INVESTIGATION OF MECHANICAL PROPERTIES FOR A Ti-Ta-Nb ALLOY

Cristiana DUMITRESCU[1], Doina RĂDUCANU[2], Vasile-Dănuț COJOCARU[3], Ion CINCĂ[4]

În această lucrare ne este prezentată tehnica de deformare plastică a unui aliaj ce are la bază titanul, prin procedeul de laminare, pentru a obține şi a îmbunătăți proprietățile mecanice şi structurale. Acest studiu se axeză în primul rând pe procesarea şi testarea din punct de vedere termomecanic, al aliajului laminat Ti-25Ta-25Nb, iar în al doilea rând se doreşte investigarea din punct de vedere structural şi mecanic al aliajului supus procedeului mai sus menționat. Astfel au fost analizate următoarele proprietăți mecanice: rezistența la rupere (σ_{UTS}), alungirea la rupere (ε_f) şi modulul de elasticitate (E).

This study focuses primarly on the thermo-mecanical processing and testing of the cold-rolled Ti-25Ta-25Nb alloy and secondly on structural and mechanical investigation on the processed alloy. Data concerning ultimate tensile strength (σ_{UTS}), yield strength (σ_{YS}), elongation to fracture (ε_f) and elastic modulus (E) were analyzed. Fracture structure investigations have put in evidence the role played by void growth.

Keywords: titanium alloy, mechanical testing, scanning electon microscopy (SEM)

1. Introduction

Materials to be used as permanent implants in the human body must be bio-compatible, corrosion resistant, tissue compatible, vital and elastic. Titanium alloys meet these requirements to a very high degree because of their excellent mechanical, physical and biological performance. In the recent developments, the most effective mean was alloying titanium with non-toxic elements (Mo, Nb, Ta, Zr) because they feature high specific strength, bio-corrosion resistance, no allergic problems and biocompatibility.

[1] PhD student, Materials Processing Department, Deformable Media Engineering Research Group, University POLITEHNICA of Bucharest, Romania, e-mail: cristiana.dumitrescu85@gmail.com
[2] Prof, Materials Processing Department, Deformable Media Engineering Research Group, University POLITEHNICA of Bucharest, Romania
[3] Lect, Materials Processing Department, Deformable Media Engineering Research Group, University POLITEHNICA of Bucharest, Romania
[4] Reader, Materials Processing Department, Deformable Media Engineering Research Group, University POLITEHNICA of Bucharest, Romania

In recent years there has been a significant development of novel implant alloys based on Ti such as Ti–Nb–Zr and Ti–Ta-Zr alloys systems. These alloys are produced from commercially pure materials (Ti, Nb, Zr and Ta) by a cold roll-milling method, followed by recrystallisation treatment, in order to remove the hardening effect. Thermomechanical processing is often performed on titanium alloys to attain a desired combination of mechanical properties. Specimens, in cold rolled and recrystallized conditions, were examined by scanning electron microscopy (SEM). These results suggested the presence of β phases.

2. Experimental procedure

Cast condition

The investigated alloy has been produced using a vacuum induction melting in levitation furnace FIVES CELES, starting from elemental components. The resulted chemical composition in wt. % was: 50%Ti; 25%Ta; 25%Nb.

Cold-rolled condition

All samples were cold rolled using a laboratory roll-milling machine Mario di Maio LQR120AS. From the resulted cold-rolled alloy, samples were cut in order to be subject to a recrystallisation treatment.

The strain obtained after a rolling pass can be calculated using the following formula:

$$\varepsilon_{pass\ i} = \frac{h_{i-1} - h_i}{h_{i-1}} \cdot 100[\%] \qquad (1)$$

where: $\varepsilon_{pass\ i}$ – represent the strain for rolling pass i;
h_{i-1} – represent the height before rolling pass i;
h_i – represent the height after rolling pass i;

Total accumulated strain after the rolling process can be calculated using the following formula:

$$\varepsilon_t = \frac{h_i - h_f}{h_f} \cdot 100[\%] \qquad (2)$$

where: ε_t – represent the total accumulated strain during rolling; h_i – represent the initial sample height before rolling process; h_f – represent the final sample height after rolling process;

The equation (2) can be rewritten as:

$$\frac{1}{\varepsilon_t} = \frac{h_i}{\varepsilon_{pass1} \cdot h_1 + \varepsilon_{pass2} \cdot h_2 + \varepsilon_{pass3} \cdot h_3 + \ldots + \varepsilon_{passn} \cdot h_n} \qquad (3)$$

Recrystallization condition

Alloy recrystallization treatment was carried out in a GERO SR 100X500/12 high temperature furnace, at a temperature of 850ºC, for 0.5h in a treatment media of argon; then the samples were cooled in air [12].

Samples in as-cast, cold-rolled and recrystallizated condition were subject to mechanical investigations. The tests were carried out using a tensile-compression testing module GATAN MicroTest 2000N. Ultimate tensile strength (σ_{UTS}), yield strength (σ_{YS}), elongation to fracture (ε_f) and elastic modulus (E) were obtained.

Structure and fractographic images were obtained sing a TESCAN Vega II – XMU SEM microscope. Structure images were obtained using a BSD detector and SD detector.

3. Results and discussion

The purpose of this paper is to present both mechanics and microstructural aspects of the investigated alloy. Therefore, the paper considers first experimental studies and efforts to analyze the changes occurred for the three stages of Ti-25Ta-25Nb alloy: as-cast sate, cold-rolled state and recrystalization state.

Casting state

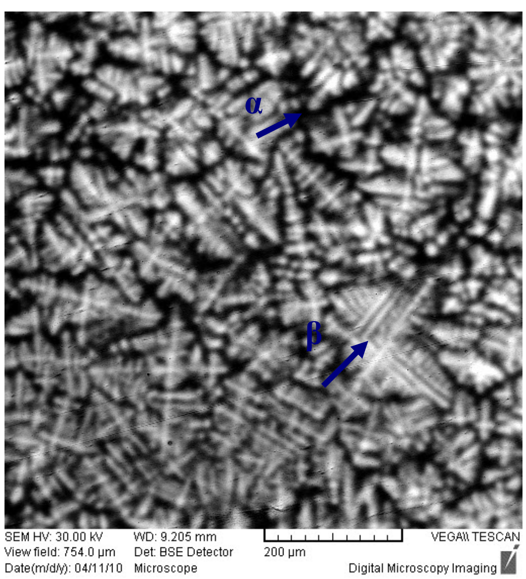

Fig. 1. Dendritic structure of as-cast Ti-25Ta-25Nb alloy

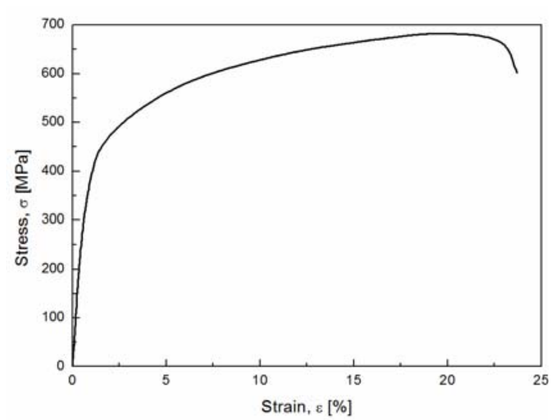

Fig. 2. Stress–strain curve of as-cast Ti-25Ta-25Nb alloy

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

The motivation to develop lower modulus alloys has lead to an increased focus on β-Ti alloys which retain a single-phase β microstructure on rapidly cooling from high temperatures. The dendritic structure of the as-cast alloy is shown in Fig. 1. The intra granular primary α precipitates is visible in this figure. These finer scale α precipitates are homogeneously distributed throughout the β matrix.

Cold rolled condition

Appling the relations described above the diagram of the total accumulated strain versus the number of passes during cold roll-milling for Ti-25Ta-25Nb alloy has been obtained

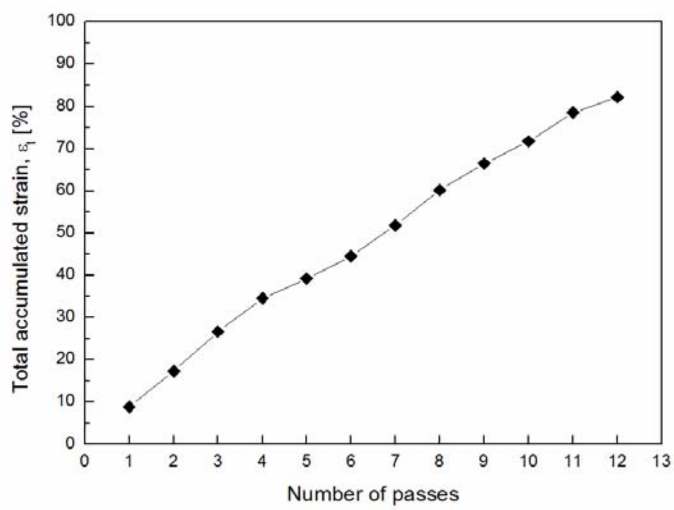

Fig. 3. Total accumulated strain and number of passes during cold roll-milling [12]

The roll-milling process was conducted in order to obtain an increase in total accumulated strain of about 6.6% between each rolling pass in the case of both investigated alloys (Fig. 3).

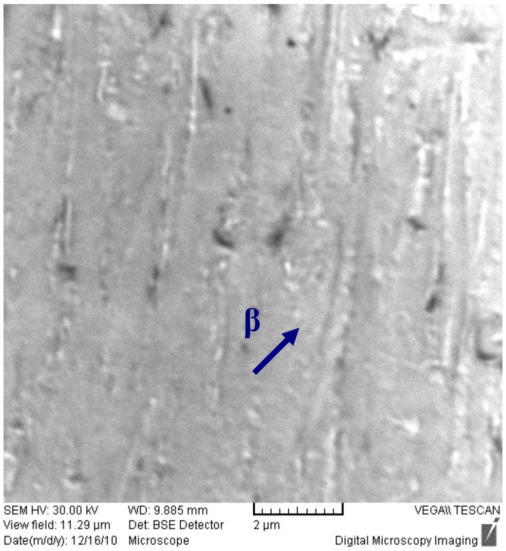

Fig. 4. Cold-rolled structure

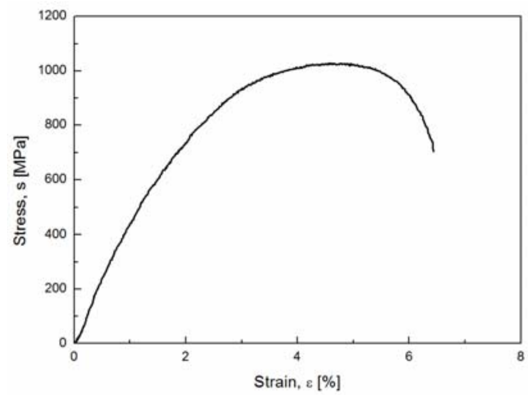

Fig. 5. Stress-strain curve of cold rolled Ti-25Ta-25Nb alloy

After the cold-rolling of Ti-25Ta-25Nb alloy, a reduction in thickness of 87-90% was observed. Therefore in the case of Ti-25Ta-25Nb alloy, a comparative stress-strain diagram analyse (Fig. 2 and 5) was carried out, which lead to the fact that for the as-cast material, the most preponderant mechanism was plastic flow. The total accumulated strain after the roll-milling process was about 82%.

The overall microstructure of Ti-25Ta-25Nb alloy is shown in Fig. 4. It can be observed the β phase microstructure which does not present a regular crystalline structure, leading to small crystalline domains. Therefore, only the β grains are visible. Thus, Ti-25Ta-25Nb alloy exhibits a higher hardness in cold-rolled condition as compared to the recrystallized one.

Recrystallization condition

Thermo-mechanical processing is often performed on titanium alloys to obtain a desired combination of mechanical properties. Therefore, in the case of Ti-25Ta-25Nb alloy a recrystallization treatment was carried out, after the cold-roll milling.

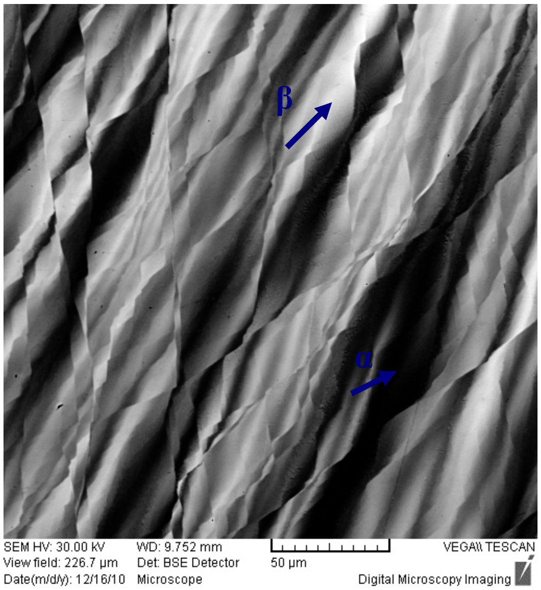

Fig. 6. Recrystallized structure

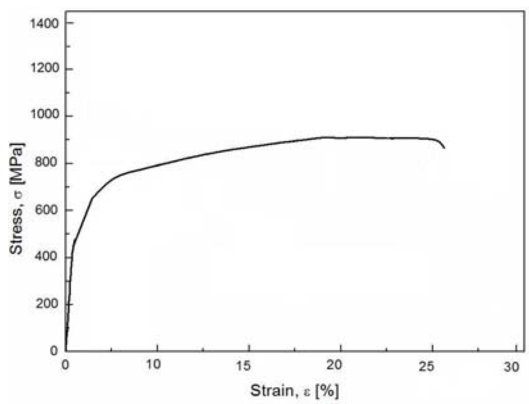

Fig. 7. Stress–strain curve for the recrystallized condition

Table 1 presents the results for the three conditions of the Ti-25Ta-25Nb alloy: as-cast, cold-rolled and recrystallized.

Table 1

Mechanical properties values for Ti-25Ta-25Nb alloy

	As-cast Ti-25Ta-25Nb alloy	Cold rolled Ti-25Ta-25Nb alloy	Recristallized Ti-25Ta-25Nb alloy
Yield strength σ_{YS} [MPa]	428.44	833.34	732.02
Ultimate tensile strength σ_{UTS} [MPa]	628.69	1028.22	892.33
Elongation to fracture ε_f [%]	24	17	26
Elastic modulus E [GPa]	40.11	54.10	56.42

As shown in Fig. 7, in the case of the recrystallized conditions the predominant mechanism of fracture for recrystallized samples is: mixing of plastic flow and fracture by ductile void growth [10]. However, it is interesting to note that though the precipitation of fine scale α is expected to aid the strengthening mechanism, β transformation has more dominant efect on the hardness of this alloy. A similar trend is observed in the experimentally measured modulus values with the recrystallized condition exhibiting a higher modulus as compared with the cold-rolled condition.

Fracture surface investigations

A scanning electron microscopic (SEM) study was undertaken in order to clarify the failure mechanism for the cold-rolling milling Ti-25Ta-25Nb samples, as well as the as-cast samples and the recristallized one.

Ductility, as opposed to brittleness, is the ability of materials to undergo plastic deformations before they break. A measure for ductility is the strain to fracture, ε_f. 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. 9).

Cleavage fracture, as well as brittle intergranular fracture, leads to fracture surfaces that are macroscopically oriented normal to the applied tensile stress. On the microscopic scale the fracture path follows the possible cleavage planes of the grains or the grain boundaries. Cleavage is the predominant fracture mode in covalently and ionically bonded materials [5].

As for the as-cast Ti-25Ta-25Nb samples fractography Fig. 8 of the test specimen revealed evidence of a mixture of plastic flow fracture by ductile void growth. The fracture surfaces indicate a ductile behaviour for the as-cast material, due to the high plastic deformation to fracture [11].

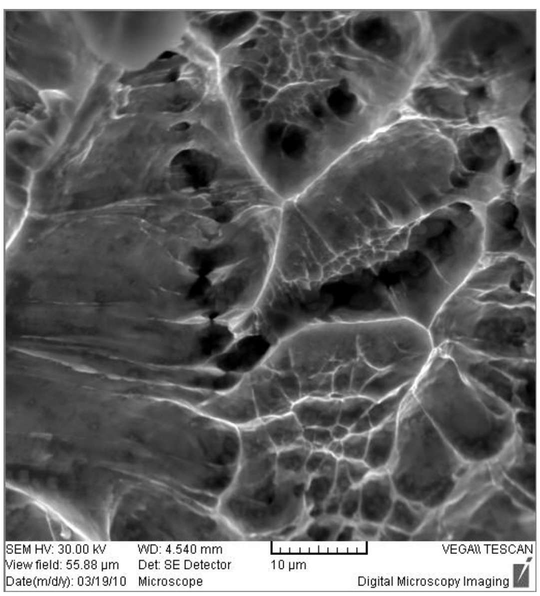

Fig. 8. SEM fractograhy of as-cast Ti-25Ta-25Nb alloy

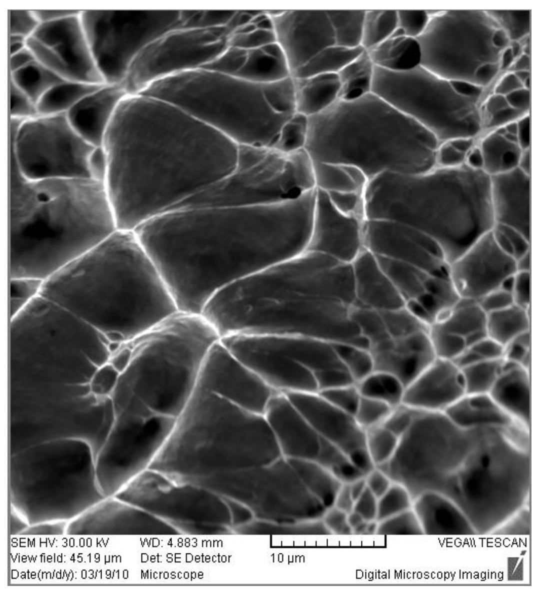

Fig. 9. SEM fractograhy of cold rolled Ti-25Ta-25Nb alloy

For the recristalized Ti-25Ta-25Nb sample, it can be observed from Fig. 10, that the predominant mechanism of fracture is a mixing of plastic flow and fracture by ductile void growth [11]. As a consequence of plastic flow, the voids grow or shrink in volume, they change their shape, and the principal axes of the voids may rotate depending on the stressing system and history.

Due to the fact that the plastic flow becomes more time dependent, the regime of ductile void growth tends to extend towards higher temperatures. This means that the void growth will continue at stresses below the instantaneous fracture stress. Due to the high plastic deformation the material has a brittle fracture mechanism, which leads to void growth and fibrous surface due to the flow (Fig. 9). Even the most brittle fractures do not occur before yield stress is reached [5].

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.

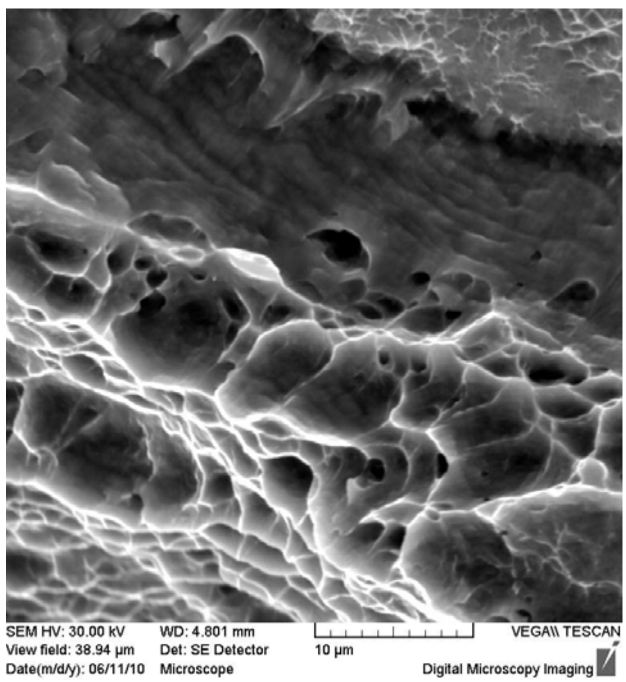

Fig. 10. SEM fractography of recrystallized Ti-25Ta-25Nb alloy

4. Conclusions

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

The most important characteristic, the elastic modulus, has a minimum value of about 40.11 GP in the case of as-cast condition, which can lead to the 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).

For β-alloys, phase transformations during solidification, heat treatment or during plastic deformation play a crucial role for the resulting mechanical properties.

Acknowledgements

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