INFLUENCE OF SILICON ADDITION ON THE PROPERTIES OF NEW TITANIUM ALLOYS

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Abstract

The mechanical characteristics and electrochemical behavior of the new titanium alloys TiMoZr, TiMoZrSi0.5, TiMoZrSi0.75 and TiMoZrSi1 were studied to determine their microstructure, corrosion behavior and mechanical properties. Following the use of the appropriate procedures, metallographic analysis showed that both samples had biphasic and dendritic structures. According to electrochemical tests in body simulation fluid, the samples' corrosion resistance increases with decreasing silicon content since silicon-containing samples corrode more quickly. Electrochemical Impedance Spectroscopy measurements were performed at various potentials, and the acquired spectra show a two-time constant system, due to the presence of a double-layer passive film on the samples. The three-point bending test for both samples demonstrated that the values of modulus of elasticity are lower than those commercial alloys and nearly to the cortical human bone, and the microhardness test showed that the samples' surfaces had soft and hard phases.

Introduction

Nowadays, due to the increasing use of biomaterials in various fields of medicine, they must have a number of characteristics: high biocompatibility, ductility, fatigue and wear resistance, osseointegration, absence of cytotoxicity and a combination of high strength and low Young's modulus equivalent to human cortical bone ranging between 10 and 30 Gpa [1–3].

About 70-80% of implants are made of metallic biomaterials [4], with Ti and its alloys being the most widely used, as they can modify their properties by changing the composition of the alloying elements, their biocompatibility with biological materials, high corrosion resistance, high mechanical performance, low modulus and high thermal stability [3,5–7]. The Ti6Al4V alloy is the most commonly used alloy for orthopaedic applications, although vanadium is a carcinogenic and toxic material and aluminium, in large concentrations, can cause dementia or Alzheimer's [8].

Consequently, it was decided to determine the effects of four different silicon concentrations on the microstructure, corrosion behaviour, quantitative microanalysis, modulus of elasticity and hardness of the new TiMoZrSix alloy by means of metallographic, electrochemical, scanning electron microscopy, three-point bending and microhardness tests.

Experimental

The study of four new alloys with Ti, Mo, Zr, varying the composition of Si, TiMoZr, TiMoZrSi0.5, TiMoZrSi0.75, and TiMoZrSi1, has been carried out with the aim of applying different tests to find out their properties. The production of these alloys was carried out using a Voltaic Arc Remelting (VAR) furnace in which a consumable electrode was melted in a vacuum at a controlled rate with the heat generated by an electric arc between the electrode and the ingot. As a previous step to electrochemical, metallographic and flexural tests, several processes should be performed, such as to embed into an epoxy resin cylinder the samples for cutting and their subsequent polishing in two stages: polishing with SiC abrasive papers of progressive grain size from 400 to 1200 grit and final polishing with 0.1 micrometer alpha alumina suspension. The samples are then submerged in an ultrasonic machine for 5 minutes to remove all traces of dirt, and then immersed in Kroll's reagent for 15 seconds. After chemical etching, the metallographic test was performed by taking images with the metallographic microscope, of the surface of the samples at different magnifications to characterize their microstructure. Moreover, electrochemical test consisted in inserting a specimen into an electrochemical cell together with Saturated Calomel Electrode (SCE) as reference and Pt electrode as counter electrode. Corrosion potential (E_{corr}), corrosion rate (v_{corr}) were determined, and Electrochemical Impedance Spectroscopy (EIS) and Pitting Potential were applied [9]. Three-point bending test were applied to find the value of the modulus of elasticity of each specimen. Finally, microhardness test was obtained following Vickers method by using a hardness tester and applying different loads.

Results and discussion

In the metallographic test, it can be observed that both samples had biphasic and dendritic structures, distinguishable for both magnifications. Furthermore, the size of dendrites decreased with the Si addition while the interdendritic zone increased. Moreover, in the corrosion tests, the samples were immersed in Ringer Grifols solution which simulates the physiological fluid of the human body the results obtained were processed by the EC-Lab software. From the plots of E_{corr} versus time, it has been observed that the corrosion potential tends to increase with time and thus a passive layer is formed, except for the TiMoZrSi0.75 sample, which corrodes. EIS measurements were performed on each specimen at different potentials to obtain the Bode Impedance plots, where the corrosion resistance increases the more positive the applied potential and the higher the impedance and phase angle values. After obtaining the polarization curves and performing the Tafel fit, it could be shown that the corrosion rate increases the higher the addition of silicon. In addition, no sample was corroded by the pitting technique. In the three-point bending test the value obtained for the modulus of elasticity of all samples is lower than commercial alloys. Furthermore, the graphs of Vickers hardness versus scan length for both samples show widely dispersed maxima and minima, as the surfaces of the samples show soft and hard areas and it is confirmed that the hardness increases the lower the percentage of silicon.

Conclusion

In this study, the effects of silicon content on the microstructure, microhardness, modulus of elasticity and corrosion behaviour of TiMoZrSix alloy in a simulated body fluid were investigated, and the following conclusions were drawn:

After the analysis of the results, it was confirmed, in the metallographic test, the biphasic and dendritic structure. On the other hand, in the electrochemical tests, both samples tended to passivate, apart from TiMoZrSi0.75, and it was demonstrated that the more positive the value of the applied potential, the greater the resistance to corrosion, presenting similar impedance values. The modulus of elasticity was lower than those of many commercial alloys. Finally, Vickers hardness values increases the lower the percentage of silicon and all samples presented soft and hard areas.

According to the results, the samples had good mechanical, chemical, and biological features, with the Ti20MoZrSi0.5 sample having slightly improved mechanical characteristics.

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