STUDY OF THE CREEP OF THE Ti-6Al-4V ALLOY WITH ATMOSPHERE CONTROLLING AT 700°C

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Abstract. *The objective of this work was to evaluate the creep behavior of the Ti-6Al-4V alloy focusing on the determination of the experimental parameters related to the creep stages. Constant load creep tests were conducted with Ti-6Al-4V alloy in air and in nitrogen atmosphere at 700°C. Results indicated at the creep resistance of the alloy in nitrogen atmosphere is greater than in air. Previously reported results about the activation energies and the stress exponents values indicate that the primary and stationary creep, for both test conditions, was probably controlled by dislocation climb. The decrease in ductility after creep in air is larger than creep under nitrogen atmosphere due to oxidation and surfaces cracks.*
Key-Words: *Ti-6Al-4V, creep, nitrogen atmosphere*

1. INTRODUCTION

Titanium and its alloys are excellent for applications in structural components submitted to high temperatures owing to their high strength to weight ratio, good corrosion resistance and metallurgical stability. Ti-6Al-4V is the workhorse of titanium industry and is extensively used in advanced jet engine components. Its high creep resistance is of great importance in enhancing engine performance [1]. However, the affinity by oxygen is one of main factors that limit its application as structural material at high temperatures. The high solid solubility of oxygen in titanium results in material loss and in the formation of hard and brittle layer during elevated temperature air exposure. The reactivity of titanium and its alloys with nitrogen is similar to its action with oxygen, where an oxide layer is formed on the surface as the nitride [2]. Advances have been observed in the development of titanium alloys with the objective of improving the creep properties, although the surface oxidation limits the use of these alloys in temperatures up to 600°C [3]. A substantial part of the creep research has been devoted to Ti-6Al-4V due to its industrial and technological importance. Its creep properties in air have been well documented. However, its creep behavior in nitrogen atmosphere has only rarely been investigated.

In this context, the purpose of this preliminary study is to evaluate the creep behavior of the Ti-6Al-4V alloy focusing on the determination of the experimental parameters related to the creep states.

2. EXPERIMENTAL PROCEDURE

The material chosen for the present study was hot-forged 12,7 mm diameter rod of commercial Ti-6Al-4V alloy with the same specifications as published by ASTM [4]. The microstructure consists of equiaxed α grains with average size about 10 μm. The β phase is present in the α grains boundaries. Tensile test was performed at 700°C in air according to ASTM standard E 21 specification [5]. The tensile properties are summarized in Table 1 namely, 0,2% yield stress (YS), ultimate tensile stress (UTS), elongation (EL) and reduction of area (RA).

Table 1 - Tensile properties of Ti-6Al-4V alloy.

T (ºC)	YS (MPa)	UTS (MPa)	EL (%)	RA (%)
700	73	193	58,3	88,2

Constant load creep tests were conducted on a standard creep machine in air and nitrogen atmosphere, at stress of 14, 42 and 56 MPa at a temperature of 700ºC. Samples with a gage length of 18,5 mm and a diameter of 3,0 mm were used for all tests. The creep tests were performed according to ASTM E139 standard [6].

3. RESULTS AND DISCUSSION

Representative creep curves of Ti-6Al-4V are displayed in Figure 1 in air and in nitrogen atmospheres.

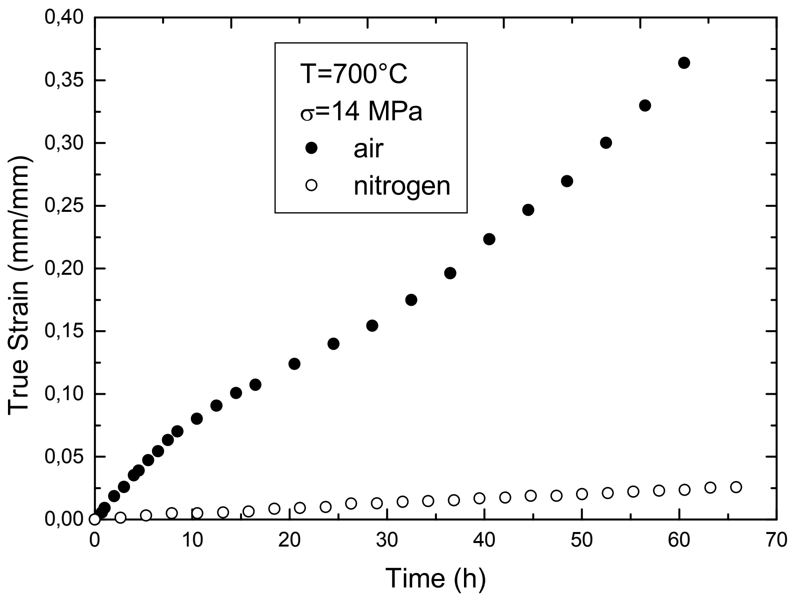

Fig. 1. Typical creep curves of Ti-6Al-4V at 700ºC / 14 MPa.

Ti-6Al4V alloy exhibits a normal creep curve consisting of primary and secondary stages. There is a relatively short initial period of decreasing primary creep rate that is 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 [7,8].

The creep tests at 700°C were interrupted before the tertiary stage, then it were not possible to calculate the strain at fracture (ε_f), time to rupture (t_r) and reduction of area (RA). Results from the creep tests at 700°C are summarized in Table 2.

Table 2 - Creep data at 700ºC.

Conditions	σ (MPa)	t_p (h)	$\dot{\varepsilon}_s$ (1/h)
Air	14	12,5	0,00396
	42	0,325	0,06426
	56	0,141	0,15656
Nitrogen	14	49,36	0,00034
	42	5,35	0,00673
	56	2,00	0,0128

The highest values of t_p and the reduction of the steady-state creep rate demonstrate the higher creep resistance of Ti-6Al-4V in nitrogen atmosphere. This fact is related with the hard and thin nitride surface layer formed during creep tests [9]. Figure 2 and 3 show the stress dependence of primary creep time and of the steady-state creep rate for both test conditions. By standard regression techniques, the results can be described in terms of power-law creep equations:

$$t_p = A\sigma^{-m} \quad (1)$$

$$\dot{\varepsilon}_s = B\sigma^{n} \quad (2)$$

where A and B are constant dependents on temperature and structure. The values of m and n are the stress exponents.

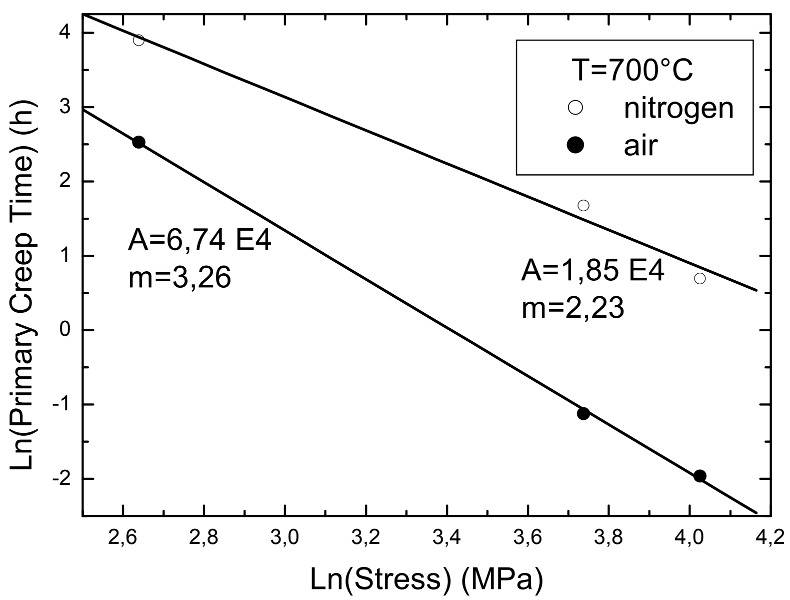

Fig. 2. Stress dependence of primary creep time in air and nitrogen atmosphere at 700°C.

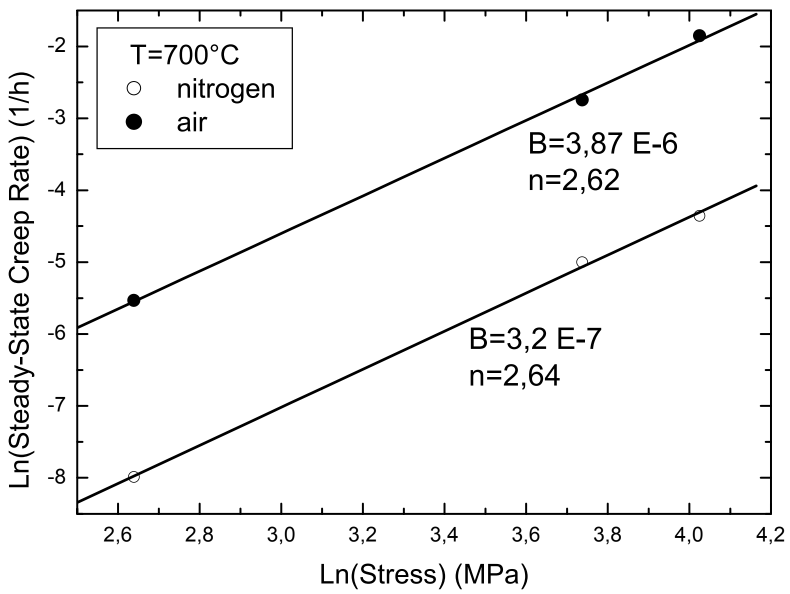

Fig. 3. Stress dependence of steady-state creep rate in air and nitrogen atmosphere at 700°C.

The measured creep stress exponents at 700ºC, in air and in nitrogen atmosphere, were 3,26 and 2,23 for primary creep and 2,62 and 2,64 for secondary creep, respectively. The values are consistent with a dislocation creep mechanisms [10].

The relation between primary creep time and steady-state creep obeyed the equation (3), where N and P are constants over limited stress and temperature ranges, such that:

$$t_p\left(\dot{\varepsilon}_s\right)^N = P \tag{3}$$

The proportionality between $\dot{\varepsilon}_s$ and t_p is presented in Fig. 4. By standard regression techniques, at 700ºC, in air and nitrogen atmosphere, the proportionality is obtained for N = 1,005 and P = 0,0261.

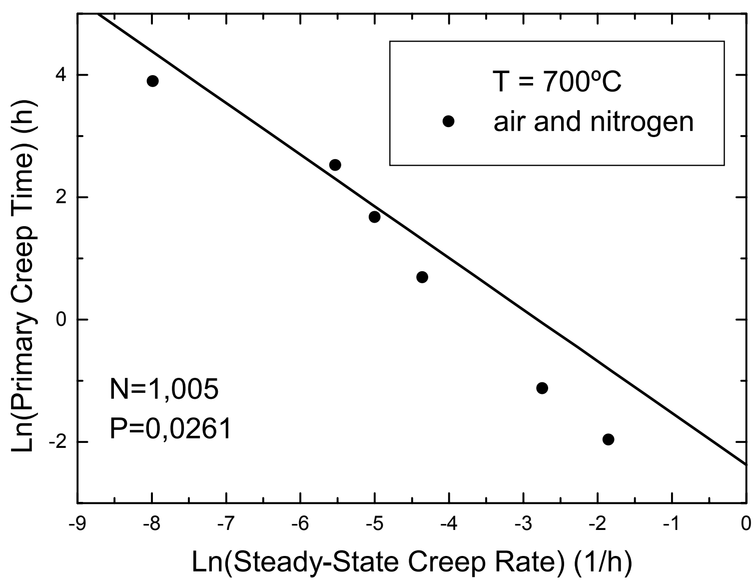

Fig. 4. Dependence of steady-state creep rate on the primary creep time.

4. CONCLUSIONS

The creep properties of Ti-6Al-4V in air and in nitrogen atmosphere were investigated at 700°C. The main results can be summarized as follows:

1. Exposure at high temperature in nitrogen atmosphere increases the creep resistance of the alloy at 700ºC in the range from 14 to 56 MPa.
2. For both test conditions the steady-state creep rate and the time to the onset of secondary creep can be described by power-law creep equations with stress exponents in the range from 2,23 to 3,26 at 700ºC.
3. The results for creep tests in air and under nitrogen atmosphere indicated that the primary creep, as well as the steady-state creep, is controlled by dislocation climb.
4. The relation between primary creep time and steady-state creep obeyed the equation $t_p\left(\dot{\varepsilon}_s\right)^N = P$, at 700ºC for N = 1,005 and P = 0,0261.

5. ACKNOWLEDGMENT

FAPESP (Proc.02/04736-7) for financial support.

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