U.P.B. Sci. Bull., Series B, Vol. 77, Iss. 3, 2015 ISSN 1454-2331

MICROSTRUCTURAL AND MECHANICAL EVALUATION OF A Ti-Nb-Ta ALLOY

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This paper presents a study on the microstructural and mechanical characteristics of a biocompatible Ti-Nb-Ta alloy. The Ti-20Nb-5Ta alloy was obtained by melting in a levitation induction melting furnace, with cold crucible. The results of investigations - microstructure and fracture surface analysis (by SEM), together with mechanical characteristics (by tensile testing and micro-hardness measurement), showed that the Ti-20Nb-5Ta alloy has a homogeneous and compact microstructure in as-cast condition, presenting a good combination of strength and ductility, with a low value of the elastic modulus, which demonstrates its suitability in biomedical applications, as dental implant alloy for example.

Keywords: dental implant alloy mechanical properties, scanning electron microscopy, titanium alloy

1. Introduction

Titanium alloys are the main materials used as biomedical devices, for biological artificial replacements of hard tissues – orthopedic devices, dental implants. The second generation of titanium biomaterials consists of non-toxic elements such as Zr, Nb, Mo, Ta and others. These alloys are particularly useful for implants, because they have high biocompatibility, strength and excellent cold deformability. Good mechanical properties, as strength, ductility and hardness,

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can be achieved by controlling the chemical composition and microstructure [1 - 6]. Lately, titanium alloys having in their composition Nb and Ta have been studied intensively, because of their good corrosion resistance, lack of allergic problems and favorable effect on the development of vital tissue vascularization; they also have good mechanical properties [2, 7 - 10]. Considerable efforts have been made in order to develop biomedical alloys with low Young's modulus and nontoxic elements. The effect of stress shielding, i.e. reduction in bone stress in vivo after the introduction of the implant, usually determines the bone resorbtion. In order to inhibit this undesired phenomenon, a low Young's modulus equivalent to that of the cortical bone is required [1]. Adjusting the quantity of β-stabilizing elements as Nb and Ta, the risk of implant failure can be reduced by lowering the elastic modulus [2]. The aim of this study was to investigate the main microstructural and mechanical characteristics of a Ti-20Nb-5Ta alloy, aimed to be used for dental implants.

2. Materials and methods

The Ti-20Nb-5Ta alloy was obtained in a FIVE CELES - MP25 levitation induction melting furnace with cold crucible, with a nominal power of 25 kW and a melting capacity of 30 cm^3, in argon protective atmosphere. The ingot mould was equipped with a cooling circuit with recycled water. The alloy's chemical composition (Table 1) was determined using SPECTRO XEPOS spectrometer equipment.

Table 1

Elemental composition of the as studied alloy

Element [% wt]		
Nb	Ta	Ti
20	5	rest

From as-cast ingots, samples were cut in order to investigate microstructural and mechanical characteristics. The samples for microstructure and micro-hardness investigations were prepared by cold-mounting in epoxy resin and grinded – polished with a procedure presented in Table 2.

Table 2

Procedure for preparation of samples for microstructure and micro-hardness investigations

Stage	Disk type	Working environment	Time, min	Rotation speed, rpm	Force, N
1	Metkon Abrasive paper-P800	Water	3 - 5	300	20-30
2	Metkon Abrasive paper-P1200	Water	3 - 5	150	20-30
3	Metkon Abrasive paper-P2400	Water	3 - 5	150	20-30
4	Metkon Textile disk - FEDO-3	Metkon DIAPAT 3μm	2 - 4	150	20-30
5	Metkon Textile disk - FEDO-3	Metkon DIAPAT 3μm	2 - 4	150	10-15

6	Metkon Textile disk - FEDO-1	Metkon DIAPAT 1μm	5	150	10
7	Metkon Textile disk - FEDO-1N	Metkon DIAPAT 0.25μm	5	150	10
8	Metkon Textile disk - METAPO-V	Metkon Colloidal Silica 0.05μm + 3% perhydrol	5	150	10

After polishing, the samples were etched for 6 – 8 seconds, using a 10% HF + 10% HNO_3 + 80% H_2O solution.

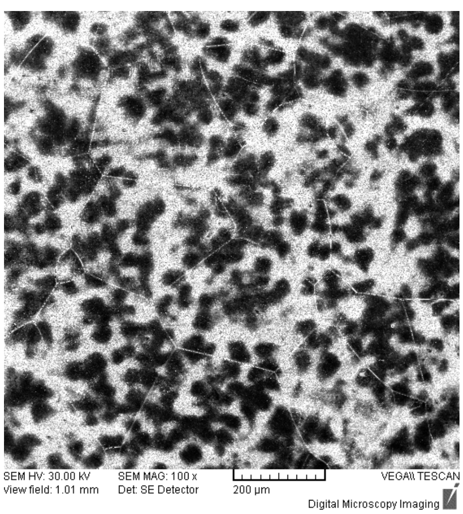
The microstructure and the fracture surfaces of the Ti-25Nb-5Ta alloy were studied using Tescan Vega II-XMU electron microscope. Two detectors were integrated to obtain the SEM images: Back-Scattered Electron detector (BSE) and Secondary Electron detector (SE).

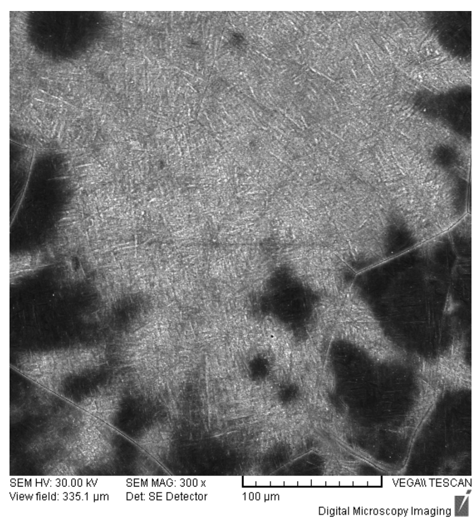
The mechanical evaluation of the studied alloy was performed with GATAN MicroTest 2000 N traction-compression module, using 2x0.6x40 mm samples and Vickers micro-hardness was determined with Wilson - Wolpert 401MVA micro-hardness tester.

3. Results and Discussions

3.1. Microstructural characteristics of the Ti-20Nb-5Ta alloy

The Scanning Electron Microscopy (SEM) micrographs of the sample from the as-cast alloy show a homogenous polyhedral microstructure, with nearly equiaxed grains (Fig. 1a). As observed in Fig. 1b, white areas reach in Nb (alloying element) are present inside the structure.





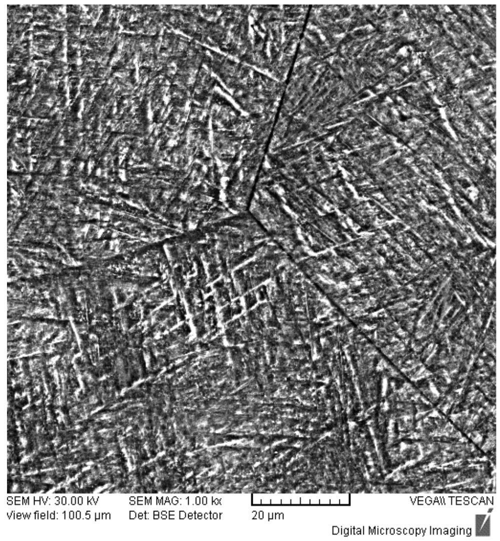


Fig.1. SEM micrographs showing the microstructure of the Ti-20Nb-5Ta alloy, with different magnifications, using SE detector (a and b) and BSE detector (c)

Needle-like structure of alpha and beta phases can be also observed inside grains (Fig. 1b and 1c). The alpha phase is shown in dark-gray color, while beta phase is shown in light-gray color (Fig. 1c).

3.2. Mechanical evaluation of the Ti-20Nb-5Ta alloy

Mechanical properties of the studied alloy were determined by the stress – strain diagram, obtained during the tensile test. The stress-strain curve (Fig. 2) revealed the main strength and deformation characteristics for the as-cast alloy. The recorded stress-strain curve has a typical elasto-plastic profile, presenting a moderate strain hardening during mechanical loading.

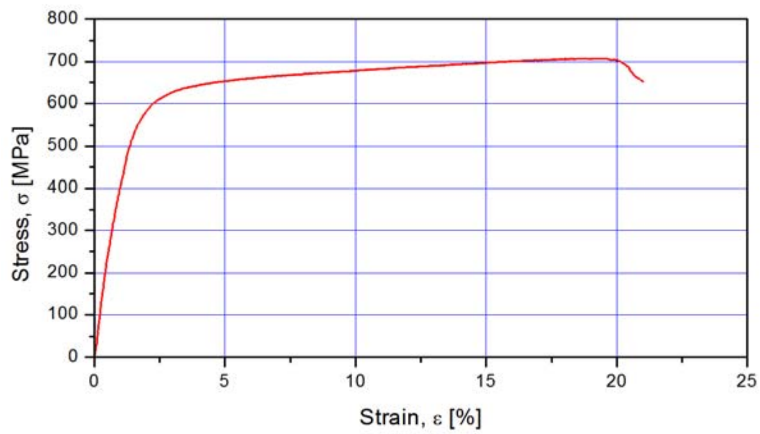


Fig. 2: Stress-strain curve of the Ti-20Nb-5Ta alloy

The important parameters obtained from the recorded stress-strain curve are as follows:

- Yield strength $\sigma_{0.2}$ = 463 MPa
- Ultimate tensile strength σ_{UTS} = 708 MPa
- Elongation to fracture ε_f = 21 %
- Elastic modulus E = 64,02 GPa

The diagram shows that the as-cast Ti-20Nb-5Ta alloy has convenient tensile strength ($\sigma_{0.2}$, σ_{UTS}) and good ductility (ε_f) as compared to other titanium alloys [11,12], these properties being very important for implants. The elastic modulus of the as-cast alloy is lower than other commercial Ti alloys [11, 12], the value of 64,02 GPa being relatively close to the value of human bone (10 – 30 GPa) [13], which shows that the alloy has a good mechanical compatibility, being suitable for implants.

Vickers micro-hardness (HV) was determined using a force of 0.2 kgf, with a 30 seconds force contact; 10 determinations were made and HV values were computed. From the initial 10 determinations, the minima and maxima were eliminated and with the rest the average value was computed. The dispersion interval for micro-hardness value was between $204HV_{0.2}$ (Fig. 3a) and $221HV_{0.2}$ (Fig. 3b), with an average of about $212,5HV_{0.2}$.

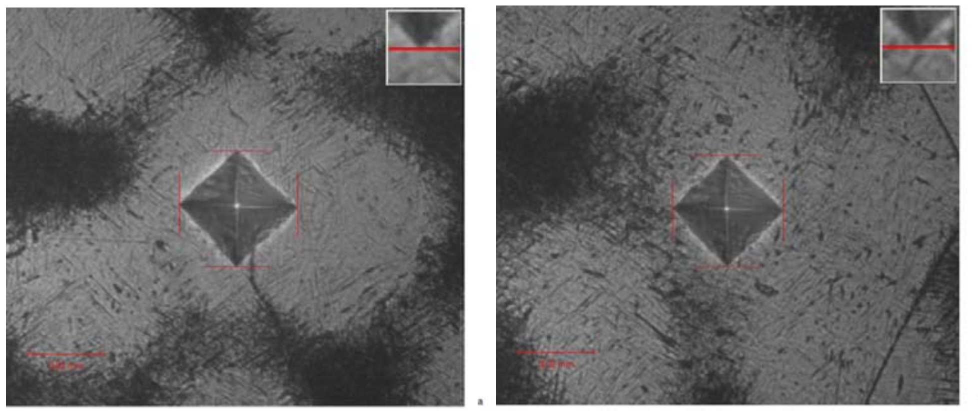


Fig. 3. Images of micro-hardness impression (a and b) for the Ti-20Nb-5Ta alloy

The fracture surfaces of the as studied Ti-based alloy after tensile test in the as-cast condition were analyzed using scanning electron microscopy.

On microscopic level, SEM images (Fig. 4) show a rough and irregular fracture surface, consisting of many micro-voids and dimples, which reveal a ductile fracture behavior.

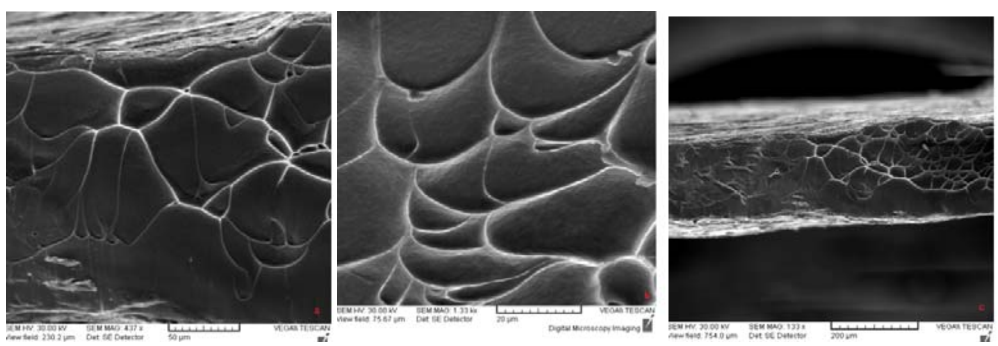


Fig. 4. (a,b,c): SEM images of the fracture surface of Ti-20Nb-5Ta alloy (with different magnifications), using SE detector

4. Conclusions

A biocompatible beta-Ti alloy Ti-20Nb-5Ta was developed and then examined in order to evaluate some microstructural and mechanical characteristics. Due to the modern synthesis method of levitation melting with cold crucible, the alloy showed a homogenous and compact microstructure in as-cast condition, characterized by nearly equiaxed beta-Ti grains. Needle-like phase conglomerations with alpha and beta phase variations, together with Nb rich areas can be also observed. The mechanical behavior of the Ti-20Nb-5Ta alloy was experimentally evaluated by tensile testing and micro-hardness measurement and found to be good in comparison to other standard titanium alloys used for biomedical applications. The Young modulus had a quite low value (E = 64.02 GPa), which can prevent the effect of stress shielding and bone absorption. The ductile fracture of the alloy, correlated with the results from the stress-strain curve, indicated a good toughness.

The good combination of strength and ductility in the as-cast condition and the low value of the elastic modulus demonstrates the high mechanical biocompatibility of the Ti-20Nb-5Ta alloy and its suitability for biomedical applications involving static or dynamic loading conditions, as for example dental implants.

Acknowledgement

The work was supported by a grant of the Romanian National Authority for Scientific Research, CCCDI- UEFISCDI, project number 239/2014. Roxana Maria Angelescu acknowledges the support of Sectoral Operational Programme Human Resources Development 2007-2013 of the Ministry of European Funds through the Financial Agreement POSDRU/159/1.5/S/134398.

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