9th INDES 2020

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The 9th International Innovation, Invention & Design Competition
INDES2020

17th May – 10th October 2020

MECHANICAL AND BIOACTIVITY PROPERTIES OF Ti-HA-xNb ALLOY MATRIX COMPOSITE PRODUCED VIA POWDER METALLURGY ROUTE FOR BONE IMPLANT

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ABSTRACT

Titanium is the most popular metallic implant for orthopedic by virtue of its excellence in mechanical properties. Nevertheless, the mismatch of elastic modulus and its bioinert behaviour have been identified as the major reasons for implantation failure. The present work investigates the mechanical performances and bioactivity of titanium-niobium-hydroxyapatite (Ti-Nb-HA) composite prepared by mechanical alloying and powder metallurgy with Nb ranging from 0 to 40 wt.%. Ti, Nb and HA powders were mixed in a planetary mill for 2 hours at 200 rpm, followed by compaction under 500 MPa and sintering at 1200 °C. Higher Nb content increased compressive strength (199.95 MPa to 300.11 MPa) and microhardness (120.97 HV to 269.90 HV) due to solid solution strengthening. However, the presence of TiO_2 and Ti_2P decreases compressive strength at 40 wt.% Nb. With the rise of Nb content, the elastic modulus was slightly decreased. The highest amount of β phase is obtained by 30 wt.% Nb (76%). Upon immersion test in HBSS for 30 days, the highest bioactivity was attained by 30 wt.% Nb. The composite with an addition of 30 wt.% Nb displayed the best properties with higher potential to provide mechanical support and bioactivity enhancement in getting similar cortical bone characteristics.

Keywords: bone implant, titanium, bioactivity, niobium, modulus

1. INTRODUCTION

Titanium (Ti) and its alloys have been extensively utilized as a permanent implant in the human body due to its remarkable properties such as good corrosion resistance and high strength-to-weight-ratio than cobalt-chromium alloys and stainless steel. This envisages titanium as a perfect candidate for implantable metal-based biomaterials. In terms of disadvantage of current titanium materials, it inflicts greater elastic modulus (100-120 GPa) than human cortical bone (10-40 GPa), leading to stress shielding problem that cause implant failure. In addition to that, the release of ion aluminium (Al) and ion vanadium (V) from Ti-6Al-4V alloy, may cause long-term health problems once the implant is embedded within the human body. In terms of the criteria of osseointegration that involves efficient bonding to surrounding tissues and bones, it is apparent that titanium does not satisfy these criteria. In order to improve titanium bioactivity, hydroxyapatite (HA) is added due to its similar bone composition. By reinforcing brittle hydroxyapatite with higher mechanical strength materials such as titanium and niobium (Nb), this will create a stronger composite that is more suitable for load-bearing implants. Niobium is non-toxic and could increase the amount of β phase and provides low elastic modulus due to high volume fraction of β phase [1]. By aiming at tailoring the mechanical properties including compressive strength and elastic modulus that are suitable for implant application, the goal of this work is also to enhance the bioactivity of composite. The combination of these properties is important for the long-term stability of the artificial implant.

2. METHOD

Ti-Nb-HA composite with different in Nb content (e.g.: 0, 10, 20, 30 and 40 wt.%) were prepared using mechanical alloying coupled with powder metallurgy method. HA was selected at 10 wt.% as this composition is beneficial to improve the material osseointegration in Ti alloy [2]. The powders of the composite were then consolidated by compaction under 500 MPa and sintered at 1200°C under the flow of argon gas. Characterization and testing such as density measurement, Vickers microhardness, compression test, density, Field Emission Scanning Electron Microscopy (FESEM), energy dispersive x-ray (EDX), x-ray diffraction (XRD), Fourier Transform Infrared Spectroscopy (FTIR) and *in vitro* bioactivity test using Hank's Balanced Salt Solution (HBSS) are further investigated.

3. RESULT AND DISCUSSION

As shown in Table 1, the value achieved in compressive strength and elastic modulus of 30 wt.% Nb (300.11 MPa, 36.80 GPa) was found almost similar with the compressive strength and modulus of cortical bone, 70-280 MPa and 10-40 GPa, respectively. Moreover, composite with 30 wt.% Nb has the highest apatite forming ability, considered as an index of bioactivity. Hence, designing the correct composite composition with Nb may enhance the mechanical and bioactivity properties of the composite to match the properties of cortical bone.

Table 1. Summary of result for Ti-Nb-HA with various Nb content

Composite (wt.% Nb)	α (%)	Mark	β (%)	Mark	% of apatite	Mark	Density (g/cm^3)	Mark
0	100	4	0	4	0.08	5	4.06	1
10	100	4	0	4	0.11	4	4.28	2
20	32	2	68	2	0.21	3	4.50	3
30	24	1	76	1	0.37	1	4.74	4
40	41	3	59	3	0.32	2	4.97	5

Composite (wt.% Nb)	Hardness (HV)	Mark	Compression strength (MPa)	Mark	Elastic modulus (GPa)	Mark	Total marks	Ranking
0	120.97	5	167.49	5	43.87	3	27	5
10	173.77	3	248.16	3	51.19	5	25	4
20	210.93	2	271.36	2	45.48	4	18	2

30	269.90	1	300.11	1	36.80	2	11	1
40	164.37	4	188.43	4	33.59	1	22	3

4. CONCLUSION

The incorporation of Nb into Ti-HA matrix results in a novel composite that offers properties to thrive as a potential candidate for bone implant and able to replace the most popular Ti-based implant biomaterials, known as Ti-6V-Al alloy.

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