

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

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## **Abstract**

The objective of this work was estimate the influence of laser treatment on the creep of the Ti-6Al-4V alloy. In the Nd:YAG pulsed laser treatment was used an environment of 40% N and 60% Ar, with 2,1 W of power and 10 m/s of speed. 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 stress of 250 MPa and 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 Ti-6Al-4V laser treated alloy was tested the effect of the oxidation was smaller and the behavior of the creep curves showed that the life time was better. There was an increasing of life time. Occurred a decreasing of steady state creep 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 that was submitted because the oxidation suffered by the material.

**Key words:** Creep; Ti-6Al-4V; Nd:YAG pulsed laser.

## **EFEITO DO TRATAMENTO SUPERFICIAL DE LASER NA FLUÊNCIA DA LIGA Ti-6Al-4V**

### **Resumo**

O objetivo deste trabalho foi estimar a influência do tratamento superficial de laser na fluência da liga Ti-6Al-4V. No tratamento de laser pulsado Nd:YAG foi utilizado uma atmosfera de 40% N e 60% Ar, com 2,1 W de potência 10 m/s de velocidade. Testes de fluência a carga constante foram realizados com a liga Ti-6Al-4V a 600°C. Os testes de fluência foram realizados em uma máquina de fluência a tensão de 250 MPa a 319 MPa e 600°C. Amostras com comprimento de 18,5 mm e diâmetro de 3,0 mm foram usadas para todos os testes. Quando a liga Ti-6Al-4V tratada por laser foi testada o efeito da oxidação foi menor e o comportamento das curvas de fluência apresentaram um maior tempo de vida. Ocorreu uma diminuição do estado de fluência estacionária em função da redução do processo de oxidação, mostrando que a liga Ti-6Al-4V apresentou seu tempo de vida fortemente afetado pelo tratamento superficial de laser que foi submetida, devido à oxidação sofrida pelo material.

**Palavras-chave:** Fluência; Ti-6Al-4V; Laser pulsado Nd:YAG.

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## 1 INTRODUCTION

Development of alloys to increase 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.<sup>(1,2)</sup>

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.<sup>(3)</sup> The sensitivity of titanium alloys to high temperature exposure is a well-known phenomenon. When titanium alloys are heated to temperatures above approximately 800°C, 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.<sup>(4)</sup> 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.<sup>(3)</sup>

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.<sup>(5)</sup>

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.<sup>(6)</sup>

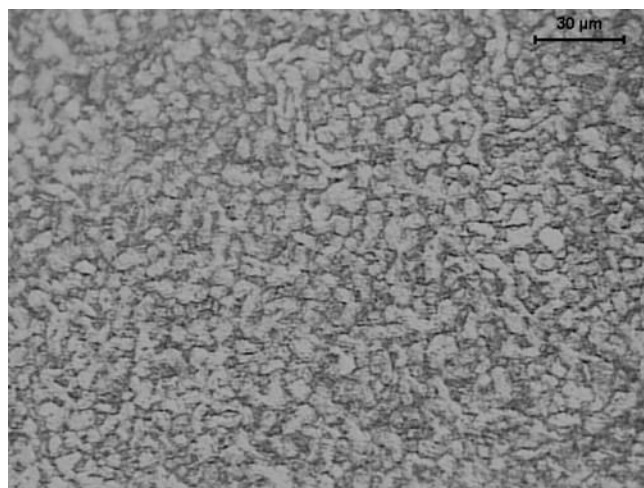
Titanium nitride thin films present interest for applications in technological areas due to their excellent hardness, wear and corrosion resistance, high melting point, chemical inertness, as well as high electrical conductivity. Titanium nitride thin films on Ti, or Ti alloy targets are usually obtained 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 orders of magnitude 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 w6x. The cubic-face-centered d-TiN (with a nitrogen percentage above 30%) is the most usual titanium nitride phase. The hexagonal  $\alpha$ -Ti(N)<sub>x</sub> phase has less than 25% nitrogen located interstitially in the hexagonal  $\alpha$ -Ti phase lattice. Moreover, in a restricted nitrogen concentration range, between 30% and 40%, other phases may be encountered: tetragonal d9-Ti<sub>2</sub>N and -Ti<sub>2</sub>N w6,7x. In general, TiN<sub>x</sub> thin films with low nitrogen concentration consist of a mixture of these crystalline phases w7–10x. Some authors have claimed that films containing tetragonal Ti<sub>2</sub>N phases have better wear and corrosion resistance than those consisting of pure cubic d-TiN w9,10x. Also, in some papers it has been claimed that the hardness of the films increases with the

increasing content of Ti<sub>2</sub>N w7–10x. However, the synthesis of purê tetragonal Ti<sub>2</sub>N films was difficult, since the phase development takes place in a restricted domain of adequate processing conditions.<sup>(7)</sup>

The aim of the present paper was to measure the influence of the laser treatment Nd:YAG for oxidation protection on creep 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.<sup>(8)</sup> The microstructure (Figure 1) consists of equiaxed  $\alpha$  grains with average size about 10  $\mu\text{m}$ . The transformed  $\beta$  phase is present in the  $\alpha$  grain boundaries.<sup>(9)</sup> Tensile testing was performed at 600°C in air according to ASTM standard E 21 specification.<sup>(10)</sup> 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, it was used ROFIN DY 033 laser and Talymap Silver 4.0 software. 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 stress of 250 and 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.<sup>(11)</sup>



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

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

<i>T</i> (°C)	<i>YS</i> (MPa)	<i>UTS</i> (MPa)	<i>EL</i> (%)	<i>RA</i> (%)
600	377	407	46	85.7



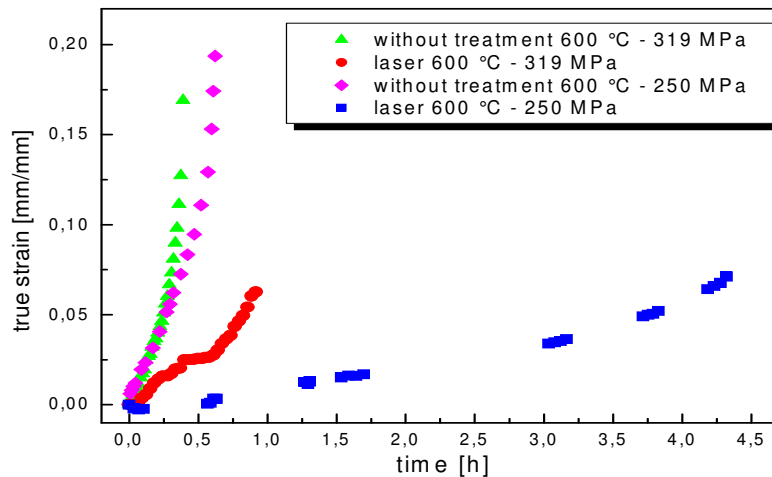
**Figure 2.** Ti-6Al-4V coated sample.

**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 $\mu\text{m}$
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	$3.1 \times 10^9 \text{ W/cm}^2$
distribution	Gaussian

### 3 RESULTS

Representative creep curves of Ti-6Al-4V are showed in Figure 3.



**Figure 3.** Typical creep curves of Ti-6Al-4V at 600°C.

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

**Table 3** - Creep data at 600°C.

Treatment	$\sigma$ (MPa)	$t_p$ (h)	$\dot{\epsilon}_s$ (1/h)	$t_f$ (h)	$\epsilon_f$ (mm/mm)	RA (%)
without treatment	250	0.03	0.1906	0.62	0.1938	75.83
laser	250	0.63	0.0127	4.32	0.0711	12.73
without treatment	319	0.01	0.5698	0.39	0.1742	62.99
laser	319	0.21	0.0357	0.92	0.0627	11.51

## 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.<sup>(12-14)</sup> 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 hardening superficial 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 hardening superficial 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).

## 5 CONCLUSIONS

Constant load creep tests were conducted with Ti-6Al-4V alloy at 600°C and stress of 250 Mpa and 319 MPa. When the Ti-6Al-4V laser treated alloy was tested the effect of the oxidation was smaller and the behavior of the creep curves showed that the life time was better. There was an increasing of life time. Occurred a decreasing of steady state creep 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 that was submitted because the oxidation suffered by the material.

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