CREEP BEHAVIOR OF Ti-6Al-4V WITH BIMODAL AND EQUIAXED MICROSTRUCTURES

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Abstract. *Titanium and its alloys are currently used in aeronautical and aerospace applications due to the combination of mechanical properties with low specific weight. Ti-6Al-4V alloy is the most used of titanium industry and is applied in blades for aircraft and steam turbines. This alloy presents some important properties as metallurgical stability, high specific strength, corrosion and creep resistance. Aiming the improvement of the Ti-6Al-4V alloy creep resistance it was performed a specific heat treatment in this alloy to obtain a microstructure called Bimodal. In this work was studied the Ti-6Al-4V creep behavior with equiaxed and Bimodal microstructures. It was used a Ti-6Al-4V alloy with equiaxed microstructure forged and annealed at 190°C for 6 hours and cooled in air. The material was heat-treated at 950°C for 60 minutes, cooled in water until room temperature. After then, the material was heated again until 600°C, kept at this temperature for 24 hour followed by air cooling in order to obtain Bimodal structure. Short-term creep tests were performed at 600°C and stress conditions of 125, 250 and 319 MPa at constant load. The alloy with Bimodal microstructure showed higher creep resistance with a longer life time in creep.*

Keywords *Ti-6Al-4V, creep, heat treatment.*

1. INTRODUCTION

Titanium and its alloys is widely applied in the aerospace, aeronautical, biomedical and chemical industries and present low specific weight, high specific strength and corrosion resistance below 600ºC [1,2].

Titanium alloys are classified as α, near-α, α/β e β, based on chemical compositon and weight % of alloying elements [3]. Alpha alloys have higher creep resistance than beta alloys, while beta alloys offers better fracture and toughness [4,5].

Ti-6Al-4V is the most important of titanium industry and has been used in aeronautical and aerospace applications, mainly in high temperature applications [6]. This alloy presents important properties as metallurgical stability, high specific strength and corrosion and creep resistance [7,8]. However the affinity with oxygen is a limit for titanium alloys applications as structural material at high temperatures. The high solubility of oxygen in titanium during exposure at high temperatures results in a formation of a hard and brittle layer and causes loss of material [9].

Aiming the improvement of Ti-6Al-4V creep resistance, 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. This technique can change materials mechanical and structural characteristics as increasing or decreasing of hardness, mechanical strength, ductility improvements, wear and heat resistance and modification of electrical and magnetic properties [10].

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 [11].

The aim of this work is to evaluate 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.

2. **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 characterization of chemical composition for major elements (wt %) is in according with the requirements of ASTM B265-89 [12]. Figure 1 shows the schematic view of the specimen creep test.

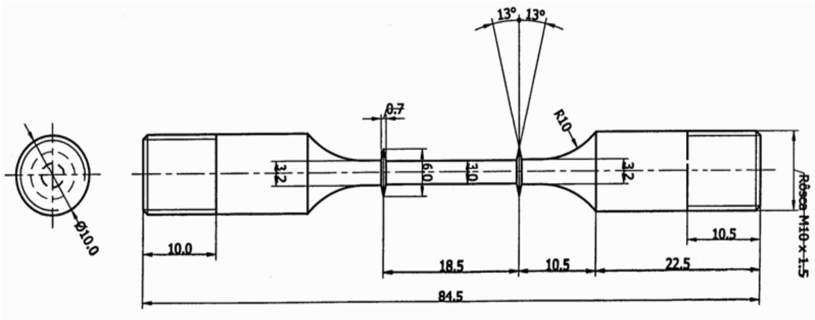


Fig. 1 Sample utilized for creep tests

2.1 HEAT TREATMENTS

Heat treatment was applied in Ti-6Al-4V alloy in order to obtain bimodal microstructure. 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 under argon gas environment for oxidation protection. The samples were thermally treated for 60 minutes and after this period of time 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.

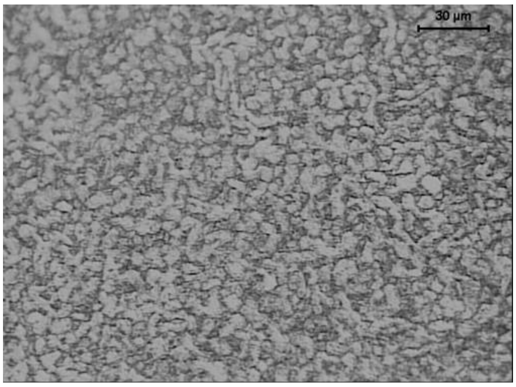
2.2 CREEP TESTS

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 [13]. 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.

The equipment and devices used for creep tests were calibrated providing a reliability of the collected data. Then it was performed one creep test for each of temperature and load condition.

3. RESULTS AND DISCUSSION

Figure 2a shows the microstructure of the annealed 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, however the heat treatment given higher mechanical resistance to the matrix.



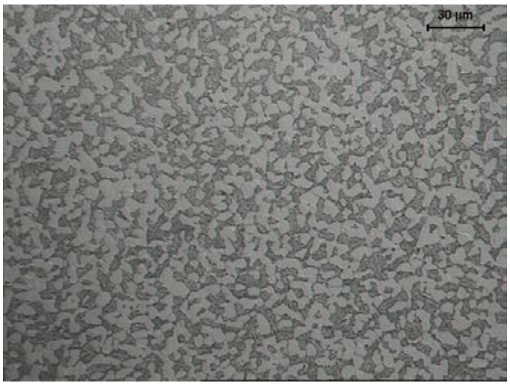


Fig. 2a – Micrograph of Ti-6Al-4V alloy as received
Fig. 2b. – Micrograph of Ti-6Al-4V with bimodal microstructure

Creep tests were performed under constant load in Ti-6Al-4V alloy with equiaxed and bimodal microstructure at 600°C under stress conditions at 125, 250 and 319 MPa. Figures 2, 3 e 4 shows the creep test curves of the material as received (equiaxed) and with bimodal microstructure. The curves present true strain ε as time function.

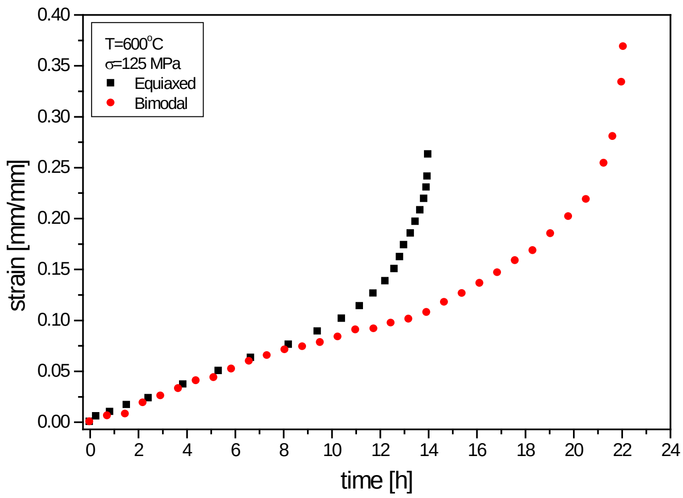


Figure 1: Creep curve at 600ºC and 125 MPa.

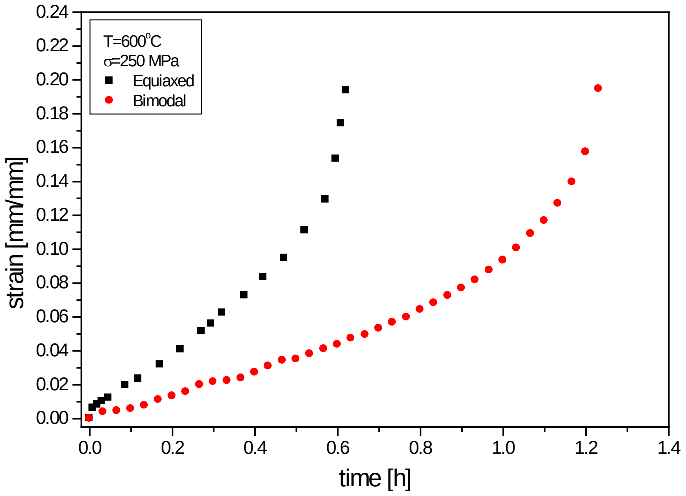


Figure 2: Creep curve at 600ºC and 250 MPa.

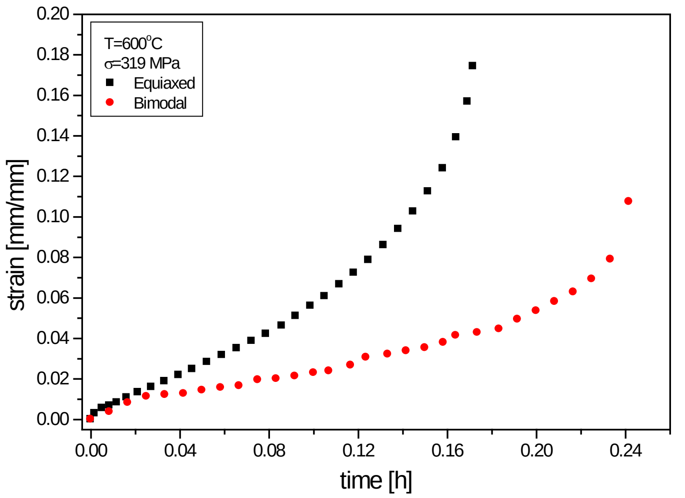


Figure 3: Creep curve at 600ºC and 319 MPa.

Creep tests were conducted until specimen fracture and show a typical three stage creep curve. It could be observed a relatively 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 thought to be associated with a stable dislocation configuration due to 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 obtained from the linear region slope of the secondary stage of creep curve; t_p is the primary creep time; t_f is the time to rupture; ε_f is the strain at fracture.

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	0,2625
Bimodal		1,46	0,00738	22,07	0,368
Equiaxed	250	0,03	0,1937	0,62	0,194
Bimodal		0,1	0,07968	1,23	0,194
Equiaxed	319	0,01	0,5638	0,17	0,1742
Bimodal		0,024	0,21953	0,25	0,107

Results from creep curves (Figures 2, 3 e 4) and Table 1, show that Ti-6Al-4V alloy with Bimodal microstructure at 600ºC in stress conditions of 125, 250 e 319 MPa has higher creep resistance with higher values of t_p and reduction of steady-state creep rate and time to rupture. This data prove that the heat treatment was more effective related on the mechanical behavior of the alloy in creep.

Conclusion

Ti-6Al-4V with Bimodal structure has higher creep resistance than Ti-6Al-4V with equiaxed structure. The heat treatment given higher mechanical resistance with higher values of t_p and reduction of steady-state creep rate and time to rupture.

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References

1 Guleryuz, H.; Cimenoglu, H. Journal of Alloys and Compounds, v. 472, p. 241–246, 2009.
2 Leyens, C.; Peters, M. Titanium and Titanium Alloys, Fundamentals and Applications, p. 263, Wiley-VCH, Germany, 2003.
3 Hamouda Ghonem. Microstructure and fatigue crack growth mechanisms in high temperature titanium alloys. International Journal of Fatigue, p. 1448-1460, v. 32, 2010.
4 I.J. Polmear, Light alloys: metallurgy of the light metals (2nd ed.), Edward Arnold, London (1989).
5 G. Lütjering, Property optimization through microstructural control in titanium and aluminum alloys, Mater Sci Eng A 263, pp. 117–126, (1999).
6 Sakai, T.; Ohashi, M.; Chiba, K; Jonas, J.J. Recovery and recrystallization of Polycrystalline nickel after hot working. Acta Metall., v. 36, p. 1781-1790, 1988.
7 Reis, D. A. P., Doctor Thesis (Space Engineering and Technology) - INPE- São José dos Campos – SP, 2005.
8 Barboza, M. J. R., Perez, E. A. C., Medeiros, M. M., Reis, D. A. P., Nono, M. C. A., Piorino Neto, F., Silva, C. R. M., Materials Science and Engineering A. v. 428, p. 319-326, 2006.
9 Reis, D. A. P.; Silva, C. R. M.; Nono, M. C. A.; Barboza, M. J. R.; Piorino Neto, P; Perez, E. A. C. Plasma-sprayed coatings for oxidation protection on creep of the Ti-6Al-4V alloy. Materials at High Temperatures. v. 22, p. 449-453, 2005.
10 Callister, W. D. Jr., Materials Science and Engineering: an introduction, 5. ed., Wiley & Sons, New York, 2000.
11 ASM Handbook, Mechanical Testing and Evaluation, pp.786- v. 8, (2000).
12 American Society for Testing and Materials. B-265-89. Philadelphia, 1990
13 American Society for Testing and Materials. E-139-06. Philadelphia, 2006.