EFFECT OF THE ATMOSPHERE IN CREEP OF Ti-6Al-4V ALLOY

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Abstract

Constant load creep tests were conducted with Ti-6Al-4V alloy in air and in nitrogen atmosphere at 600°C. Results indicate that the creep resistance of the alloy in nitrogen atmosphere is greater than in air. The results also show that the steady–state creep rate and the time to the onset of secondary creep follow power- law creep equations, with stress exponents of 4,57 and 6,0 for the primary creep and 4,26 and 5,31 for the steady-state creep. 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 creep-rupture data follows the Monkman-Grant relationship. The decrease in ductility after creep in air is larger than creep under nitrogen atmosphere due to oxidation and surfaces cracks.

Keywords: Ti-6Al-4V; Creep; Nitrogen atmosphere

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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 influence of the atmosphere on the creep behavior of a Ti-6Al-4V alloy for short-term tests.

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 600°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).

Constant load creep tests were conducted on a standard creep machine in air and nitrogen atmosphere, at stress of 125, 250 and 319 MPa at a temperature of 600°C. 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.].

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

T (°C)	YS (MPa)	UTS (MPa)	EL (%)	RA (%)
600	377	407	46	85,7

3. Creep results and discussion

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

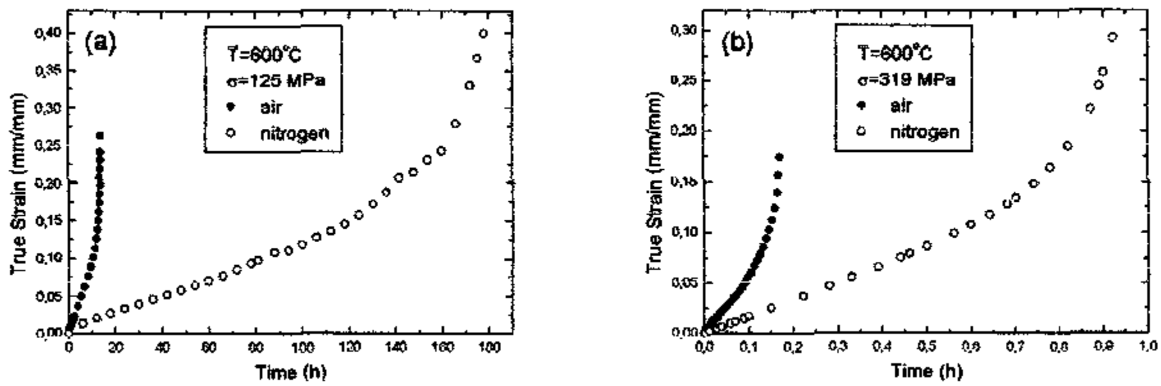

Fig. 1. Typical creep curves of Ti-6Al-4V: a) at 600°C / 125 MPa; b) at 600°C / 319 MPa.

Ti-6Al4V alloy exhibits a normal creep curve consisting of primary, secondary and tertiary stages. There is a relatively short initial period of decreasing primary creep rate that is associated with hardening due to the accumulation of dislocations and final short period of sharply increasing tertiary creep rate those results from the initiation and growth of damage such as cavities and necking. 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].

Results from the creep tests are summarized in Table 2, which show the values of primary creep time (t_p) defined as the ending of primary creep, secondary creep rate ($\dot{\varepsilon}_s$), strain at fracture (ε_f) and time to rupture (t_r).

Table 2 - Creep data at 600°C.

Conditions	σ (MPa)	t_p (h)	$\dot{\varepsilon}_s$ (1/h)	ε_f (mm/mm)	t_r (h)	RA (%)
	125	0,833	0,00901	0,263	14,0	75,83
Air	250	0,031	0,1597	0,194	0,62	75,83
	319	0,012	0,499	0,174	0,17	62,99
	125	24,0	0,00104	0,399	178	82,64
Nitrogen	250	0,353	0,03169	0,341	3,68	65,97
	319	0,089	0,1665	0,293	0,92	56,44

The highest values of t_p and t_r and the reduction of the steady-state creep rate demonstrate that 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.

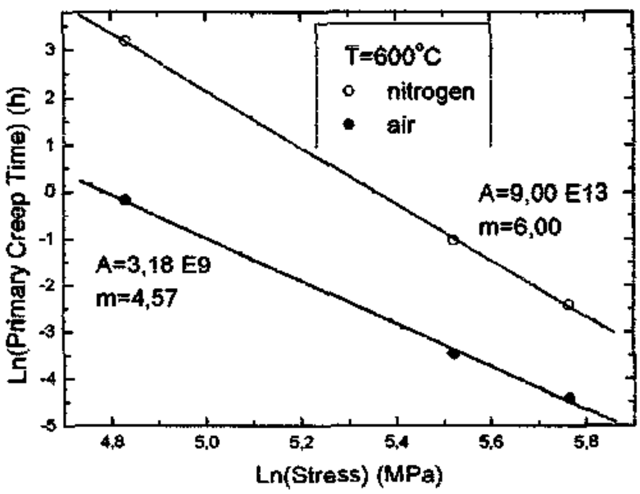

Fig. 2. Stress dependence of primary creep time in air and nitrogen atmosphere.

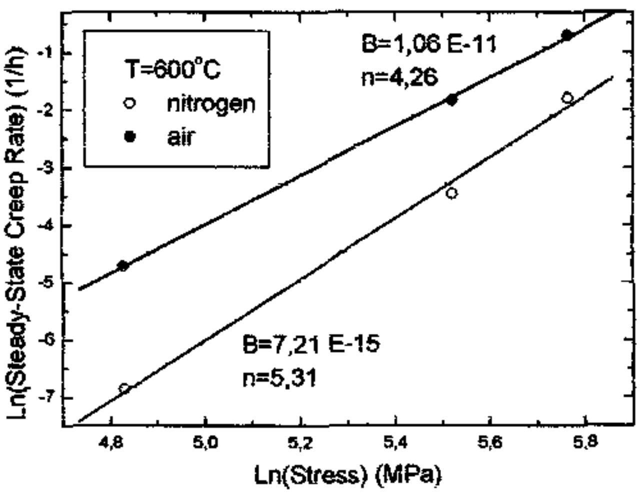

Fig. 3. Stress dependence of steady-state creep rate in air and nitrogen atmosphere.

The stress exponents obtained all lie in the range from 4,26 to 6,0. Previously reported results about the apparent activation energies of creep in air indicate that Q_p = 309 kJ/mol and Q_s = 319 kJ/mol for primary and secondary creep, respectively [10,11]. These values correspond to the activation energy of lattice self-diffusion of titanium in the α phase [12]. The correlation between Q_p and Q_s and the stress exponents may indicate that the creep is controlled by dislocation climb for both test conditions [13,14].

Despite differences in the test conditions, the creep-rupture data follow the Monkman-Grant relationship [15], as show in Figure 4, and can be described as:

$$t_r(\dot{\varepsilon}_s)^M = C \quad (3)$$

By standard regression techniques, the proportionality between $\dot{\varepsilon}_s$ and t_r is obtained for M = 1,094 and C = 0,091 in nitrogen atmosphere and in air.

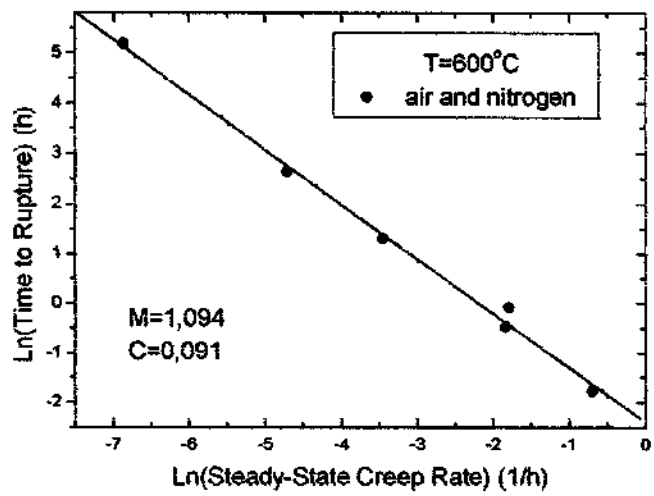

Fig. 4. Dependence of steady-state creep rate on the time to rupture.

The values of ε_f are plotted as a function of applied stress in Figure 5. In the case of Ti-6Al-4V the decrease in ductility after creep in air is larger than creep under nitrogen atmosphere.

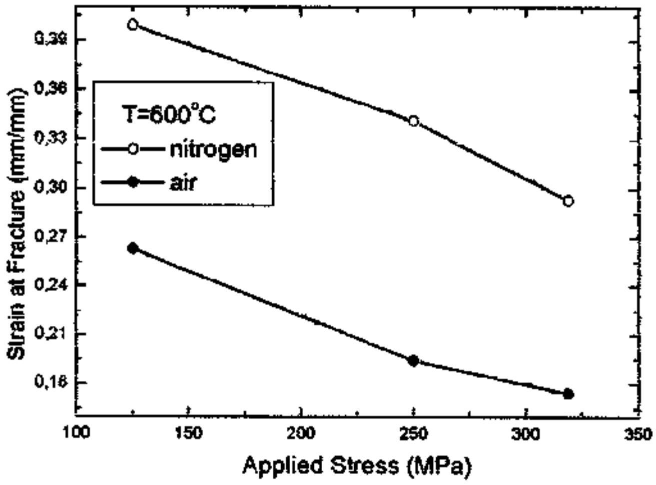

Fig. 5. Strain at fracture as a function of applied stress.

The ductility loss could be correlated with the depth of air contamination. It must be recognized that the effect of the contaminated layer on creep properties is dependent on the test specimen geometry, as well as, the chemical reactivity of titanium is dependent upon temperature. The metal combines with oxygen to from a long series of oxides from TiO to Ti_7O_{12} [2,16,17]. Therefore, the variation in ductility with the applied stress can be correlated with oxidation effects and surface cracks due to elevated temperature exposure in air.

4. Conclusions

The creep properties of Ti-6Al-4V in air and in nitrogen atmosphere were investigated at 600°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 600°C in the range from 125 to 319 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 4,26 to 6,0.

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 time to rupture and steady-state creep rate obeyed the equation $t_r(\dot{\varepsilon}_s)^M = C$, with M = 1,094 and C = 0,091 in air and in nitrogen atmosphere.
5. The decrease in ductility in air is larger than in nitrogen atmosphere and is correlated with oxidation effects and surface cracks.

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