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Effect of a blast coating process on the macro- and microstructure of Grade 5 titanium foam

Conor F. Dunne [a], Barry Twomey [b], Kenneth T. Stanton [a,*]

[a] UCD School of Mechanical and Materials Engineering, University College Dublin, Belfield, Dublin 4, Ireland
[b] ENBIO Ltd., NOVA UCD, Belfield Innovation Park, Dublin 4, Ireland

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ABSTRACT

This work investigates the deposition of a hydroxyapatite (HA, $Ca_{10}(PO_4)_6(OH)_2$) coating onto titanium foam using a blast process and the effect of the process on the macro- and microstructure of the titanium foam. Light microscopy, scanning electron microscopy and energy-dispersive x-ray spectroscopy were used to examine the coating deposition and the macro- and microstructure of the titanium foam. After blasting the macrostructure did not exhibit signs of excessive abrasion or collapsing of the structure that may affect functionality of the foam. Similarly, microstructure was unaffected by the coating process as there is gross plastic deformation and no thermally induced change such as α-case.

1. Introduction

Titanium and titanium alloys are commonly used in the fabrication of artificial joints due to their light weight, high biocorrosion resistance, biocompatibility and mechanical properties [1]. However, the relatively high stiffness and bioinert nature of titanium may result in stress shielding and poor bonding between the implant and surrounding bone which in turn, may result in loosening and failure of the implant. Porous titanium foams have been developed to address the issue of high stiffness and to provide surface area for bone ingrowth to enhance fixation [2]. These foams are manufactured using various powder sintering and pressurised pore expansion methods. A comprehensive review of these productions methods is provided by Dunand [3].

Hydroxyapatite (HA, $Ca_{10}(PO_4)_6(OH)_2$) is a biocompatible, biodegradable, osteoconductive, mineral phase and one of the primary constituents of bone. It has been used as a coating for orthopaedic implants as its presence has been shown to promote bone formation [4,5]. Various techniques have been used to deposit HA coatings onto bulk titanium such as plasma spray [6], electrophoretic deposition [7] and sol–gel deposition [8] however these techniques exhibit relatively poor bond strengths (≈ 25 MPa [6], ≈ 10 MPa [7] and ≈ 25 MPa [8] respectively). In conjunction with this, the high temperature of the plasma spray technique gives rise to the formation of unwanted phases and amorphisation of the coating while the coating produced is relatively thick (≈ 70 μm) making it unsuitable for coating titanium foams without altering or occluding pore size [9].

The present work investigates the application of HA onto titanium foam using an ambient temperature coating technique known as CoBlast™. CoBlast was developed to address the problems associated with high temperature coating techniques, such as the formation of unwanted phases, amorphisation of the coating and poor adherence of the coating [9,10]. The CoBlast process utilises a co-incident stream of abrasive blast medium and a stream of coating medium particles to modify the substrate surface. The proposed mechanism for adhesion is that the abrasive roughens the surface while simultaneously disrupting the surface passivation layer of the substrate thereby exposing the reactive metal. The coating particles then react with the reactive metal to form an intimate chemical bond [9]. The adhesion of the coating to the substrate is believed to be due to a combination of tribo-chemical bond formation and mechanical interlock between the coating and the metal substrate [11]. The CoBlast process produces a thin (< 10 μm), highly adherent coating (≈ 60 MPa) [9] making it potentially suitable for coating titanium foams.

Previous work where coating of Grade 2 titanium with HA resulted in cold working of the substrate and significant grain deformation [9,10]. Therefore, the abrasive nature of the process could potentially alter the macrostructure of the foam by crushing pores and this in turn could inhibits the functionality of the material. Thus the key aim of this work is to examine what influence the coating process has on the macro- and microstructure of the titanium foam and to assess the reach of coating with this line of sight process.

2. Materials and methods

Titanium foam (Grade 5; Ti6Al4V) (Ceramed, Lisbon, Portugal) $20 \times 20 \times 20\ mm^3$ was used as the substrate. Hydroxyapatite (HA)

* Corresponding author. Tel.: +353 17161918; fax: +353 17161942.
E-mail address: kenneth.stanton@ucd.ie (K.T. Stanton).

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(SAI, France) with a particle size of 25–60 μm and a sintered apatite (sHA) (HIMED, USA) with a particle size < 106 μm were used as the coating medium and blast medium respectively. The samples were prepared by spraying the coating medium and blast medium simultaneously in the same stream through a single de Laval nozzle at the titanium foam with a jet pressure of 0.55 MPa, at a height of 50 mm with an axial travel speed of 13 mm/min and raster offset of 3.5 mm. Further process information and a schematic of the process can be seen in Refs. [8], [9]. Cross sections of the titanium foam were prepared in order to assess coating thickness and to examine the influence of coating process. The cross-sections were examined using a Lecia MEF4M (Wetzlar, Germany) optical microscope with reflected light and a FEI Quanta 3D FEG DualBeam (FEI Ltd, Hillsboro, USA) scanning electron microscope (SEM) in backscatter mode with an attached EDAX EDX APOLLO XV Silicon Drift Detector. Energy-dispersive x-ray spectroscopy (EDX) line profiles were used to examine HA deposition. To prepare the cross sections for analysis, the samples were mounted in a polyester resin, then ground and polished to a 0.04 μm finish, rinsed with water and iso-propanol respectively and dried with a stream of warm air. The polished samples were etched in Kroll's solution for 15 s to reveal the microstructure and subsequently rinsed thoroughly with water and then isopropanol and dried with a stream of warm air. X-ray diffraction was carried out on flat as-supplied and coated Ti_6Al_4V

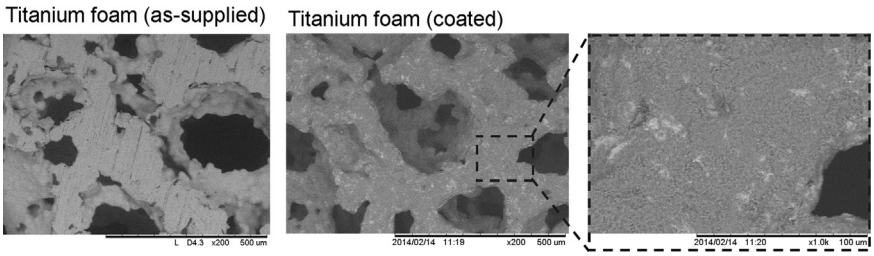

Fig. 1. SEM images of the surface of as-supplied titanium foam (left) and coated titanium foam (middle). The image on the right shows the surface of the coated foam.

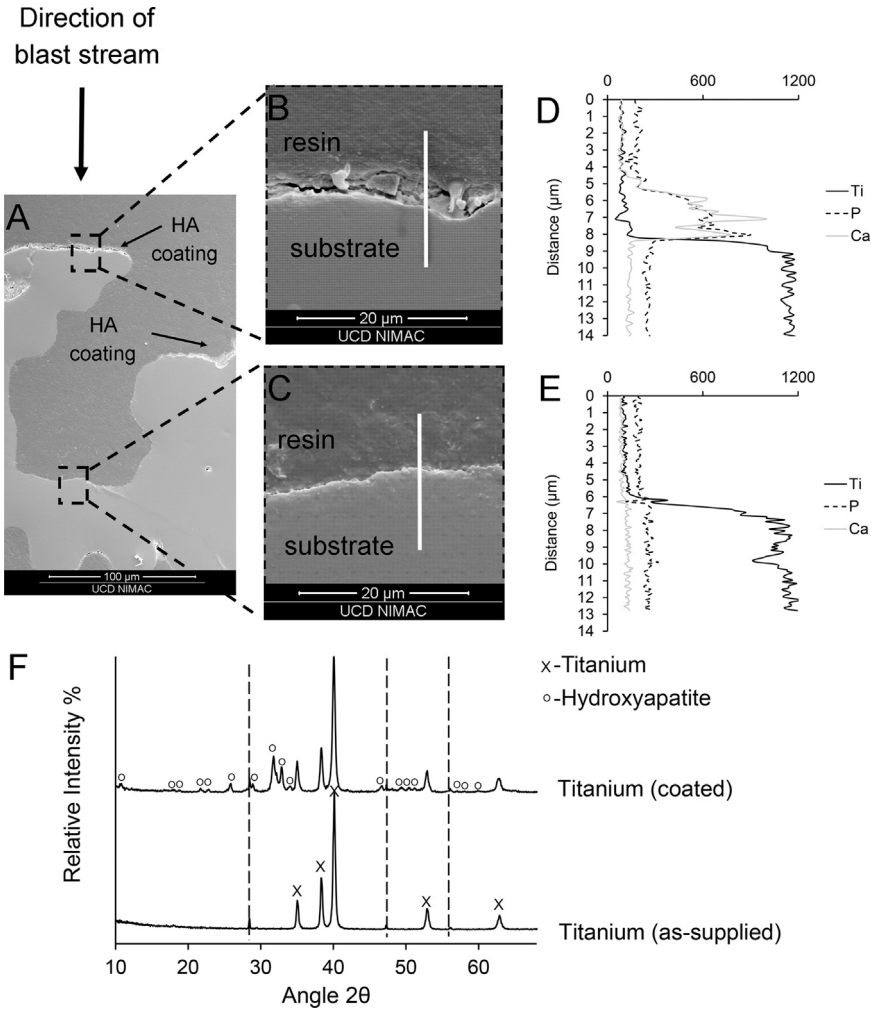

Fig. 2. SEM of coated titanium foam (A). Image (B) shows a cross-section of a coated piece of titanium foam, the white line indicates the path of the elemental line profile. Image (D) shows the EDX line profile across a coated piece of titanium foam. Image (C) shows a site not directly exposed to the blast stream. Image (E) shows the EDX line profile across a site not directly exposed to the blast stream. Image (F) shows the XRD traces of the titanium before and after treatment. The dashed lines correspond to silicon.