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The work presented during 21<sup>st</sup> INTERNATIONAL CORROSION CONGRESS & 8<sup>th</sup> INTERNATIONAL CORROSION MEETING in the month of July of 2021.

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Poster  Oral

A decisão final será do Comitê Técnico.

## Corrosion of dental implants made of Ti-6Al-4V connected to 316L SS in aggressive environment

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### New Abstract

Implants made of dissimilar alloys, such as Ti-6Al-4V, connected to abutment of stainless steel (SS), are being considered for application as dental implants leading to galvanic corrosion. Body fluids are corrosive electrolytes that contain aggressive ions, such as chlorides, leading to localized attack at weak points of the passive film on materials used for implants fabrication. Another reason of apprehension concerning corrosion is the method of joining the different materials. This might lead to small gaps between the two materials and promote crevice conditions that stimulate localized corrosion. In this study, the corrosion resistance of a Morse taper dental implants made of Ti-6Al-4V alloy in contact to a prosthetic abutment of 316L, with the two parts joined by mechanical forces consisting of strikes, using different numbers of strikes (3, 5 and 7), was studied. The study was carried out by SVET technique in phosphate buffer solution (PBS) with an addition of H<sub>2</sub>O<sub>2</sub> and pH adjust to 3 to simulate inflammatory conditions. The results showed high electrochemical activity at the interface between the two alloys. SVET maps showed that the Ti alloy acted as anode whereas the 316L SS as cathode. At the interface of the dissimilar alloys, large amounts of corrosion products accumulated showing the effect of the galvanic corrosion. This was mainly observed for the samples with 3 strikes for joining both alloys. The electrochemical activity was the lowest for the dental implant mounted with 5 strikes. SVET maps and SEM images showed a strong effect of crevice corrosion for the implants joined by lowest number of strikes among the testes.

**Keywords:** dental implants, inflammatory conditions, galvanic corrosion.

### 1 Introduction

In order for a dental implant to be flawless and durable, one of the most important factors is the way in which the connection between the abutment and the implant is made, since a lower adjustment between the parts can result in a larger microgap region, which can lead to accumulation of microorganisms, glycoproteins and entrance of saliva and other components of body fluids that can act as an electrolyte between body fluid and dental implant. This must accelerate the corrosion of the implant [1-2].

Most dental implant systems consist of two parts (prosthetic abutment and implant) and the connection between them must be made with the correct tool and with a torque determined by the manufacturer, producing the necessary force to fit them. The proper fitting prevents

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loosening of the abutment since chewing can decrease the stability between the abutment and the implant. Studies have related the size of the gap regions between the implants and the prosthetic abutment with biological and/or mechanical complications, such as fatigue failure and also inflammatory conditions, such as peri-implantitis [2-4].

Dental implants with a Morse taper connection present a better sealing of the abutment-implant interface compared to other types of fitting, for instance, the external and internal hexagonal. However, the literature shows that in the space between the implant and the prosthetic abutment, bacterial or fluids might infiltrate, as well as macromolecules of tissue and saliva fluids, facilitating bacterial proliferation in the internal region of the implant. [5-8]. As soon as a dental implant is inserted in the oral region, it will contact several conditions, including bacteria that can colonize the internal regions of the implants and also the implant-abutment interface, leading to local acidification and increasing the metal susceptibility to corrosion [9-10].

The size of the gap between the prosthetic abutment and the implant interferes with the probability of bacterial colonization, leading to local acidification. In addition, at the interface abutment-implant oxygen presents difficult access, creating conditions for crevice corrosion. When the implant-abutment connection is made of different alloys, the set is susceptible to galvanic corrosion due to the potential difference leading to in vivo galvanic cells [9-11].

The objective of this work is to study the corrosion mechanism of the alloys combination of titanium alloy ASTM F1108-14 Gr 5 (Ti-6Al-4V), used as implant, and stainless steel (SS) AISI 316 L, as a prosthetic abutment, both parts joined by strikes, specifically 3, 5 or 7 strikes, in a phosphate buffered saline (PBS) with addition of hydrogen peroxide and pH adjusted to 3 for simulation of inflammatory conditions.

## 2 Materials e Methods

The samples used in this study consisted of a Ti-6Al-4V dental implant Morse taper connected to a stainless steel prosthetic abutment. The abutments were fixed with the use of a torquimeter and different number of strikes were used for the fixation: 3, 5 and 7 strikes, at 0.05 J of energy. The samples were embedded in a cold curing resin and then sequentially ground with SiC paper #800, #1200, #2000 and #4000. Subsequently, the surface of the samples was polished with 1 $\mu$ m diamond paste and stored in a desiccator until use.

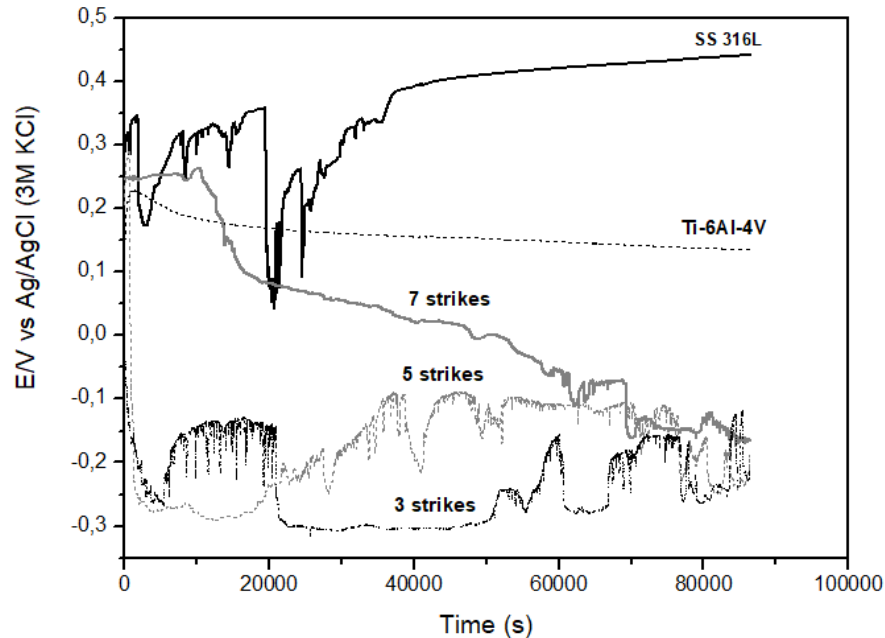
The electrolyte used in the electrochemical tests was a phosphate buffer solution (PBS) with the addition of 1% hydrogen peroxide and pH adjusted to 3, simulating crevice and inflammatory conditions.

Open circuit potential measurements were performed as a function of time of immersion in the electrolyte for a period of 24 hours. The electrochemical set-up used consisted of a three-electrode cell, with a platinum wire as counter electrode, an Ag/AgCl (3M KCl) as reference electrode, and the junction implant-abutment as the working electrode.

Scanning Vibrating Electrode Technique (SVET) tests were performed with insulated Pt-Ir deposited platinum black probes as vibration electrode. The vibration electrode was placed ( $100 \pm 3$ )  $\mu$ m above the surface of the sample. All experiments were performed in a Faraday cage at ( $20 \pm 2$ ) °C, for 24 hours using the PBS solution with 1% hydrogen peroxide (pH 3) as electrolyte. The surface exposed to the electrolyte was characterized by Scanning Electron Microscopy (SEM) after SVET tests.

### 3 Results and discussions

Figure 1 shows the variation of open circuit potential with time of immersion for the three types of samples used in this study for 24 hours of test and also for the SS 316L and the Ti Gr 5 separately in the PBS solution.



**Figure 1. Open circuit potential measurement of the samples in function of the time for 24 hours in PBS solution.**

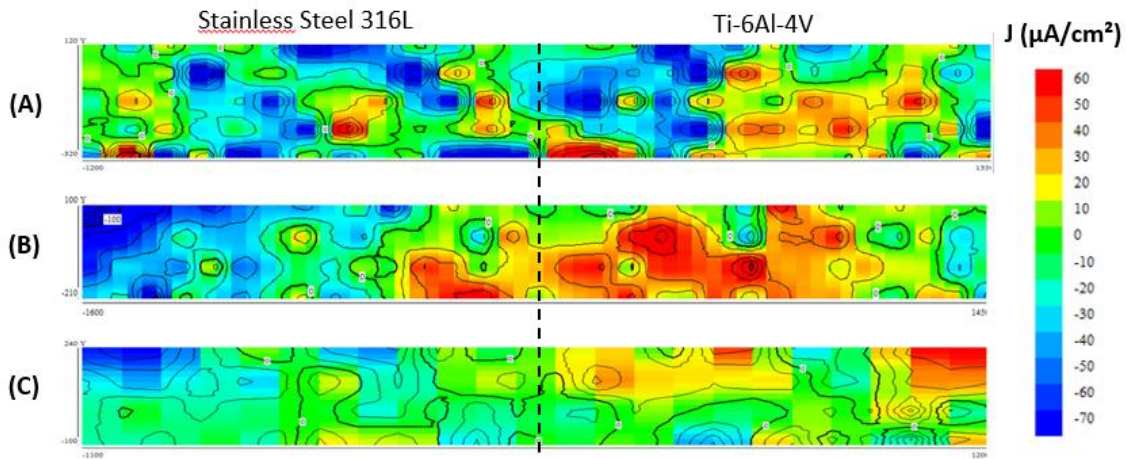
The results presented (Figure 1) show the effect of the number of strikes for assembling the parts by mechanical imbrication of the Ti alloy implant to 316 L prosthetic abutments on the electrochemical behavior of the assembled materials. The stainless steel 316 L separately presented higher potentials than the Ti alloy during all the period of measurement showing that it will act as cathodic sites when coupled to the Ti alloy. The potential oscillations observed for the SS until nearly 4000 seconds, however, show that it tends to localized attack until its stabilization. Table 1 presents the initial and the potential after 24 hours, for all the conditions tested. The lower potentials of the coupled alloys compared to the two alloys tested separately, suggest a strong effect of crevice conditions and, possibly, galvanic coupling. The results in Table 1 also show that the nobility of open circuit potential increased with the number of strikes.

**Table 1 – Potential values of the samples (initial and final) mV**

	$E_{\text{initial}}$ (mV)	$E_{\text{final}}$ (mV) 24 hours
<b>SS 316L</b>	308	441
<b>Ti-6Al-4V</b>	161	136
<b>7 strikes</b>	246	-161
<b>5 strikes</b>	208	-190
<b>3 strikes</b>	-42	-217

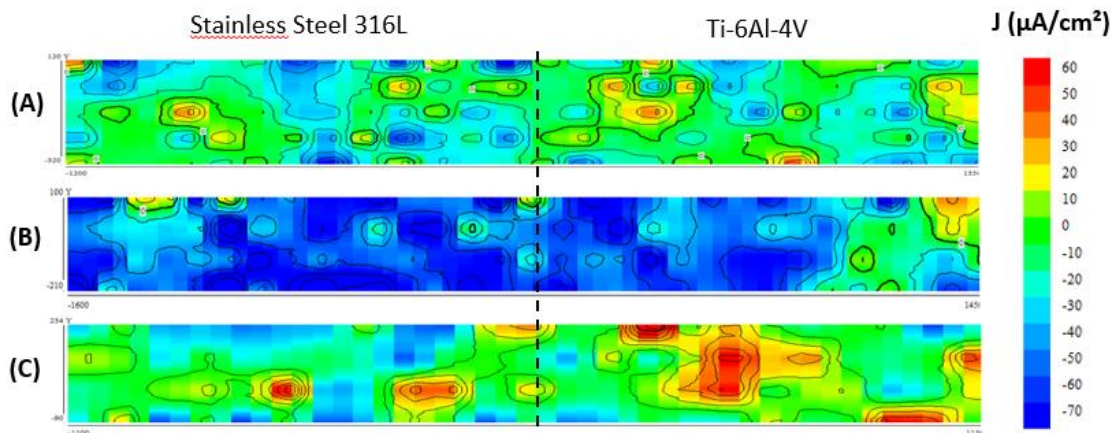
The implant-abutment sample that used 7 strikes showed higher and nobler potentials throughout the test time, with the sample potential dropping significantly after 11,000 seconds. The assembled sample corresponding to 5 strikes and 3 strikes showed potential instabilities typical of attack to the passive film and pits nucleation. The results also indicated that the set that used 3 strikes showed the largest potential drop soon after exposure to the electrolyte showing the intense attack to the passive film on this type of sample, which was found to be mainly located at the abutment-implant junction.

Figure 2 compares the electrochemical behavior of the samples corresponding to 3 (A), 5 (B) and 7 (C) strikes for assembling the implant Ti-6Al-4V and abutment 316L SS exposed for 2 hours to the electrolyte.



**Figure 2 - SVET maps for the Ti-6Al-4V alloy (implant) assembled to SS 316L (abutment) by mechanical imbrication corresponding to (A) 3 strikes, (B) 5 strikes and (C) 7 strikes after 2 hours of exposure in PBS solution.**

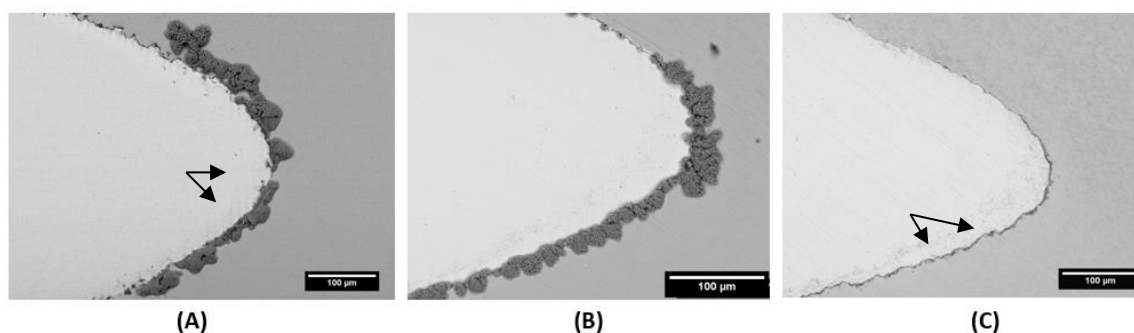
It is easily seen that the lowest electrochemical activity among the tested samples was related to the sample assembled with 7 strikes. It can be observed that the Ti alloy acted preferentially as anodic sites (red sites) compared to the SS 316L, although anodic activity was also seen on the SS mainly near to the interface between the alloys. It is also interesting to note that for the sample with 7 strikes, anodic sites (red sites) were mainly located on the Ti alloy and not exactly at the interface between the two alloys, but some anodic activity was also seen at areas near to the interface of both alloys (yellow sites).



**Figure 3 - SVET maps for the Ti-6Al-4V alloy (implant) assembled to AISI 316L stainless steel (abutment) by mechanical imbrication corresponding to (A) 3 strikes, (B) 5 strikes and (C) 7 strikes after 24 hours in PBS solution**

Figure 3 shows SVET maps for the tested samples after 24 hours in the electrolyte. The results show decreased electrochemical activity between 2 and 24 hours for the most active samples (3 and 5 strikes) whereas increased activity for the sample with 7 strikes that is followed by the potential decrease and potential oscillations as the potential approaches  $-0.05\text{V}$  after approximately 1 hour of test.

Surface observation after 24 hours of test showed large amounts of corrosion products located at the interface of both alloys, that is, the most electrochemically active areas at the surface. For the samples assembled with 3 and 5 strikes, the corrosion products originated mainly at the gaps between the two alloys at their interface. This is likely related to the crevice conditions at these sites, besides galvanic coupling, but were predominantly deposited on the Ti alloy, that corresponded to the anodic sites, as it is shown in Figure 4. It is interesting to note from SVET maps (Figure 3) that for the sample corresponding to 7 strikes, anodic activity mainly occurred on the Ti alloy and not exactly at the interface between the two alloys, as it was seen for the other types of samples.



**Figure 4.** Scanning electron microscopy for the samples with (A) 3, (B) 5 and (C) 7 strikes, after 24 hours immersion in PBS solution (pH 3 and 1wt. %  $\text{H}_2\text{O}_2$ ).

However, when the surface was observed by SEM after 24 hours of test, the mostly attacked areas were associated to the surface of the SS, as indicated by arrows. This was due to local acidification resulting from the corrosion reactions mainly located at the gaps between the two alloys due to crevice conditions. The electrochemical activity resulted in further decrease of the local pH leading to etching of the SS surface near to the interface. For the sample with 7 strikes much lower amounts of corrosion products were observed and this was related to the lower gaps at the alloys interface. This result suggests that the mechanism of corrosion predominant between the two assembled alloys, it is the crevice conditions originated at the interface which is dependent on the number of strikes in the corrosion mechanism of the tested systems.

#### 4 Conclusions

The results of this study led to the following conclusions:

1. The electrochemical activity at the tested samples assembled by mechanical imbrication was mainly located at the interface between implant (Ti alloy) and abutment (SS 316L) and resulted in deposition of large amounts of corrosion products.
2. In the samples with large quantities of corrosion products deposited, the electrochemical activity decreased, mainly at the interface implant-abutment.
3. The electrochemical activity decreased with the number of strikes used for connection of the two parts, implant and abutment, being mainly related to the gap/crevice at the interface.

4. Crevice conditions were mainly responsible for the corrosion behavior at the interface of implant-abutment samples assembled showing the effect of the number of strikes on the electrochemical behavior.

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