



Mechanical and Biological Performance of Titanium Hydroxyapatite Composites for Biomedical Applications

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Abstract

Research findings indicate that alloys derived from titanium are widely applied in orthopaedic implants as a result of their good mechanical strength, anti-corrosive property, and biocompatibility. However, their limited bioactivity and mismatch in mechanical behaviour compared to bone often lead to stress shielding and reduced biological performance. This study investigates the mechanical and biological performance of titanium hydroxyapatite composites developed for biomedical applications. Reinforcement was added to titanium alloy powder (Ti6Al4V, 20 μm) using laboratory-prepared hydroxyapatite (5.5 μm) at varying weight percentages (10, 20, 30, and 40 wt% HA) using the powder metallurgy technique. The blended powders were compacted at 200 MPa. Sintering was performed in an argon atmosphere at 1100°C for 2 hours. Density evaluation was performed on the prepared composites using Archimedes' principle, compressive strength using a digital compression testing machine, and structural morphology analyzed using SEM. Results showed that density decreased with increasing hydroxyapatite content, while sintered materials had increased density relative to unsintered samples due to consolidation during sintering. There was a drop in compressive strength with increasing HA content, with the 90%Ti6Al4V–10%HA composite exhibiting the maximum recorded compressive strength (23.2 MPa) and the 60%Ti6Al4V–40%HA composite showing the lowest (5.7 MPa). The strength values obtained fall within the range of human trabecular bone (0.1–30 MPa.), indicating suitability for orthopaedic applications. The study concludes that Ti6Al4V/HA composites demonstrate promising potential for biomedical implant applications, although optimization of hydroxyapatite content and porosity is necessary to achieve improved mechanical and biological performance.

Keywords: Titanium, Ti6Al4V; Hydroxyapatite; Powder Metallurgy; biomaterials; porous materials.

1.0 Introduction

Studies have shown a new developed generation of materials that can function as implants. Alloys derived from titanium are foremost in this category because of their good mechanical and corrosion properties as well as their biocompatibility [1]. Various researches have reported a mismatch of mechanical attributes that occur between titanium and the natural human bone, resulting in stress shielding [2]. This challenge tends to limit the performance of titanium as implants for orthopaedic purposes.

Researchers have introduced a solution to overcome this challenge by developing a novel material using diverse manufacturing techniques. One of these techniques is the reinforcement of a second material like hydroxyapatite with titanium to form composites, which would then be used as implants [3]. Hydroxyapatite, a bio-ceramic brittle material possesses similar properties to the human bone [4].

Some studies have considered the adoption of hydroxyapatite as a structural enhancer for titanium to produce materials developed through powder metallurgy process [5]. Hydroxyapatite HA, which exists in the natural bone in form of nanocrystals is a ceramic phase of calcium and phosphorus. Hence, reinforcing it with titanium promotes excellent cell activities at the implants' outer layer and facilitates accelerated healing [6].

In addition, hydroxyapatite possesses special features like biocompatibility, osteoconductivity osteoinductivity, the ease of forming, and strong bonds to bone tissues. It has found wide range acceptance in dental and orthopaedic applications [7]. When sourcing for materials to synthesize orthopaedic implants, titanium as well as its alloys are usually given preference owing to their beneficial features over steel and cobalt alloys. Titanium possesses a reduced elastic modulus compared to steel implants. This is the reason why it is preferred over every other implants whose Young's Modulus are higher than the human bone [8]. The implication of this is that titanium's stiffness is similar to what is obtained for the human bone and would ease a balanced load shearing between the it and the surrounding bone. This benefit ultimately reduces the risk of stress shielding. Besides, it prevents bone loss and also enhances the durability and stability of the implant in humans.

In addition, unlike steel implants, titanium is non-magnetic, making it easier to use MRI scanning for patients' diagnosis. Titanium also provides a long-life span to implants due to its corrosion resistance when subjected to physiological solutions [9].

Another limitation to the performance of titanium is minimal bio activity, making it difficult to bond easily with local tissues. Although it possesses adequate mechanical properties of which no further improvement is

necessary to improve it, yet, it cannot effectively perform tissue interaction with implant surfaces to enhance accelerated rate of healing [10].

Several studies have revealed the essential benefits of reinforcing hydroxyapatite HA to various implant materials. Among them is cell adhesion and proliferation. In this study, hydroxyapatite powder prepared from the laboratory is used to reinforce titanium in various weight percentages before being compacted and sintered. The sintered composites are therefore subjected to mechanical tests to determine the optimum composite composition. The study is designed to investigate the mechanical and biological performance of titanium hydroxyapatite (Ti6Al4V/HA) materials engineered for medical applications.

1.1 Table Presentation

Table 1: Powder size

Material	Size (d10) (μm)
Titanium (Ti6Al4V)	20.00
Hydroxyapatite (HA)	5.5

Table 2: Densities of green and sintered samples

S/N	Wt % of hydroxyapatite	Density of green samples (g/cm^3)	Density of sintered samples (g/cm^3)
1	10	2.97	3.0
2	20	2.9	2.92
3	30	2.8	2.88
4	40	2.77	2.85

Table 3: Compressive strength of the sintered composites

S/N	Wt % of hydroxyapatite	Compressive strength (MPa)
1	10	23.2
2	20	14.7
3	30	7.8
4	40	5.7

1.2 Presentation of Figures





Figure 1: (a) ethylene glycol (binder), and Ti6Al4V alloy powder, and hydroxyapatite (b) Ti6Al4V powder being weighed on a weighing balance (c) 15mm diameter x 15mm green samples produced (d) 15mm diameter x 60mm green samples produced (e) hydraulic press (f) prepared moulds for samples

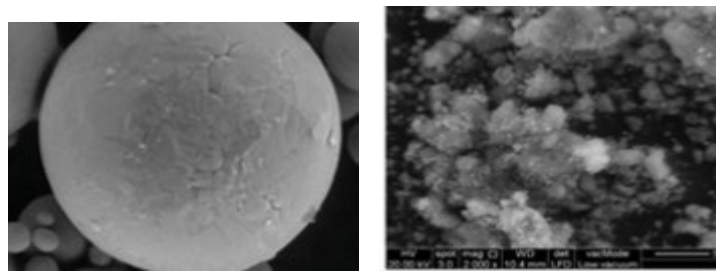


Figure 2: SEM image for (i) Ti6Al4V, and (ii) Hydroxyapatite



Figure 3: Physical observation of (i) green part and (ii) sintered part

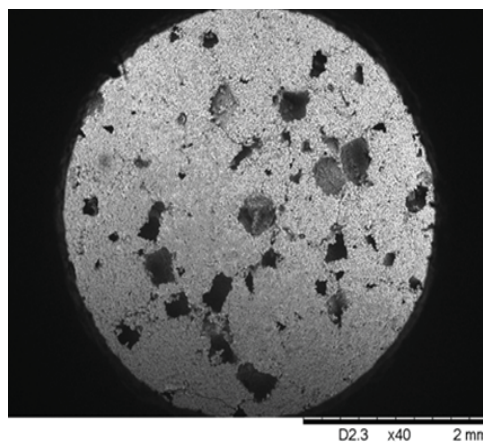


Figure 4: Pores shown on sintered composite after sintering

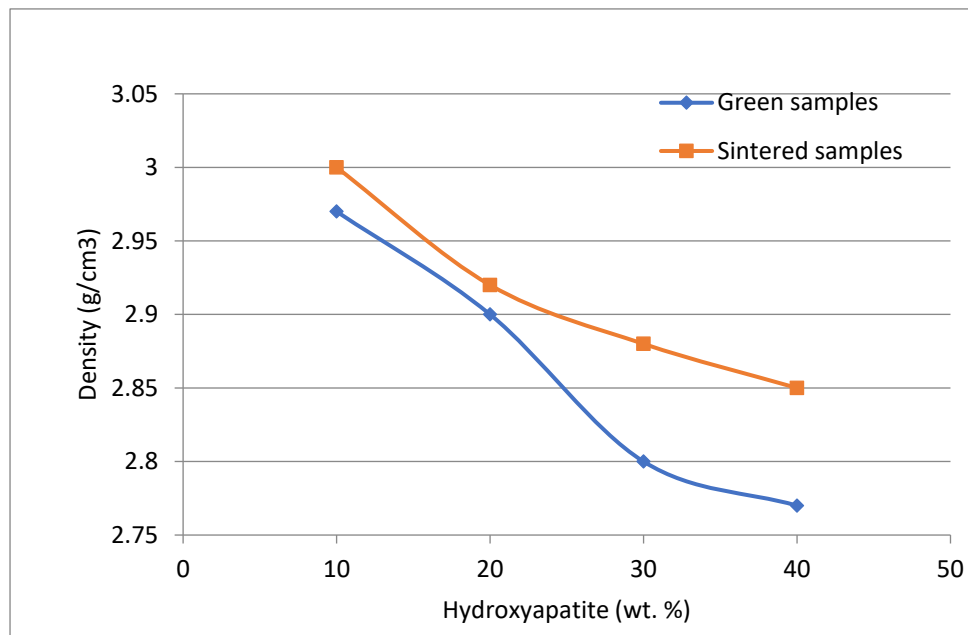


Figure 5: Influence of hydroxyapatite on density of green and sintered composites

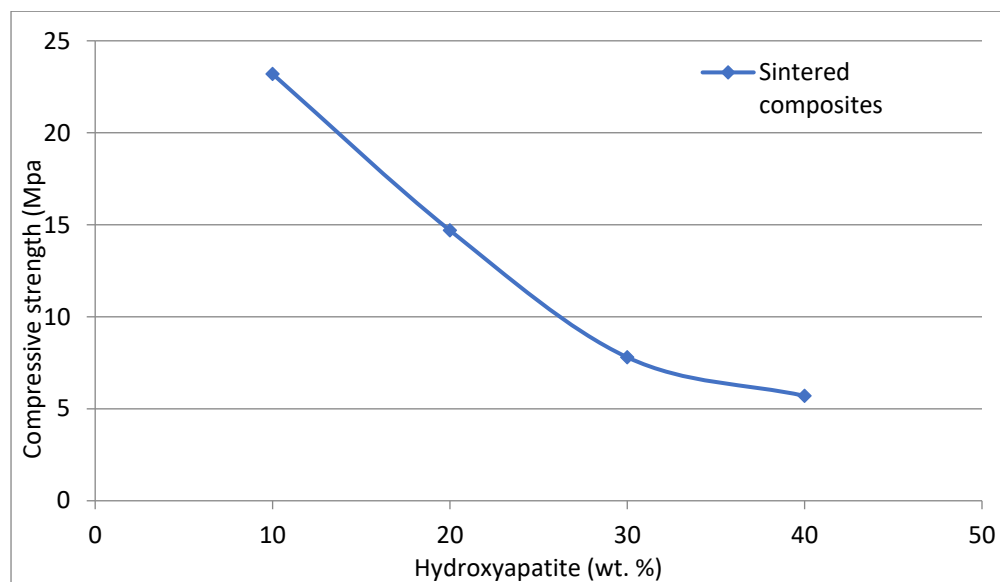


Figure 6: Influence of hydroxyapatite on compressive strength of the sintered samples

2.0 Methodology

Samples of four varying formulations were developed with varied weight percentages of titanium and hydroxyapatite as shown in Figure 3. The compositions are 90%Ti6Al4V, and 10% HA, 80%Ti6Al4V, and 20% HA, 70%Ti6Al4V, and 30% HA, 60%Ti6Al4V, and 40% HA. They were measured inside a clean and dried container and thoroughly mixed. Then ethylene glycol which serves as a binding agent and distilled water were added and mixed up thoroughly. They were then compacted into the designed moulds and consolidated in a hydraulic press using an applied force of 200Mpa at room temperature. The compacted composites successfully exit the moulds and came out as green samples.

The green composites were then sealed in a vacuum tube and subjected to sintering in a vacuum furnace in an argon gas-controlled environment at 1100°C for two hours holding time with temperature increasing at a rate of 9°C/min. Figure 1(c) and (d) illustrates the prepared samples. Using Archimedes principle, the densities of the unsintered and sintered materials were determined.

They were subjected to mechanical and biocompatibility tests to evaluate their performance. Determination of density (in weight percentages) for both the sintered and green composites was carried out using Archimedes principle. Further testing was conducted on them for compressive strength using a Chen Lab digital compression testing machine. The samples' microstructures were determined via SEM.

3.0 Results and Discussion

3.1 Determination of density

It was observed that the surface of the samples features some pores on them after sintering. This is also supported by the image produced from the scanning electron microscope (SEM) in Figure 2, which confirmed the porous structure of the sintered composites. It was observed that the pores on the sintered samples demonstrate a considerable influence on their densities. The higher the hydroxyapatite content in the samples, the lower the density and vice versa, as displayed in Table 2. A likely explanation for this observation is the fact that the density of hydroxyapatite powder is lower compared to titanium. It was also observed that the sintered samples possess higher density than the green samples as a result of the sintering operation. The weight of the implant, its biocompatibility as well as its ability to integrate successfully with bone tissues are key factors that depend on its density. With a lower density, the implant's mechanical features are close to that of the human bone and the adverse effect of bone weakening is averted. The pores identified on the implant aids its stability and osseointegration with its surrounding tissue.

3.2 Compressive strength

Results indicated that compressive strength decreases with increase in hydroxyapatite content of the sintered composites (Figure 6). The sample with composition 90%Ti6Al4V, and 10% HA possesses the highest compressive strength (23.2 Mpa), while the sample with composition 60%Ti6Al4V, and 40% HA featured the lowest compressive strength (5.7 Mpa). It can be asserted that since hydroxyapatite is a bioceramic brittle material, its reinforcement with titanium leads to strength reduction. However, the strength of the sintered samples can be geared towards suiting biomedical by controlling the amount of hydroxyapatite added to the composite. Compressive test results show that the values obtained were in the range of that of the human bone.

Furthermore, the compressive strength is influenced by the porous structure of titanium hydroxyapatite composite as shown in Figure 4. At the pores area, localized stresses are shown. However, to enhance the optimum mechanical properties of the porous composite, further research could be conducted to balance the occurrence of porosity and hydroxyapatite content, since they are inter-related. The implication of this to patients is that although the porous structure of the implant (titanium hydroxyapatite composite) can enhance bone integration and its biocompatibility, the occurrence of excessive porosity may cause undesirable effects such as boosting localized stress points in the joints and also reduce compressive strength. Hence, if the porous structure is not properly optimized, the implant risks being weakened or failure when put to service.

4.0 Conclusion

In the present study, titanium hydroxyapatite composites (Ti6Al4V/HA) of four different weight percentage compositions at ratio of 9:1, 8:2, 7:3 and 6:4 were successfully developed using powder metallurgy technique. The composites were subjected to mechanical tests and the following conclusions were made:

- i. The densities of the Ti-HA composites were reduced with an increase in hydroxyapatite content in them. Sample 90%Ti6Al4V, and 10% HA recorded the maximum density.
- ii. As the HA content in the sintered composites increase, there is a decrease in their mechanical features. The 90%Ti6Al4V, and 10% HA composite possesses the highest compressive strength of 22.5Mpa.
- iii. The optimum HA weight percentage that balances mechanical strength and biological performance is 10%. This is evident from Table 2 and 3.
- iv. The newly fabricated titanium hydroxyapatite composite is a potential material that can be utilized for biomedical applications. However, further research work can enhance its optimum features and biological performance.

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