COMPARATIVE STUDY OF TI AND TI ALLOY FOR POSSIBLE MEDICAL APPLICATION

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Abstract

In the realm of modern medicine, the quest for innovation and improvement is relentless. One significant development that has transformed the landscape of medical devices and implants is the use of titanium and titanium alloys. Just as Titan stands as a resilient moon in the outer reaches of our cosmic neighborhood, titanium and its alloys have emerged as robust and versatile materials for a wide array of medical applications.

From orthopedic implants to dental prosthetics, and even in cutting-edge biomedical engineering, titanium's exceptional combination of strength, biocompatibility, and corrosion resistance has made it an indispensable asset in modern medicine.

Titanium and its alloys are not just elements on the periodic table; they are key elements in the quest for stronger, longer-lasting, and more effective medical treatments and devices.

Introduction

In the biomedical field one of the most widespread materials is Titanium but it's not flawless, the need of improvement is in fact real, it possesses high biocompatibility and high corrosion resistance, but its mechanical properties such as high Young's modulus and density make it troublesome for bone applications due to stress shielding phenomena, we propose a alloy R4 Ti15Mo7Zr15Ta1Si, that might be able to overcome Titanium, thanks to the mixture of different elements in its compositions that give it fantastic mechanical properties, close to the one of human bone, avoiding the all present stress shielding phenomena.

To do so we need first to test the corrosion resistance of the material to be able to demonstrate that it can compare with Titanium, in fact one of the most critical problems in human body is material degradation via corrosion.

Experimental

We were able to learn about the properties of the alloys by doing several experiments to determine the impact of titanium and titanium addition in one of the samples. The chemical make-up of the study samples is titanium and Ti15Mo7Zr15Ta1Si (62% Ti, 15% Mo, 7% Zr, 15% Ta, and 1% Si). These alloys were created using a vacuum arc remelting furnace (VAR), which utilized the heat produced by an electric arc between the electrode and the ingot to gradually fuse a consumable electrode in a vacuum at the "Gheorghe Asachi" Technical Faculty of Materials Science and Engineering. A portion of the ingots were given to Las Palmas de Gran Canaria University for analysis and processing.

Epoxy resin was first put to molds in a 4:1 ratio to prepare the surfaces of the two samples for embedding. The samples were then longitudinally sliced at a thickness of 1 to 1.5 mm using a Buehler IsoMet 4000 precision saw (Buehler, Lake Bluff, IL, USA).

The surfaces were then ground and polished in two steps using the Struers TegraPol-11 polishing machine (Struers ApS, Ballerup, Denmark): initially, with progressive grit silicon carbide papers from 280 to 1200, and then, for the final polish, with 0.1 microns of alpha alumina suspension to polish the surfaces to a mirror finish. The experimental techniques used to prepare samples for metallography were in accordance with ASTM E3-11(2017).

The samples were then heated "Ultrasons-HD" ultrasonic equipment from J.P. Selecta (JPS, Barcelona, Spain) for ten minutes to remove any residual traces of dirt or impurities.The phases and compounds that make up a metallic substance, as well as any impurities or potential mechanical faults, are grouped spatially in metallography.

Each specimen's surface was photographed using the Axio Vert.A1 MAT ZEISS optical metallographic microscope (Jena, Germany) in order to investigate the microstructure.

Each sample was immersed in Kroll's reagent, consisting of 20 mL glycerin, 30 mL hydrochloric acid, and 10 mL nitric acid, at intervals of approximately 15 s, and the attacked surface was photographed following. The test was finished in three tries.In an electrochemical cell with three electrodes—the samples served as the working electrodes, the reference electrode was a saturated calomel electrode, and the counter electrode was a platinum electrode—the samples were consecutively added for the electrochemical tests.

The area of each sample was determined in order to carry out the tests. The mmol/L values for the Grifols Laboratories' Ringer solution (Barcelona, Spain) were Na+ 129.9, Cl 111.7, C3H5O3 27.2, K+ 5.4, and Ca2+ 1.8.

The Corrosion Potential vs time, linear polarization and Electrochemical Impedance Spectroscopy procedures were carried out using the BioLogic Essential SP-150 potentiostat from Seyssinet-Pariset in France. The tests were carried out at 25°C in an aerated Ringer solution.Using the "Ecorr vs. time" method, the corrosion potential was measured over the course of 24 hours with potential readings of 10 V and potential recordings made every 300 s or 200 mV apart. The gathered information was used to create a potential vs. time graph, which may show a tendency toward passivation or corrosion over time or remain constant.

Results and discussion

1. Corrosion Potential

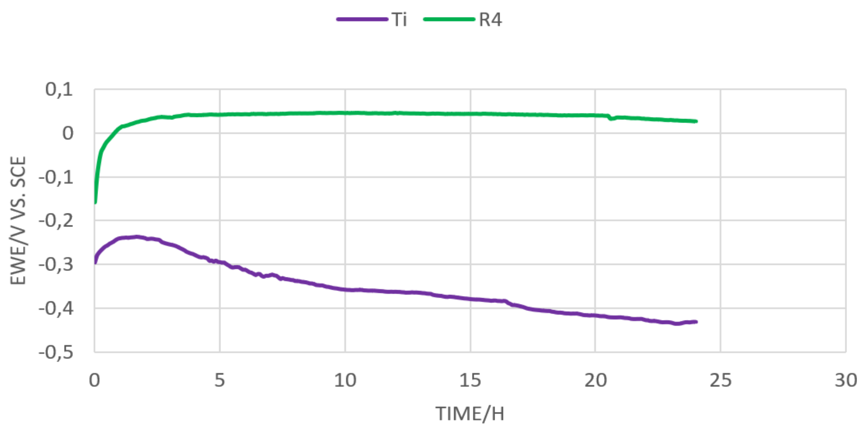

Fig. 1 – Corrosion potential vs time in Ringer solution

This graph about corrosion potential (Fig. 1) shows that the pure Ti element tends to slowly corrode while the R4 tends to be passive.

2. Bode Phase and Bode Impedance

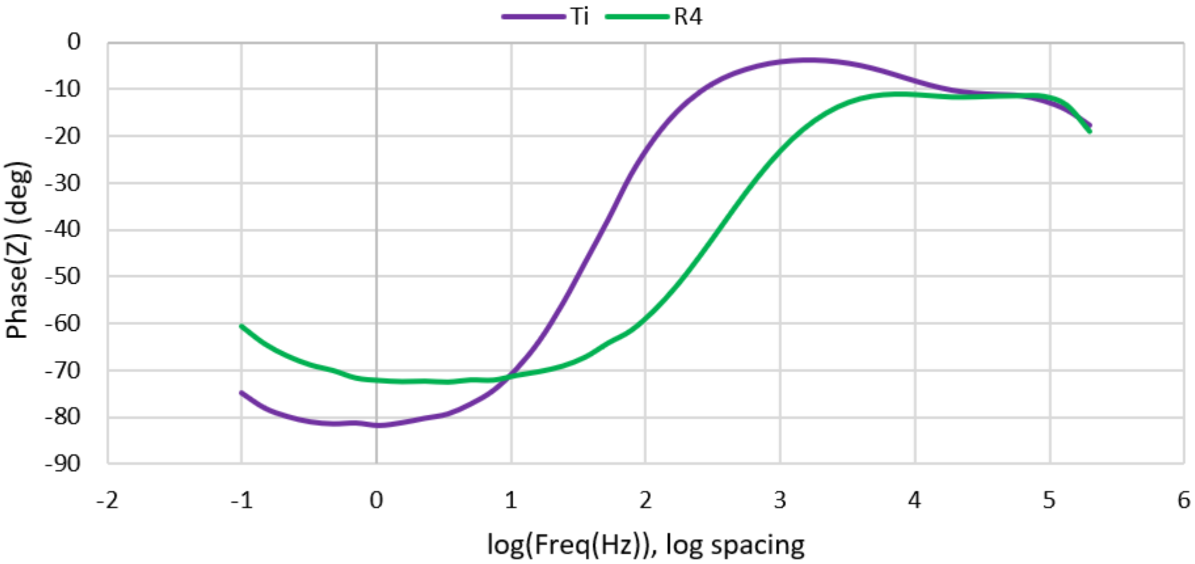

Fig. 2 – Bode-phase spectra in Ringer solution

When evaluating the Bode-Phase, as depicted in (Fig. 2), we can observe a consistent pattern in both Titanium and R4 alloy. This pattern reveals a compact zone with a low phase angle.

The Bode Phase is an important aspect of impedance spectroscopy used to assess the electrochemical behavior of materials. In the context of corrosion resistance, a low phase angle signifies that the impedance of the material is primarily resistive rather than capacitive. In simpler terms, this means that the material has a strong ability to hinder the progression of corrosive processes, the compact, low-phase-angle region in the Bode Phase plot is a promising sign of their performance in the face of corrosive factors, underlining their suitability for a wide range of industries and applications.

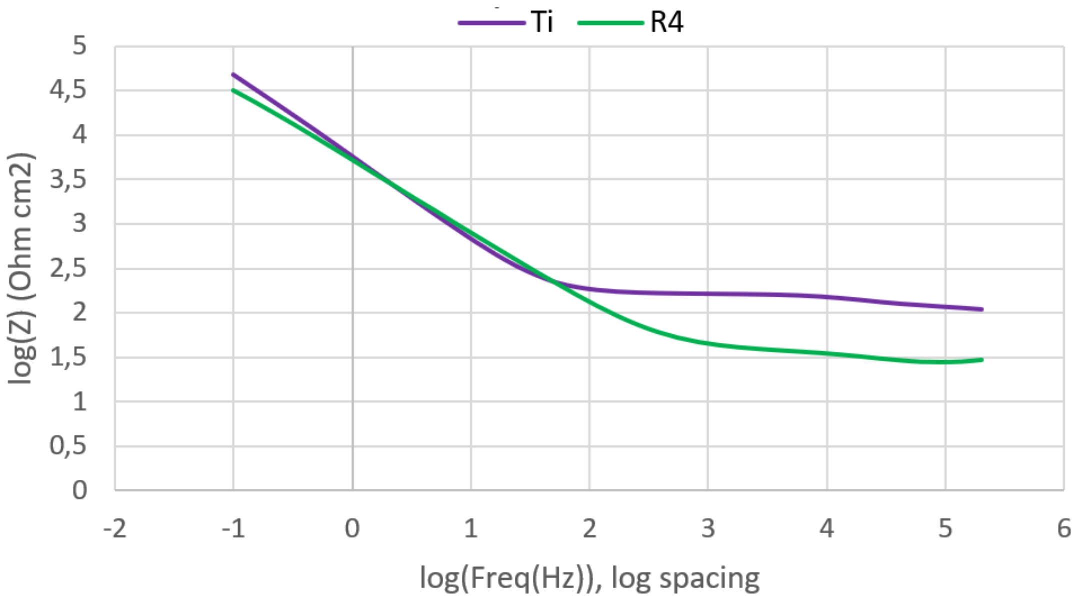

Fig. 3 – Bode_IZI spectra in Ringer solution

The observed behavioral difference between R4 and Titanium in this particular situation takes on significant relevance. The fact that R4 exhibits a more protracted diminishment with increasing frequency points to a few crucial facts: first, the Bode Impedance analysis (Fig. 3) is an effective tool that provides insights into the electrochemical behavior of materials; second, the observed behavior of R4 with its protracted diminishment as frequency increases highlights its exceptional potential for applications requiring robust corrosion resistance and stability across a wide range of conditions.

3. Nyquist

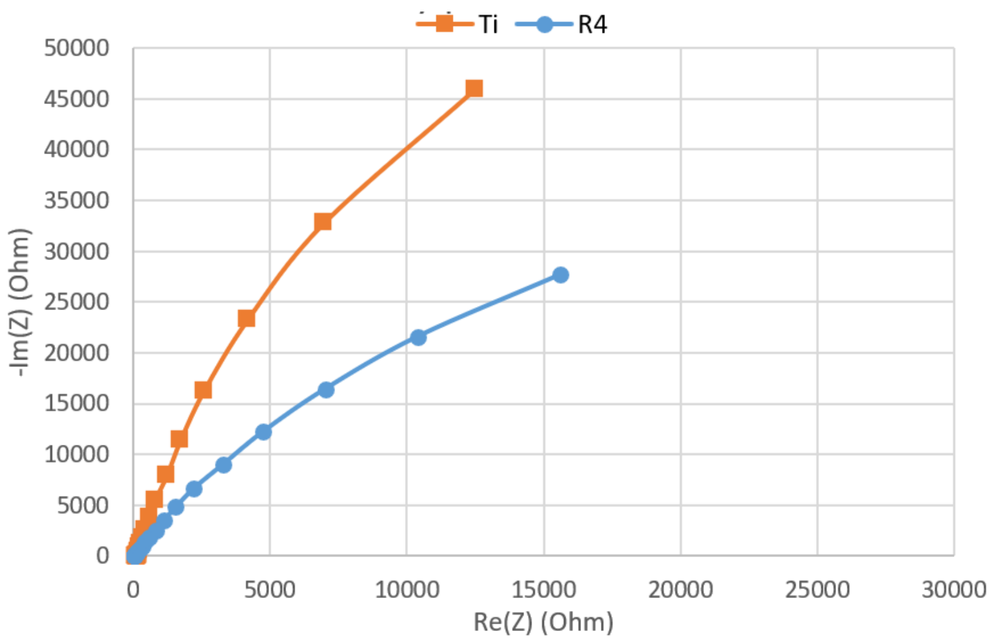

Fig. 4 – Nyquist

Diagrama Nyquist este o altă tehnică importantă în analiza electrochimică utilizată pentru a evalua comportamentul unui material în ceea ce privește impedanța și răspunsul la frecvență. Când comparăm diagrama Nyquist a titanului cu cea a aliajului R4, putem observa diferențe care oferă informații valoroase despre comportamentul lor electrochimic.

According to the Nyquist plots, Titanium has a better impedance response than R4, which indicates that it is more resistant to corrosive conditions.

4. Corrosion rate

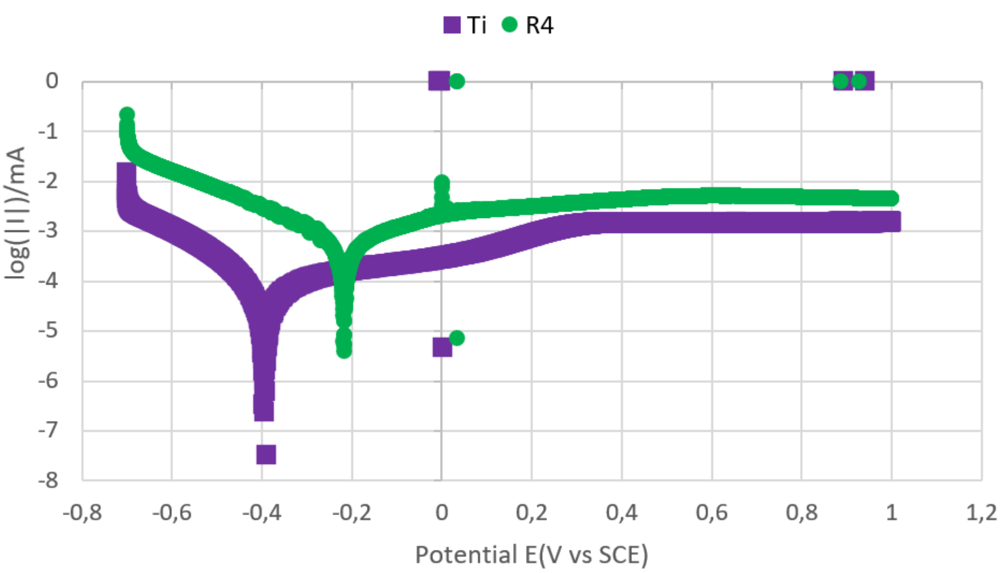

Fig. 5 – Liniar polarization curves for the samples in Ringer solution

In conclusion, the fact that both treated materials have a tendency to passivate and create an oxide shield is encouraging evidence of their capacity to resist corrosion, and this quality has important ramifications for their use in medical field. The R4 alloy stands out due to its more consistent passivation response, which makes it the material of choice in real-world applications where durability and long-term corrosion protection are crucial.

The selection of materials is crucial for medical applications such the production of orthopedic implants, surgical equipment, and other vital medical devices. These items must endure sterilizing processes, bodily fluids, and possibly long-term implantation in the human body because they frequently come into contact with bodily fluids and tissues.

Conclusion

The behavior of pure Ti material and the R4 alloy were compared, and important insights into their potential for use in medicine were gained. Both materials show a propensity to create a passive layer, which points to their potential for corrosion resistance. But the R4 alloy stands out because it exhibits a more reliable and effective passivation reaction.

This discovery is exceptionally significant in the medical industry when it comes to choosing materials. The stability of R4's passivation suggests that it can provide much greater durability and longevity compared to materials with less stable passivation reactions since it can keep its integrity in conditions like biological fluids and even inside the human body.

In order to ensure the security and efficiency of medical equipment, this comparative research helps with material choice and engineering decisions. In conclusion, it can be said that pure Ti material is still a possibility in some situations, while the R4 alloy offers a preferable option for medical applications, offering improved potential for performance and long-term protection.

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