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MECHANICAL PROPERTIES OF Ti-47Nb AND Ti-30Nb-8Zr ALLOYS

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Abstract. A new generation of beta Ti-Nb-Zr and Ti-Nb alloys with considerable deformation capacity during compression tests, high ductility, and great mechanical strength with the closest elastic modulus of the bone has been studied to replace the commercial Ti-6Al-4V alloy. In this investigation, the compressive mechanical properties and microstructure of Ti-47Nb and Ti-30Nb-8Zr alloys were analyzed and compared with those of the cpTi grade 4. The Ti-30Nb-8Zr alloy has higher compressive strength than Ti-47Nb and cpTi grade 4. The Ti-30Nb-8Zr alloys presented β matrix with equiaxed grains without precipitates and with α -martensitic phase with precipitates. The Ti-47Nb alloy presents highest ductility.

Keywords: Ti- β alloys, Ti-Nb, Ti-Nb-Zr, Mechanical Properties, Microstructural Properties.

1. INTRODUCTION

For a material to be used as a biomedical device, it must have adequate chemical and mechanical properties. The mechanical properties of the biomaterials are selected according to their specific application. For orthopedic applications, it is requirements a high mechanical performance associated with a lower modulus of elasticity is required.

Metallic materials are widely used in orthopedic implants because of their high mechanical strength. Currently, stainless steel 316 ELI (ASTM F138), cobalt-chromium alloys (ASTM F75 and F90), the titanium alloy Ti-6Al-4V (ASTM F136) are the most commonly used materials for orthopedic applications (Geetha, *et al.*, 2009). However, according to a study carried out by Rae, 1981 these materials have reduced biocompatibility due to the presence of aluminum, vanadium, cobalt, chromium. Furthermore, Pires, *et al.*, 2009 have accentuated the problem of the low fatigue strength and high modulus of elasticity can result in failures. The high modulus of elasticity of these materials (> 100 GPa) when compared to bone (30 GPa) may result in a phenomenon known as stress shielding, which prevents the adequate transfer of stress from the implant to the bone. The high elastic modulus of orthopedic implants has resulted in deleterious effects for the patient as it leads to bone loss and the need for a second surgery to remove the implant (Chen and Thouas, 2015).

Titanium beta alloys have a lower modulus of elasticity and have been developed to increase mechanical biocompatibility with bone (Geetha, *et al.*, 2009). These alloys are obtained when sufficient amounts of β -stabilizing elements are added in the titanium matrix which stabilize the β phase at room temperature. β -stabilizers are Nb, Mo, Ta, Cr, Fe, V, etc. On the other hand, Al, N, H, O, C are α stabilizing elements. The elements Zr and Sn are classified as neutral because they do not act directly in the stabilization of the phases of the titanium alloys (Lampman, 1992). The Ti-47Nb and Ti-30Nb-8Zr alloys are classified as beta alloys because they have a microstructure composed of the beta phase. Due to their structural characteristics, these alloys present superior mechanical properties, associating high mechanical performance for the application of biomaterials and a modulus of elasticity close to the human bone. The mechanical and structural properties of Ti-47Nb and Ti-30Nb-8Zr alloys were characterized and analyzed for the application of orthopedic implants.

2. EXPERIMENTAL PROCEDURE

For the characterization of the mechanical properties, Ti-47Nb and Ti-30Nb-8Zr alloys were received in the form of a round bar with a diameter of 6.07 and 20 mm, respectively.

From the bars, specimens were cut for the mechanical characterization by compression and structural characterization by X-ray diffraction (XRD), optical microscopy and scanning electron microscopy (SEM). The results of the tests of compression were compared with cp Ti grade 4.

For compression testing, samples were polished following the procedure of preparation and analysis of ASTM E92 (2003). Compressive strength was obtained using the EMIC universal machine model DL-10000 (EMIC Equipment and Testing Systems LTDA, São José dos Pinhais, PR, Brazil). ASTM E09 was used and a loading rate of 1 mm / min was applied.

The X - ray diffraction experiments were performed using a PANalytical X'Pert PRO diffractometer with PIXcel detector equipped with a monochromatic copper source ($\lambda = 1.54$). A quantitative phase analysis was obtained by refinement using the Rietveld method implemented in the PANalytical's HighScore Plus version 3.0e (3.0.5) 2012 software. Micrographs of the microstructure of the alloys were obtained by optical microscopy and SEM following the preparation procedures of the samples described in the ASTM E407 - 07 standard. Kroll reagent (6% HNO₃, 2% HF and 92% H₂O) was used for acid attack. The Zeiss optical microscope model Axio Scope equipped with the Zen Software Imaging version 2.3 with a digital camera axiocam icc5 and a scanning electron microscope FEI Quanta FEG 250 were used for the characterization of the microstructure.

3. RESULTS AND DISCUSSION

Figures 1 and 2 show the results for XRD. As expected for the high amount of Nb in the Ti-47Nb alloy, it is possible to see in Figure 1 that the microstructure is composed exclusively of β -phase. This result is similar to others in the literature, for example Hon, *et al.*, 2003. It is worth to note that the alloy presents high texture, since almost only (1 1 0) planes diffracted. The others plane from CCC structure of β -phase are mixed with the noise.

The result for Ti-30Nb-8Zr alloy is presented in Figure 2. Since the presence of Nb is at 30%, one can see that not only the β -phase is present but also the martensitic phase α'' . The parameters found for the lattice of the α'' phase were $a = 3.1$, $b = 4.88$ e $c = 4.7$. Furthermore, the presence of Zr shifted the diffraction angles to the right as demonstrated in Geetha, *et al.*, 2004.

The phases parameters found is similar to the ones found by other authors, for example Cremasco, *et al.*, 2011. Despite the fact that Zr suppress the α'' phase at room temperature (Zhou, *et al.*, 2009), the amount of Zr and Nb in the studied alloy was not enough for that as presented in Figure 2.

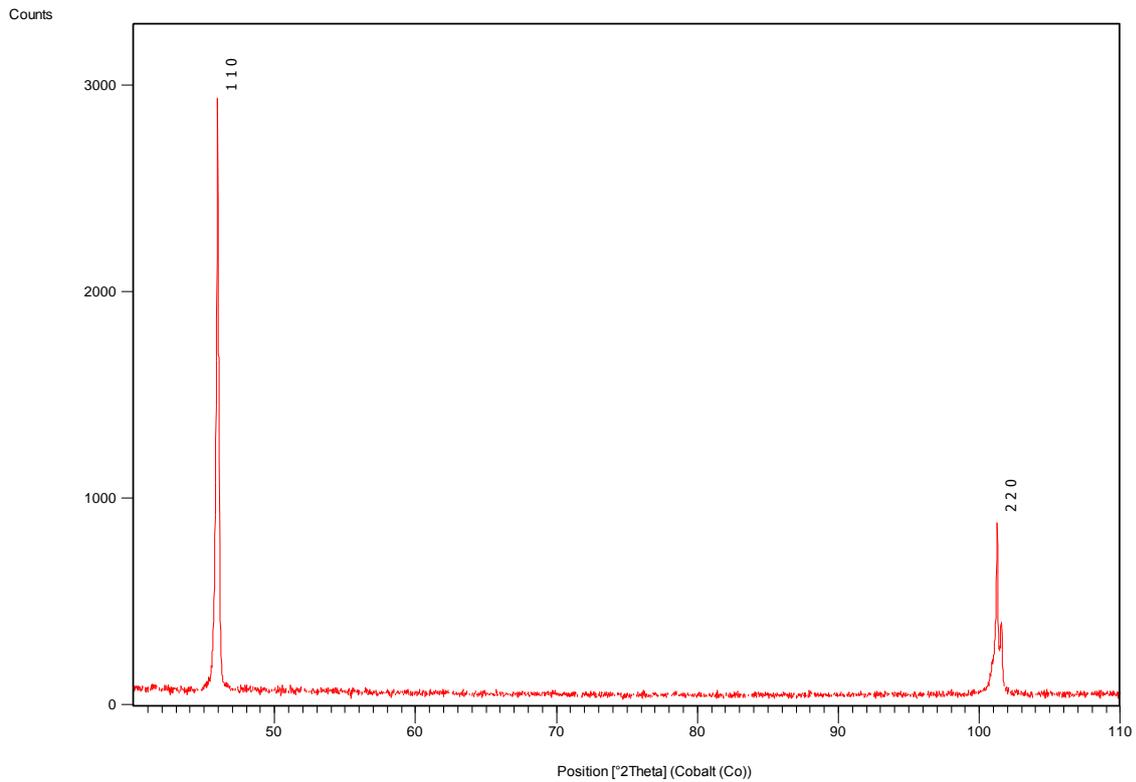


Figure 1 – XRD analysis of the Ti-47Nb alloy.

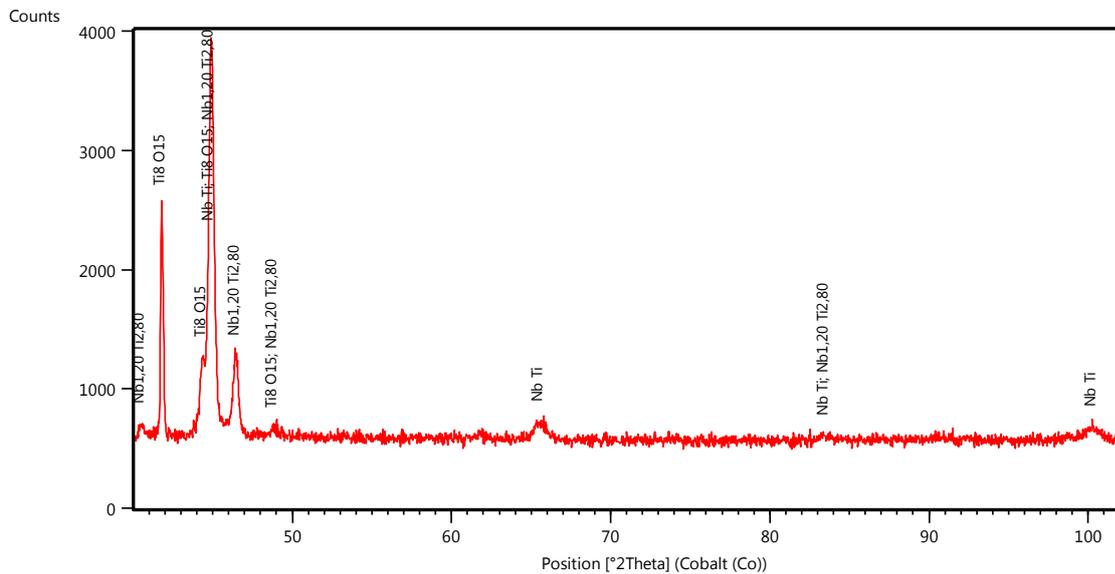


Figure 2 – XRD analysis of the Ti-30Nb-8Zr alloy.

Figure 3 shows the optical microscopy results of Ti-47Nb alloy, which has equiaxed grains with sizes between 50 and 300 μm . In Figure 4, one can see for the Ti-30Nb-8Zr alloy one can see a homogeneous distribution of the grains with smaller grain size than the previous alloy (from 5 up to 50 μm). Moreover, it is possible to observe several precipitates of α'' phase as showed in Figure 2.

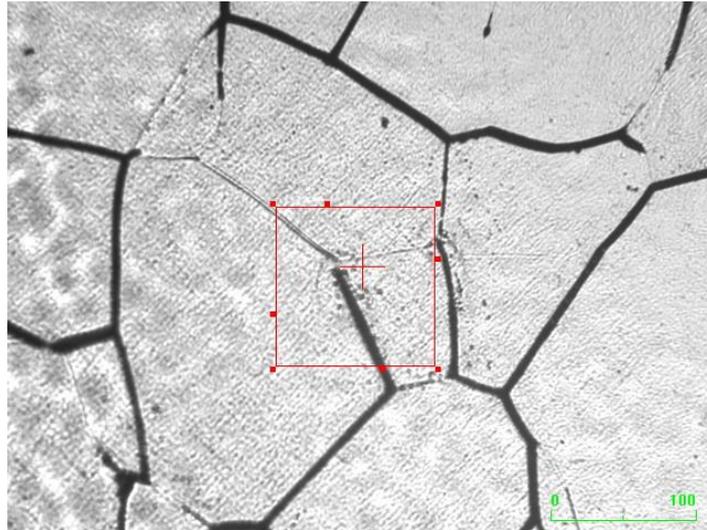


Figure 3 – Optical microscopy of the Ti-47Nb alloy.

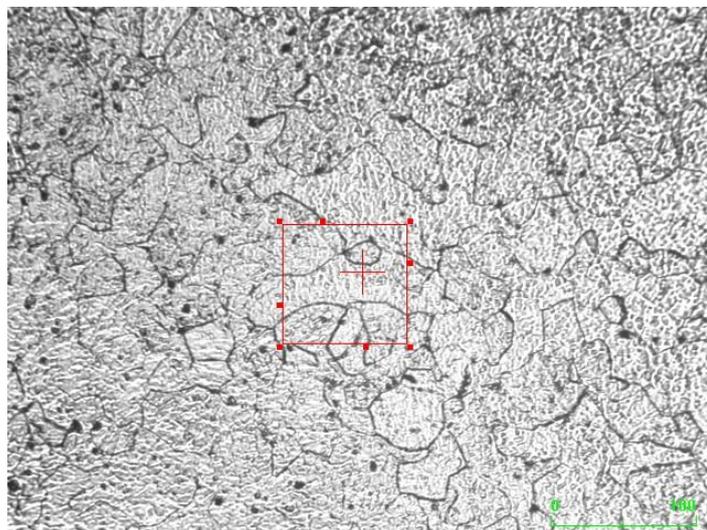


Figure 4 – Optical microscopy of the Ti-30Nb-8Zr alloy.

Based on the result presented in Figure 5, it is possible to observe that the improvement in compression strength of the alloy Ti-30Nb-8Zr compared with cpTi grade 4 is significant.

This result can be associated with three main factors: lower grain size, presence of Nb and Zr and presence of martensitic α' phase. There is also the possibility of the presence of the metastable ω phase, which also improve tensile, compression strength and hardness, although elongation decreases significantly. Comparing Tables 1 and 2, one can see that the difference is statistically significant in the significance level of 5% for the increase in compression strength and decreases the strain.

The addition of Zr, which remains in solid solution, also contributed to the increase the compression strength, since the difference in atomic radius creates distortions in the lattice and interact with dislocations. In addition, Zr contributed to reduce the strain of the alloy as argued by Zhou, *et al.*, 2009.

As expected the ductility of Ti-47Nb alloy is significantly higher than cpTi grade 4 due to the presence of β phase where dislocations have higher mobility. Since the optical images showed that the Ti-47Nb has higher grains size, one way to improve it is mechanical properties is throughout thermo-mechanical treatments that reduce grain size. The results for Ti-47Nb alloy is presented on Table 3.

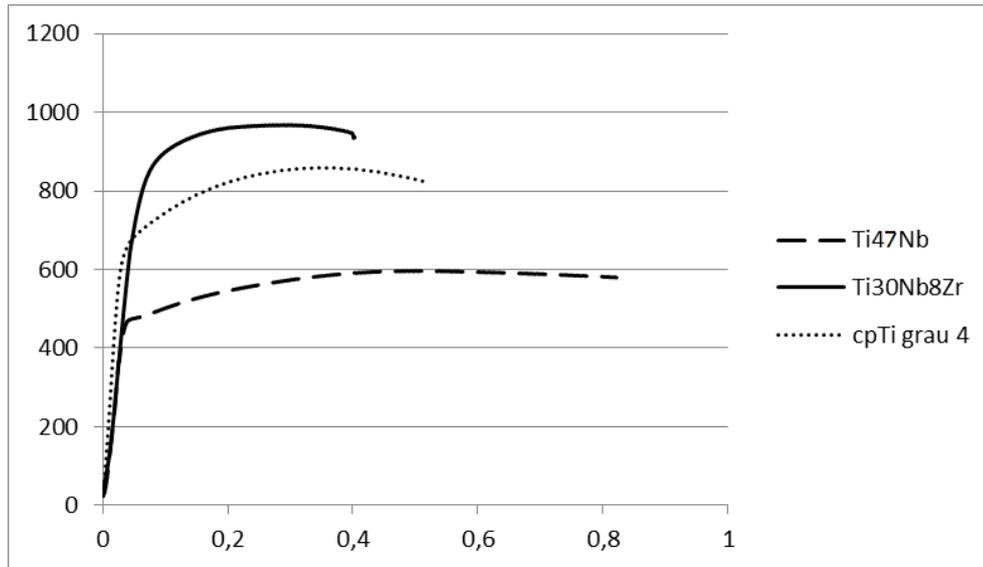


Figure 5 - True compression-strain curve.

Table 1 - summarized compression results for cpTi grade 4.

cpTi grau 4			
Sample	Strain (%)	Yield strength	Compression Strength
1	0,55	638	858
2	0,53	618	825
3	0,51	635	859
4	0,52	627	847
Mean	0,52	627	844
Stand. Deviation	0,017	9	17
Cnf. Inter. 95%	0,52 a 0,54	625 a 634	840 a 854

Table 2 - summarized compression results for Ti-30Nb-8Zr.

Ti-30Nb-8Zr			
Sample	Strain (%)	Yield strength	Compression Strength
1	0,40	796	969
2	0,51	788	972
3	0,47	783	955
4	0,43	797	965
Mean	0,46	791	965
Stand. Deviation	0,047	6,7	7
Cnf. Inter. 95%	0,43 a 0,48	788 a 794	961 a 969

Tabela 3 - summarized compression results for Ti-47Nb.

Ti-47Nb			
Sample	Strain (%)	Yield strength	Compression Strength
1	0,82	471	594
2	0,87	468	595
3	0,91	471	588
4	0,81	569	602
Mean	0,87	495	595
Stand. Deviation	0,045	49,5	7
Cnf. Inter. 95%	0,83 a 0,88	470 a 519	592 a 597

Since Ti-47Nb alloy is composed exclusively by β phase, it was already expected a lower mechanical property. Although Ti-30Nb-8Zr alloy also has the presence of β phase, the presence of Zr and the martensitic α'' phase increased the compression strength of the alloy. Moreover, it is also possible that the metastable ω phase was not suppressed completely during fabrication process, although it was not detected in the XRD test.

4. CONCLUSION

The Ti-30Nb-8Zr compressive strength was improved by the presence of α'' -phase. The addition of Zr acts as a solid solution in the Ti-30Nb-8Zr alloy. However, it resulted in a 12% reduction in ductility compared to cpTi.

The Ti-47Nb alloy presented the highest compressive strain due to the presence of the stable β -phase in room temperature. Although this is a desirable property, the impact in yield strength and compression strength was significant, suggesting the necessity of further thermomechanical treatments in order to improve mechanical strength.

Ti-30Nb-8Zr and Ti-47Nb alloys seem promising for being used as biomaterial.

5. ACKNOWLEDGEMENTS

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7. RESPONSIBILITY NOTICE

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