24-27 September 2025

5th GLOBAL CONFERENCE on ENGINEERING RESEARCH

Proceedings Book

ISBN: 978-625-94317-8-9

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Influence of Zirconium on Microstructure, Corrosion Resistance and Hardness of Titanium-Based Biomaterials

Cristina Jiménez-Marcos[1], Julia Claudia Mirza-Rosca[*,1,2], Madalina Simona Baltatu[2], Petrica Vizureanu[3]

[*]: cristina.jimenez112@alu.ulpgc.es, ORCID: 0000-0001-9260-9937

[1]: *Mechanical Engineering Department, Las Palmas de Gran Canaria University, Las Palmas de Gran Canaria, Spain*

[2]: *Materials Engineering and Welding Department, Transilvania University of Brasov, Brasov, Romania*

[3]: *Department of Technologies and Equipments for Materials Processing, Gheorghe Asachi Technical University of Iasi, Iasi, Romania*

ABSTRACT

Introduction

The quality of life and longevity of people have improved due to advances in medicine and biomaterials. However, there is a risk with musculoskeletal diseases, as well as with the life cycles of implantable devices. To prevent revision surgeries, biomaterials require high biocompatibility, ductility, fatigue and wear resistance and an elastic modulus matching human cortical bone, alongside being non-cytotoxic. Titanium alloys are commonly used in orthopedic surgery due to their biocompatibility and mechanical properties. Titanium alloys are commonly used in orthopedic surgery for their biocompatibility and mechanical properties. However, the standard Ti-6Al-4V alloy releases aluminum ions, related to neurodegenerative conditions, and vanadium ions, which is considered toxic and carcinogenic. Consequently, research focuses on novel alloys, such as Ti-Mo and Ti-Mo-Zr, which are expected to be less toxic and more corrosion resistant. This study examines the microstructure, microhardness and chemical properties of two titanium alloys to facilitate their application in biomedical devices to improve patient quality of life and reduce the need for revision surgeries.

Experimental

Two titanium alloys, Ti15Mo and Ti15Mo7Zr, were produced with vacuum arc melting using pure metal powders. The melting process was conducted in an argon atmosphere and involved six remelts to ensure homogeneity, resulting in uniform ingots. The new ingots were cut using a precision saw and embedded in epoxy resin. Subsequently, the samples are then polished in two stages: first, they are rough-polished with progressive-grit silicon carbide abrasive paper, from P280 to P2500 and then they are given a final polish with a 0.1-micron alpha alumina suspension to achieve a mirror finish. Finally, the samples are then cleaned with an ultrasonic machine to remove all traces of dirt and material.

Microstructural analysis was performed using an optical microscope after a 40-second etching in Kroll reagent. Elemental composition was determined by scanning electron microscopy coupled with energy-dispersive X-ray spectroscopy (EDX). Vickers microhardness was measured ten times per sample for 15 seconds each, using progressive loads of 5, 25, and 50 gf. Indentation diagonal lengths were automatically converted to microhardness values by the associated software, with Vickers hardness plotted against the number of indentation.

Corrosion behavior was evaluated using electrochemical techniques in Grifols Lactate Ringer's solution with a three-electrode setup: a working electrode (the sample), a platinum counter electrode, and a saturated calomel reference electrode (SCE). The tested methods included 24-hour open circuit potential measurement, linear polarization, and electrochemical impedance spectroscopy.

Results and discussion

The optical microscope images of the samples studied exhibits a β-phase with a body-centered cubic (BCC) structure due to the presence of Mo element for Ti15Mo. Conversely, Ti15Mo7Zr exhibits a dendritic two-phase structure after the chemical attack. EDX quantification provides a summary of the average chemical compositions of the alloys investigated, which shows close agreement with the theoretical concentrations of the chemical elements, with only slight differences due to local heterogeneities or measurement uncertainty.

In the microhardness test, it can be seen that when higher loads are applied, the average hardness values of each sample tend to decrease, as does the standard deviation. Ti15Mo7Zr has the maximum values of hardness in every load applied.

The zirconium sample showed a higher corrosion potential and greater corrosion resistance. Bode diagrams showed a tendency for impedance values and phase angles to increase when more positive corrosion potentials were applied, with the R(QR)(QR) circuit best matching the measured values.

Conclusions

This study examined the corrosion behavior, hardness, and microstructural characteristics of two newly developed titanium alloys that contain biocompatible elements. Due to the zirconium's addition, a clear difference in microstructure can be seen. Ti15Mo7Zr exhibits greater corrosion resistance due to a more robust passive layer and slightly higher microhardness maximum values, indicating uniformity and optimal mechanical performance. These results support the potential of these novel alloys for use in biomedical applications.

Keywords—*Titanium alloys; Metallography; Corrosion; Microhardness*