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Determination of Creep Parameters of Ti-6Al-4V with Bimodal and Equiaxed Microstructure

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Abstract. Ti-6Al-4V is the most used of titanium alloy and presents some important properties as metallurgical stability, high specific strength, corrosion and creep resistance [1]. The aim of this study is to evaluate the creep behavior of Ti-6Al-4V alloy with equiaxed and bimodal microstructures and determine the creep parameters of Ti-6Al-4V in these conditions. It was used a Ti-6Al-4V alloy forged and annealed at 190°C for 6 hours and cooled in air. The material in this condition shows an equiaxed microstructure. For bimodal microstructure, the material was heat-treated at 950°C for 60 minutes and cooled in water until room temperature. After this the material was heat-treated at 600ºC for 24 hours and cooled in air until room temperature. Creep tests were performed at 600°C in stress conditions of 125, 250 and 319 MPa at constant load. The alloy with Bimodal microstructure shows higher creep resistance with a longer life time in creep.

Introduction

Titanium and its alloys are utilized in different industries as aeronautic, aerospace, chemical, biomedical and others due the combination of mechanical properties with low specific weight and corrosion resistance in temperatures below 600ºC [2,3,4,5].

The most important alloy of titanium industry is the Ti-6Al-4V composed of $\alpha + \beta$ phases with aluminum as α stabilizer and vanadium as β stabilizer. This alloy combines attractive properties with good workability and it has been widely used in aeronautical and aerospace industries in high temperature applications, so it is important to understand its deformation behavior in high temperature [6,7]. Ti-6Al-4V has high creep resistance, however, its affinity with oxygen limited applications at high temperature.

Ti-6Al-4V strength is quite sensitive to microstructure and the microstructural control by thermo-mechanical treatments at temperatures in the dual phase region has been extensively studied [8].

Aiming to improve creep resistance of Ti-6Al-4V, a specific heat treatment was done in Ti-6Al-4V alloy. Heat treatment is a group of heating / cooling operations in determined conditions with the purpose of giving special properties for materials [9].

Creep deformation is defined as any permanent inelastic strain that occurs when a material is subjected to a sustained stress. Deformation rate depends not only on the magnitude of the applied stress, but also on time and temperature. In addition, the creep rate depends on the grain size and distribution [10].

In this work was evaluated the creep behavior of Ti-6Al-4V alloy with equiaxed and bimodal microstructures. Creep tests were performed at 600°C in stress conditions of 125, 250 and 319 MPa at constant load. The alloy with bimodal microstructure shows higher creep resistance with a longer life time in creep.

Experimental Procedure

It was used Ti-6Al-4V in cylindrical bars form, acquired from Multialloy Eng. Mat. Ltda, in forged condition, annealed at 190ºC for 6 hours and cooled in air. The material in this condition has an equiaxed structure. The characterization of chemical composition for major elements (wt %) is in compliance with the requirements of ASTM B265-10 [11]. Figure 1 shows the schematic view of the specimen creep test.

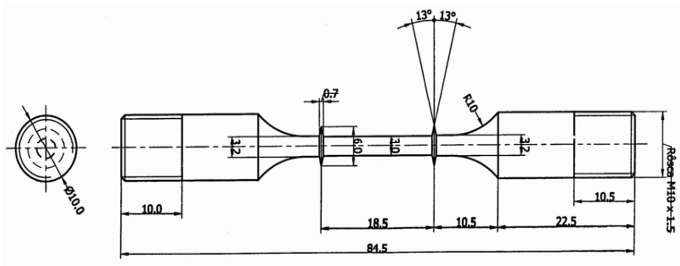

Figure 1 - Sample utilized for creep tests

Heat Treatment. Heat treatment was applied in Ti-6Al-4V alloy in order to obtain bimodal structure. The samples were encapsulated in a 21 mm internal-diameter quartz tube and the air was removed from the tube by pulling vacuum with a pump. The samples were placed in the Lindberg / Blue furnace (model STF 54434C). The furnace was heated up to 950ºC and was thermally treated for 60 minutes and then the samples were cooled in water until room temperature. After this the material was heated again until 600°C, kept at this temperature for 24 hour followed by air cooling in order to obtain the Bimodal structure.

Creep Tests. Short-term creep tests were performed under constant load at Mayes furnace. The furnaces are adapted with automatic control system developed by BSW Tecnologia, Indústria e Comércio Ltda. The creep tests were performed according to ASTM E139-06 standard [12]. For elongation and temperature data collection for the samples was used Antares Software. A transductor (LVDT Schlumberger D 6.50) was used to measure the elongation and thermocouple (Cromel-Alumel AWG24) for temperature control.

Results and Discussion

Heat Treatment. Figure 2a shows the microstructure of the equiaxed Ti-6Al-4V alloy. It could be observed α grains (HCP) and dark regions that define the presence of β phase (BCC) along the grain boundaries of the alloy.

Figure 2b shows the bimodal microstructure obtained after heat treatments. Bimodal structure has similar microstructure and grain size compared to equiaxed structure, however the heat treatment given higher mechanical resistance due to the presence of martensitc phase in the darker region of the picture. The presence of martensitic phase was confirmed by X-ray diffraction as showed in figure 3.

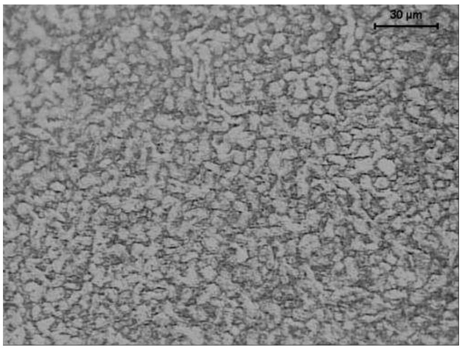

Figure 2a – Ti-6Al-4V equiaxed structure.

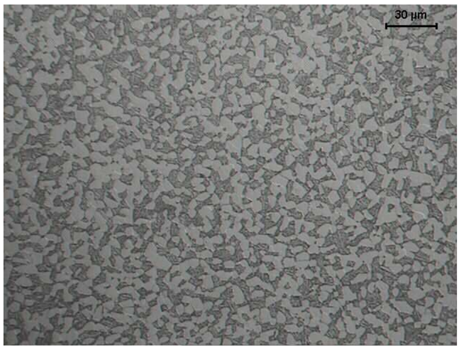

Figure 2b – Ti-6Al-4V bimodal structure.

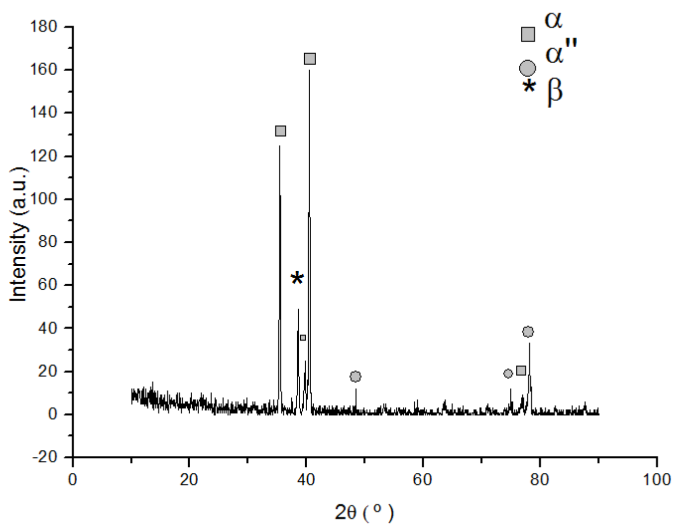

Figure 3 – X-ray diffraction of Bimodal structure.

Creep Test. Creep tests were performed under constant load in Ti-6Al-4V alloy with equiaxed and bimodal structure at 600°C under stress conditions at 125, 250 and 319 MPa. Figures 4, 5 and 6 shows the creep test curves of the material with equiaxed and with bimodal structure.

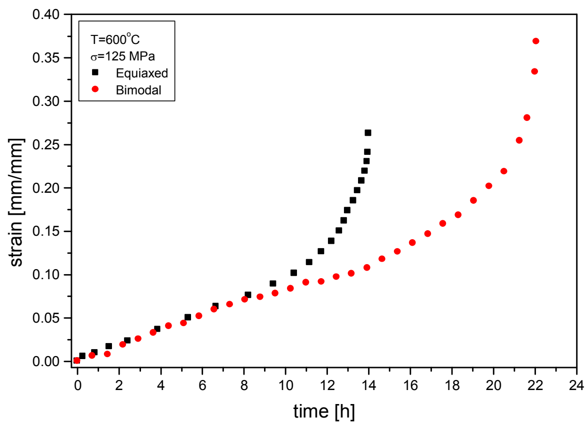

Figure 4 - Creep curve at 600ºC and 125 MPa.

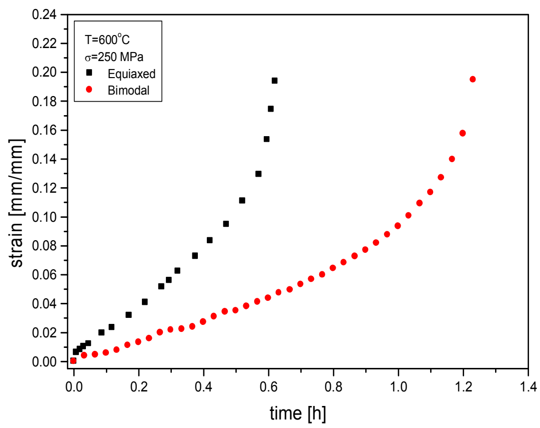

Figure 5 - Creep curve at 600ºC and 250 MPa

Creep tests were conducted until specimen fracture and show a typical three stage creep curve. It is observed a relative short initial period of decreasing primary creep rate associated with hardening due to the accumulation of dislocations. However, most of the creep life is dominated by a constant creep rate that is associated with a stable dislocation configuration due to the recovery and hardening process. Table 1 shows the experimental parameters obtained at 600°C, where σ is the applied stress; $\dot{\varepsilon}_s$ is steady-state creep rate; t_p is the primary creep time; t_f is the time to rupture; ε_f is the strain at fracture.

Table 1 - Creep results of equiaxed and bimodal structure.

Condition	σ (MPa)	t_p (h)	$\dot{\varepsilon}_s$ (1/h)	t_f (h)	ε_f (mm/mm)
Equiaxed	125	0.83	0.0098	14.00	0.263
Bimodal		1.46	0.0074	22.07	0.368
Equiaxed	250	0.03	0.1937	0.62	0.194
Bimodal		0.10	0.0797	1.23	0.195
Equiaxed	319	0.01	0.5638	0.17	0.174
Bimodal		0.024	0.2195	0.25	0.107

Based on the results above, bimodal structure at 600º C in stress conditions of 125, 250 and 319 MPa has higher creep resistance with higher values of t_p and reduction of steady-state creep rate and time to rupture. The data shows the heat treatment was effective and improve creep resistance.

The stress dependence with the steady-state creep rate for bimodal structure is showed in Figure 7. Using standard regression techniques, the results can be described in terms of power-law creep equation (eq 1):

$$\dot{\varepsilon}_s = B\,\sigma^n \tag{1}$$

where n is the creep stress exponent and B is the structure-dependent constant and these parameters are usually determined from a number of constant load creep tests.

The stress exponent value indicates that the steady-state creep is controlled by dislocation mechanism at 600ºC [13].

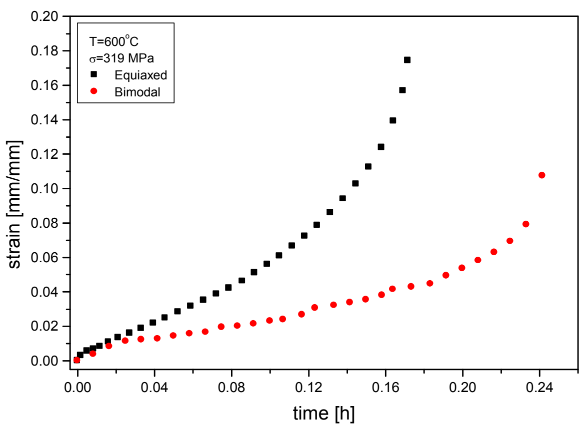

Figure 6 - Creep curve at 600ºC and 319 MPa.

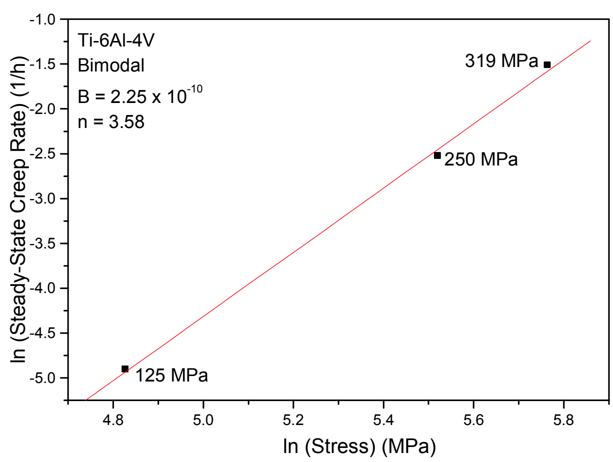

Figure 7 - Stress dependence of steady-state creep rate for Bimodal structure at 600ºC.

Conclusion

Ti-6Al-4V with Bimodal structure has higher creep resistance than Ti-6Al-4V with equiaxed structure. The heat treatment presented higher creep resistance, higher values of t_p and lower steady-state creep rate.

The stress exponent value indicates that the steady-state creep is controlled by dislocation mechanism at 600º C.

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