# COMPARATIVE STUDY OF TRIBOCORROSION PROPERTIES OF SOME BIO-BASED MATERIALS IN SIMULATED ARTIFICIAL SALIVA

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***Abstract:***

*In this study, the tribocorrosion behavior of the materials utilized in manufacturing of biomedical implants (Ti-6Al-4V and Co-Cr alloys) was studied in a laboratory simulated artificial saliva (SAS) solution by using a linear reciprocating ball-on-plate tribometer with an integrated electrochemical cell. The open circuit potential (OCP) and the friction coefficient were monitored during the reciprocating ball-on-plate test. During the OCP tribocorrosion tests, the generated wear debris was transferred into the SAS and increased its optical density of the solution along with large scatters in the OCP potential and friction coefficient. In accordance with its poor tribocorrosion performance, Ti-6Al-4V alloy provided a large amount of wear debris transfer into the SAS along with the heavy metal attachment to the contact surface of the alumina ball and heavy fluctuations in the OCP potential and friction coefficient values during the sliding. This suggests that the Co-Cr alloy has a higher load bearing capacity than the Ti-6Al-4V alloy.*

**Keywords**: BIO-BASED MATERIALS, Co-Cr, Ti-6Al-4V, TRIBOCORROSION TEST.

## *1. Introduction*

Titanium (Ti) and cobalt chrome (Co-Cr) metal alloys are the most attractive metallic materials for biomedical applications (dental implants and orthopedic prostheses) essentially because these alloys generally present good biocompatibility, good mechanical properties, good corrosion resistance combined with low inflammatory potential [1]. However, poor tribocorrosion behavior of metallic biomaterials in the body fluids has continued to be a major concern [2]. Besides, the presence of particulate corrosion and wear products in the tissues adjacent to the implant can cause various osteoblast integrity issues, which may lead to reduction of osseointegration [3 - 5]. Hence, selection of a metal implant needing both excellent resistance to corrosion, and mechanical properties that satisfy the tribological stresses placed on it during function in a fluid system is indispensable.

In the present investigation, I have conducted a comparative study on the tribocorrosion behavior of Ti-6Al-4V and Co-Cr alloys for biomedical applications, and thereby suggests an appropriate material for biomedical implants.

## *2. Methods and Procedures*

The tribocorrosion behavior of the Ti-6Al-4V and Co-Cr alloys was studied in simulated artificial saliva (SAS) solution by using a ball-on-disk reciprocating tribometer coupled with a three electrode electrochemical cell, which is illustrated in Fig. 1. The Ti-6Al-4V and Co-Cr alloys were served as the working electrode (WE), the saturated calomel electrode (SCE) was the reference electrode (RE) and the platinum electrode was the counter electrode (CE). Reciprocating sliding wear tests were performed in a reciprocating mode with a 1.7 cm $s^{-1}$ sliding rate under 10 N applied load for 45 min. The counter body was an alumina ball with 10 mm diameter. The choice of alumina ball as the counter body was made because of its high hardness, high wear resistance, chemical inertness and electrical insulating properties. The ball holder was made of a polymeric material to prevent the corrosion effects. During the test, alloy with an area of 2 $cm^2$ was exposed to the corrosive electrolyte. The wear scars were also evaluated by a Scanning Electron Microscopy (SEM). Finally, contact surfaces of alumina balls were examined using an Optical Microscope (OM). After the OCP tribocorrosion tests, microhardness measurements were performed in the wear scar and on the unworn surface of alloys by using the Shimadzu HMV microhardness tester with a Vickers pyramid indenter under indentation load of 100 g.

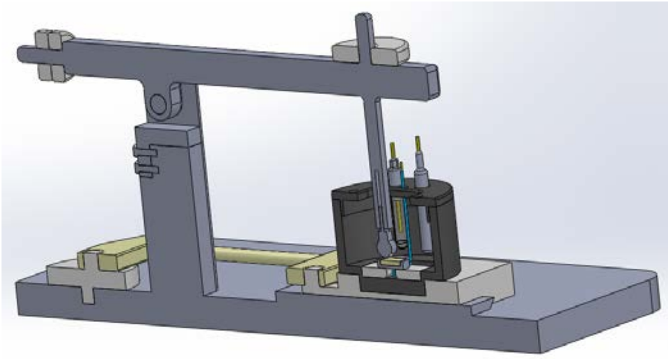
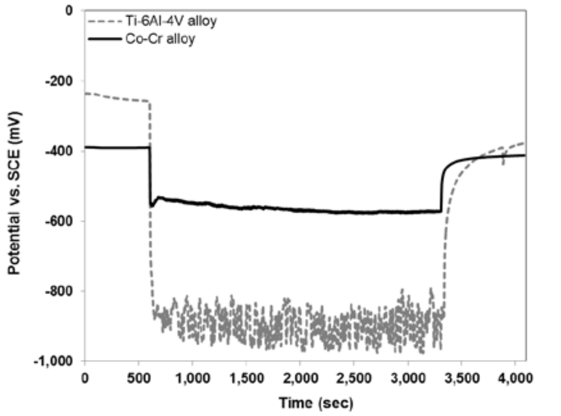


***Fig. 1*** *Schematic representation of reciprocating tribometer coupled with electrochemical cell.*

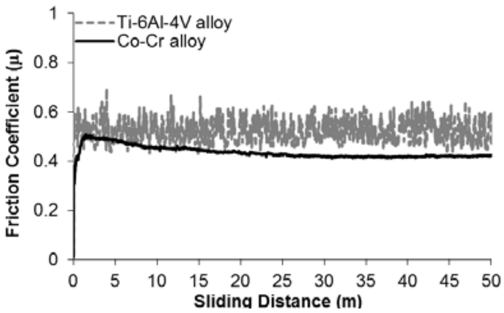
By the end of the OCP tribocorrosion tests, optical densities of SAS solution were measured using a UV-Spectrophotometer. Freshly prepared SAS was analysed as the reference to evaluate the optical densities of solutions After the spectrophotometric measurement of freshly prepared SAS solution by using fix visible light (wave length: 250 nm), the data obtained was automatically adjusted to zero in order to determine the optical densities of the SAS solutions utilized in the OCP tribocorrosion tests [4].

## *3. Results and Discussions*

The evolution of the open circuit potential (OCP) with time before, during, and after the sliding are given in Fig. 2 for Ti-6Al-4V and Co-Cr alloys, together with the friction coefficient values obtained during the sliding. When rubbing is started, the OCP shifts to more cathodic values (-858 mV vs SCE in Ti-6Al-4V alloy, -550 mV vs SCE in Co-Cr alloy) when compared to the initial potential (-257 mV vs SCE in Ti-6Al-4V alloy, -391 mV vs SCE in Co-Cr alloy). When the evolution of OCP is considered (Fig. 2 a), it can be seen that the Co-Cr alloy presented a smaller drop on the potential on the onset of the sliding as compared to the Ti-6Al-4V alloy. During the sliding, the OCP of Co-Cr alloy maintains at around -550 mV, which nobler than Ti-6Al-4V alloy (in between -850 mV and -950 mV). Thus, the OCP drop and fluctuation reflect the extent of depassivation caused by the counter ball [5]. Once rubbing stops, depassivation in the wear scar ceases and the OCP recovers the initial value established before rubbing. Similar behavior has also been reported in the literature [6]. On the other hand, Fig. 2 b shows the evolution of the friction coefficient with sliding distance for the Ti-6Al-4V and Co-Cr alloys under the lubrication of saliva solution. As shown in Fig. 2 b, the Ti-6Al-4V alloy showed friction coefficient values in the range of 0.4 – 0.6 with relatively large fluctuations; however the friction coefficient of the Co-Cr alloy reached a steady state value of about 0.42 with minor fluctuations and its friction coefficient was slightly lower than the Ti-6Al-4V alloy. The considerable scatters in the OCP potential and friction coefficient values were evident for Ti-6Al-4V alloy through out the testing period (Fig. 2), which can be attributed to the abrasive effect of wear products removed from the worn surface [5, 6].




(a)




(b)

***Fig. 2** The evolution of the (a) OCP and (b) friction coefficients monitored as a function of sliding distance during the OCP tribocorrosion tests.*

Fig. 3 presents representative SEM images of the worn surfaces of the Ti-6Al-4V and Co-Cr alloys at the end of the OCP tribocorrosion tests. It is clearly seen that the width of the wear scar of Co-Cr alloy was narrower than that of the Ti-6Al-4V alloy. The wear scar of Ti-6Al-4V alloy showed a combination of abrasive and adhesive wear mechanism as evidenced by the scratches with a very large plastic flow over the entire scar length and microcrack perpendicular to the sliding direction (see the arrow in Fig. 3 a). This large plastic flow resulted in work hardening as confirmed by the microhardness values listed in Table 1. According to the difference in microhardness values obtained inside and outside of the wear scar after the OCP tribocorrosion test (Table 1), the extent of hardening for the Ti-6Al-4V alloy was higher than the Co-Cr alloy. This hardening mechanism may also contribute to the formation of the microcrack on the worn surface of Ti-6Al-4V alloy. Similar behaviour was reported by Doni et al. [6] for Ti-6Al-4V/alumina ball tribo-pair immersed in an 8 g/l of NaCl solution. In comparison, the worn surface topography of the Co-Cr alloy was characterized by a mild abrasive wear mechanism (Fig. 3 b). Therefore, it can be said that the differences on the wear mechanisms of both alloys could be attributed to the differences in hardness and repassivation kinetics inside the wear scar.

During the tribocorrosion test for the Ti-6Al-4V alloy, noticeable amounts of wear debris in the SAS solution were detected even with a naked eye. As illustrated in Fig. 4, the wear debris generated from Co-Cr alloy was very few as compared to the Ti-6Al-4V alloy in accordance with its better tribocorrosion performance.

***Table 1:** Microhardness values measured after tribocorrosion tests at OCP.*

| Alloys | Microhardness ($HV_{0.1}$) | |
|---|---|---|
| | Outside[a] | Inside[b] |
| Ti-6Al-4V | 355±14 | 416±6 |
| Co-Cr | 516±14 | 525±8 |

[a]Outside – Measurements made outside of the wear track.
[b]Inside – Measurements made inside of the wear track.

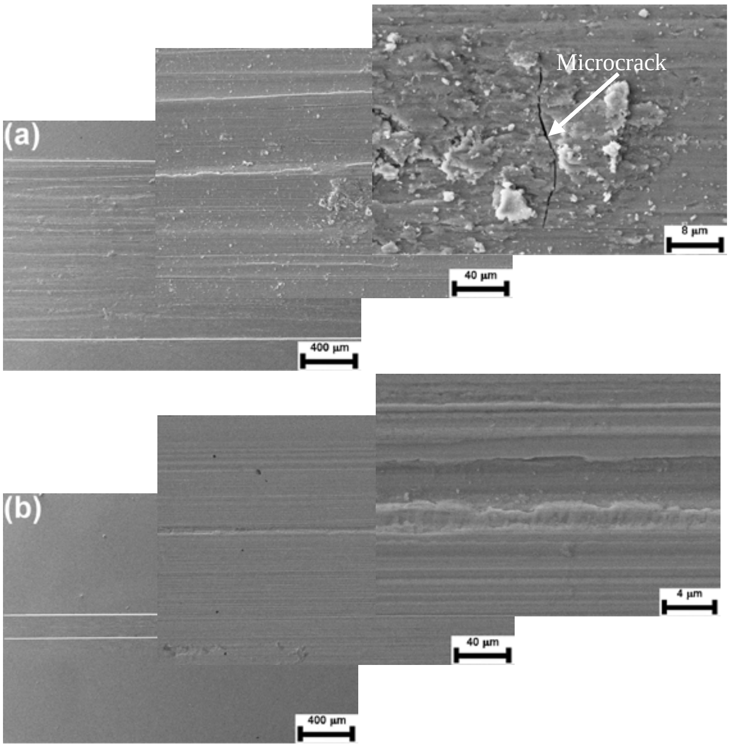



***Fig. 3** SEM pictures of the wear tracks after the OCP tribocorrosion tests of the (a) Ti-6Al-4V and (b) Co-Cr alloys (low and high magnifications).*

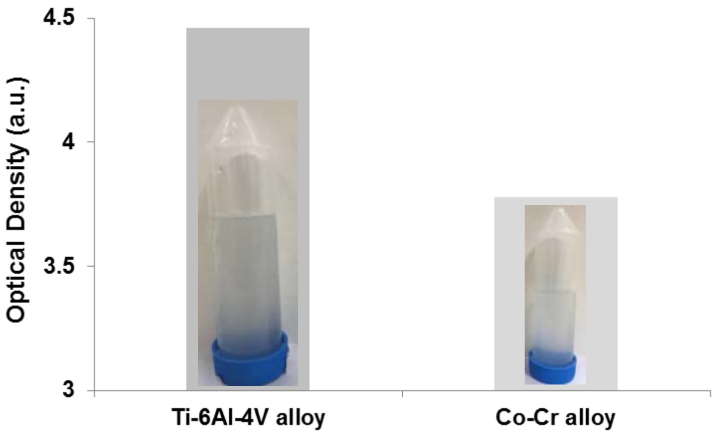



***Fig. 4** The variation of optical density of SAS solution utilized in the OCP tribocorrosion tests.*

The alumina balls were investigated using OM to identify possible damage (Fig. 5). Wear of Ti-6Al-4V alloy caused darkening at the contact surface of the alumina counter ball (Fig. 5 a). This behavior could be related to the accumulation of wear debris in the SAS solution. On the other hand, some material transfer from the Co-Cr alloy was observed on the alumina ball (Fig. 5 b).

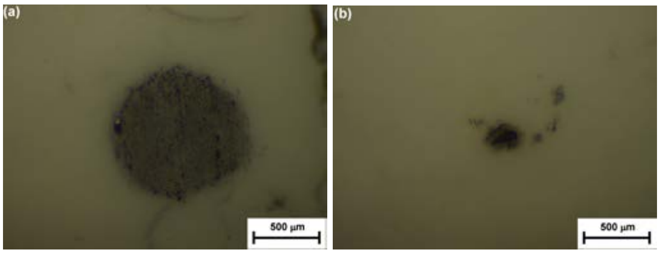



***Fig. 5*** *OM images of the alumina balls after sliding against the (a) Ti-6Al-4V and (b) Co-Cr alloys.*

## 4. Conclusion

In conclusion, the Ti-6Al-4V alloy showed relatively poor tribocorrosion performance and caused heavy surface damage on the alumina counter ball with increasing the coefficient of friction. The wear debris generated from Ti-6Al-4V alloy led to an increase optical density of the SAS solution along with heavy fluctuations in the OCP potential and friction coefficient values through out testing period compared to the Co-Cr alloy. However, considering the implants applications, the Ti-6Al-4V alloy was found to be the best candidate with relatively low elastic modulus and outstanding biocompatibility in comparison to Co-Cr alloy. Thus, surface modifications of this alloy for the load bearing applications are very important for achieving further developed biocompatibility and the second removal surgical operation can be avoided.

## Acknowledgements

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## 5. Literature

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