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# TRIBOCORROSION PROPERTIES OF TITANIUM ALLOY MODIFIED BY ELECTRICAL DISCHARGE MACHINING

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**Abstract.** *Titanium and its alloys are widely used in the biomedical field, especially in orthopedic implants due to its biocompatibility, good mechanical properties and corrosion resistance. However they do not exhibit good performance when submitted to tribocorrosion conditions (simultaneous action of wear and corrosion). Electrical Discharge Machining (EDM) is a non-conventional machining process where a desired shape is obtained by using electrical discharges (sparks) that promotes the material removal. Depending on the machining parameters and electrolyte, EDM can also be used to improve surface properties. The aim of this work was to investigate the tribocorrosion behavior in titanium alloy surfaces (Ti6Al4V), modified in different conditions. The samples were machined using different dielectric fluids rich in carbon with different times of electrical discharges. The new surfaces were characterized in relation to roughness, morphology, chemical composition, and tribocorrosion to assess wear rate, coefficient of friction and corrosion potential. The best results were obtained for samples milled using conventional EDM fluid as dielectric fluid, because it formed a surface rich in carbon containing TiC, increasing its resistance to wear. Samples machined with diluted glycerin in water as a dielectric fluid showed no major improvement over the titanium alloy (Ti6Al4V) without surface modification.*

**Keywords:** *Titanium alloy. EDM. Tribocorrosion.*

## 1. INTRODUCTION

Titanium and its alloys are materials that are widely used in the biomedical field, especially as orthopedic and dental implants, due to its biocompatibility, excellent mechanical properties and resistance to corrosion. However, when implanted under certain specific conditions, this material can suffer the simultaneous action of corrosion and wear processes, especially in implants where there is a relative movement between the titanium alloy and other surfaces (Geetha, *et al.*, 2009). The action of these two simultaneous factors is called tribocorrosion (Mischler, 2008). Despite its extensive use as an implant material, titanium and its alloys do not show good resistance in these adverse conditions. Several methods of surface modification are then used to improve tribological properties. Among them, the EDM process is a non-conventional machining technique that improves wear resistance through the modification of the titanium surface, changing also microstructural properties, crystalline structure and chemical composition (Harcuba, *et al.*, 2012). The general objective of this work was to investigate the tribological and tribocorrosion behavior of titanium alloy surfaces (Ti6Al4V) modified by EDM under different conditions.

## 2. EXPERIMENTAL PROCEDURE

Ti6Al4V alloy samples were initially prepared by polishing using SiC sandpaper, following by ultrasonically cleaning with acetone, alcohol and deionized water. In order to compare the values before and after the EDM process, samples were characterized in relation to the average roughness (Ra) using the Taylor Hobson rugosimeter. Averages of five measurements were performed on each sample with 3 mm measuring length and 0.8 mm cutoff. The penetration electro-erosion machine used was Robofotm 30 (Charmilles). The machining parameters (Table 1) were chosen based

on previous studies in our group (Amorim *et al.*, 2009). A sample was used for each selected machining parameter and a sample of Ti6AlV without surface modification for comparison. For the characterization of the machined samples, the measurements of the average roughness (Ra) were carried out again, followed by the analysis of the morphology using SEM (Scanning Electron Microscopy) and composition by EDS (Energy Dispersive Spectroscopy). To verify the formation of titanium carbide TiC on the surface of the machined samples, an XRD (X-Ray Diffraction) analysis was performed using a drive axis 2theta, scan range of 30-80 degrees and with 1 deg/min of scan speed. Wear and corrosion resistance analysis of the obtained surfaces was done using the tribocorrosion method. Before starting the tribocorrosion assays, the OCP (open circuit potential) monitoring was carried out for 2 hours, the reference electrode used was Calomel. Following, it was waited 1 hour for stabilization before starting the tests. The electrolyte used in the tests was the phosphate buffer solution (PBS) and the normal loading used was 10N with a counterpart of alumina ball. The movement had an amplitude of 1 mm per cycle and the total distance described was 10 m. Two tests per sample were performed. Finally, the samples were analyzed again in the SEM for comparison and discussion in order to find the best EDM parameter for the tests.

Table 1. EDM parameters.

Dielectric Fluid	Machining Regime	Current (A)	Duration of electrical discharge ( $\mu$ s)	Voltage (V)	Electrode polarity
Conventional Fluid (Hydrocarbon)	Finishing	3	3.2	160	Negative
			12.8		
D.I. Water +5% Glycerin	Finishing	3	3.2	160	Positive
			12.8		

### 3. RESULTS AND DISCUSSION

As a result, SEM images were obtained before and after tribocorrosion tests. From the images before tribocorrosion test was observed that the samples machined using conventional fluid as dielectric fluid obtained a more homogeneous and less rough surface, different from the samples machined with 5% glycerol diluted in water, which can be observed a heterogeneous surface.

From EDS, it was observed a difference in chemical composition between the machined surfaces. A higher percentage of carbon in the machined samples using the conventional fluid as dielectric fluid was observed, when compared to ones machined using glycerin diluted in water. Increase in the amount of carbon on the surface of the alloy leads to the increase in hardness due to formation of titanium carbide TiC, improving the wear resistance (Stráský et al; 2011). Figure 1 shows the XRD analysis which proof the formation of TiC in the machined samples and can be observed the formation of titanium oxide in the samples machined with glycerin diluted in water. It was observed that roughness of the surface increases after the machining and the larger the roughness, the greater the coefficient of friction (Hascalik et al; 2007). Samples machined with water-diluted glycerin as dielectric fluid had the highest roughness values.

Observing the images after tribocorrosion test it is concluded that the wear tracks obtained on the surfaces machined with the conventional fluid, do not reach the substrate, only present a superficial wear of the modified layer (Figure 2). However, the surfaces machined with glycerin dissolved in water showed significant wear, as evidenced by the total exposure of the substrate (Figure 3).

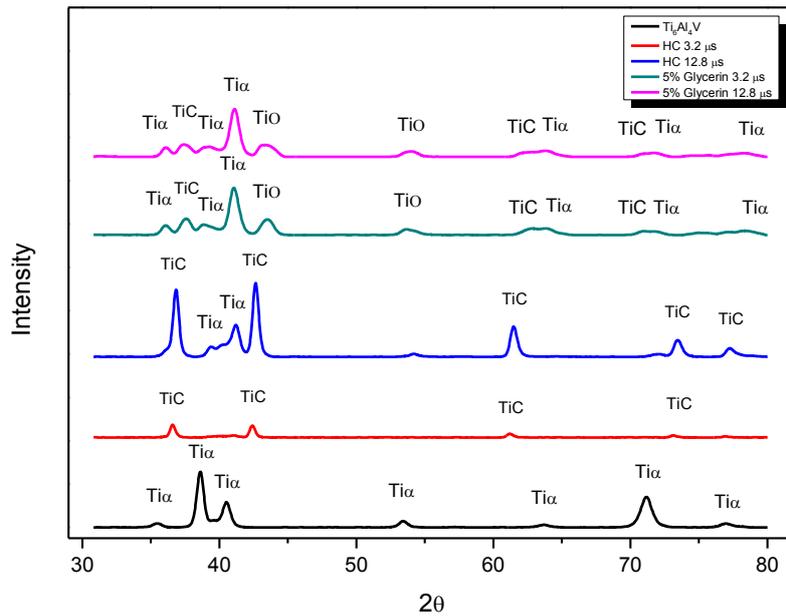


Figure 1. XRD analysis of the machined samples compared to the unmodified alloy, showing the formation of TiC on the surfaces.

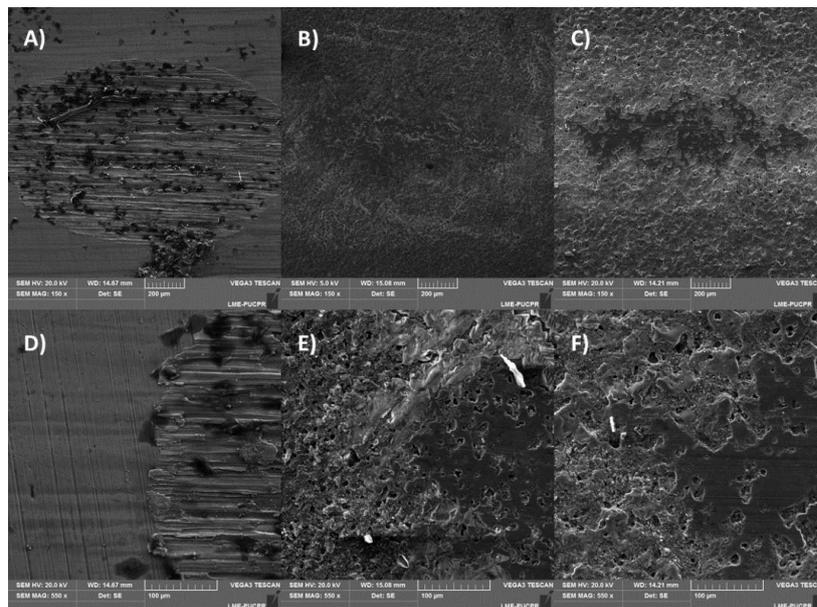


Figure 2. Comparison of the tribocorrosion traces of the samples machined with conventional fluid. Images A) and D) present the Ti<sub>6</sub>Al<sub>4</sub>V alloy track. The images B) and E) present the sample track with discharge time of 3.2 μs and the images C) and F) present the sample track with discharge time of 12 μs.

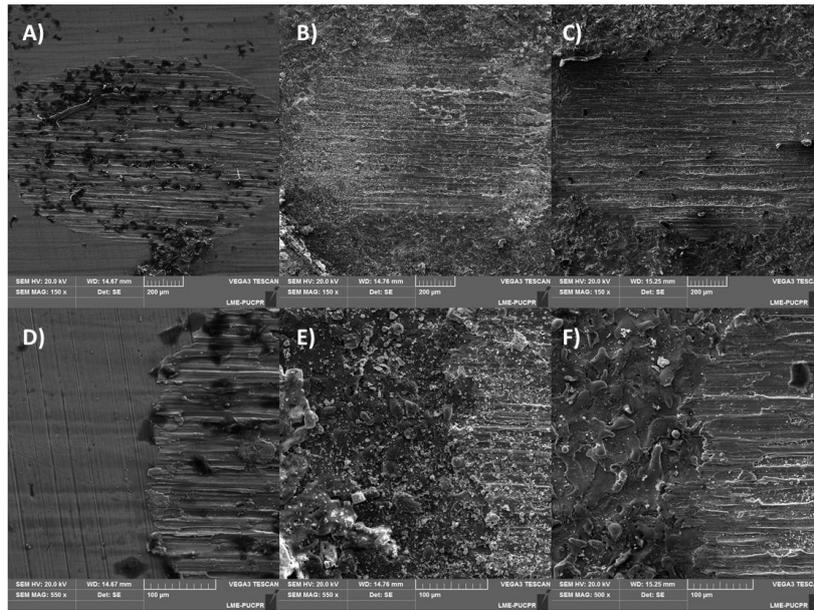


Figure 3. Comparison of the tribocorrosion trails of the machined samples with 5% glycerol diluted in water. Images A) and D) present the Ti6Al4V alloy track. The images B) and E) present the sample track with discharge time of 3.2  $\mu$ s and the images C) and F) present the sample track with discharge time of 12  $\mu$ s.

Tribocorrosion results were divided into two parts: the comparison of the coefficient of friction during the test and the corrosion potential curves for each sample. Figure 4 shows that the samples machined with water-diluted glycerin had a behavior like the unmodified alloy, presenting a high coefficient of friction, mainly with slip distances above 3 meters. Samples machined with the conventional fluid presented a decrease in the coefficient of friction during the whole test, indicating that the higher resistance of the modified layer influenced positively the coefficient of friction.

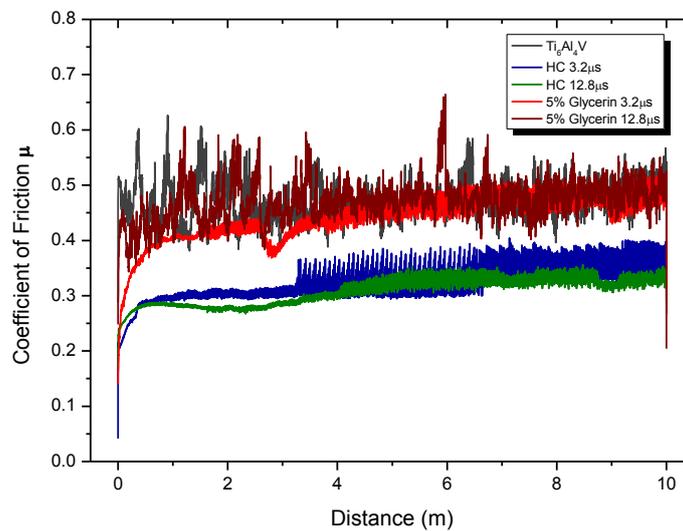


Figure 4. Comparative graph between the coefficients of friction of the different machining configurations.

Figure 5 presents the comparison of the monitoring of the  $E_{corrV}$  corrosion potential by the test time of the different machining conditions.

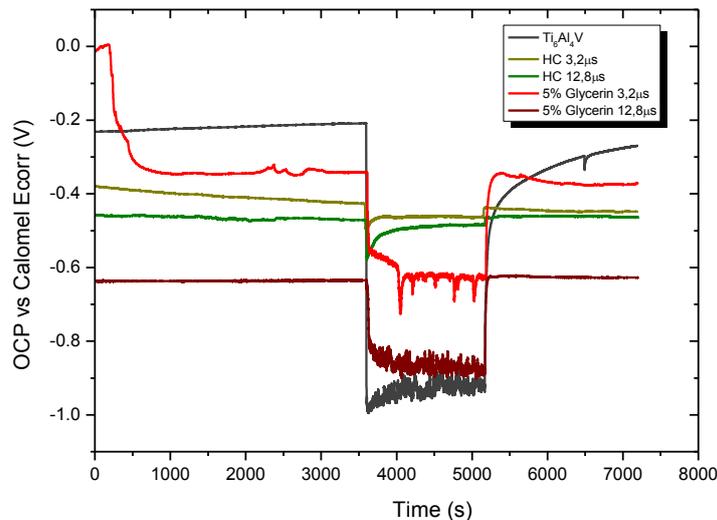


Figure 5. Comparison of corrosion potential curves ( $E_{corr}$ ) of the samples machined with conventional fluid and 5% glycerol diluted in water with the Ti6Al4V alloy

The lower the  $E_{corr}$  fall when the tribo test started and the more positive, the lower the corrosion tendency of the sample (Mischler, 2008). As can be seen from the results found, samples machined with the conventional fluid obtained a significant improvement in corrosion and showed a better recovery when finished the test than the unmodified alloy. Already as samples machined with a glycerin diluted in water there is a behavior similar to that of the untreated Ti6Al4V alloy.

#### 4. CONCLUSIONS

Titanium alloys machined using conventional fluid as dielectric fluid were the ones that presented the best tribocorrosion resistance. Its modified surface, according to the microstructural analysis showed a large percentage of carbon in its composition, which caused the hardness of its surface to increase and, consequently, reduce the rate of wear and corrosion, due to formation of TiC occurs. The best condition in relation to the duration of electric discharge was the 3.2 $\mu$ s, which presented the lowest roughness, corrosion potential, friction coefficient and wear rate.

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#### 6. RESPONSIBILITY NOTICE

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