*Materials Science Forum Vols. 660-661 (2010) pp 235-240*
*Online available since 2010/Oct/25 at www.scientific.net*

*doi:10.4028/www.scientific.net/MSF.660-661.235*



# EVALUATION OF HEAT TREATMENT AND CERAMIC COATING IN CREEP OF TI-6AL-4V

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**Keywords:** Ti-6Al-4V; heat treatment; plasma-sprayed coatings; creep

**Abstract.** This study aimed to evaluate the resistance of a Ti-6Al-4V alloy in creep after heat treatments. It was used a Ti-6Al-4V alloy in cylindrical bars forms, forged condition and annealing at 190°C for 6 hours and cooled in air. The microstructure of Ti-6Al-4V alloy was evaluated after heat treatment and was submitted to creep tests at 600°C and stress conditions from 125 to 319 MPa at constant load. The Widmanstätten structure was obtained by heat treatment. Yttria (8 wt.%) stabilized zirconia (YSZ) with a CoNiCrAlY bond coat was atmospherically plasma sprayed on Ti-6Al-4V substrates by Sulzer Metco Type 9 MB. The alloy with Widmanstätten structure and ceramic coating shows greater resistance to creep and oxidation with a longer life time in creep. At higher stress condition, 600ºC and 319 MPa, the Ti-6Al-4V alloy with ceramic coating didn't show higher creep resistance. This condition presented higher $t_p$ value and the $\dot{\varepsilon}_s$ value. It occurred because at high stress condition the coating is very fragile, decreasing your creep resistance.

## Introduction

The search for alloys with improved high-temperature specific strength and creep-resistance properties for aerospace applications has led in the last decades to sustained research activities to develop new alloys and/or improve existing ones [1]. 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 [2]. A substantial part of the creep research have been devoted to Ti-6Al-4V alloy because its technological and industry importance. Its high creep resistance is very important in the turbine use [3 - 4].

There are many factors that affect the characteristics of creep of metals. These include the melting temperature, the modulus of elasticity and grain size. In general, the higher the melting temperature, the higher the modulus of elasticity, and larger grain size, the better the resistance of a material to fracture. Regarding the grain size, smaller grains allow more slippage between the grain boundaries [5]. In the deformation processes occurs sliding grain boundaries, which may also create holes that facilitate the rise of dislocations. It occurs intermittently over time, causing a not uniform deformation along the grain boundary. Such slippage become important with increasing temperature and with low stress [6]. Thus, smaller grains by having the largest area of the boundaries allow greater slippage between the grain boundaries, which results in higher creep rates. The most common method of changing microstructures is through various types of heat treatments, each one designed to produce a specific structure [5]. The goal of heat treatment is to change the mechanical and structural characteristics of materials in each application [7].

However, the affinity by oxygen is one of main factors that limit the application of titanium and its alloys as structural material at high temperatures [8]. 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 [9]. 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 [10].

Since a few decades, plasma spraying is an established technique to produce thick coatings for protection against heat, corrosion and wear. Practically all materials that can be melted without decomposition can be deposited as coatings on virtually all reasonably heat resistant substrates. Also, very large areas of complex geometries can be coated [11].

In recent years, aircraft engine designers have been considering the use of thermal barrier coatings (TBC's) for thermal protection of hot section turbine components. A two-layer coating system consisting of a 0.25-0.51-mm plasma-sprayed stabilized zirconia outer layer and a 0.10-0.20-mm *M*CrAlY inner layer (where *M* = Ni, Co, Fe, or combinations of these elements) has generally been the preferred configuration. Of key importance to the engine designer is the mechanical and chemical interaction of the thermal barrier coating and the engine component to which it is applied. To consider these interactions the designer requires a description of both the physical and mechanical properties of each layer of the thermal barrier coating [12 - 15].

Thermal barrier coating (TBC) systems, consisting of yttria partially stabilized zirconia (YSZ), thermally grown oxide (TGO) and a metallic bond coat, are finding applications for thermal protection of hot-section parts in gas turbine engines [16-20].

The aim of the present paper was to evaluate the resistance of a Ti-6Al-4V alloy in creep after heat treatments and compare to the influence of the plasma-sprayed coatings for oxidation protection on creep of the Ti-6Al-4V alloy.

## Experimental procedure

### Heat treatment

It was used the refractory furnace of Lindberg / Blue trade mark to the treatment of the samples. They were put in a quartz tube and it was used a vacuum pump to remove air from the quartz tubes at the encapsulation. The argon gas was injected in the quartz tubes to avoid oxidation of the samples. A pickling solution of HF- 0.2 mL/$HNO_3$- 2 mL / $H_2O$-30 mL was used to wash the samples after the treatment.

### Heat treatment to obtain a Widmanstätten structure

The Lindberg / Blue furnace was heated up to 1050°C and the samples were heated for 30 minutes. After this time samples were cooled inside the furnace at a rate of 6Cº/ min until room temperature. The samples already at room temperature were removed from the furnace and put in acid solution.

### Plasma sprayed coating

Yttria (8 wt.%) stabilized zirconia (YSZ) (Metco 204B-NS) with a CoNiCrAlY bond coat (AMDRY 995C) was atmospherically plasma sprayed on Ti-6Al-4V substrates by Sulzer Metco Type 9 MB.

### Creep tests

Creep tests were realized using MAYES machines from Instituto Tecnológico de Aeronáutica - ITA. In the furnace were adapted electrical systems and controllers according to ASTM E139/83 standardization [21]. Antares Software was used to collect the data on the elongation of the samples and the measuring of temperature in pre determined periods of time. It was used a transducer-type

LVDT Schlumberger D 6.50 to obtain measures of elongation and it was used Cromel-Alumel thermocouple type AWG24 to control temperature.

## Results and discussions

### Heat treatment

Figure 1 shows the microstructure of the annealed Ti-6Al-4V alloy as received obtained by optical microscope.

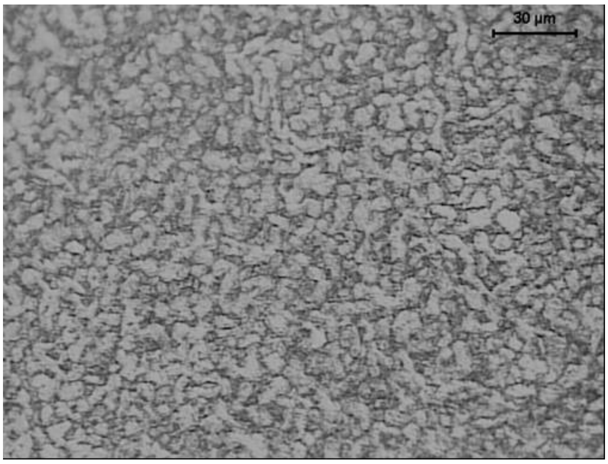


Fig. 1. Ti-6Al-4V alloy micrograph as received.

Figure 2 shows the image obtained by optical microscope from Ti-6Al-4V alloy after heat treatment of Widmanstätten structure. It could be observed an increasing size of the grains and a tough microstructure caused by the heat treatment.

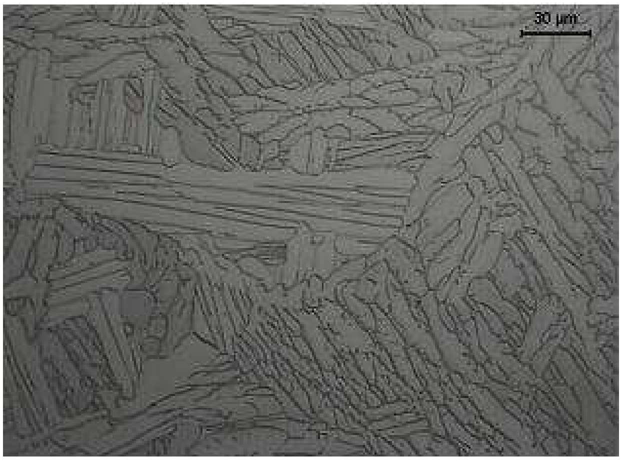


Fig. 2. Ti-6Al-4V alloy micrograph of Widmanstätten structure.

### Plasma sprayed coating

Figure 3 shows the image of the ceramic coating, obtained by SEM, utilized in Ti-6Al-4V substrate.

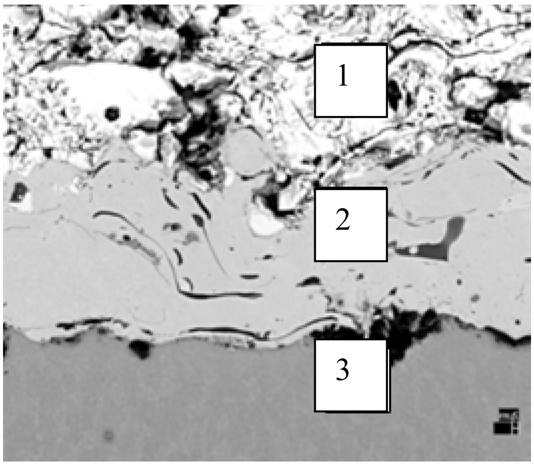


Fig. 3. Micrograph obtained by SEM of the coating used in the Ti-6Al-4V substrate:
1) ceramic coating, 2) metallic coating and 3) Ti-6Al-4V substrate.

**Creep tests**

Figure 4 shows the creep curves of the Ti-6Al-4V alloy at 600°C, 250 and 319 MPa, under conditions without treatment (as received), with Widmanstätten structure and with ceramic coating, corresponding to the real deformation ε as function of time t.

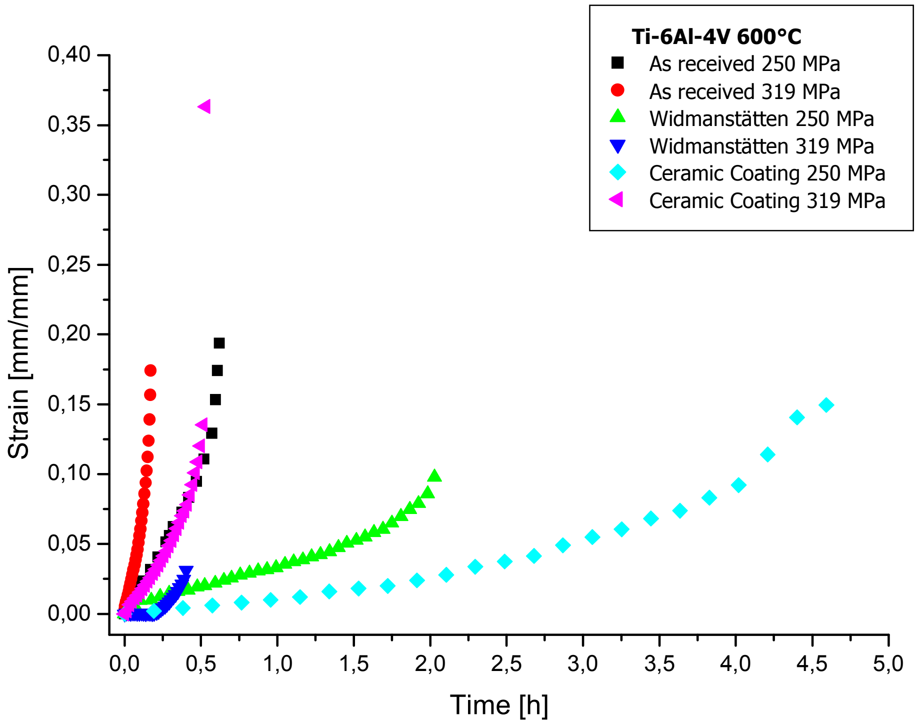


Fig. 4. Creep curves of Ti-6Al-4V alloy at 600ºC, 250 and 319 MPa, without treatment, Widmanstätten structure and ceramic coating.

Table 1 shows the relationship of the main experimental parameters obtained at 600°C, from experimental curves, which σ is stress, $\dot{\varepsilon}_s$ is the rate of stationary creep, obtained obtained through the rate of linear region of the curve (secondary state). The amount of $t_p$ is the constant relative time to primary time, obtained in the final stage of primary and / or early stage of secondary stage. The value $t_f$ is the final time of fracture and $\varepsilon_f$ corresponds to the fracture strain. Ti-6Al-4V alloy with ceramic coating showed higher creep resistance at 600ºC and 250 MPa, this condition presented higher $t_p$ value and lower $\dot{\varepsilon}_s$. At higher stress condition, 319 MPa, the Ti-6Al-4V alloy with ceramic coating didn't show higher creep resistance. This condition presented higher $t_p$ value and the $\dot{\varepsilon}_s$ value. It occurred because at high stress condition the coating is very fragile, decreasing your creep resistance.

Table 1. Creep data of Ti-6Al-4V alloy at 600°C.

| Treatment | σ [MPa] | $t_p$ [h] | $\dot{\varepsilon}_s$ [1/h] | $t_f$ [h] | $\varepsilon_f$ [mm/mm] |
|---|---|---|---|---|---|
| As received | 250 | 0.03 | 0.1947 | 0.62 | 0.1938 |
| Widmanstätten | | 0.17 | 0.0306 | 2.03 | 0.0977 |
| Ceramic Coating | | 0.38 | 0.0104 | 4.59 | 0.1490 |
| As received | 319 | 0.01 | 0.6004 | 0.17 | 0.1742 |
| Widmanstätten | | 0.03 | 0.0525 | 0.40 | 0.0311 |
| Ceramic Coating | | 0.03 | 0.1401 | 0.51 | 0.1353 |

**Conclusions**

The microstructure of Ti-6Al-4V alloy was evaluated after heat treatment and was submitted to creep tests at 600°C and stress conditions from 125 to 319 MPa at constant load. The alloy with Widmanstätten structure and ceramic coating shows greater resistance to creep at 600ºC and 250 MPa with a longer life time in creep. At higher stress condition, 600ºC and 319 MPa, the Ti-6Al-4V alloy with ceramic coating didn't show higher creep resistance. This condition presented higher $t_p$ value and the $\dot{\varepsilon}_s$ value. It occurred because at high stress condition the coating is very fragile, decreasing your creep resistance.]

**Acknowledgments**

FAPESP, CAPES and CNPq for financial support.

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**Advanced Powder Technology VII**
doi:10.4028/www.scientific.net/MSF.660-661

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doi:10.4028/www.scientific.net/MSF.660-661.235