 350-500 µm.

Percentage porosity and average pore size in metallic foams have very deep and persuasive effect on the mechanical properties of the structure. During experimentation, the foams having porosities greater than 75 % were found to be very fragile and did not have adequate strength. As therefore Figure 3a delineates that by increase in volume % of the salt which actually up shoots % porosity which results in curtailment of compressive strength and Young's modulus. Likewise, increase in particle salt size has the same effect due to proliferation of pore size. Similar trend was also examined in previous literature during fabrication of Ti foams [14]. For a material to be used as biomedical implant, it must satisfy the criteria listed in Table 1. By comparing Figure 3b and Table 1, during experimentation foam fabricated by using 60 volume % of the salt and having particle sizes of 100-180 µm and 350-500 µm, satisfied the cancellous bone criteria.

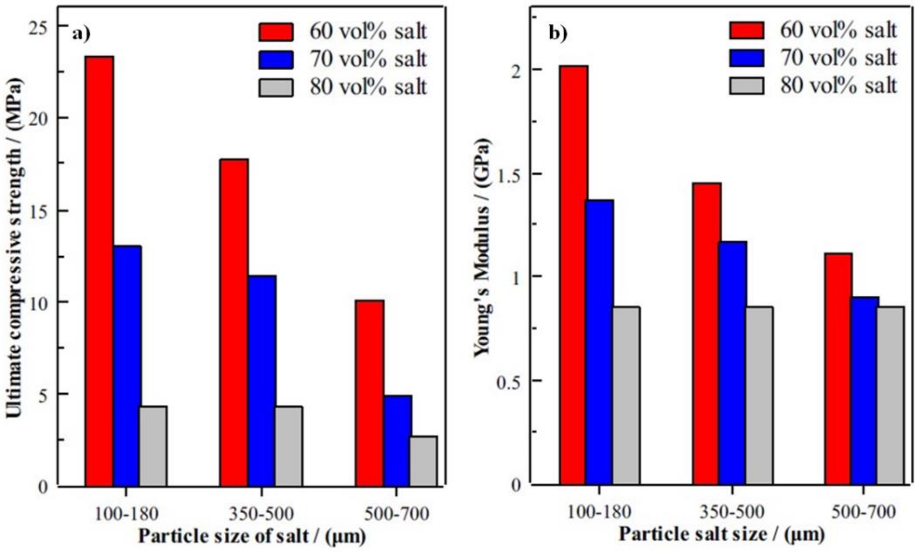

Figure 3:Influence of particle size and volume % of salt used on (a) Compressive strength (b) Young's modulus

Table 1: Compression properties of bones

Type of Bones	Modulus (GPa)	Compressive Strength (MPa)
Cancellous bone	0.01-3 [2]	15-35 [21]
Crotical Bone	4.4-28.8 [2]	49-148 [22]

Titanium exists in two different allotropic forms, i.e., HCP α phase and BCC β phase. α is low temperature phase while β is high temperature phase, whereas transformation of α to β occurs at 882 ^{o}C [17]. Ti-6Al-4V contains Aluminium and Vanadium which are α and β phase stabilizers, respectively. XRD analysis of as received Ti-6Al-4V powder and sintered Ti-6Al-4V samples are shown in Figure 4 (a) and 4(b), respectively. In Figure 4(b) in addition to α-phase peaks, a small peak at 39.5^{o} is also observed which is characterized as β-phase. On the other hand, on such peak was observed in Figure 4(a). Similar peak at 39.5^{o} was also observed and characterized as β-phase in previous literature during fabrication of Ti-6Al-4V metallic foams through space holder (magnesium) [16]. Figure 4(c) is the SEM image of sintered Ti-6Al-4V sample having lamellar type of structure consisting of β phase indicated by bright lathe structure whereas α phase forms dark platelets. Cooling rates from β-phase region has an impact on the thickness of the plates which in turn has an effect on mechanical properties of the structure of metal foam [18].

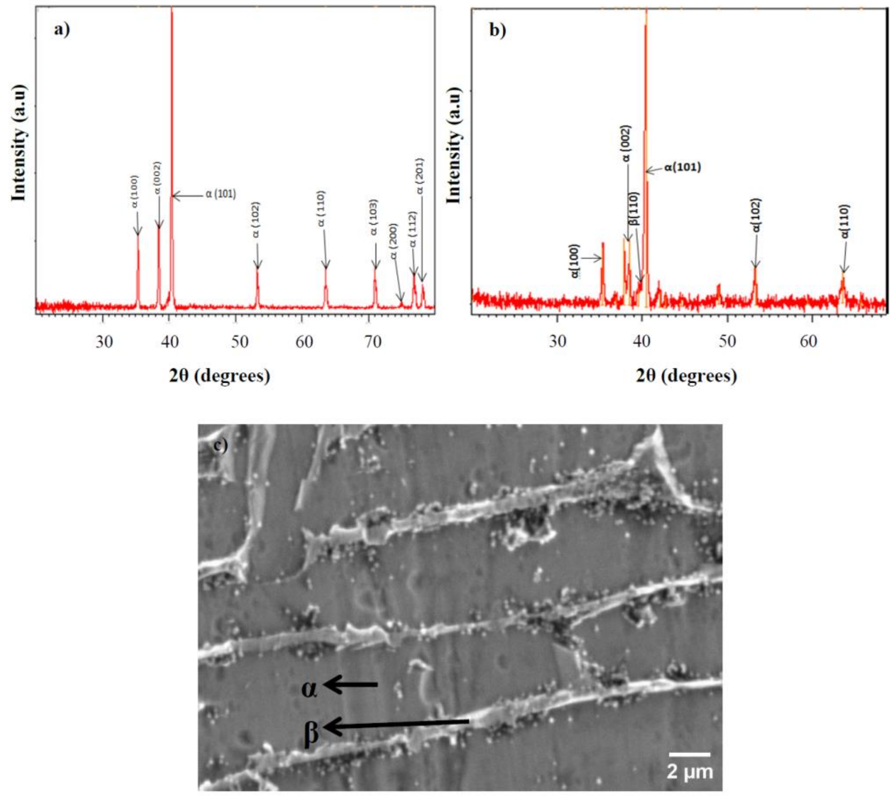

Figure 4:(a) XRD of as Ti-6Al-4V received powder (b) XRD of sintered (c)SEM image of sintered Ti-6Al-4V metal foams

4. CONCLUSIONS

In this work role of pore size and percentage of porosity were determined to assess and optimize mechanical properties of Ti-6Al-4V alloy foam to consider their application for biomedical applications. It was demonstrated that the samples fabricated with 100-180 In this work role of pore size and percentage of porosity were determined to assess and optimize mechanical properties of Ti-6Al-4V alloy foam to consider their application for biomedical applications. It was demonstrated that the samples fabricated with 100-180 µm and 350-500 µm with porosity 60 volume % has satisfied the properties equivalent to that of cancellous bone properties. In future research, the fabrication of Ti-6Al-4V metal foams with mechanical properties analogous to those of critical bones is to be pursued. Furthermore, a comparative study will be conducted with NiTi metal foams.

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