Author's Accepted Manuscript

www.elsevier.com/locate/jmbbm

Characterization of Ti6Al7Nb Alloy Foams Surface Treated in Aqueous NaOH and $CaCl_2$ Solutions

Ezgi BÜTEV, Ziya ESEN, Şakir BOR

PII: S1751-6161(15)00514-7
DOI: http://dx.doi.org/10.1016/j.jmbbm.2015.12.040
Reference: JMBBM1755

To appear in: *Journal of the Mechanical Behavior of Biomedical Materials*

Received date: 25 September 2015
Revised date: 23 December 2015
Accepted date: 24 December 2015

Cite this article as: Ezgi BÜTEV, Ziya ESEN and Şakir BOR, Characterizatio of Ti6Al7Nb Alloy Foams Surface Treated in Aqueous NaOH and CaCl Solutions, *Journal of the Mechanical Behavior of Biomedical Material* http://dx.doi.org/10.1016/j.jmbbm.2015.12.040

Characterization of Ti6Al7Nb Alloy Foams Surface Treated in Aqueous NaOH and $CaCl_2$ Solutions

Ezgi BÜTEV[1, 2, a,*], Ziya ESEN[1, b], Şakir BOR[2, c]

[1]Çankaya University, Materials Science and Engineering Department, 06810, Ankara/Turkey
[2]Middle East Technical University, Metallurgical and Materials Engineering Department, 06800, Ankara/Turkey
[a]ebutev@cankaya.edu.tr, [b]ziyaesen@cankaya.edu.tr, [c]bor@metu.edu.tr

Corresponding author[*]: Çankaya University, Materials Science and Engineering Department, 06810, Ankara/Turkey. Tel: +90 3122331392, E-mail address: ebutev@cankaya.edu.tr (E. Butev)

Abstract

Ti6Al7Nb alloy foams having 53-73% porosity were manufactured via evaporation of magnesium space holders. A bioactive 1 µm thick sodium hydrogel titanate layer, $Na_xH_{2-x}Ti_yO_{2y+1}$, formed after 5 M NaOH treatment, was converted to crystalline sodium titanate, $Na_2Ti_yO_{2y+1}$, as a result of post heat treatment. On the other hand, subsequent $CaCl_2$ treatment of NaOH treated specimens induced calcium titanate formation. However, heat treatment of NaOH-$CaCl_2$ treated specimens led to the loss of calcium and disappearance of the titanate phase. All of the aforementioned surface treatments reduced yield strengths due to the oxidation of the cell walls of the foams, while elastic moduli remained mostly unchanged. Accordingly, equiaxed dimples seen on the fracture surfaces of as-manufactured foams turned into relatively flat and featureless fracture surfaces after surface treatments. On the other hand, Ca- and Na-rich coating preserved their mechanical stabilities and did not spall during fracture. The relation between mechanical properties of foams and macro porosity fraction were found to obey a power law. The foams with 63 and 73% porosity met the desired biocompatibility requirements with fully open pore structures and elastic moduli similar to that of bone. In vitro tests conducted in simulated body fluid (SBF) showed that NaOH-heat treated surfaces exhibit the highest bioactivity and allow the formation of Ca-P rich phases having Ca/P ratio of 1.3 to form within 5 days. Although Ca-P rich phases formed only after 15 days on NaOH-$CaCl_2$ treated specimens, the Ca/P ratio was closer to that of apatite found in bone.

Keywords: Ti6Al7Nb alloy foam, mechanical properties, hydrothermal treatment, simulated body fluid.

1. Introduction

Research on long-lasting and biocompatible biomedical materials has become more common as the average human life expectancy has increased. Titanium and its alloys have been used frequently in load-bearing hard tissue replacements due to their unique combination of properties such as mechanical properties closer to that of bone, good biocompatibility, high resistance to corrosion and wear (Geetha et al., 2009; Long and Rack, 1998; Nouri et al., 2010). However, ‘’stress shielding’’ problem which arises due to differences in elastic modulus between bone and implant may lead to bone resorption and loosening of the dense titanium implant. Therefore, titanium foams with suitable elastic moduli have been preferred in some bone replacements to lessen the mechanical mismatch. Although numerous methods are available for the production of porous metallic materials (Alvarez and Nakajima, 2009; Dunand, 2004; Ryan et al., 2006), only few are capable of obtaining open-pore structures, which promote molecular transport and osteogenesis. Powder metallurgical processes for titanium foams rely on removal of space holders from the titanium-space holder powder mixture at relatively low temperatures without causing excessive oxidation of titanium. The processes are mainly based on thermal removal of space holder materials, e.g. carbamide (urea) (Bram et al., 2000), ammonium hydrogen carbonate particles (Imwinkelried, 2007), polymer granules (Rausch and Banhart, 2002) and metallic powders like magnesium (Esen and Bor, 2011, 2007; Ryan et al., 2006). The space holders utilized should have lack of solid solubility in titanium, be