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# Tribocorrosion Behavior of *Ti6Al4V* Machined and Burnished Components for Biomedical Application

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**Abstract.** Nowadays, the increased average age of patients and the decreased age at which arthroplasty is carried out represents a reason for the necessity of higher quality standards for prostheses.

In particular, tribocorrosion generates an irreversible transformation of the materials and the release of particles and metal ions in toxic concentrations in the biological environment in which the systems are implanted. One of the most used materials for prosthetic implants is the Ti6Al4V alloy but its tribological behavior is still challenging for the application. Employing and optimizing severe plastic deformation processes represents a way to obtain prostheses with superior performance improving patients' quality of life and reducing the burden on National Health Cares.

*Ti6Al4V* bars have undergone machining with semi-finishing parameters and burnishing processes. Tribocorrosion tests have been performed in a custom-made cylinder-on-disk configuration employing Al2O3 counterparts and phosphate buffer solution with the addition of albumin as simulated body fluid. The effects of sole machining and its combination with burnishing on surface quality and specific wear rate (SWR) have been assessed with respect to as received surface conditions. Optical microscopy, stylus profilometry and sample weighing before tests and at specific intervals during the tests have been employed for characterization. As a main result, it has been found that burnishing process is able to improve SWR of *Ti6Al4V* samples with respect to both as received and machined samples. Furthermore, the overall behavior of tribological system is gradually improved first employing sole machining and then combining machining and burnishing, reducing SWR of counterparts as well.

## Introduction

The hip joint is one of the most affected body parts by replacement due to disabling diseases such as osteoarthritis, rheumatoid arthritis and femoral-neck fractures. Every year, more than one million surgeries are performed worldwide [1]. Nowadays, improvements in prosthesis design and materials employed is a trending topic [2]. Over time, different materials have been used such as glass, polymers, metal alloys, ceramics, composites in order to improve the quality and performance of the implants [3]. Titanium and, in particular, its $\alpha + \beta$ alloys such as *Ti6Al4V*, are among the most used materials because of their optimal performances. In fact, in the biomedical field, it continues to be one of the most used materials in prostheses thanks to its good corrosion resistance, high biocompatibility and its reliable mechanical properties as a replacement for hard tissues [4]. When titanium is exposed to air, it develops a thin oxide layer on the surface that protects it from corrosion and prevents ions from passing into solution; this has fostered its use in orthopaedics for components such as necks and femoral stems [5].

On the other hand, other types of widely used materials are the ceramics, introduced in total hip replacement to address the friction and wear problems that exist between metal-on-metal joints and with metal-on-polyethylene joints [6]. For example, alumina has a higher hardness than metallic materials and it shows a high thermal conductivity coefficient. Furthermore, alumina has high thermodynamic stability, chemical inertia and excellent corrosion resistance. It is one of the main ceramics used in the biomedical field due to its friction conditions, high wear resistance; it has good performance in compression conditions but weak resistance to tensile stresses. Usually it is used for the femur head but it can easily break, causing the formation of several large debris with consequent implant failure [7]. Hip prostheses surface damage could be also caused by fretting. This phenomenon occurs when two surfaces are in mutual contact and slithering each other. As a consequence, the surface oxide layer for the passive material (titanium, in this case) is broken in some points, where the nucleation and advancement of fatigue cracks are carried out, this leads to adverse reactions by the tissues up to implant failure [5].

Surface modification operations can play an important role in improving the lifetime of the implant [8]. Properties changes by surface modification can be induced through different kinds of processing, such as: i) mechanical, e.g. burnishing, sandblasting and grinding processes; ii) physical, through plasma and laser treatments; iii) chemical, using acid and/or alkaline solutions.

Concerning burnishing process, it is based on pressing a rolling tool in continuous contact on the component surface. The high pressure causes a deep plastic deformation a smoothing of the surface [9]. This surface finishing process produces an elasto-plastic deformation in the surface and subsurface and the affected layer thickness depends on the involved material and the chosen process parameters. The application of this process leads to wear resistance improvement, together with surface hardness, fatigue and corrosion resistance increase [10].

Tribocorrosion is the phenomenon related to material transformation caused by the simultaneous action of wear and corrosion. The tribocorrosion behaviour of a material depends on the properties of the involved mating materials, on the mechanics of the tribological contact and is affected by the physico-chemical properties of the working environment.

This paper aims to assed, through an experimental campaign of tribocorrosion tests in simulated body fluid, the behaviour of post-burnishing *Ti6Al4V* samples and $Al_2O_3$ counterparts, with respect to as produced and machined conditions, in order to how the introduction of burnishing process contributes in improving wear endurance.

## Materials and Methods

In this work, the investigated material is the *Ti6Al4V* alloy. *Ti6Al4V* bars have undergone machining and burnishing processes to assess the effects of secondary processes on tribological performance. In fact, the effects of sole machining (as turned - AT) with semi-finishing parameters and its combination with burnishing (machining+burnishing, as burnished - AB) have been studied with respect to as received condition (AR), Table 1 reports machining and burnishing parameters [11]. Mean roughness *Ra* of samples before the tests was measured through a stylus profilometer and found to be 0.72 (0.04) µm, 1.01 (0.03) µm, 0.22 (0.015) µm for AR, AT and AB, respectively.

Table 1 – Process parameters.

| **Process parameters** | | |
|---|---|---|
| | Machining | Burnishing |
| Speed | 30 m/min | 150 m/min |
| Feed rate | 0.15 mm/rev | 0.05 mm/rev |
| Depth of cut | 0.1 mm | - |
| Force | - | 1500 N |

For tribological tests, cylinder-on-disk mating configuration has been chosen, employing $Al_2O_3$ counterparts in simulated body fluid, according to [12] and performing two repetitions per test. Fig. 1 shows an image of tribological configuration is given. Tribological testing parameters have been selected according to literature [3, 4] and are: 5 cm/s as sliding speed, 10 mm as siding radius.

Specific wear rate ($SWR$) has been calculated through gravimetrical method and Equation 1 according to [15], employing a balance with a sensitivity of 0.01 mg. Samples have been weighed and optically analysed before the tests and at specified intervals by pausing and restarting tests [16], the intervals are reported in Table 2. Counterparts have been weighed before and at the end of the tests to avoid the introduction of repositioning issues.

$$SWR = \frac{Volume\ loss\ [mm^3]}{Normal\ Load\ [N] \cdot Sliding\ Distance\ [m]}\ . \tag{1}$$

Table 2 – Test interruption intervals [16].

| **Sliding distance [m]** |
|---|
| 10 |
| 100 |
| 500 |
| 1000 |
| 3000 |
| 5000 |

## Results and Discussion

Analysing surfaces of samples (Fig. 1) it can be found that on *Ti6Al4V* furrows parallel with respect to sliding direction are present, generated from abrasive wear and mixed two- and three- body abrasion, respectively because of contact with surface asperities of the counterparts and wear debris. The same wear mechanisms take place regardless of sample processing. Fig. 2 shows images of some an $Al_2O_3$ counterpart, displaying some surface pits and cracks generated because of the poor toughness of the material.

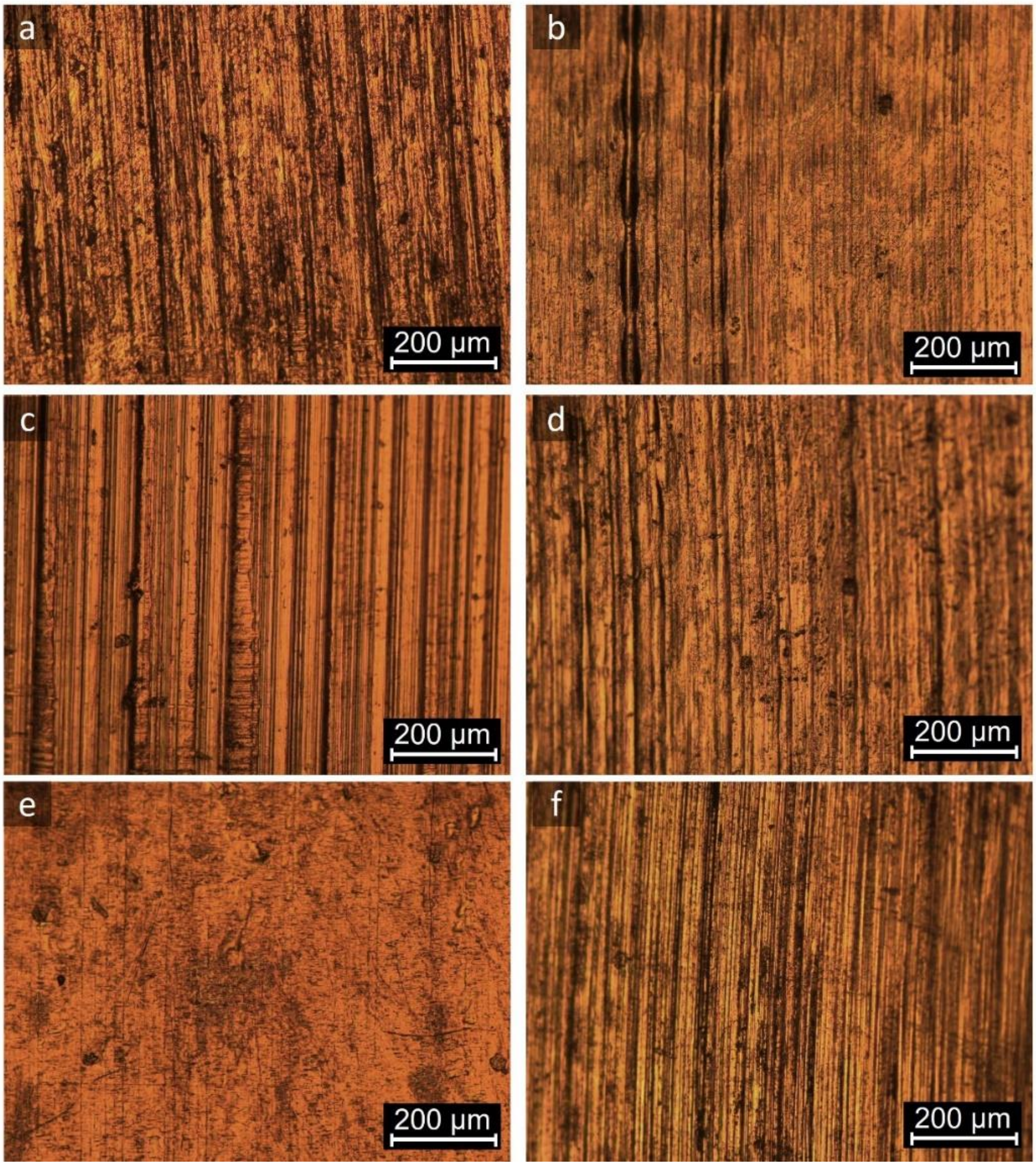


Figure 1 – Sample surfaces before and after the tests: a, b) As Received - AR, c, d) As Turned - AT, e, f) As Burnished - AB.

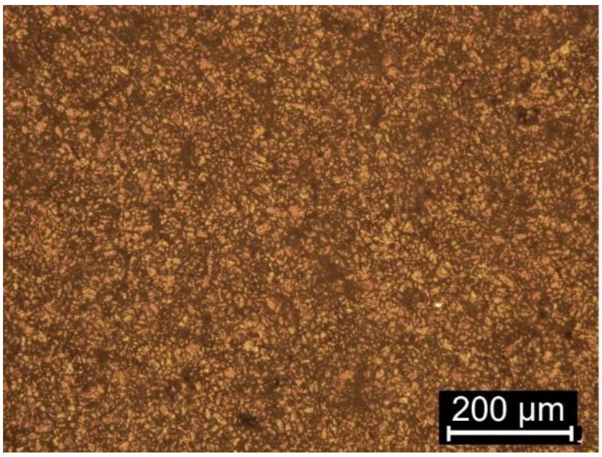


Figure 2 – Surface of a counterpart after the test.

Concerning *SWR*, reported in Fig. 3, it can be observed that in the first part of the tests AB samples show better performance with respect to AR and AT ones. By measuring the wear track area an estimation of depth with respect to worked surface can be made showing that up to 3000 m of distance covered, wear track depth below the surface is in the order of 200 µm. As a matter of fact, it has been demonstrated that the effects of burnishing process under these conditions in terms of hardness and residual stresses are accentuated up to the mentioned depth below surface, and gradually decrease [11] thus giving an explanation to the above. Another concurrent factor is given by the reduction of surface asperities on AB surfaces with respect to the other conditions, as demonstrated by surface analysis and roughness measurements. For covered distance between 3000 m and 5000 m, *SWR* reaches a stable value, similar for all tested samples.

Concerning *SWR* for $Al_2O_3$ counterparts, a further confirmation is given for tribological behaviour improvement given by secondary processes. In fact, *SWR* decreases with the introduction of semi-finishing and burnishing, as shown in Fig. 4.

The experimental campaign thus shows the possibility to improve tribocorrosion resistance of *Ti6Al4V* alloy employing secondary processes, in particular roller burnishing.

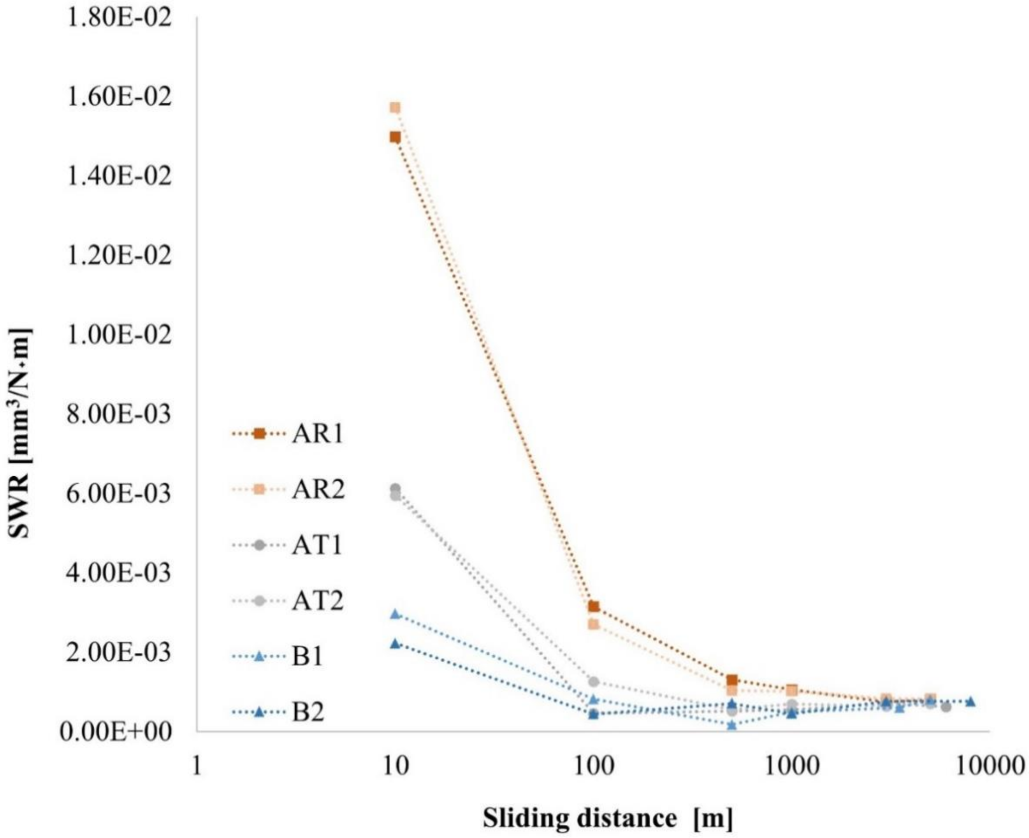


Figure 3 – Specific wear rate for tested samples.

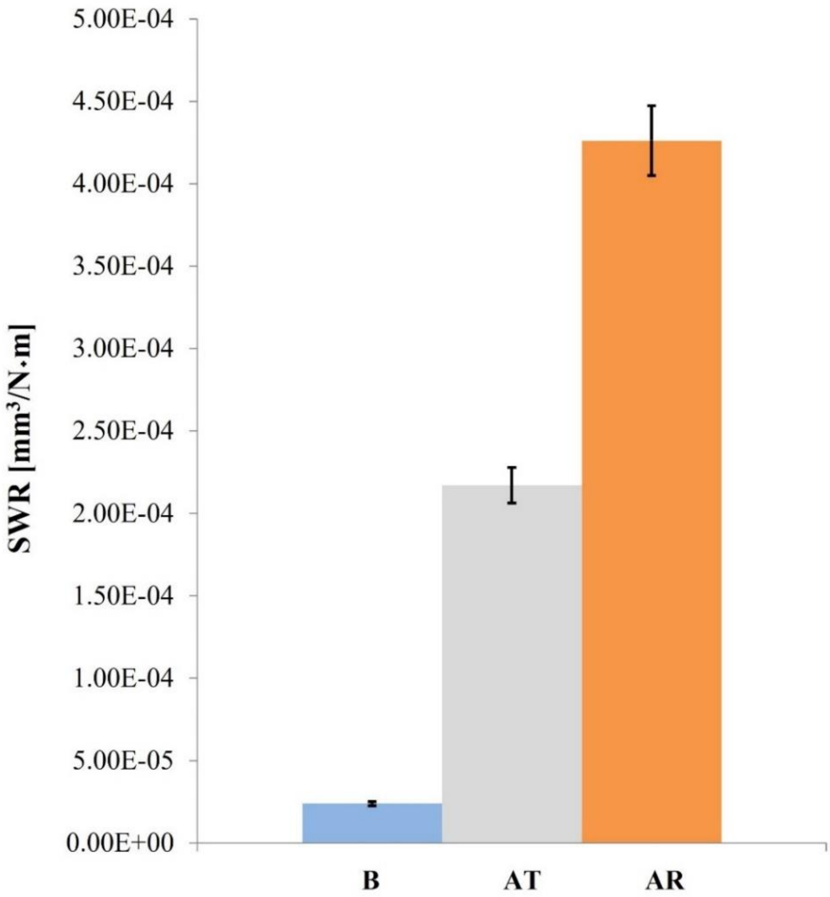


Figure 4 – Mean specific wear rate for counterparts.

**Conclusion**

On completion of the experimental campaign, it has been found that:

- Under these conditions, burnishing process is able to improve *SWR* of *Ti6Al4V* samples with respect to both as received and machined ones;
- The overall behaviour of tribological system is gradually improved first employing sole machining and then combining machining and burnishing, reducing *SWR* of counterparts as well.

Some limitations of this study concern the introduction of possible interference factors during the tests: i) related to interruptions of the tests in order to perform measurements, which could in part affect the results ii) the employment of simulated body fluid, which can only in part represent working conditions in body environment, iii) the analysis of one set of testing parameters. Thus, further tests will be performed to assess the validity of presented results.

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