# The evaluation of mechanical properties for a Ti-Ta-Nb biocompatible alloy

V. D. COJOCARU[a,b], T. GLORIANT[c], D. M. GORDIN[c], E. BERTRAND[c], D. RADUCANU[b], I. CINCA[b*], I. DAN[d]
[a] *National Institute for Research and Development in Microtechnologies, Bucharest - Romania*
[b] *University Politehnica of Bucharest, Bucharest - Romania*
[c] *UMR CNRS 6226 Sciences Chimiques de Rennes/Chimie-Métallurgie, Rennes Cedex - France*
[d] *SC R&D Consulting and Services, Bucharest - Romania*

Titanium alloys are extensively used in a variety of applications due to their good mechanical properties and corrosion resistance. Recently, β-type Ti alloys composed of non-toxic elements have received much attention, because they feature not only high specific strength, bio-corrosion resistance, no allergic problems and biocompatibility. Recent studies revealed that a compromise along the biomedical constrains mentioned above can be obtained by designing Ti alloys which use the most biocompatible elements, i.e. Ta, Nb, Mo, Mb and Zr, as alloy ingredients for stabilizing the β-phase. A Ti-25Ta-25Nb β-type titanium biocompatible alloy was subjected to thermo-mechanical processing and testing. Three states were investigated: as-cast, cold-rolled and recrystallized. Data concerning ultimate tensile strength ($\sigma_{UTS}$), yield strength ($\sigma_{YS}$), elongation to fracture ($\varepsilon_f$) and elastic modulus (E) were analysed. The fracture surfaces of the investigated samples were also analysed.

(Received March 10, 2011; accepted July 25, 2011)

*Keywords*: Titanium alloy, Biocompatibility, Thermomechanical processing

## 1. Introduction

The ideal biomaterial for medical implant applications, especially for load-bearing joint replacements, is expected to exhibit excellent biocompatibility with no adverse cytotoxicity, excellent corrosion resistance, and a good combination of mechanical properties such as high strength and low elastic modulus. In comparison with other metallic biomaterials, titanium and titanium alloys are more biocompatible, more corrosion resistant and can exhibit low elastic modulus [1-3].

Current metallic biomaterials include stainless steels, cobalt-based alloys and titanium-based alloys and its alloys are widely used as implants in orthopedics, dentistry and cardiology due to their outstanding properties such as high strength, enhanced biocompatibility, relatively good fatigue resistance and high level of hemocompatibility. Considerable efforts are now made by material engineers to develop biomedical alloys with low modulus and non-toxic elements [4-5].

Thermomechanical processing is often performed on titanium alloys to attain a desired combination of mechanical properties. Specimens, in as-cast, cold rolled and recrystallized conditions, were examined by scanning electron microscopy (SEM). These results suggested the presence of β phases.

## 2. Experimental

### 2.1. Material synthesis

The investigated alloy has been produced using a vacuum induction melting in levitation furnace FIVES CELES with nominal power 25 kW and melting capacity 30 $cm^3$, starting from elemental components. Resulted chemical composition in wt.% was: 70%Ti; 25%Ta; 25%Nb [5].

From as-cast alloy samples were cutted in order to investigate the mechanical proprieties in as-cast state.

### 2.2. Cold rolling

From as-cast alloy samples were cutted in order to process them by cold-rolling.

The cold-rolling process was made using a laboratory roll-milling machine Mario di Maio LQR120AS [6]. The roll-milling process was conducted in order to achieve on each rolling step a deformation degree of about 6.6%. The total accumulated strain after the roll-milling process was about 82%.

From cold-rolled alloy samples were cutted in order to investigate the mechanical proprieties in cold-rolled state.

### 2.3. Recrystallization treatment

From cold-rolled alloy samples were cutted in order to process them by recrystallization treatment.

Alloy recrystallization treatment was made in a GERO SR 100X500/12 – high temperature furnace. Recrystallization parameters were as follows: recrystallization temperature: 850$^0$C; recrystallization duration: 0.5 h; treatment media: argon; cooling media: air [6].

**2.4. Mechanical testing**

Samples in as-cast, cold-rolled and recrystallizated state were subject to mechanical investigations in tensile tests. The tests were carried out using a tensile-compression testing module GATAN MicroTest 2000N [5-6]. Samples with aprox. 0.35x1.65x40 mm dimensions were used. Ultimate tensile strength ($\sigma_{UTS}$), yield strength ($\sigma_{YS}$), elongation to fracture ($\varepsilon_f$) and elastic modulus (E) were obtained. Main testing parameters were as follow: testing speed 0.4 mm/min; testing temperature 20°C.

**2.5. Fracture surfaces analysis**

All samples were subjected to fracture surfaces investigations, using a TESCAN VEGA II – XMU SEM microscope [6-7]. The investigations were performed in order to analyse the mechanisms of fracture in the case of as-cast, cold-rolled and recrystallized state of Ti-25Ta-25Nb alloy.

## 3. Results and discussion

**3.1 Cold roll-milling**

The roll-milling process was conducted in order to achieve on each rolling step a deformation degree of about 6.6%. The total accumulated strain after the roll-milling process was about 82% (see fig. 1).

**3.2. Mechanical testing**

Mechanical tests were performed on samples found in three states: as-cast, cold-rolled and recrystallizated states (see Fig. 2 - 4).

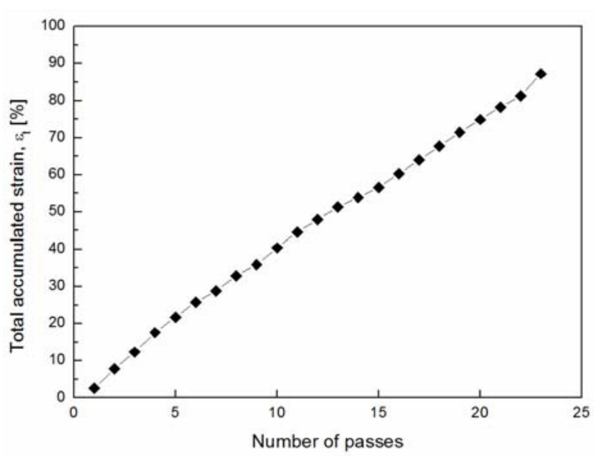



*Fig. 1. Total accumulated strain and number of passes during cold roll-milling.*

As presented in Fig. 2 – 4, one can observe an increase in the ultimate tensile strength ($\sigma_{UTS}$) for cold-rolled material (1028.22 MPa) due to strain-hardening and for recrystallized materials (892.33 MPa) in comparison with as-cast state (682.69 MPa), while the yield limits ($\sigma_{YS}$) for both cold-rolled and recrystallized materials have appropriate values (730 – 880 MPa) in comparison with as-cast material (428.44 MPa). In case of cold-rolled material the elongation to fracture ($\varepsilon_f$) has the smaller value (~17%) that in the case of as-cast and recrystallized materials (~24%; ~26%).

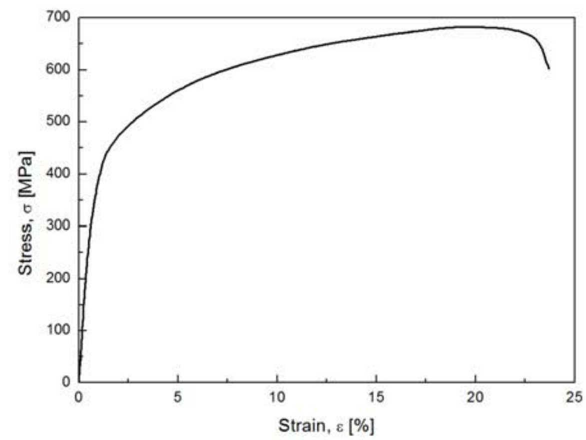



*Fig. 2. Stress–strain curve of as-cast state.*

All states show mechanical characteristics suitable for using in orthopaedic implants.

The most important characteristic, the elastic modulus, has a minimum value of about 40.11 GP in the case of as-cast state, which can lead to conclusion that in the case of orthopaedic implants the most suitable state is as-cast state, due to the fact that the elastic modulus is very close to human bone (30 - 40 GPa).

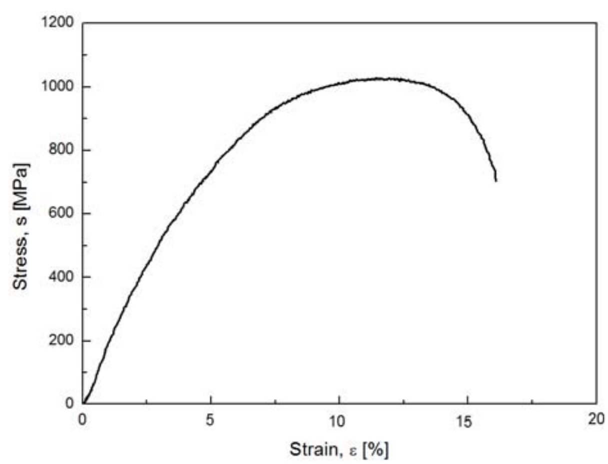



*Fig. 3. Stress-strain curve of cold rolled state.*

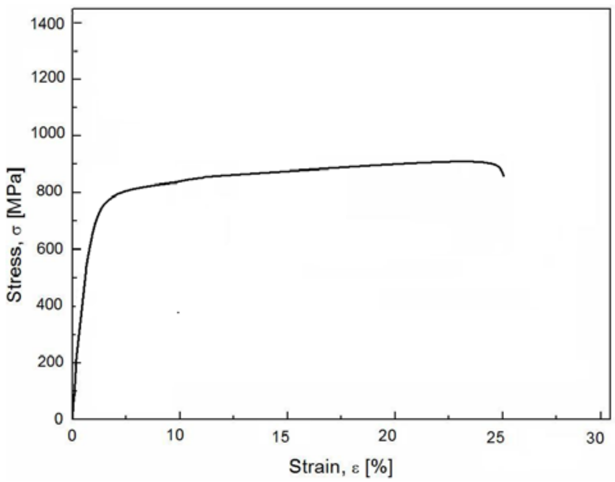



*Fig. 4. Stress-strain curve for recrystallized state.*

### 3.3. Fracture surfaces

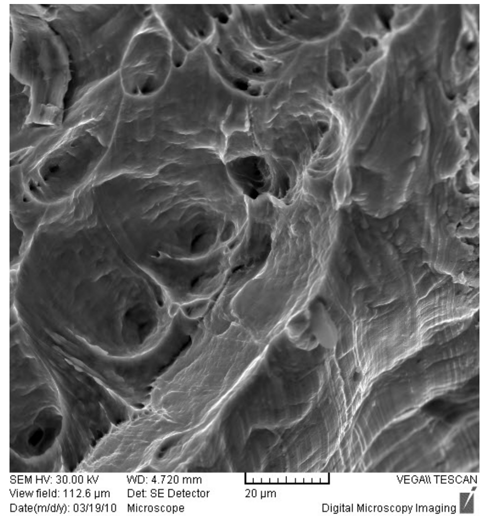
The fracture surfaces were investigated in order to observe the predominant fracture mechanisms presented in the as-cast, cold-rolled and recrystallized material states.

*As-cast material.*

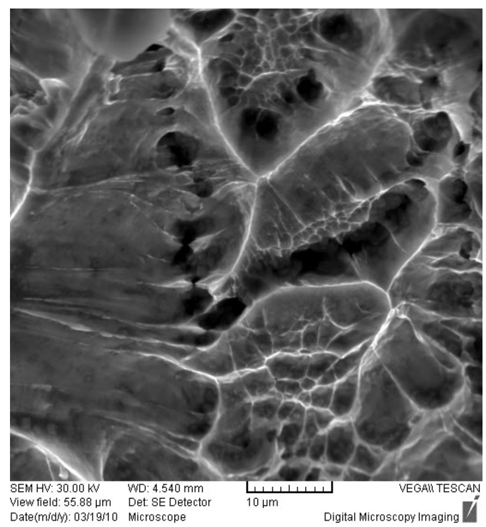
Fractography of the tensile test specimens revealed evidence of a mixture of plastic flow fracture and ductile void growth in the case of as-cast material, figure 5 (a) and (b). It can be seen that the initial sample exhibited a typical ductile fracture by the presence of void nucleation. The fracture it is brittleness because of the high plastic deformation that generate void growth. Because of the plastic flow the surface of material are fibrous.

Due to the fact that the plastic flow becomes more time dependent, the regime of ductile void growth tends to extend towards higher testing temperatures. This means that tha void growth will continue at stresses below the instantaneous fracture stress.

Due to the high plastic deformation Ti-25Ta-25Nb alloy exhibits a ductile fracture mechanism, which leads to void growth and fibrous surface due to the plastic flow, Fig. 5 (a).




(a)

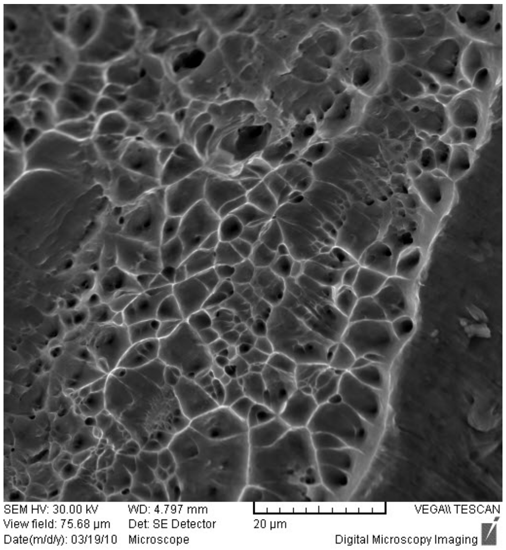



(b)

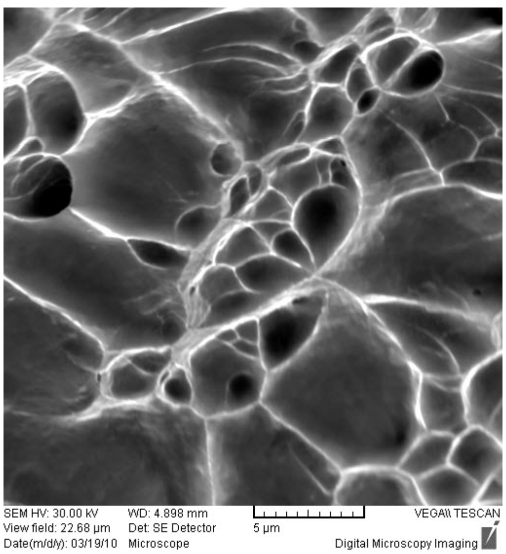
*Fig. 5. Scanning electron microscope fractographies of as-cast state (a) and (b).*

*Cold-rolled material*

Ductility, as opposed to brittleness, is the ability of materials to undergo plastic deformations before it breaks. A measure for the ductility is the strain to fracture, $\varepsilon_f$. Ductility is a desirable material property, since plastic flow tends to reduce stress peaks at notches and cracks and to smoothen the stress distribution. The ductility depends on the predominant fracture mechanism.




(a)




(b)

*Fig. 6. Scanning electron microscope fractographies of cold-rolled state (a) and (b).*

In Fig. 6 (a) and (b) one can observe that the fracture mechanism for cold-rolled material consist in a mixing of two fracture mechanisms, the predominant ductile void growth mechanism and cleavage fracture mechanism. Only small areas in wich cleavage fracture is present are observed.

Application to the ductile fracture problem of void growth in the neck of a tensile specimen demonstrates the accelerating effect of void growth due to interactions between voids. Therefore plastic flow localization may occur after significant void growth or immediately after void nucleation.

*Recrystallized material*

For recrystallized material a surfaces fractography is presented in figure 7, one can observe that the predominant mechanism of fracture for recrystallized state consist in a mixing of mixing of plastic flow and fracture due to ductile void growth, both are characteristics of ductile behaviour. The plastic flow component in the case of recrystallized state is smaller than in the case of as-cast state.

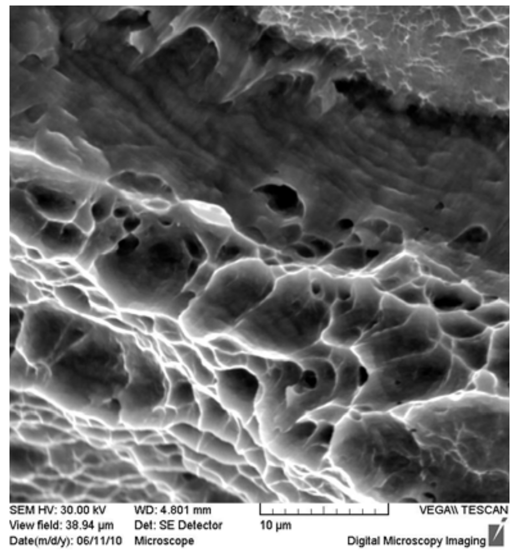



*Fig. 7. Scanning electron microscope fractography of recrystallized state.*

## 4. Conclusions

From all experiments data concerning changes in mechanical properties for as-cast, cold-rolled and recrystallized states were obtained. The ultimate tensile strength and yield strength of cold-rolled and recrystallized states have higher values then in the case of as-cast state.

The cold-rolled alloy exhibits an increase in mechanical properties due to strain-hardening.

Different fracture mechanisms were observed in all cases. The predominant fracture behaviour for as-cast and recrystallized consist in a mixture of plastic flow fracture and ductile void growth mechanisms while in the case of cold-rolled material also the cleavage fracture mechanism can be observed. Because of high plastic deformation fibrous surface due to the plastic flow can be observed also.

As a general remark it can be observed that from a biological point of view (low elastic modulus requirement) the as-cast state exhibit most suitable state (approx. 40 GPa); in the case of cold-rolled and recrystallized state higher values are obtained (approx. 54 – 56 GPa).

**Acknowledgements**

This paper was supported by the project "Dezvoltarea Resurselor Umane prin Cercetare Postdoctorala in Domeniul Micro si Nanotehnologiilor", Contract POSTDRU/89/1.5 /S/63700, project co-funded from European Social Fund trough Sectorial Operational Program Human Resources 2007-2013.

## References

[1] M. Tane, A. Akita, T. Nakano, K. Hagihara, Y. Umakoshi, M. Niinomi, H. Nakajima, Acta Materialia **56**, 2856 (2008)
[2] P. John, S. Buenconsejo, H.Y. Kim, S. Miyazaki, Acta Materialia **57**, 2509 (2009)
[3] D. Raducanu, V.D. Cojocaru, I. Cinca, I. Ichim, A. Schin, Journal of Optoelectronics and Advanced Materials **9**, 3346 (2007)
[4] R. Mythili, S. Saroja, M. Vijayalakshmi, Materials Science and Engineering A **454-455**, 43 (2007)
[5] P. M. Anderson, J.R. Rice, Scripta Met. **20**, 1467 (1986)
[6] C. Dumitrescu, V. D. Cojocaru, D. Raducanu, I. Cinca, A. Vulcan, International Conference "3rd International Conference on Advanced Materials and Sysyems - *ICAMS 2010*", 187-192 (2010)
[7] C. Dumitrescu, V.D. Cojocaru, D. Raducanu, I. Cinca, International Conference "Advances in Engineering and Management - *ADEM 2010*", 51-52 (2010)

*Corresponding author : ion.cinca@mdef.pub.ro