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TRIBOLOGICAL STUDIES OF EDM MODIFIED TITANIUM SURFACES

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Abstract. Titanium alloys are the most used metallic materials for biomedical applications for hard tissue replacement due to their excellent mechanical properties, biocompatibility, and good corrosion properties. However, they present poor wear and corrosive wear resistance properties, leading to undesired biological responses by the wear debris and ionic dissolution of the metal. The Electrical Discharge Machining (EDM) is a non-conventional manufacturing technique, which promotes material removal by electric discharges. During the EDM process, the sample surface is submitted to metallurgical modifications by the cast and recast of a thin layer over the machined surface. The aim of this work is to evaluate the influence of the EDM process parameters on the mechanical properties of the Ti6Al4V alloy. Ti6Al4V samples were machined in a sinking EDM machine, using finishing machining parameters. Graphite round bars (25.4 mm diameter and grain size of 10 μm) were used as an electrode and hydrocarbon fluid, deionized water containing glycerin and hydrocarbon fluid containing silicon powder as the dielectric solution. Surface properties were evaluated by scanning electron microscopy (SEM/EDS) and glancing angle X-ray diffraction (GAXRD). Results show that the formation of a recast layer composed of titanium carbide (TiC) increases the hardness and the wear resistance of titanium alloys.

Keywords: Titanium, Surface Modification, EDM, Mechanical Properties, Wear.

1. INTRODUCTION

Titanium metal and its alloys are widely used in orthopedic and dental implants due to its excellent mechanical properties and biocompatibility (Dong and Bell, 2000), but they have low resistance to the simultaneous action of the wear and the corrosion which is called tribocorrosion that is a phenomenon of material degradation (Mathew *et al.*, 2009)

The electrical discharge machining (EDM) is the non-conventional technique which promotes material removal by electric discharges and can be used as a surface modification process. The process promotes the removal of the material by small electric discharges between the part to be machined and a tool usually called an electrode. The electrode piece assembly is immersed in a dielectric (hydrocarbon) fluid, where the electrode is energized and when approaching the material occurs the formation of electric arcs that cause the melting, evaporation and, consequently, removal of the material. However, part of this melted material resolidifies incorporating elements from the dielectric fluid. During the EDM process in titanium alloys using dielectric fluid rich in carbon, a thin layer containing titanium carbide (TiC) is formed (Chang-bin *et al.*, 2011). In the work published by Amorim (2013), electroerosion tests on titanium alloy Ti6Al4V were carried out, where the formation of resolidified layers with thicknesses ranging from 5 to 25 μm containing titanium carbides and having a hardness of up to 100 HV higher than the base alloy.

The addition of powder particles to the dielectric fluid facilitates and improves the efficiency of the machining process together with the parameters suitable for the process, the materials most used for machining with EDM are Ni, Fe, Co, Al, Cr, Cu, Ti, Si, SiC, Mo and graphite. (Singh, 2011)

Molonetti (2015) observed that the addition of Si and Mn powder in the AISI H13 steel electrodes, the resolidified layer presented a lower roughness than a high hardness, the X-ray diffractograms in the samples machined with silicon indicate the presence of two phases containing Silicon (Silicon Carbide (SiC) and Ferro Silicon (FeSi)).

Modifications in the composition of the dielectric fluid and in the EDM process parameters may alter the composition and properties of the solidified layer, thus altering the mechanical properties of the Ti6Al4V alloy. The aim of this work is evaluate the surface properties of Ti6Al4V alloy modified by EDM using Silicon powder mixed hydrocarbon based dielectric fluid and glycerin water based dielectric fluid.

2. EXPERIMENTAL PROCEDURE

Ti6Al4V samples were mechanically polished using SiC paper and ultrasonic cleaned in acetone and water. EDM tests were performed using a Roboform 30 penetration EDM machine (Charmilles), using the machining parameters for finishing machining and are described in Table 1 (Amorim, 2013). Graphite round bars with 25.4 mm of diameter and grain size of 10 μm were used as an electrode. Three different dielectric fluid were tested: (1) Conventional commercial dielectric fluid for EDM "Eletron" (hydrogenated hydrocarbon); (2) an aqueous solution of Glycerin ($\text{C}_3\text{H}_8\text{O}_3$) 20 % vol.; and (3) Conventional dielectric fluid with addition of silicon powder (Si) (concentration of 5 g/L)

Table 1. Conditions of the samples machined.

Dielectric Fluid	Regime	Current (A)	Discharge Duration (μs)	Voltage (V)	Electrode Polarity
Conventional Dielectric fluid	Finish	3	12.8	160	Negative
Conventional Dielectric fluid + Si	Finish	3	12.8	160	Positive
Conventional Dielectric fluid + Si	Finish	3	12.8	160	Negative
Conventional Dielectric fluid + Si	Finish	3	25.0	160	Negative
D.I.Water + 20 % Glycerin	Finish	3	12.8	160	Positive

After the machining process, samples were ultrasonic cleaned, and characterized using a Scanning Electron Microscope (SEM). EDS analysis was used to verify if the chemical elements from the dielectric fluid were effectively incorporated in the modified layer. XRD tests (Shimadzu, DRX-7000) were performed using a $\text{CuK}\alpha$ radiation, voltage of 40 V and current of 30 mA, range of 30° to 80°. Wear tests were made using the linear displacement tribometer (CSM Instruments). Tests were carried out with a load of 5 N, for a distance of 10 m, with a slip speed of 1 cm/s, using an alumina sphere as counter body.

3. RESULTS AND DISCUSSION

Surfaces machined with conventional fluid are more uniform when compared to the surface machined with glycerin (Fig. 1), but they present several cracks due to the time that the electric discharge was acting on the sample during the EDM process, and to the conventional dielectric fluid used in those samples. Presence of cracks can lead to a layer with low resistance to wear.

Regarding the chemical composition (Table 2) all the machined samples showed the incorporation of the carbon in the surface. Only for the sample machined with glycerin it was identified a significant amount of oxygen. The oxygen found in the chemical analysis is associated with the Titanium Oxide (TiO) phase, formed during the EDM process through the dissociation of the water molecules where there is the release of Hydrogen and incorporation of the Oxygen by the Titanium.

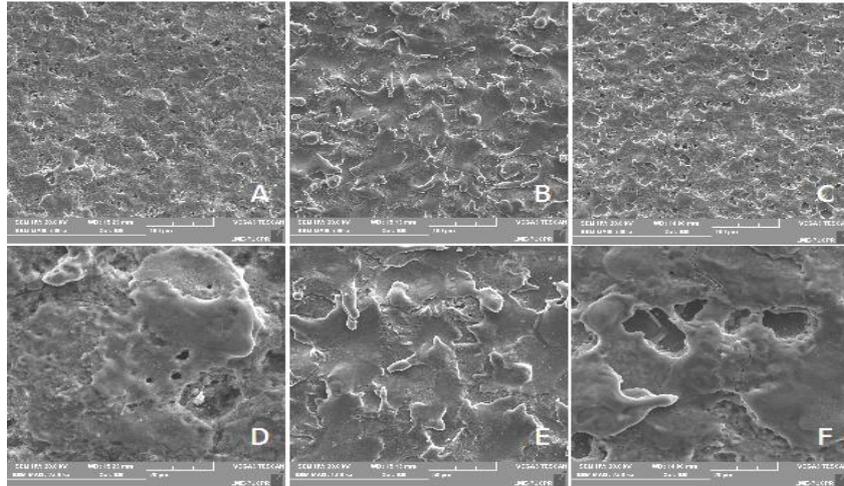


Figure 1. Comparative image among samples machined with glycerin and conventional fluid and conventional fluid containing silicon powder. Images A, D were machined with conventional fluid, glycerin B, E diluted in deionized water and the images, C and F formed plants with conventional fluid containing silicon powder.

For samples machined with conventional fluid containing addition of silicon powder, the presence of the element on the obtained surface is almost imperceptible.

Table 2. Results of the chemical analysis of the machined samples.

Element	Weight. %	σ
Conventional Dielectric fluid		
Ti	75,1	0,3
C	18,9	0,3
V	3,3	0,1
Al	2,7	0,1
Conventional Dielectric Fluid + Si – Negative Polarity		
Ti	69,2	0,3
C	24,6	0,3
V	3,2	0,1
Al	3,0	0,1
Si	0,1	0,0
Conventional Dielectric Fluid + Si - Positive Polarity		
Ti	56,6	0,5
C	38,3	0,5
V	2,4	0,2
Al	2,5	0,1
Si	0,2	0,0
Conventional Dielectric Fluid + Si – Negative Polarity - Discharge Duration 25 μs		
Ti	48,6	0,3
C	46,5	0,4
V	2,0	0,1
Al	2,7	0,1
Si	0,1	0,0
D.I.Water + 20% Glycerin		
Ti	56,6	0,3
C	3,9	0,2
V	2,4	0,1
Al	3,5	0,1
O	33,8	0,6

Figure 2 shows the crystalline phases from the machined surfaces. Formation of titanium carbide is confirmed by the presence of TiC phase only for samples machined with conventional fluid (with or without addition of Si powder),

which leads to an increase in the surface hardness. Samples machined with glycerin presented peaks of TiO. No crystalline phase containing Si was observed from XRD diffractograms.

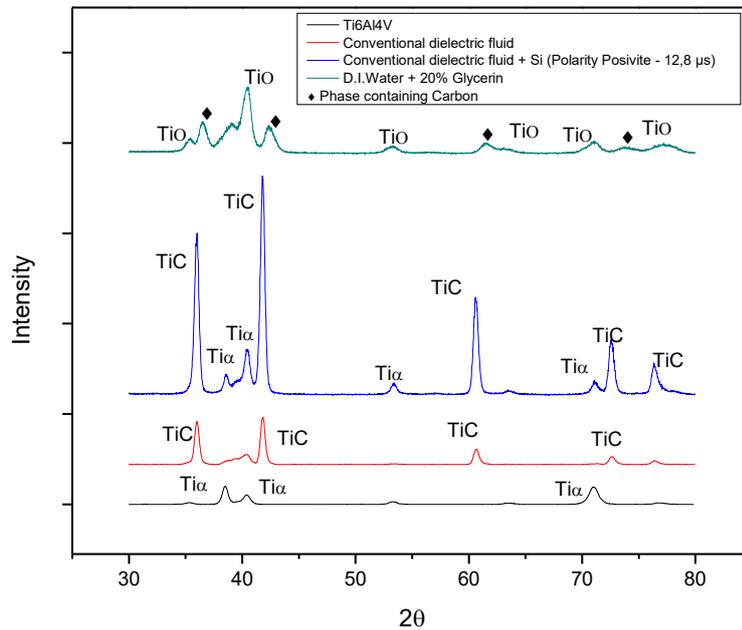


Figure 2. X-ray diffractograms of the machined samples.

Figure 3 shows the wear tracks obtained after the sliding tests. It is possible to observe that the wear is larger on the untreated surface (Fig. 3a) than for the machined surface (Fig. 3b). There is an increase of wear resistance for samples machined using conventional dielectric, which is associated to the formation of TiC phases. This improved wear resistance could be associated with an increase in the hardness of the modified samples.

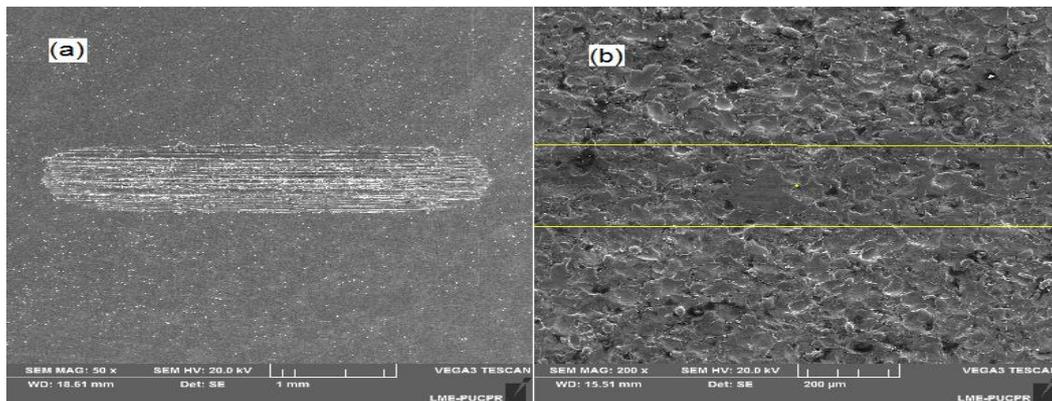


Figure 3. Wear test (a) sample without treatment, (b) sample with treatment.

The non-incorporation of silicon into the material may be due to the choice of the parameters used to perform the machining, as well as the chemical composition of the material.

4. CONCLUSION

The EDM process with different dielectric fluids produces a modified layer on Ti alloys, composed of TiC with higher hardness and higher wear resistance.

5. ACKNOWLEDGEMENTS

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