Electrochemical comparative study of corrosion behavior in physiological conditions of conventional and powder metallurgy titanium alloys

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Abstract

It has been performed an **electrochemical study of two titanium alloys** employed in the manufacture of orthopedic implants, **Ti6Al4V** and **Ti6Al7Nb**, obtained through **powder metallurgy (PM).** For comparison purposes, **conventional Ti6Al4V** has also been investigated. Samples were immersed in a simulated body fluid and incubated at 37°C for different times. Under these experimental conditions, it has been **compared the influence of the processing method** of alloys (PM or conventional) **and their composition in the corrosion resistance.** Reproducibility and corrosion resistance of these alloys were evaluated by mean of **electrochemical impedance spectroscopy (EIS).** All of them showed good reproducibility and high impedance modulus value approximately on the order of **10^6 Ω.** Although no significant differences in the evolution of the corrosion behavior for different immersion times has been found; the **Ti-6Al-7Nb PM** delivers a steady growth of corrosion resistance from day one until twelve weeks immersion; showing **the best performance** between the two studied compositions. By mean of scanning electron microscopy, **no** evidence of **pitting corrosion phenomenon** was observed.

Motivation

Stem (Ti6Al4V)

Corrosion Resistance:

Ti-6Al-4V (F) **Ti-6Al-4V (PM)** **Ti-6Al-7Nb (PM)**

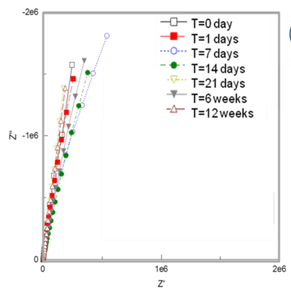
Processing method **Composition**

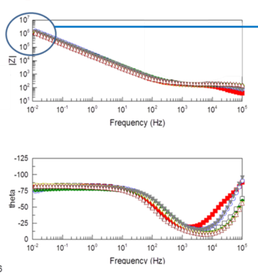
Stem (Ti6Al7Nb)

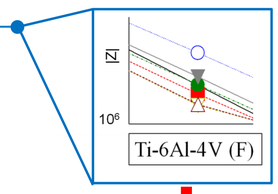
Results

Electrochemical Impedance Spectroscopy (EIS) study

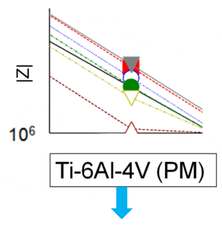
✓ **Evolution of three alloys along the immersion time:**



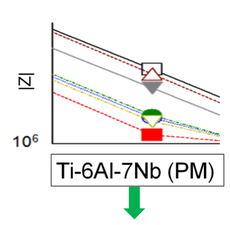




Ti6Al4V (F)
Highest |z|: 7 days

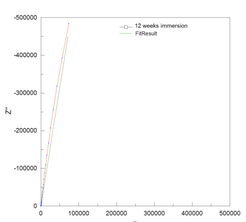


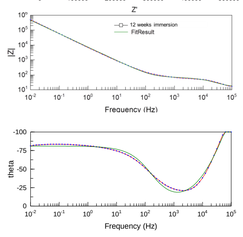
Ti6Al4V (PM)
Highest |z|: 1 day and 6 weeks



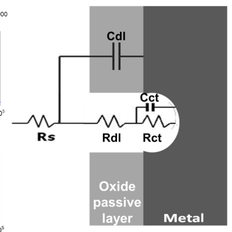
Ti6Al7Nb (PM)
Highest |z|: 12 weeks

✓ **Equivalent electrical circuit & corrosion mechanism:**

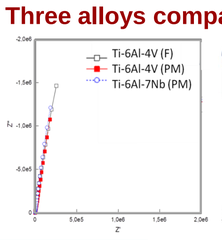


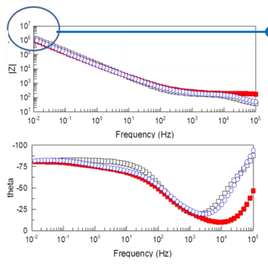


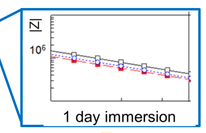
- ✓ *Good visual fit*
- ✓ *Results with physical meaning*
- ✓ *Errors < 5%*
- ✓ *Chi-squared ≈ 8x10^{-3}*



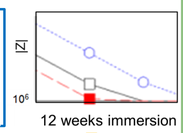
✓ **Three alloys comparison for a certain immersion time:**





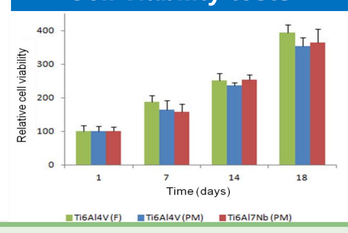


Shortest time
Highest |z|: *Ti6Al4V (F)*



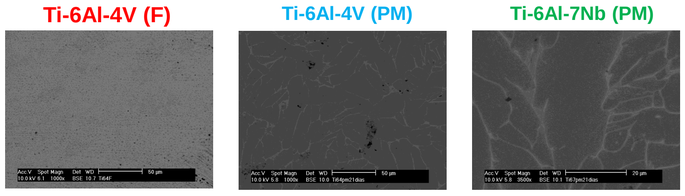
Longest time
Highest |z|: *Ti6Al7Nb (PM)*

Cell viability tests



SEM characterization

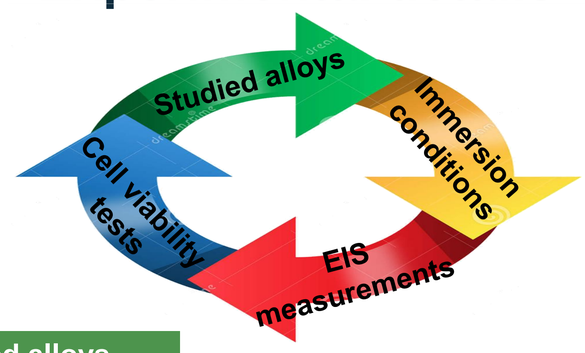
Ti-6Al-4V (F) **Ti-6Al-4V (PM)** **Ti-6Al-7Nb (PM)**



Conclusions

- The three studied alloys: **Ti6Al4V (F), Ti6Al4V (PM) y Ti6Al7Nb (PM)** show **excellent corrosion resistance (|z|>10^6Ω) in physiological conditions from day one until twelve weeks immersion.**
- Although **no significant differences in the evolution of the corrosion behavior**, for different immersion times it has been found; the **Ti-6Al-7Nb** alloy processed by **PM delivers a steady growth of corrosion resistance from day one until twelve weeks immersion**; showing the best behavior between the three alloys.
- It has been shown how **powder metallurgy allows obtaining materials with similar or superior corrosion resistance in physiological conditions than alloys obtained conventionally.**
- **MSC viability of cells grown on Ti6Al4V (PM) and Ti6Al7Nb (PM) alloys is similar to the conventional Ti6Al4V alloy.**

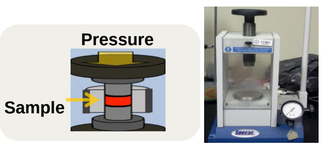
Experimental details



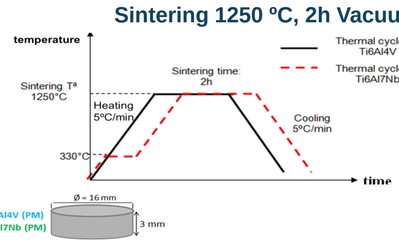
Studied alloys

→ ***Ti6Al4V & Ti6Al7Nb Powder Metallurgy alloys***

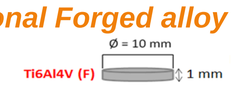
Uniaxial Pressing 600 MPa



Sintering 1250 ºC, 2h Vacuum 10^{-5} mbar



→ ***Ti6Al4V Conventional Forged alloy***



Ti6Al4V ELI medical grade (Surgival SL)

Immersion conditions

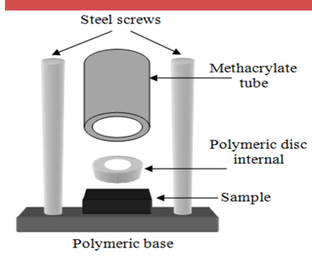
Simulated body fluid composition:

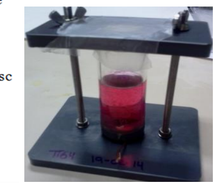
DMEM (Dulbecco's modified Eagle's medium)
+
fetal bovine serum (15%)
+
antibiotics

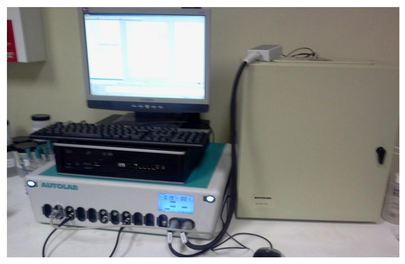
Immersion time:
1, 7, 14, 21 days
&
6, 12 weeks

Equipment:
Incubator (37ºC)

EIS measurements





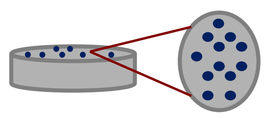


Autolab Potentiostat PGSTAT302N

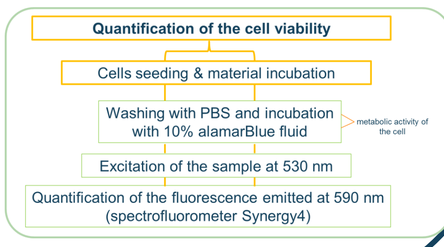
Counter electrode	Reference electrode	Working electrode	Frequency	Amplitude	Tª / Volume
Platinum	Ag/AgCl/KCl (0,197mV vs ENH)	Surface sample (0.28cm^2)	10 mHz – 10 KHz	±10 mV	Tª atmosphere 20 mL

Cell viability tests

Ti-6Al-4V (F)
Ti-6Al-4V (PM)
Ti-6Al-7Nb (PM)



Human mesenchymal stem cells isolated from bone marrow (MSC) seeded on the materials



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