THE INFLUENCE OF HIGH TEMPERATURE EXPOSURE IN CREEP OF THE TI-6Al-4V ALLOY

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Abstract. *The titanium affinity by oxygen is one of main factors that limit the application of their alloys as structural materials at high temperatures. Notables advances have been obeserved in the development of titanium alloys with the objective of improving the specific high temperature strength and creep-resistance properties. However, the surface oxidation limits the use of these alloys in temperatures up to 600ºC.*

The objective of this work was estimate the influence of the oxidation in the life time in creep of the Ti-6Al-4V alloy. The samples were analyzed by High Resolution X-Ray Diffraction, Scanning Electronic Microscopy (SEM), Atomic Force Microscopy (AFM) and microhardness test The samples of Ti-6Al-4V were polished and treated during 24 hours at 600°C and observed the oxidation behavior in each case using argon, nitrogen and air atmospheres. The oxidation was more aggressive in air atmosphere, forming TiO_2 film in the surface. The oxidation produced a material loss through the growth of the oxide layer and the hardening by oxygen dissolution.

Using the Ti-6Al-4V alloy produced specimens to creep test. The specimens were tested by creep at 600ºC in argon, nitrogen and air atmospheres using 250 MPa. When the Ti-6Al-4V was treated in argon and nitrogen atmospheres the effect the oxidation is smaller and the behavior of the creep curves shows that the useful life is better in atmospheres not so oxidant, there is an increasing of ductility of material (final deformation) and useful life. Occurs a decreasing of steady state creep in function of the reduction of oxidation process, showing that for the Ti-6Al-4V alloy their useful life is strongly affected by the atmosphere that is submitted because the oxidation suffered by the material.

Keywords: *Ti-6Al-4V, oxidation, high temperature.*

1.INTRODUCTION

Titanium naturally resists corrosion from acids, alkalis, and natural, salt and polluted waters. In fact, titanium's resistance to seawater is equivalent to that of platinum. This is because titanium is a reactive metal, spontaneously forming a hard, protective oxide film when it comes in contact with any oxygen – as in air or water. If the film is scratched or damaged, as long as oxygen is present it will heal itself. The protective film also makes titanium very resistant to erosion. In high velocity process streams and in rapidly flowing seawater, it can be at least twenty times more erosion resistant than copper-nickel alloys. Titanium's naturally occurring oxide film also gives the metal its unique, softly shimmering beauty. When the thickness of the film is increased (through anodic oxidation) it changes the appearance of the metal over a spectrum of colors [1].

The chemical reactivity of titanium is dependent upon temperature. The metal's action with other substances proceeds more readily at elevated temperatures. This property is specially exemplified by the metal's extreme reactivity to the gases of the atmosphere at high temperatures. This necessitates the use of inert atmospheres for hot working and surface protection for high temperature applications. The rapid combination of titanium with the reactive gases of the atmosphere above 510°C produces surface scale. With larger intervals of time and increase in temperature, the gases diffuse into the lattice. The metal combines with oxygen to form a long series of oxides from TiO to Ti_7O_{12}, each of which exhibits a different hue and at short time exposures, a rainbow-colored surface film is produced. Although this surface oxidation proceeds at 510°C, no appreciable diffusion into the lattice occurs below 704°C. Ignition of the metal occurs in air at 1204°C, and a pure oxygen atmosphere reduces this temperature to 610°C. Its burning is accompanied by a very bright incandescence, a state which is also produced in a nitrogen atmosphere at temperatures above 816°C.

The reactivity of titanium with nitrogen is similar to its action with oxygen where a yellow-brown scale is formed on the surface as the nitride [2]. Titanium nitride has attracted interest due to its characteristic high hardness and gold-yellow color, and is widely applied as a surface coating [3]. Nitrogen will diffuse into the lattice with a restricted depth of penetration. This property has been employed in the nitride casing of the metal. Most unique of the gas-titanium reactions is that between hydrogen and the metal. The reaction proceeds at temperatures slightly above room temperature, and as much as 400 cc of the gas can be absorbed by one gram of titanium. In small amounts the gas adds as an interstitial, but at higher concentrations the hydride TiH is formed. The addition of hydrogen to titanium is only stable, however, below 360°C; above this temperature the gas is evolved and burns. Early work employed this action to form a protective atmosphere around the metal during some hot processes. The burning hydrogen being evolved penetration by any other gas. However, since the gas is not recoverable, the cost is prohibitive [2]. It has long been known that oxygen, like nitrogen and carbon, can significantly harden titanium alloys, however, little work on the oxidation of titanium alloys has been undertaken from a surface engineering viewpoint [4].

2. EXPERIMENTAL

The Ti-6Al-4V alloy was in the form of ingot with length of 1m and 1,27cm of diameter, acquired from Multialloy Eng. Mat. Ltda, forged and annealed at 190ºC during 6 hours and air cooled. The Ti-6Al-4V alloy was cutted in form of disk with length of 0,5cm and 1,27cm of diameter. The characterization of the chemical composition of main elements (wt%), was adequate of the ASTM regulation (B265-89) [5], using the Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) in an ARL equipment 3410 model [6].

The samples were analyzed by High Resolution X-Ray Diffraction (difratometer X'Pert – MRD Philips with a PW 3050 goniometer), Scanning Electronic Microscopy (microscopy LEO 435 VPI model), Scanning Force Microscopy (microscope Shimadzu SPM-9500J3), Surface Profiler (Tencor) and microhardness test (Digital Microhardness Tester Future Tech FM model). The

samples of Ti-6Al-4V were polished and treated during 24 hours at 600°C and observed the oxidation behavior in each case using argon, nitrogen and air atmospheres.

Using the Ti-6Al-4V alloy produced specimens to creep test. The specimens were tested by creep at 600ºC in argon, nitrogen and air atmospheres using 250 MPa.

3. RESULTS

The results obtained by ICP-OES were of 89,16 wt% of Ti, 6,61 wt% of Al and 4,23 wt% of V. The High Resolution X-Ray Diffraction results show that only for the sample treated in air atmosphere presented the forming TiO_2 film in the surface (Figure 1The oxidation was more aggressive in air atmosphere, forming TiO_2 film in the surface, observed by High Resolution X-Ray Diffraction and the sample color was dark gray. In argon and nitrogen atmospheres the oxidation suffered by material was not detected by High Resolution X-Ray Diffraction, just color change was observed (blue in argon and yellow in nitrogen).

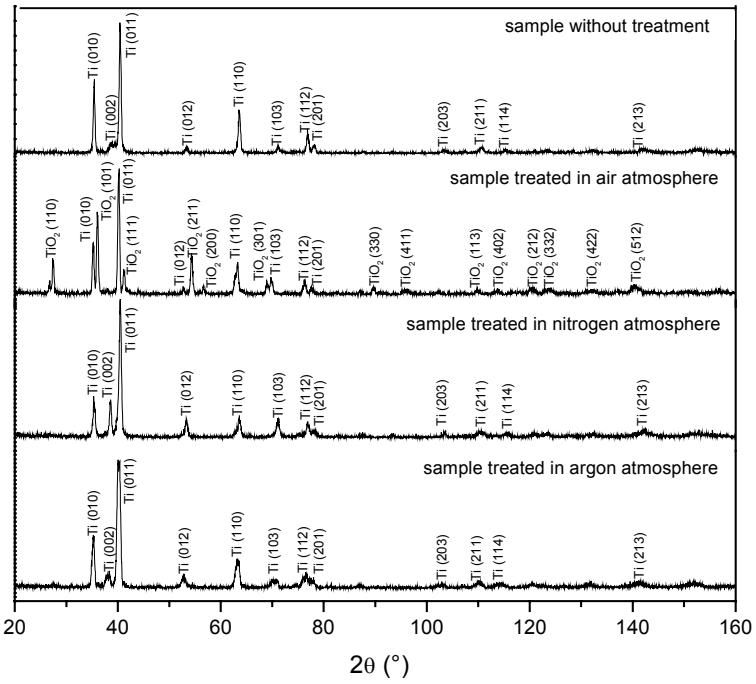

Figure 1. High Resolution X-Ray Diffraction of the Ti-6Al-V samples treated in different conditions of atmosphere

The Figure 2 shows microstructures obtained by SEM of one sample without treatment and one treated at 600°C in air atmosphere. In samples tested in argon and nitrogen atmospheres the microstructure were very similar to the sample no treated.

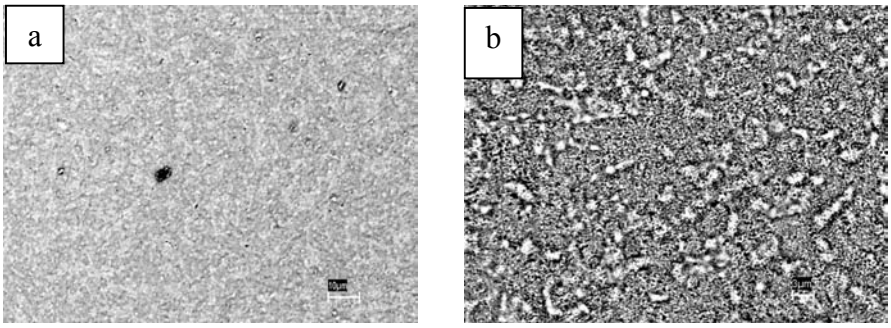

Figure 2. Microstructures obtained by SEM of one sample without treatment (a), and one treated at 600°C in air atmosphere (b)

The oxidation layer was approximately 0,81μm and its surface roughness was approximately 50 nm in the case of highest oxidation when formed TiO_2 film (Figure 3).

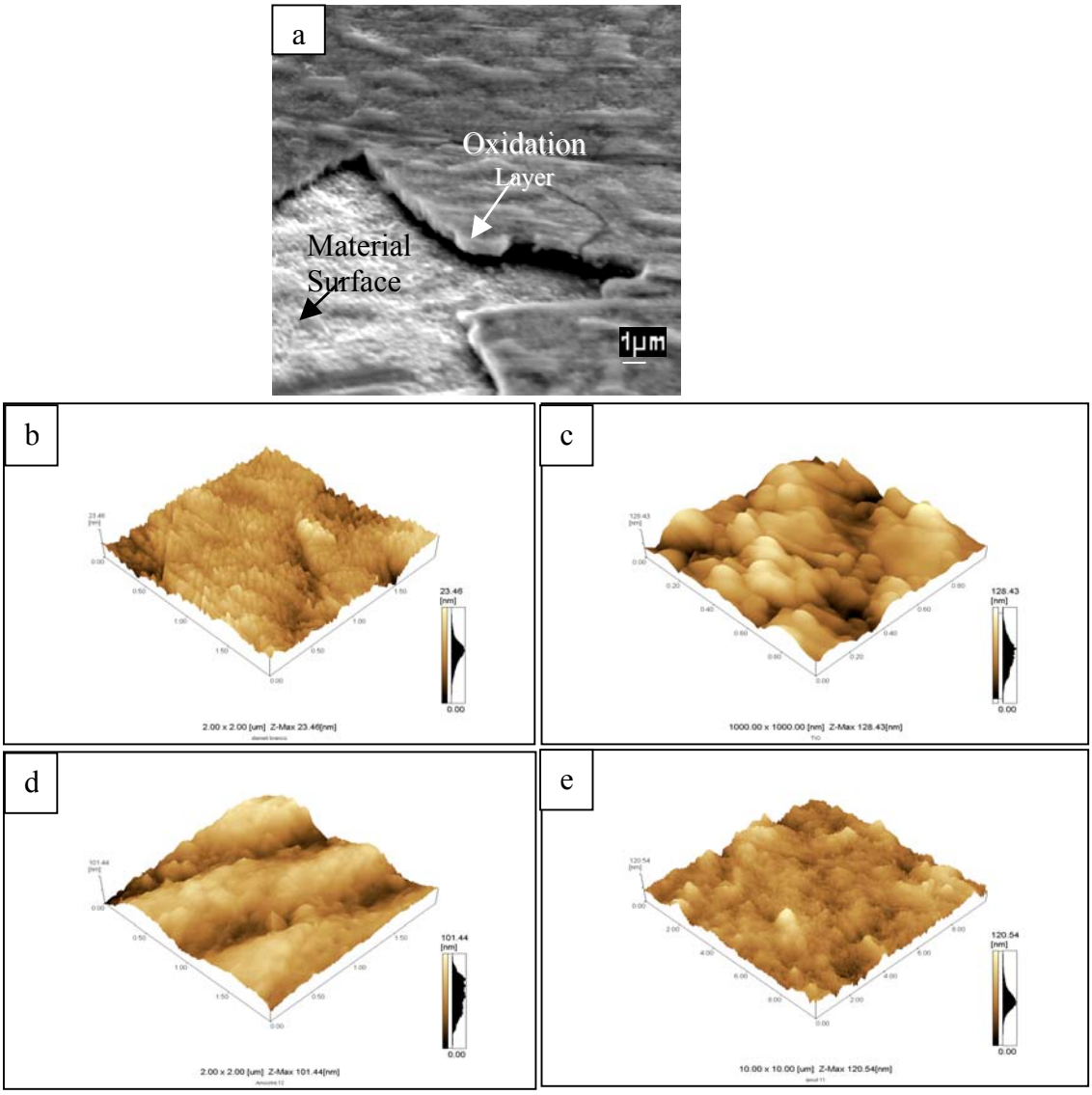

Figure 3. Microstructure of oxidation layer by SEM from the sample treated in air atmosphere (a), surface roughness obtained by AFM from the sample without treatment (b), sample treated in air atmosphere (c), sample treated in nitrogen atmosphere (d) and sample treated in argon atmosphere (e).

The surface roughness was approximately 2 nm in the sample without treatment, 17 nm in the sample treated in nitrogen atmosphere and 13 nm in the sample treated in argon atmosphere.

The samples microhardness was 781 HV to air atmosphere; 495 HV to nitrogen atmosphere and 393 HV to the sample treated in argon atmosphere, showing that the oxidation brought to the microhardness increasing (Table 1).

Table 1. Microhardness measures of the Ti-6Al-V samples treated in different conditions of atmosphere

Sample	*Microhardness (HV)*
without treatment	336
air atmosphere	781
nitrogen atmosphere	495
argon atmosphere	393

The Figure 4 shows the creep curves obtained at 600ºC in argon, nitrogen and air atmospheres using 250 MPa.

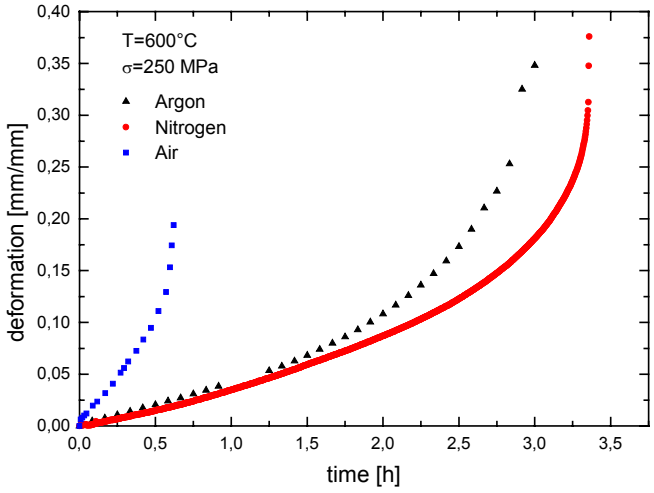

Figure 4. Creep curves at 600°C and 250MPa obtained in argon, nitrogen and air atmospheres.

When the Ti-6Al-4V was treated in argon and nitrogen atmospheres the effect the oxidation is smaller and the behavior of the creep curves shows that the useful life is better in atmospheres not so oxidant, there is an increasing of ductility of material (final deformation) and useful life. Occurs a decreasing of steady state creep in function of the reduction of oxidation process, showing that for the Ti-6Al-4V alloy their useful life is strongly affected by the atmosphere that is submitted because the oxidation suffered by the material.

4. CONCLUSIONS

The oxidation layer was approximately 0,81μm and its surface roughness was approximately 50 nm in the case of highest oxidation when formed TiO_2 film. The surface roughness was approximately 2 nm in the sample without treatment, 17 nm in the sample treated in nitrogen atmosphere and 13 nm in the sample treated in argon atmosphere.

The samples microhardness was 781 HV to air atmosphere; 495 HV to nitrogen atmosphere and 393 HV to the sample treated in argon atmosphere, showing that the oxidation brought to the microhardness increasing.

When the Ti-6Al-4V was treated in argon and nitrogen atmospheres the effect the oxidation is smaller and the behavior of the creep curves shows that the useful life is better in atmospheres not so oxidant, there is an increasing of ductility of material (final deformation) and useful life.

5. ACKNOWLEDGMENT

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