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Sputtering Deposition to Modify the Corrosion Resistance Properties of Ti6Al4V Biomaterials

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***Abstract* - New biomedical material was prepared by enhancing medical-grade Ti6Al4V alloy to replace biological tissue or to help stabilize a biological structure, such as bone tissue to aid the healing process. We report on the deposition of bioactive hydroxyapatite (HA) coatings with a suitable structure on Ti6Al4V alloy substrate using the RF magnetron sputtering method. HA depositing has been employed for improving corrosion resistance and the biocompatibility of medical Ti6Al4V alloy. The phase composition was determined by using XRD measurements. X-ray diffraction peaks of HA (111), (211), (222), (213), (004) directions were observed. Electrochemical measurements were obtained for the uncoated Ti6Al4V alloy and HA coated in simulated body fluid (SBF) solution. A clear improvement in the corrosion resistance was observed for HA-coated Ti6Al4V rather than for uncoated specimens. The results showed that the corrosion rate was reduced to 6.83088×10^{-3} mm/y for the sputtering deposited samples compared with 8.709372×10^{-3} mm/y for the uncoated specimens.**

Keywords - Corrosion, Hydroxyapatite, Sputtering, Surfaces modification, Ti6Al4V.

INTRODUCTION

Ti6Al4V alloys are getting a lot interest in applications of the biomedical field. In both dental and medical fields for its excellent balance of mechanical properties, excellent corrosion resistance, excellent biocompatibility, light weight. It's mainly utilizing for implant devices change failed hard tissue, for example, artificial knee joints, dental implants, artificial hip joints, bone plates [1]. The HA compound has a chemical composition close to that of the bone with biocompatibility and bioactivity features that make it a gold standard in the field of biomaterials. Hydroxyapatite is known to be bioactive, meaning bone growth is supported directly on the material's surface when placed next to the bone. This response of hydroxyapatite sets it apart from the other CaP phases and has led to routine use in orthopaedic surgery in both powder and bulk form (Shi 2006). Wong et al. (1995) compared the osseointegration of commercial implants in the trabecular bone of mature miniature pigs for 12 weeks. Their results showed excellent osseointegration of the HA-coated implant. More recent studies (Cao et al. 2006, Froimson et al. 2007) have also shown the successful osseointegration of HA coatings with surrounding bone tissue after an HA-coated implant was placed within the living bone. Cao et. al. produced HA-coated carbon/carbon (carbon-fiber-reinforced carbon) composites, an alternative to the traditional metal stem used in total-hip arthroplasties, and placed these implants into the tibia of rabbits. Froimson et al. recently concluded that plasma-sprayed HA-coated titanium implants showed excellent osseointegration during 10-year follow-ups of 147 consecutive primary hip arthroplasties performed in 133 patients by a single surgeon during a 2-year interval. While HA has demonstrated its ability to integrate with bone tissue it does not possess ideal mechanical properties to serve as a major load-bearing implant. Many orthopedic implants are based on the use of metallic alloys such as stainless steel or titanium alloy. Metals, however, do not form a direct bond with the bone. Therefore there is interest in applying bioactive coatings to metal implants. Deposition of HA coatings has been achieved by a number of methods, including plasma spraying [5-7], ion implantation [8,9], plasma sputtering[10-12], sol-gel coating[13-15], biomimetic methods[16-18], and electrophoretic deposition (EPD) [19-21]. Among these methods, plasma sputtering is a fairly rapid and inexpensive way of producing a dense and uniform coating on substrates even with complex geometries.

In this paper, Ti-6Al-4V alloy will be coated with a layer of hydroxyapatite using RF magnetron sputtering method , then samples will be examined by examination of X-ray diffraction (XRD), scanning electron microscope (SEM) and atomic force microscope (AFM), and then corrosion tests represented by measuring the open circuit potential(OCP) and measuring a scheme of Polarization (Tafel) to determine the corrosion rate, and for evaluating the results for their potential use in medical applications.

MATERIALS AND METHODS

The Ti6Al4V alloy substrates with a diameter of (2cm) were used for depositing the HA coatings. Samples were prepared from Ti6Al4V alloy and smoothed with a polishing paper composed of silicon carbide with a granular size of 500 microns. And chemically clean them with a solution consisting of (O2, HF, and HNO_3) in volumetric proportions (3: 1: 6), respectively. Samples were washed with 96% ethanol using an ultrasound bath for 10 minutes and twice, after which the samples were washed. With distilled water using an ultrasound basin for 10 minutes once. The samples were coated by RF magnetron sputtering deposition method. The sputtering chamber was evacuated to less than 5×10^{-5} mbar, throttled and the sputtering gas pressure was 2×10^{-3} mbar with a discharge power 200Watt, and sputtering time of 3 hour. All coated samples were exposed to low-pressure plasma for 30 minutes. When used with oxygen plasma, can augment the hydrophobicity of nonporous HA surfaces and the osseoconductivity of Ti6Al4V disc via increased water penetration of inner porous structures. The corrosion tests were achieved by (PARSTAT 2273, USA) using simulated body fluid (SBF) as a corrosion environment, Ringer solution (Chemical Composition is explained in Table 1 with adjusted pH 7.4.

TABLE 1
THE CONCENTRATION OF SBF

Sample	Constituent	Weight(gm/l)
1	NaCl	9
2	KCl	0.43
3 4	CaCl2 NaHCO3	0.24 0.20

RESULTS AND DISCUSSIONS

The XRD pattern shows that the pure titanium successfully coated with a thin layer of hydroxyapatite using RF magnetron sputtering method, where the peaks in 2θ = 22.9, 31.77, 46.7, 49.46, 53.14 according to ICDD 09-0432 indicate the presence of hydroxyapatite, and there is no shifting in the peaks, that indicates there is no changing in lattice parameters as shown in Fig .1.

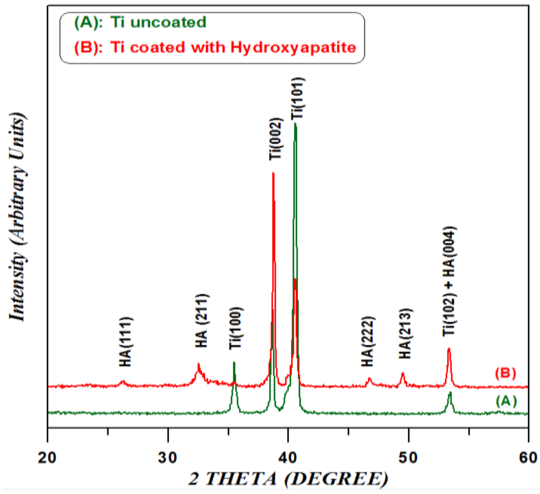

FIGURE 1
THIS FIGURE DEPICTS XRD PATTERNS OF TI6AL4V ALLOY (A) AS PREPARED, AND (B) COATED BY HA COATING

Fig. 2 shows the representative surface morphologies of HA coatings. As shown in Fig. 2, coatings contained the denser HA structure, fine particles, with few big particles sprinkled on the surface. In addition, the titanium substrate was partially coated with a thin coating. SEM image clearly demonstrates particles having uniform, homogenous distribution and the deposited films consists of closely HA nanoparticles with very small diameters. Fig. 3 shows the AFM images of HA thin films deposited on Ti6Al4V substrate. The coating surface was observed to be roughened and made up of larger agglomerated particles.

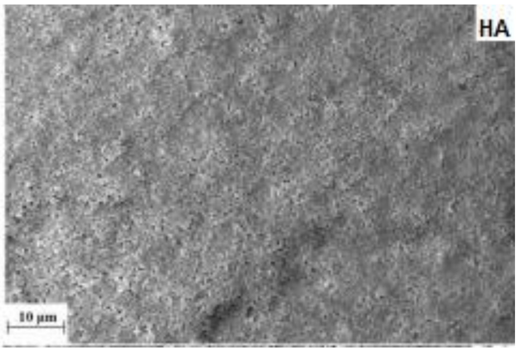

FIGURE 2
THIS FIGURE DEPICTS SEM IMAGES FOR HA LAYER DEPOSITED ON TI6AL4V SUBSTRATES

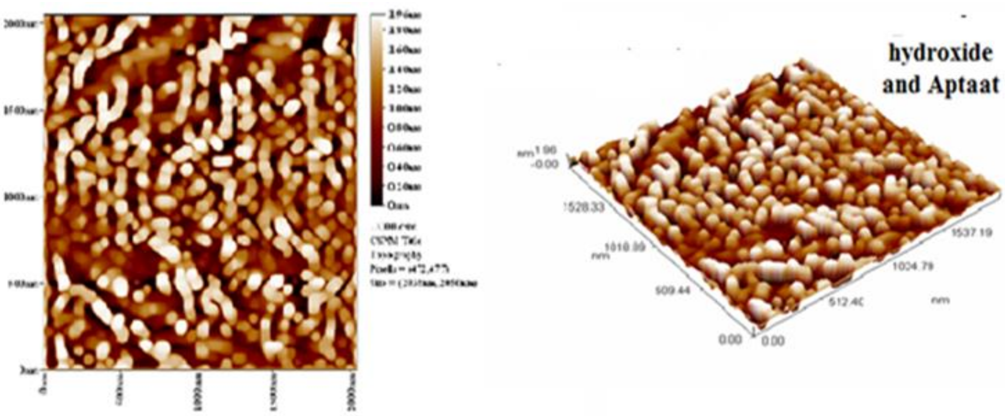

FIGURE 3
THIS FIGURE DEPICTS AFM IMAGES FOR HA LAYER DEPOSITED ON TI6AL4V SUBSTRATES

The corrosion behavior of titanium coated with shows a slight reduction in corrosion rate from 8.709372×10^{-3} mm/y to 6.83088×10^{-3} mm/y as shown in Fig. 4 which represents the comparison of polarization curves (Tafel) for coated and uncoated samples. We observed also the change in passivation region been wider (i.e. more passive) as shown in table (2) for corrosion test results.

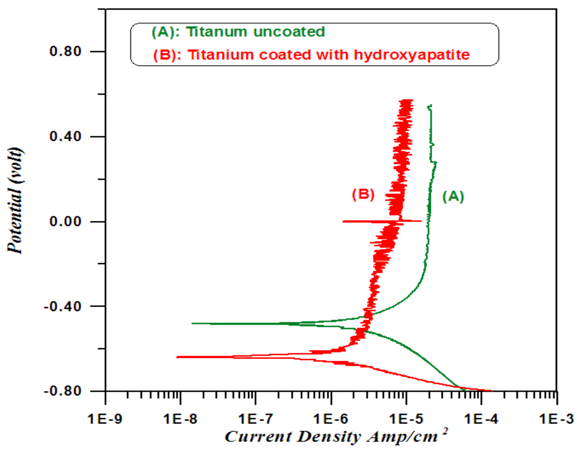

FIGURE 4
THIS FIGURE DEPICTS THE POLARIZATION CURVES (TAFEL) FOR TI6AL4V ALLOY (A) AS PREPARED, AND (B) COATED BY HA COATING

TABLE 2
CORROSION MEASUREMENTS FOR TI6AL4V ALLOY (1) AS PREPARED, AND (2) COATED BY HA LAYER

Sample	E cor.(Volt)	I cor. (Amp)	Cor. rate (mm/y)
1	-0.474	1.02×10^{-6}	8.709372×10^{-3}
2	-0.631	8.00×10^{-7}	6.83088×10^{-3}

CONCLUSIONS

We successfully obtained HA coatings using the RF magnetron sputtering method. Electrochemical parameters provided from an electrochemical investigation done on the HA single layer show improvement in the corrosion resistance were decreasing the corrosion potential Ecorr and current Icor. This development in the alloy specifications will be an important input for using it in medical applications as surgical implants. Is the proper section in the paper to thank all the people who helped you most in carrying out your research work. For example, a supervisor, a sponsoring institution, a funding body, and your colleagues or other researchers who have helped in the preparation and agreed to share with you their unpublished results. Acknowledge people's help and contribution will ensure the integrity of your research. It is also worth remembering that the style of writing the acknowledgement should be in a professional manner, so try to avoid any emotional or personal thoughts.

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REFERENCES

[1] Shi, D., & Xuejun, W. (2006). *Bioactive ceramics: structure, synthesis, and mechanical properties.* Introduction to biomaterials.

[2] Wong, M., Eulenberger, J., Schenk, R., & Hunziker, E. (1995). Effect of surface topology on the osseointegration of implant materials in trabecular bone. *Journal of biomedical materials research, 29*(12), 1567-1575.

[3] Cao, N., Ma, Q.S., Sui, J.L., Wang, Q.X., Lü, Y.P., Chen, Y.M., & Li, M.S. (2006). The experiment of plasma-sprayed HA coatings on carbon/carbon composites in bone. *Surface Review and Letters, 13*(04), 423-428.

[4] Froimson, M.I., Garino, J., Machenaud, A., & Vidalain, J.P. (2007). Minimum 10-year results of a tapered, titanium, hydroxyapatite-coated hip stem: an independent review. *The Journal of arthroplasty, 22*(1), 1-7.

[5] Yan, L., Leng, Y., & Weng, L.T. (2003). Characterization of chemical inhomogeneity in plasma-sprayed hydroxyapatite coatings. *Biomaterials, 24*(15), 2585-2592.

[6] Cheang, P., & Khor, K.A. (1996). Addressing processing problems associated with plasma spraying of hydroxyapatite coatings. *Biomaterials, 17*(5), 537-544.

[7] Xue, W., Tao, S., Liu, X., Zheng, X., & Ding, C. (2004). In vivo evaluation of plasma sprayed hydroxyapatite coatings having different crystallinity. *Biomaterials, 25*(3), 415-421.

[8] Baumann, H., Bethge, K., Bilger, G., Jones, D., & Symietz, I. (2002). Thin hydroxyapatite surface layers on titanium produced by ion implantation. *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, 196*(3-4), 286-292.

[9] Hamdi, M., & Ide-Ektessabi, A. (2003). Preparation of hydroxyapatite layer by ion beam assisted simultaneous vapor deposition. *Surface and coatings Technology, 163,* 362-367.

[10] Ding, S.J. (2003). Properties and immersion behavior of magnetron-sputtered multi-layered hydroxyapatite/titanium composite coatings. *Biomaterials, 24*(23), 4233-4238.

[11] Yamashita, K., Matsuda, M., Arashi, T., & Umegaki, T. (1998). Crystallization, fluoridation and some properties of apatite thin films prepared through rf-sputtering from CaO–P2O5 glasses. *Biomaterials, 19*(14), 1239-1244.

[12] Van Dijk, K., Schaeken, H.G., Wolke, J.G.C., & Jansen, J.A. (1996). Influence of annealing temperature on RF magnetron sputtered calcium phosphate coatings. *Biomaterials, 17*(4), 405-410.

[13] Hsieh, M.F., Perng, L.H., & Chin, T.S. (2002). Hydroxyapatite coating on Ti6Al4V alloy using a sol–gel derived precursor. *Materials chemistry and physics, 74*(3), 245-250.

[14] Kim, H.W., Koh, Y.H., Li, L.H., Lee, S., & Kim, H.E. (2004). Hydroxyapatite coating on titanium substrate with titania buffer layer processed by sol–gel method. *Biomaterials, 25*(13), 2533-2538.

[15] Weng, W., Zhang, S., Cheng, K., Qu, H., Du, P., Shen, G., & Han, G. (2003). Sol–gel preparation of bioactive apatite films. *Surface and Coatings Technology, 167*(2-3), 292-296.

[16] Song, W.H., Jun, Y.K., Han, Y., & Hong, S.H. (2004). Biomimetic apatite coatings on micro-arc oxidized titania. *Biomaterials, 25*(17), 3341-3349.

[17] Chou, Y.F., Chiou, W.A., Xu, Y., Dunn, J.C., & Wu, B.M. (2004). The effect of pH on the structural evolution of accelerated biomimetic apatite. *Biomaterials, 25*(22), 5323-5331.

[18] Stoch, A., Jastrzębski, W., Brożek, A., Stoch, J., Szaraniec, J., Trybalska, B., & Kmita, G. (2000). FTIR absorption–reflection study of biomimetic growth of phosphates on titanium implants. *Journal of Molecular Structure, 555*(1-3), 375-382.

[19] Meng, X., Kwon, T.Y., Yang, Y., Ong, J.L., & Kim, K.H. (2006). Effects of applied voltages on hydroxyapatite coating of titanium by electrophoretic deposition. *Journal of Biomedical Materials Research Part B: Applied Biomaterials: An Official Journal of The Society for Biomaterials, The Japanese Society for Biomaterials, and The Australian Society for Biomaterials and the Korean Society for Biomaterials, 78*(2), 373-377.

[20] Wei, M., Ruys, A.J., Swain, M.V., Kim, S.H., Milthorpe, B.K., & Sorrell, C.C. (1999). Interfacial bond strength of electrophoretically deposited hydroxyapatite coatings on metals. *Journal of Materials Science: Materials in Medicine, 10*(7), 401-409.

[21] Wei, M., Ruys, A J., Milthorpe, B.K., Sorrell, C.C., & Evans, J.H. (2001). Electrophoretic deposition of hydroxyapatite coatings on metal substrates: a nanoparticulate dual-coating approach. *Journal of Sol-Gel Science and Technology, 21*(1), 39-48.