Surface & Coatings Technology 301 (2016) 94–99

Contents lists available at ScienceDirect

Surface & Coatings Technology

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

Electrophoretic deposition (EPD) of nano-hydroxyapatite coatings with improved mechanical properties on prosthetic Ti6Al4V substrates

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ARTICLE INFO

Article history:
Received 29 October 2015
Revised 16 December 2015
Accepted in revised form 18 December 2015
Available online 21 December 2015

Keywords:
Electrophoretic deposition
Hydroxyapatite coating
Nanometer feature size
SEM
XRD
Nanoindentation

ABSTRACT

This work aims at studying the synthesis of hydroxyapatite (HAP) coatings by electrophoretic deposition (EPD) of a nano-sized powder. In this research, the variation of the potential and the deposition time, two essential experimental parameters, is explored. It has been established by scanning electron microscopy combined with energy-dispersive X-ray spectroscopy (SEM–EDXS) and X-ray diffraction (XRD) that the best results are obtained for deposition of the coating at 10 V during 10 min. Subsequently, the electrophoretic deposition was followed by thermal treatment of the samples in a controlled atmosphere to enhance their mechanical properties (hardness and Young's Modulus), key parameters to improve the lifespan of the implant materials. In this way, an innovative synthesis process has been developed to produce nano-HAP coatings with appropriate dimensional features known to provide an improved biological response.

1. Introduction

Most of the implant materials used in orthopedic surgery are made of titanium or its alloys well-known for their appropriate mechanical properties required to replace the bone in vivo [1]. However, their capability to adhere to bone tissue is unsatisfactory and may result in wear debris that can lead to inflammatory reactions [2]. Thus, in order to improve osseointegration and biocompatibility of medical implants, the titanium alloys are commonly coated with hydroxyapatite (HAP), a bioceramic material with a chemical composition close to that of the bone. Consequently, the implant is able to establish a direct chemical bond with the surrounding bone tissue, resulting in increased lifespan inside the body [3,4]. Various techniques were developed to produce hydroxyapatite coatings such as plasma spraying [5], magnetron RF-sputtering [6], micro-arc oxidation [7], electrophoretic deposition [8], and many other techniques. Among them, electrophoretic deposition is a technique that consists in the migration of bioceramic powder particles in suspension under the effect of an electric field. Therefore, the particles agglomerate and form the coating at the surface of the implant used as an electrode [9]. A very interesting aspect of this technique is the possibility

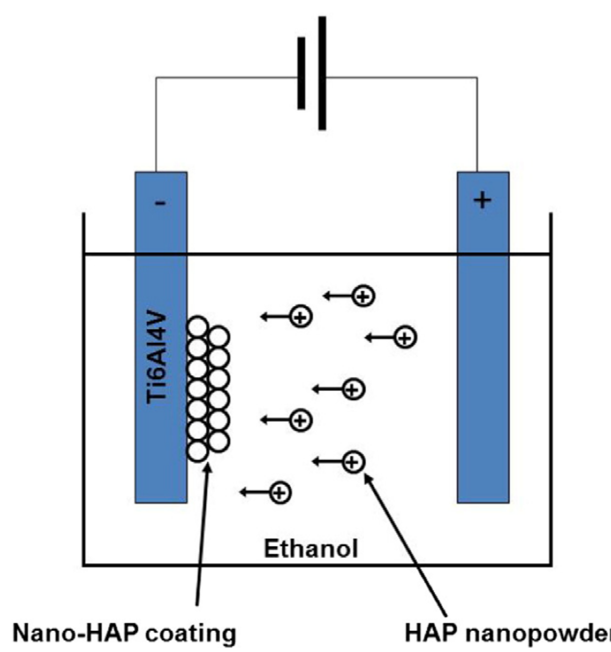

Fig. 1. Sketch of the electrophoretic deposition process.

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http://dx.doi.org/10.1016/j.surfcoat.2015.12.058

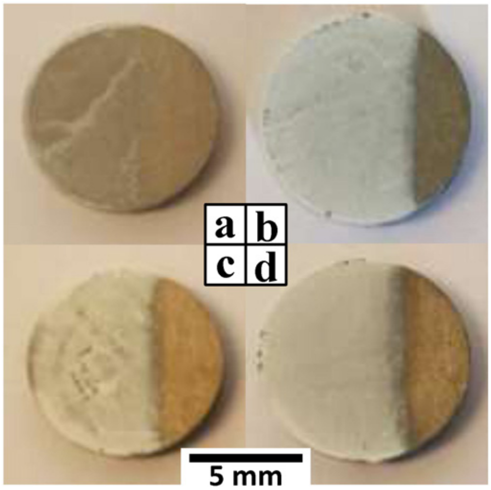

Fig. 2. nano-HAP coating obtained in 10 min. by EPD at (a) 5 V, (b) 10 V, (c) 15 V and (d) 20 V.

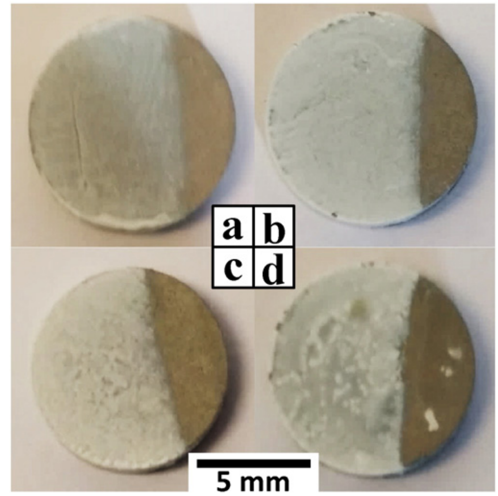

Fig. 4. nano-HAP coating obtained at 10 V by EPD in (a) 5 min., (b) 10 min., (c) 15 min. and (d) 20 min.

to carry out the deposition of hydroxyapatite coatings from nano-sized powders, in contrast to other deposition techniques that generally produce coatings with micrometric features. In particular, several research groups have established that nano-metric surface features may be more desirable as they impact positively the response of osteoblasts owing to the importance of nanoscale interactions during cellular recognition of biomolecules, organization of the extracellular matrix, hierarchical structure of tissues, etc. [10]. As a result, it may be more advantageous to engineer surfaces with nanoscale features as a way to further enhance the osteoinduction, osteoconduction, and osseointegration of the HAP coating deposited on the titanium alloy implant [11,12]. Moreover, as the process is carried out inside a liquid medium, it requires after deposition a thermal treatment to evaporate the solvent trapped within the nano-HAP coating and to improve its mechanical properties. This thermal treatment has to be carried out in a controlled atmosphere to prevent any alteration of the titanium alloy substrate as we demonstrated in recent work [13]. In conclusion, the present work aims at producing, for the first time, a nano-HAP coating with enhanced mechanical properties by electrophoretic deposition.

2. Materials and methods

2.1. Electrophoretic deposition (EPD)

Electrophoretic deposition (EPD) was carried out in a suspension prepared by dispersing 2 g of HAP nano-powder in 25 mL of ethanol. The commercial nano-powder (Aldrich) had a particle size below 200 nm. The suspension of HAP was obtained by ultrasonic dispersion (50 kHz) for 40 min. The particles became positively charged in contact with ethanol, and therefore cathodic EPD was performed (Fig. 1) [14].

Two Ti6Al4V disks (12 mm in diameter and 4 mm in thickness) were used as metallic electrodes. They were cleaned by ultrasonication with acetone and then with water prior to deposition. The distance between the two metallic electrodes was set at 20 mm. The Ti6Al4V disk positioned at the cathode to receive the coating had a surface roughness of 2 μm, produced by grit-blasting with alumina. EPD was performed at room temperature. Various voltage and deposition times were tested. Finally, the as-deposited coatings were air dried at room temperature for 24 h.

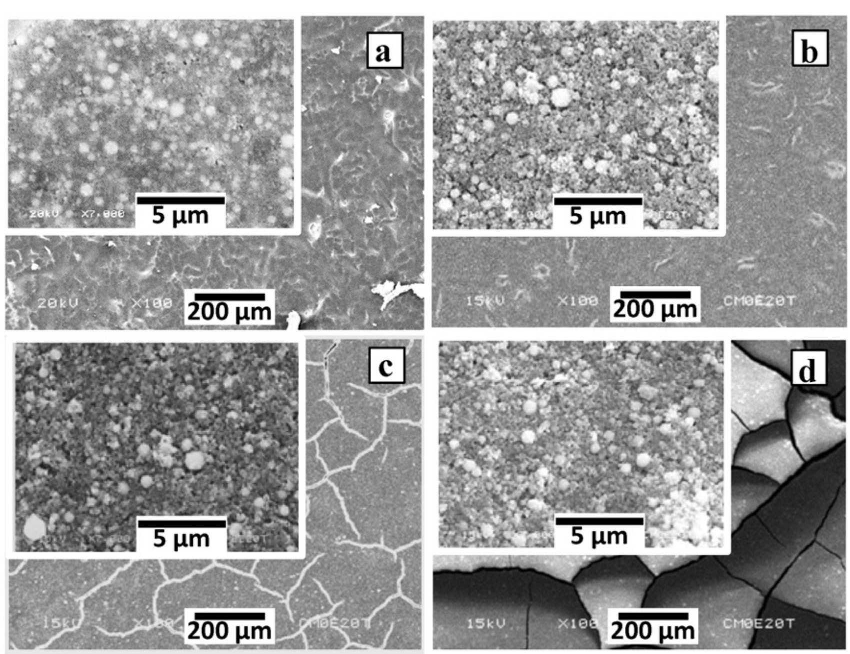

Fig. 3. SEM micrograph at low magnification of the nano-HAP coating obtained in 10 min. by EPD at (a) 5 V, (b) 10 V, (c) 15 V and (d) 20 V. (The insets show high magnification images.)