Journal of Alloys and Compounds 1010 (2025) 177966

Contents lists available at ScienceDirect

Journal of Alloys and Compounds

journal homepage: www.elsevier.com/locate/jalcom

Mechanical and biocompatibility studies on additively manufactured Ti6Al4V porous structures infiltrated with hydroxyapatite for implant applications

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ARTICLE INFO

Keywords:
Ti6Al4V
Stress-shielding
Compressive strength
Hydroxyapatite infiltration
Non-linear buckling
Biocompatibility

ABSTRACT

The additive manufacturing of Ti6Al4V enables customized implant production with precise control over microstructure and mechanical properties. A key challenge in Ti6Al4V implants is stress shielding, which is alleviated by introducing porosity to match the implant's Young's modulus to that of bone. However, this reduces compressive strength. This study investigates enhancing compressive strength and osseointegration of porous Ti6Al4V by infiltrating it with hydroxyapatite (HA). Optimized cubic-porous Ti6Al4V specimens with square pores were fabricated using Laser Powder Bed Fusion (LPBF) and infiltrated with HA via the sol-gel method. Biocompatibility was assessed through corrosion rate analysis, cell attachment studies, and electrochemical analysis (EIS and PDP). XRD confirmed the presence of HA and other biominerals formed after the immersion of the Ti6Al4V/HA samples in SBF. Compression tests and degradation analysis were conducted by immersing the samples in simulated body fluid (SBF). The Ti6Al4V/HA specimens had compressive properties within the range of bone, with a maximum compressive strength of 239.4 ± 6.7 MPa and Young's modulus of 5.5 ± 0.1 GPa after immersion in simulated body fluid (SBF) for 7 days. The corrosion rate for the same sample was found to be 0.72 mm/year.

1. Introduction

Biomedical implants are gaining so much attention in the field of medical science and research, as they mimic the natural human bone and they are now used to treat heart conditions, bone fractures, and several other medical complexities [1,2]. Compared to the implants which are made up of ceramics and polymers, metallic implants offer greater strength, high resistance to corrosion and wear, and excellent biocompatibility properties [2]. On account of all these properties, metallic implants are used for the replacement of hip and knee as they are load-bearing bone structures [3]. The most common implant materials are stainless steel, titanium and its alloys (in particular Ti6Al4V), Co-Cr (Cobalt-Chromium), and Ni alloys [2]. Each of these implant materials has its advantages and disadvantages. For instance, stainless steel implants are not suitable for long-term use, particularly in load-bearing applications, due to their significant effects on the patient [4]. Amongst all these metallic implants, Ti6Al4V is preferred mostly as it exhibits a higher strength-to-weight ratio, has a lower density (4.43 g/cm^3), provides greater corrosion resistance, and has excellent biocompatibility [4]. When comparing the mechanical properties, the compressive strength for bulk Ti6Al4V is around 200 MPa, and for cortical bones, the value is within the range of 15–200 MPa [3]. In the case of Young's modulus, for human cortical bone, it is in the range of 3–30 GPa, whereas for bulk Ti6Al4V it is around 110–120 GPa [3]. This mismatch of Young's modulus between the human bone and implant causes the stress-shielding effect. It refers to a condition where the implant experiences a maximum amount of load, causing the nearby bone to experience a lesser amount of load. As a result of this, the bone begins to weaken over time which ultimately leads to implant loosening [3], bone resorption, and premature failure [5]. To eliminate this effect, pores are introduced into the bulk structure [5,6]. By the introduction of pores to a specific level and achieving the correct porosity percentage,

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https://doi.org/10.1016/j.jallcom.2024.177966
Received 25 September 2024; Received in revised form 29 November 2024; Accepted 4 December 2024
Available online 5 December 2024

Ti6Al4V/HA and shifted the paradigm of the implant materials toward the potential metallic-ceramic biocomposite, by proving that it has both bio and mechanical compatibility making it suitable for load-bearing implant applications.

CRediT authorship contribution statement

Saai Aashique A G S: Writing – original draft, Project administration, Methodology. **Banu Pradheepa Kamarajan:** Writing – review & editing, Validation, Investigation, Formal analysis. **Arthik A Riju:** Software, Methodology, Data curation. **Vijayaragavan S:** Writing – original draft, Validation, Software, Resources. **Rajeshkumar G:** Resources, Project administration. **kalayarasan Mani:** Writing – review & editing, Resources, Investigation, Formal analysis. **Adhiyamaan Arivazhagan:** Writing – review & editing, Visualization, Supervision, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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