Materials Letters 187 (2017) 64–67

Contents lists available at ScienceDirect

Materials Letters

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

Mechanical and microstructural characteristics of commercial purity titanium implants fabricated by electron-beam additive manufacturing

Yong-Keun Ahn[a], Hyung-Giun Kim[a], Hyung-Ki Park[a], Gun-Hee Kim[a], Kyung-Hwan Jung[a,b], Chang-Woo Lee[a], Won-Yong Kim[c], Sung-Hwan Lim[d], Byoung-Soo Lee[a,*]

[a] Gangwon Regional Division, Korea Institute of Industrial Technology (KITECH), Gwahakdanji-ro 137-41, Gangneung-si, Gangwon-do 25440, Republic of Korea
[b] KIMM Metal 3D Printing Convergence Research Team, Daejeon 34103, Republic of Korea
[c] Research institute of Advanced Manufacturing Technology, Korea Institute of Industrial Technology (KITECH), Gaetbeal-ro 156, Incheon 21999, Republic of Korea
[d] Department of Nano Applied Engineering, Kangwon National University, Chuncheon 200-701, Republic of Korea

ARTICLE INFO

Keywords:
Biomaterials
Electron-beam additive manufacturing
Commercial purity titanium
Porous materials
Intermetallics

ABSTRACT

Electron-beam additive manufacturing (EBAM) is a layer-by-layer additive manufacturing technique. In this study, the mechanical and microstructural characteristics of commercial purity (CP) titanium implants with various porosities, fabricated by EBAM, were examined. The results show that the CP-titanium implants were composed of fine grains and Fe-Ti intermetallic compounds with a size of 40 nm. In addition, they exhibit high yield strength and a low elastic modulus that are comparable to those of human bone.

1. Introduction

Titanium and its alloys, particularly Ti-6Al-4V, are used in medical devices including dental and orthopedic implants due to their relatively low density, good strength, and excellent corrosion resistance [1–11]. Since Ti-6Al-4V has an excellent strength of 1 GPa, it is a suitable material for biomedical applications. However, Ti-6Al-4V is composed of cytotoxic elements such as aluminum and vanadium, which may cause severe problems once released inside the human body [2]. To overcome the potential aluminum and vanadium toxicity, many new Ti alloys have been developed [3]. Although new Ti alloys without cytotoxic alloying elements have been developed over the past few decades, they remained at the clinicopathological stage in past years [2]. Furthermore, several studies have shown that the elastic modulus of new Ti alloys is much higher than that of human bone, which can give rise to a stress-shielding effect, causing bone resorption and leading to the eventual failure of the metallic implant fixation [3,4]. Porous metallic structures have been used to overcome this drawback, and they improve not only the mechanical mismatch but also bone ingrowth, bringing stable long-term fixation [3]. For fabrication of porous metallic structures, numerous techniques such as powder sintering [5], freeze drying [6], and laser engineered net shaping (LENS) [7] have been studied. However, these techniques are limited when constructing the precise external shapes of internal pore architecture and porous implants. Recently, EBAM using metallic powder including titanium-based alloys [8,9], cobalt-based alloys [10,11], nickel-based alloys [12], copper-based alloys [13], and stainless steel [14] was introduced to fabricate complex 3-D structures. The EBAM technique builds 3-D objects via selective melting of metallic powders with an irradiating electron beam. Ti-6A1-4V with a porous structure was fabricated by EBAM in order to produce orthopedic implants with a low elastic modulus [9]. Since metallic implants fabricated via EBAM have similar mechanical strength to native bone, the stress-shielding effects in vivo can be avoided, and the implants match well with irregular defects encountered in particular domains, such as the skull or maxillofacial and bone joint regions [15]. Cellular Ti-6Al-4V structures with interconnected macro porosity fabricated by EBAM had favorable long-term stability and were found suitable for orthopedic applications [16]. Nevertheless, most research has focused on Ti-6Al-4V [9,15,16], while there have only been a few studies on porous CP-titanium implants [17].

In this study, to understand the characteristics of porous CP-titanium implants corresponding to the diverse structure with various porosities, we designed and fabricated the porous CP-titanium implants by EBAM; then, we investigated the mechanical properties and microstructures.

* Corresponding author.
E-mail address: leebs@kitech.re.kr (B.-S. Lee).

http://dx.doi.org/10.1016/j.matlet.2016.10.064
Received 10 August 2016Received in revised form 29 September 2016Accepted 15 October 2016
Available online 18 October 2016

2. Experimental procedure

The material used in this study was CP-titanium powder supplied by Advanced Powder and Coatings Inc., Canada. The CP-titanium powder had a spherical shape and particle-size distributions were d_{10}=54 µm, d_{50}=77 µm, and d_{90}=117 µm. All CP-titanium implants were built via EBAM using an Arcam EBM-A2X device (Arcam AB, Mölndal, Sweden). CP-titanium implants were constructed in a cylindrical shape with dimensions of 7 mm (diameter)×10 mm (height), and a layer thickness of 85 µm. The major build parameters of the EBAM process for CP-titanium implant fabrication were acceleration voltage, electron-beam power and scanning speed. The electron-beam power is varied between 4–18 mA, acceleration voltage of 60 kV and scanning speed of 400 mm s^{-1}. The internal structures of CP-titanium implants

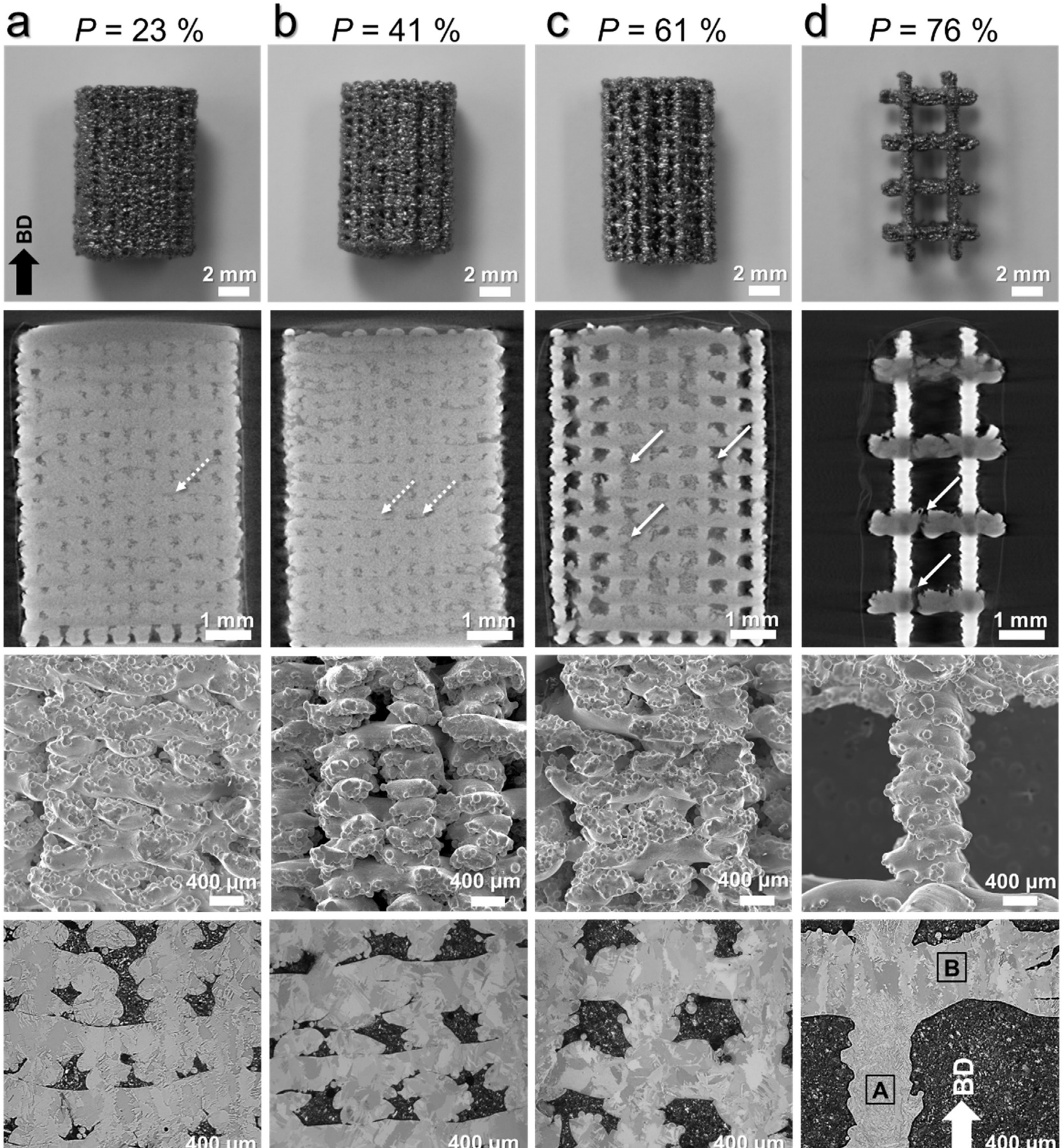

Fig. 1. Photographs, micro-CT images, SEM micrographs and optical micrographs of CP-titanium implants, fabricated by EBAM, possessing different porosity (*P*); (a) 23%, (b) 41%, (c) 61% and (d) 76%. BD indicates the building direction of the EBAM process. The micro-CT images taken are of transverse sections at the center of the CP-titanium implants.