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INFLUENCE OF LASER TREATMENT ON THE CREEP OF THE Ti-6Al-4V ALLOY

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Abstract

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. However, the affinity by oxygen is one of main factors that limit its application as structural material at high temperatures. The objective of this work was to estimate the influence of laser treatment on the creep of the Ti-6Al-4V alloy. Constant load creep tests were conducted with Ti-6Al-4V alloy at 600°C. The creep tests were conducted on a standard creep machine at stresses from 125 to 319 MPa. Samples with a gage length of 18.5 mm and a diameter of 3.0 mm were used for all tests. When the laser treated Ti-6Al-4V was tested the effect of the oxidation was smaller and the behavior of the creep curves showed that the life time was longer. There was an increasing of the material ductility (final strain) and life time. It was also observed a decreasing of steady state creep rate in function of the reduction of oxidation process, showing that for the Ti-6Al-4V alloy their life time was strongly affected by the superficial treatment.
Key words: Creep; Liga Ti-6Al-4V; Nd:YAG pulsed laser.

INFLUÊNCIA DO TRATAMENTO DE LASER NA FLUÊNCIA DA LIGA Ti-6Al-4V

Resumo

Titânio e suas ligas apresentam excelentes propriedades para aplicação em componentes estruturais para altas temperaturas, tais como alta resistência, baixa massa específica, boa resistência a corrosão e estabilidade metalúrgica. O objetivo deste trabalho foi avaliar a resistência da liga Ti-6Al-4V em fluência após tratamentos superficiais de laser pulsado Nd:YAG. Foi utilizada a liga Ti-6Al-4V na forma de barras cilíndricas, na condição forjada e recozida a 190 °C durante 6 horas e resfriada ao ar. A liga Ti-6Al-4V após tratamentos superficiais de laser pulsado Nd:YAG foi submetida a ensaios de fluência de 500 a 700 °C e tensão de 125 a 520 MPa, na modalidade de carga constante. Para o tratamento de laser pulsado Nd:YAG utilizou-se uma atmosfera de 40% N e 60% Ar, com potência de 2,1 W, velocidade de 10 m/s. Os resultados obtidos sugerem que o tratamento superficial por laser Nd:YAG na liga Ti-6Al-4V conferiu maior resistência à fluência.
Palavras-chave: Fluência; Ti-6Al-4V alloy; Laser pulsado Nd:YAG.

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1INTRODUCTION

The development of alloys with increased creep strength, so permitting the use of higher turbine entry temperatures, has resulted in a general reduction in chromium and increase in aluminum content of nickel superalloys. This has had relatively little effect on high-temperature oxidation resistance, but has had a very significant adverse effect on corrosion resistance in the lower temperature range in salt-contaminated environments. Such environments are experienced by aircraft operating between airfields with approaches low over the sea with relatively short sector times. Improvements in aero gas turbine performance in terms of power, efficiency and weight have necessitated the use of high specific-strength, low-density materials.(1,2)

One of the major factors limiting the life of titanium alloys in service is their degradation due to gaseous environments, in particular, the one containing oxygen, especially at elevated temperatures, during the long term use.(3) The sensitivity of titanium alloys to high temperature exposure is a well-known phenomenon. When titanium alloys are heated to temperatures above approximately 800ºC, oxygen, hydrogen and nitrogen penetrate into them. The penetration of the above elements is thought to be undesirable because it increases hardness and brittleness while decreasing the toughness of the alloy.(4) Interaction of titanium alloys with oxygen not only causes loss of the material by formation of oxides, but also causes embrittlement in the subsurface zone of the component due to oxygen enrichment.(3)

Titanium alloys is one of the most technologically important materials in the aeronautic and aerospace field for its high strength and lightweight. However, this material does not possess satisfactory tribological property. For this reason, surface strengthening of titanium alloys has attracted much attention.(5)

Laser oxidation or nitridation of titanium surfaces are interesting for local hardening and improvement of wear resistance. It is known that melting of the surface layer to enhance the chemical reactions, avoiding significant vaporization and particulates removal, represents the main requirement in direct laser surface oxidation or nitridation of metallic targets in controlled reactive atmospheres.(6)

Titanium nitride thin film is used for applications in technological areas due to their excellent hardness, wear and corrosion resistance, high melting point, chemical inertness, as well as high electrical conductivity. Titanium nitride thin films on Ti, or Ti alloy targets are usually obtained by thermal, or plasma nitriding and have a good adherence to the metal. The use of laser radiation for nitriding w1–5x is an interesting alternative because of the higher reaction rates as compared to conventional techniques. In addition, in case of short focused laser pulses, the reduced heat-affected zones both in lateral dimensions and depth ensure the accurate spatial control of the process, i.e. the change of the surface properties of the irradiated area without affecting the bulk. According to the equilibrium phase diagram of the Ti–N system, several crystalline phases can exist.(6) The cubic-face-centered d-TiN (with a nitrogen percentage above 30%) is the most usual titanium nitride phase. The hexagonal a-Ti(N)*x* phase has less than 25% nitrogen located interstitially in the hexagonal a-Ti phase lattice. Moreover, in a restricted nitrogen concentration range, between 30 and 40%, other phases may be encountered: tetragonal d9-Ti2N and -Ti2N w6.7x. In general, TiN*x* thin films with low nitrogen concentration consist of a mixture of these crystalline phases.(7-10) Some authors have claimed that films containing tetragonal Ti_2N phases have better wear and corrosion resistance than those consisting of pure cubic d-TiN.(9,10) Also, in some papers it has been claimed that the hardness of the films increases with the increasing content of Ti_2N.[7-10] However, the synthesis of pure tetragonal Ti_2N films is difficult task, since the phase development takes place in a restricted domain of adequate processing conditions.[7]

The aim of the present paper was to measure the influence of the laser treatment Nd:YAG (oxidation protection) on creep behavior of the Ti-6Al-4V alloy. A substantial part of the creep research has been devoted to Ti-6Al-4V due to its industrial and technological importance.

2 EXPERIMENTAL PROCEDURE

The chosen material 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.[8] The microstructure (Figure 1) consists of equiaxed α grains with average size about 10 μm. The transformed β phase is present in the α grain boundaries.[9] Tensile testing was performed at 600℃ in air according to ASTM standard E 21 specification.[10] 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*). The Ti-6Al-4V laser treated alloy is shown in Figure 2. The initial creep stress levels were determined from the elevated temperature tensile properties given in Table 1. The Nd:YAG laser treatment parameters used are presented in Table 2, and it was also used the ROFIN DY 033 laser and Talymap Silver 4.0 software. Constant load creep tests were conducted with Ti-6Al-4V alloy at 600℃. The creep tests were conducted on a standard creep machine at stresses from 125 to 319 MPa. Samples with a gauge 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.[11]

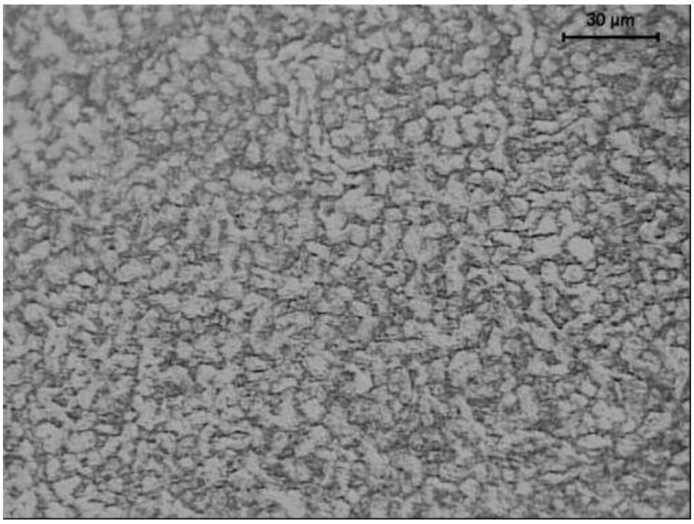

Figura 1. Micrograph of Ti-6Al-4V alloy as-received.

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

T (ºC)	*YS* (MPa)	*UTS* (MPa)	*EL* (%)	*RA* (%)
600	377	407	46	85.7

Figura 2. Ti-6Al-4V laser treated sample.

Table 2 – Laser treatment parameters

Parameters	Nd-YAG Laser
power	1.6 - 10 W
focal length lens	100-160 mm
laser scanning speed	50 mm/s
environment	40% N + 60% Ar
depth above the specimen surface	0.2-4,5 µm
distance between focusing lens -target	89 mm
laser pulsed energy	1.9-9.0 mJ
diameter laser spot	0.17-0.98mm
diameter central zone	0.04-0.24 mm
incident laser intensity	3.1 x10^9 W/cm^2
distribution	Gaussian

3 RESULTS

Representative creep curves for Ti-6Al-4V, with and without laser treatment, are showed in Figure 3 (ST refers to a sample without treatment).

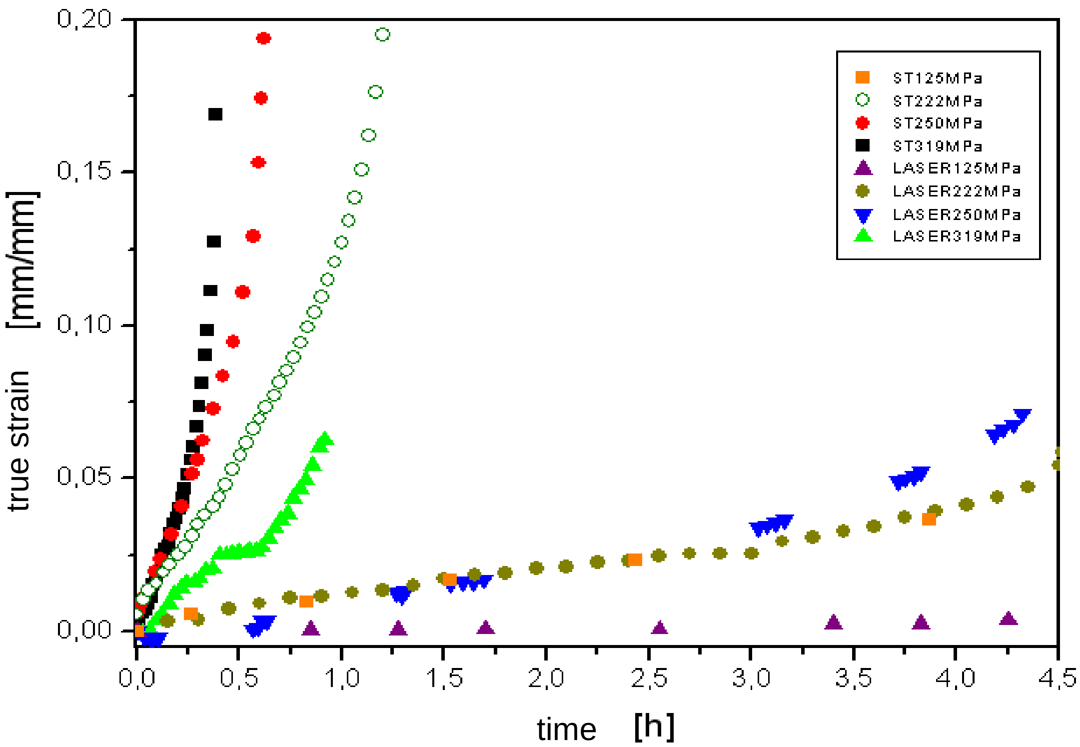

Figura 3. Typical creep curves for Ti-6Al-4V, with and without laser treatment, at 600ºC.

Results from the creep tests at 600℃ are summarized in Table 3, which shows the values of stress (σ), primary creep time (t_p), secondary creep rate ($\dot{\varepsilon}_s$), final creep time (t_f), final strain (ε_f) and reduction of area (RA).

Table 3 - Creep data at 600℃

Treatment	**σ (MPa)**	**t_p (h)**	**$\dot{\varepsilon}_s$ (1/h)**	**t_f (h)**	**ε_f (mm/mm)**	**RA (%)**
ST (without treatment)	125	0.83	0.0090	14.0	0.2630	75.83
Laser	125	25.5	0.0001	125	0.1901	22.94
ST	222	0.09	0.0916	1.23	0.2130	76.64
Laser	222	0.45	0.0080	4.52	0.0600	12.72
ST	250	0.03	0.1597	0.62	0.1938	75.83
Laser	250	0.63	0.0127	4.32	0.0711	12.73
ST	319	0.01	0.4990	0.17	0.1742	62.99
Laser	319	0.21	0.0357	0.92	0.0627	11.51

Figure 4 shows the stress dependence of the steady-state creep rate for both test conditions.

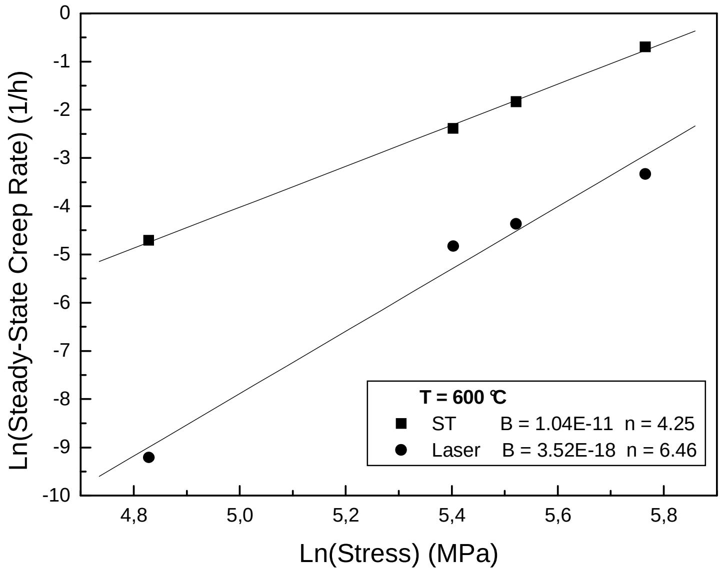

Figura 4. Stress dependence of steady-state creep rate at 600℃.

4 DISCUSSIONS

Figure 3 shows that most of the creep life of this alloy is dominated by a constant creep rate that is thought to be associated with a stable dislocation configuration due to recovery and hardening process.[12-14] The higher creep resistance of Ti-6Al-4V is observed in laser treated samples in all cases.

The reduction of the steady-state creep rate (Table 3) demonstrates that the higher creep resistance of Ti-6Al-4V is observed in laser treated samples. This fact is related to the superficial hardening formed in Ti-6Al-4V alloy by the laser treatment. It is a well known fact that hard surface and interstitial solid solutions increase the creep resistance of certain alloys. The superficial hardening during creep tests, increases rupture life. It is possible that controlled penetration of oxygen into the alloy Ti-6Al-4V could increase its creep resistance without seriously altering its ductility.[4]

By standard regression techniques, the results can be described in terms of power-law creep equation:

$$\dot{\varepsilon}_s = B\sigma^n \quad (1)$$

The material parameters B and n are usually determined from a number of constant load creep tests.

The stress exponents obtained, all lie in the range from 4.25 to 6.46. Previously reported results about the apparent activation energies of creep in air indicate that Qs = 319 kJ/mol for secondary creep.[13,15] The results indicate that the steady-state strain rate $\dot{\varepsilon}_s$, may be described by equation (1). In this case, the author consider that the value, n = 3.8, is low for a two-phase system, but is in agreement for the stress dependence founded in pure metals and solid solutions. The stress exponent for pure titanium at 650℃ is 5, which is reasonabl e for a pure metal.[16]

The correlation between Qs and the stress exponents may indicate that the creep in the secondary stage is controlled by dislocation climbs.

5 CONCLUSIONS

Constant load creep tests were conducted on Ti-6Al-4V alloy at 600℃ and stresses from 125 to 319 MPa. When the Ti-6Al-4V laser treated alloy was tested the oxidation effect was smaller and the behavior of the creep curves showed that the life time was longer. There was an increasing of life time. It was also verified a decreasing of steady state creep rate according to the reduction of oxidation process, showing that for the Ti-6Al-4V alloy their life time was strongly affected by the superficial treatment. The correlation between Qs and the stress exponents may indicate that the creep in the secondary stage is controlled by dislocation climbs.

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