TRIBOLOGICAL BEHAVIOUR OF SMAT (SURFACE MECHANICAL ATTRITION SURFACE) TREATED TITANIUM

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Abstract. *The main goal of this work was to analyze the tribological behavior of a titanium alloy (Ti6Al4V) that has been submitted to SMAT (Surface Mechanical Attrition Surface) and the influence of nanostructure in the particle morphology. The SMAT treatment was used and the titanium alloys samples were tested in a reciprocating linear tribometer with a varying quantity of cycles. The resulting coefficient of friction and wear area curves were analyzed. The debris was analyzed through a Scanning Electronic Microscopy. The authors expect to increase the available knowledge of the nanostructure that's achieved by doing a SMAT treatment to improve the tribological behavior of the specified titanium alloy.*

Keywords*: SMAT, Titanium alloy, nanostructure, tribological behaviour*

1. INTRODUCTION

1.1. Motivation:

Titanium is a widely used element when a material with a high corrosion resistance, low Young module values, low density and high flexibility is required. The commercially pure titanium and some of its alloys also show a relevant characteristic: high biocompatibility. This characteristic make titanium to be used in many high performance applications, for example, in chemical appliances, aeronautical and in orthopedic prostheses. Thousands of hip and dental prostheses are implanted every year. (Goodman, 2007)

The titanium alloy (Ti6Al4V) shows the best combination of wear and corrosion resistance when compared to the pure titanium. (Brunette *et al*. 2000)

Allergic reactions to metals used in orthopedic implants represent a rare phenomenon. Biocompability studies show that hypersensitivity and excessive immune reaction to the metallic biomaterials used in implants probably occur in less than 1% of all the knee total prosthesis. (Goodman, 2007)

Many researches are being conducted in the advanced biomaterials utilization in artificial prostheses, in special in the hip joint. The main objective in to minimize the biomechanical complications, specially the excessive wear and the corrosion process of the implanted materials. (Huang and Lu, 1996) and (Troyon, 2006)

In this work, the nanostructural layers of titanium alloys will be studied. The samples will be submitted to a surface mechanical attrition treatment (SMAT). Some studies mention that the nanostructural layers have important characteristics and have higher performance. For example, a higher hardness, resistance and plasticity. (Huang and Lu, 2006 and Troyon, 2006 and Zhu *et al.*, 2004).

1.2. SMAT Treatment:

The surface optimization and the material composition are important when they are submitted to a sliding contact, since many failure occur due to mechanisms that involve tribological or thermochemical reactions (for example, corrosion and wear).

The SMAT treatment is used as a surface treatment, being an effective method to produce plastic deformation in nanometrical scale by refining of the superficial grains without affecting the chemical composition. (Zhu *et al*, 2004).

The SMAT treatment is relatively new. The surface plastic deformation is obtained through a mechanical process that, basically, consists in a vacuum cylindrical chamber which holds the sample and steel balls with a diameter of 1 to 10mm, with minimum surface roughness. A high frequency generator promotes resonance in the steel balls, making them to be throw randomically against the sample. Some parameters can be controlled in this process: vibrational frequency, balls size, distance between the balls and the sample. (Zhang and Hansen, 2007).

Another use for the SMAT is an intermediate layer between the sample material and some other surface treatment. For example, the DLC deposition process generates high tensions and the surface adhesion of the sample can be low. An intermediate treatment as the SMAT can increase this adhesion, avoiding the coating delamination. (Reuter *et al*, 2006).

2. METHOD AND RESULTS:

The studied samples were made from titanium alloy with the requirements settle in the ASTM F136 standard – Standard Specification for Wrought Titanium-6 Aluminum-4 Vanadium ELI (Extra Low Interstitial) Alloy for Surgical Implants Applications. The alloy had its chemical composition analyzed to assure that it was as specified.

The chemical composition is showed in Table 1. The Figure 1 shows the metallography of the titanium alloy, with the absence of the alpha case, a pre-requirement to the approval in the ASTM F136 standard.

The mechanical characteristics of the alloy are shown in the table2.

Table 1. Titanium alloy chemical requirements

Element	Composition	Obtained Results
Carbon, max	0,08	0,011
Hidrogen, max	0,012	0,0029
Nitrogen, max	0,05	0,119
Oxygen, max	0,13	0,1173
Aluminum	5,5-6,5	6,19
Iron, max	0,25	0,23
Vanadium	3,5-4,5	4,06
Titanium	balance	balance

Table 2. Titanium alloy annealed mechanical properties

Properties	Specified	Obtained Results
Tensile Strength (M Pa)	860	1044
Yield Strength 0,2% (M Pa)	795	919
Elongation (50mm), %	10	13,5

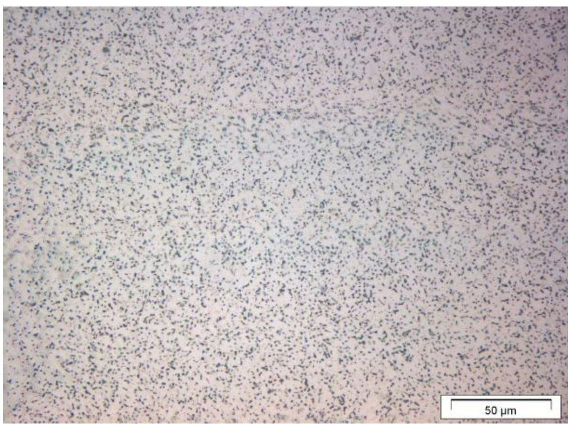


Figure 1. Titanium alloy metallography analysis

The SMAT treatment was done in the *Institute Charles Delaunay*, in the *Université de Technology de Troyes*, France. The treatment parameters were: time: 15 minutes, balls: 3mm diameter and balls material: steel.

The tribological tests were made with a reciprocating linear tribometer. The samples were submitted to 2000, 3000, 4000 and 5000 cycles. The tribometer ball was made from steel 316, a biocompatibility material. The sliding speed was 2.5 cm/s and the normal load was 5N.

The samples were characterized by Scanning Electronic Microscopy. Below we can observe the samples treated with SMAT (Figure 2a, c, e, and g) and titanium alloy samples without SMAT (Figure 2b, d, f, and h).

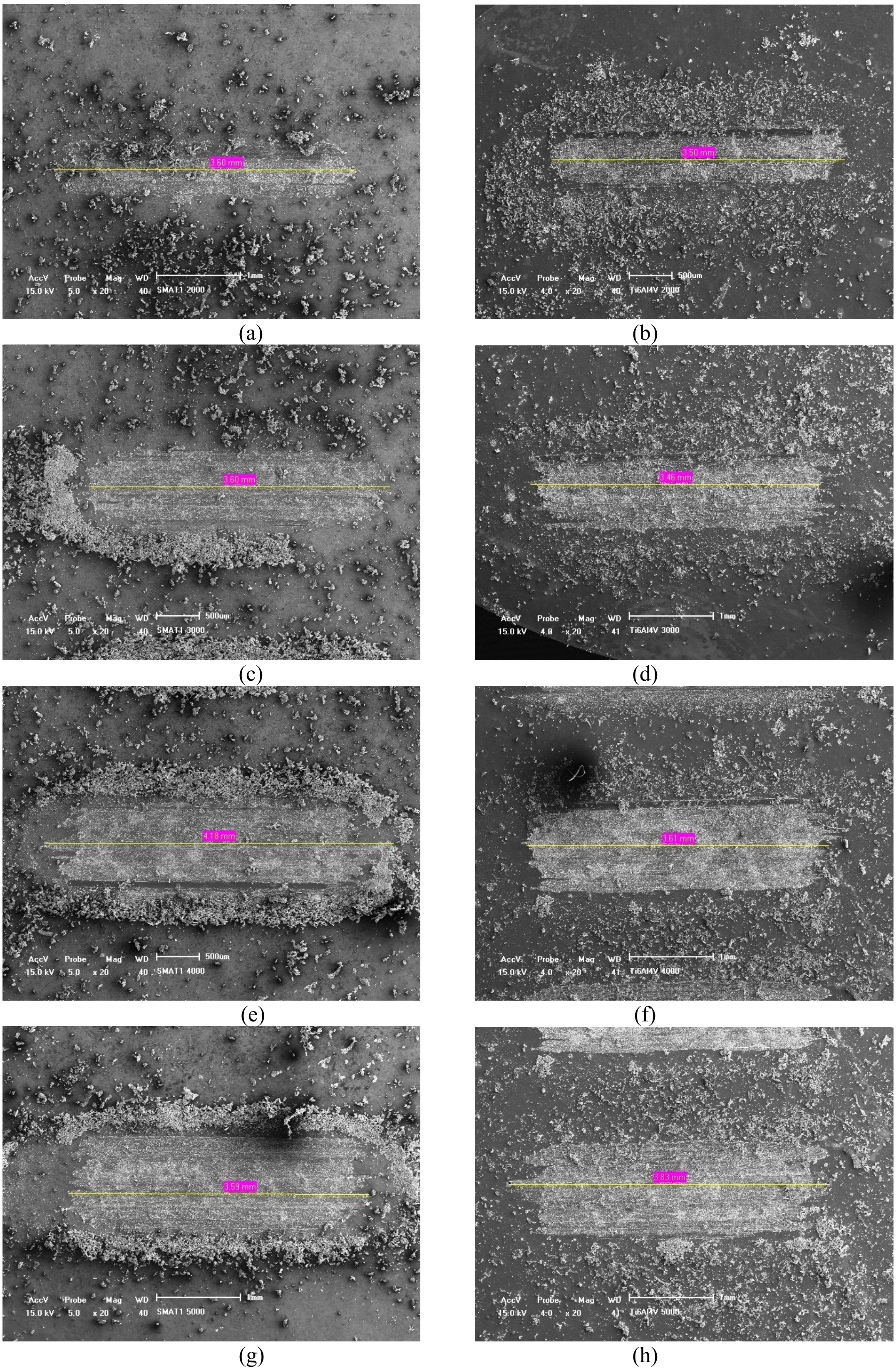
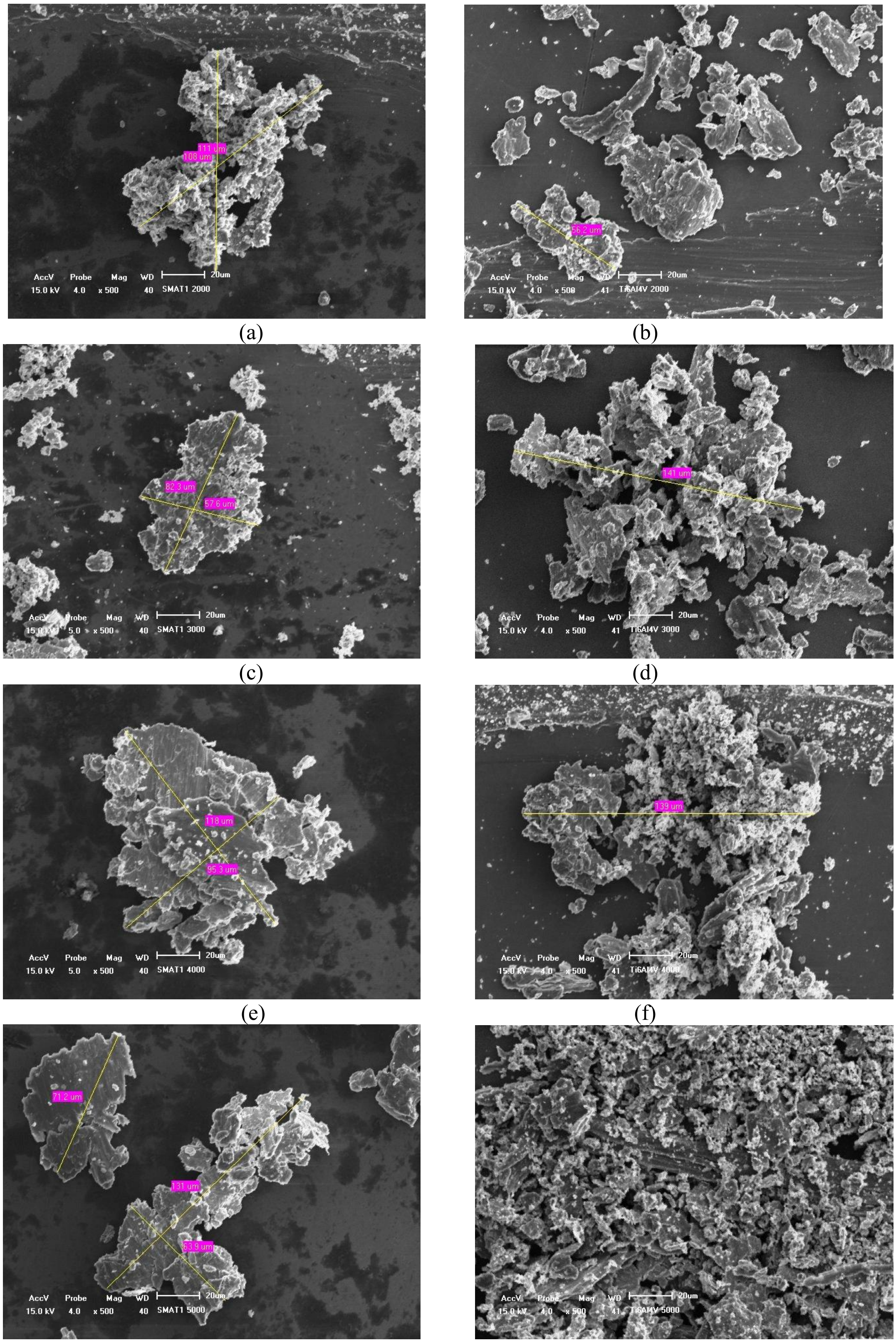


Figure 2. SMAT samples wear track before (a) 2000 cycles, (c) 3000cycles, (e) 4000cycles and (g) 5000cycles.
Titanium samples wear track before (b) 2000 cycles, (d) 3000cycles, (f) 4000cycles and (h) 5000cycles.



(a) (b) (c) (d) (e) (f) (g) (h)

Figure 3. SMAT fragments obtained in the wear track before (a) 2000 cycles, (c) 3000cycles, (e) 4000cycles and (g) 5000cycles. Titanium fragments obtained in the wear track before (b) 2000 cycles, (d) 3000cycles, (f) 4000cycles and (h) 5000cycles.

In the figure 3, we showed the fragments of the both conditions: titanium SMAT samples and the titanium without SMAT treatment samples. The fragments were characterized by Scanning Electronic Microscopy. The number of cycles used were 2000, 3000, 4000 and 5000 cycles.

In our work, the fragments were analyzed in the state that they were left exactly after the wear test, which means that the fragments were analyzed over the sample wear track. It's expected to find some fragments glued together.

We can observe in the figure 2 and 3, that the fragments from the SMAT-treated sample are glued together while in the Ti-alloy (Ti6Al4V) the fragments are sparse. The wear track was very similar among the samples, independently of the number of cycles. All they were very regular, without noticeable points of delamination.

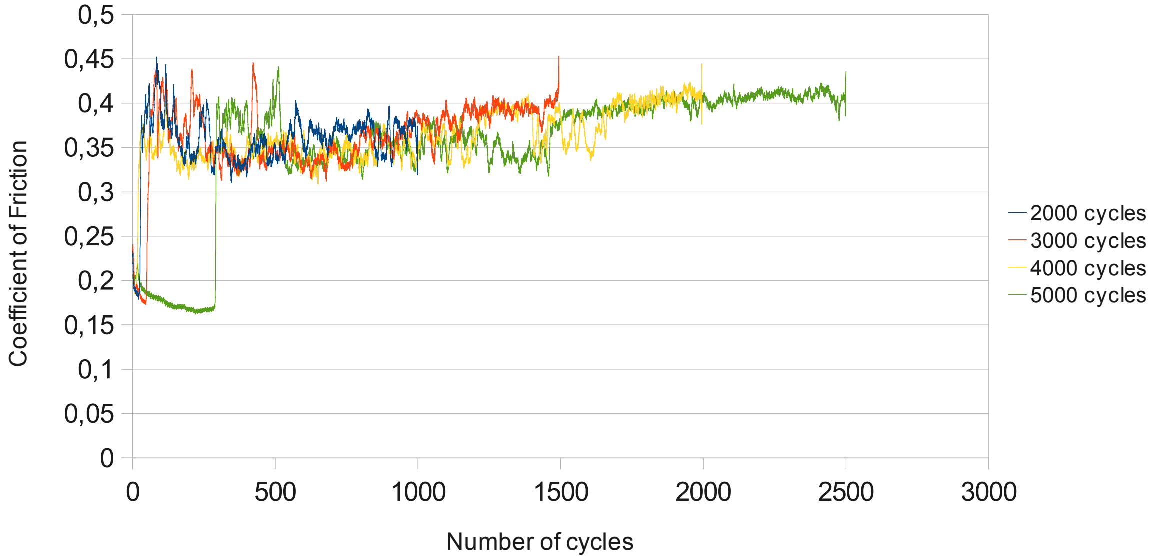


Figure 4. Titanium with SMAT wear curve results

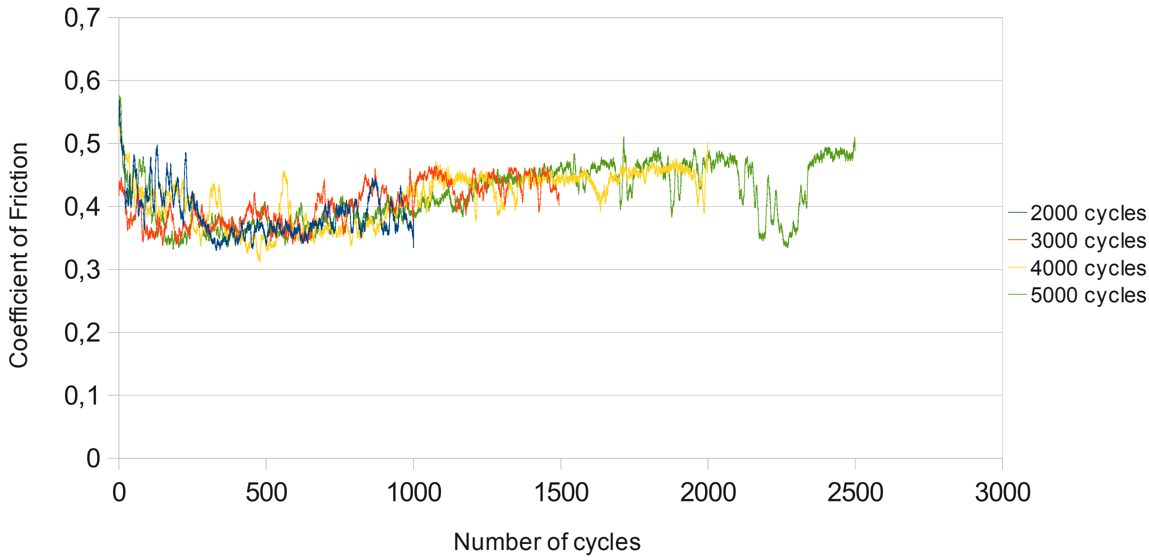


Figure 5. Titanium without SMAT wear curve results

The coefficient of friction in the samples treated with SMAT were slightly lower to the coefficient of friction from the samples that did not receive treatment. In the SMAT-treated samples, the coefficient value was between 0.32 – 0.44 and in the titanium samples it was between 0.32-0.49.

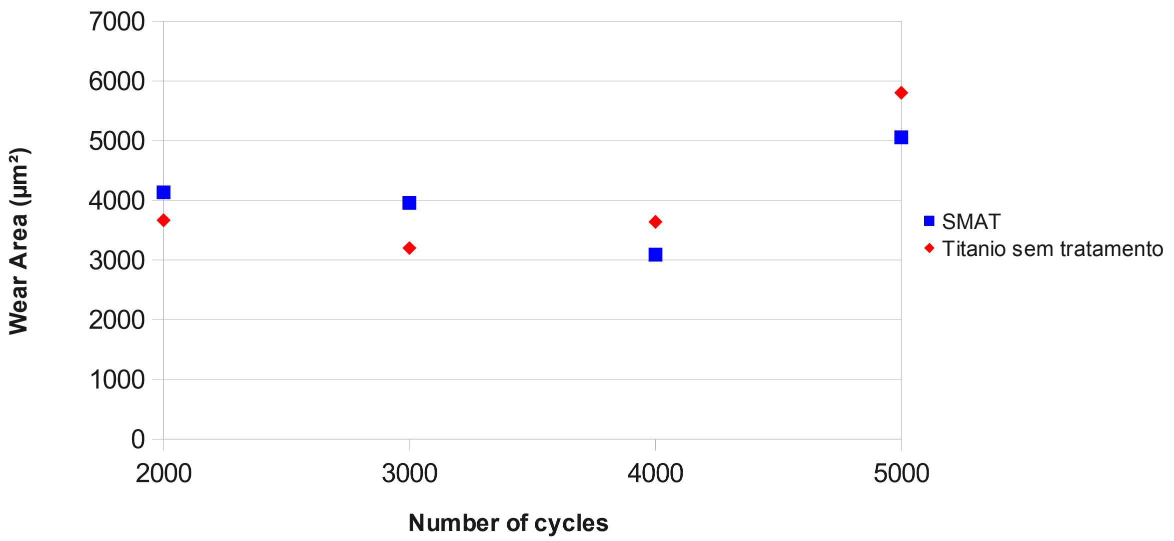


Figure 6. Wear area in the tow samples analyzed

We can observe in figure 6 that the SMAT treatment has considerably influence in the wear track. We can observe two minimum values in the two curves. It is reasonable to think that this occurrence is because the fragments were compacted, that after some number of cycles it were removed and for this moment they acted like a third body, and the new particles of debris were removed.

According to the wear area graphs, we can conclude that nanostructure of the SMAT treatment affects the tribological behavior of the Titanium. The fragments morphology shows the influence of the SMAT treatment since we have a smaller agglomeration of the particles. The fact that we have a smaller wear area for the samples not treated with SMAT with the smaller number of cycles can be explained by this agglomeration.

As expected, the SMAT treatment also produced a smaller coefficient of friction, increasing the tribological behavior of the titanium alloy.

3. ACKNOWLEDGEMENTS

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