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A Study on Corrosion Behaviour of SS316L and Ti-6Al-4V Dental Implant Materials

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Abstract. This paper represents the study carried out on the corrosion behaviour of SS316L and Ti-6Al-4V, which are used as implants in dental applications. This study was carried out to determine the corrosion performance and corrosion resistance of implant materials in physiological conditions of the human body. The results were evaluated through precision measurement of parameters namely electrochemical impedance spectroscopy (EIS) and open circuit potential (OCP). The corrosion tests were carried out in a three electrode cell system for a duration of 3 hours at 37°C in hanks balanced salt solution, which was used as the corrosion testing medium. The results showed that the corrosion potential (E_{corr}) was increasing and reached a maximum value of 0.147 and 0.108 for SS316L and Ti-6Al-4V, respectively. Hence the study revealed that SS316L exhibits better corrosion properties than Ti-6Al-4V to overcome problems encountered with vanadium.

Keywords: SS316L, Ti-6Al-4V, Hanks balanced salt solution, OCP, EIS.

INTRODUCTION

Biomaterial is a viable substance that can be used either independently or as part of a system that treats, compliments or replaces organ, tissues or human body and performs its function. Such a material may be naturally occurring or synthetic. Biomaterials should possess properties such as biocompatibility, bio inertness, and high wear resistance and corrosion resistance [1].

A dental implant is a substitute for an artificial tooth, which replaces the original tooth in the jaw bone [4]. Precious metals that were used in dentistry are Ag, Au, Steel and their alloys because of their good resistance to corrosion, ductility and castability. During early days the high cost of these materials led to the development of base metal alloys for dentistry applications. These base metals exhibited better aesthetics and mechanical properties in some oral environment applications. As a result certain base metals were preferred due to their lower density and good mechanical properties. The most commonly used base metals in dentistry are Stainless Steel, Titanium, cobalt-chromium, nickel-Titanium [5].

When a metal is placed in a medium, it results in the release of ions into the microenvironment. This causes deterioration of the metal and we define this as corrosion. When corrosion takes place in a dental implant, it decreases the fatigue life of the implant and eventually affects the strength of the implant, thus resulting in mechanical failure of the implant [6]. The implant can also undergo fracture because of fatigue. Inside the human mouth, saliva and salt have the effect of weak electrolyte, resulting in many forms of electrochemical corrosion. The corrosion of the dental implants depends on oxidation and reduction reactions and also on certain factors that physically prevent corrosion. Corrosion of metallic implants is given more importance because it may affect the mechanical integrity

Table 1. Composition of the SS316L and Ti-6Al-4V materials.

	C	Si	Mn	P	S	Cr	Mo	Ni	N	Fe
SS316L	0.03	0.408	1.731	0.041	0.030	16.680	2.057	10.311	0.10	Bal
	Ti	AL	V	Fe	C	N	H	O	–	–
Ti-6Al-4V	89.765	6	4	0.1	0.01	0.015	0.03	0.08	–	–

and biocompatibility of the implant materials. Corrosion can also be influenced by the pH changes occurring in the human body. Implant corrosion can be determined through physical characteristics such as thermodynamic forces in which corrosion can occur through reduction or oxidation reactions and kinetic barrier like surface oxide layer which temporarily avoids corrosion reactions. The corrosion issues are not limited to local problems because the particles that are produced due to corrosion may transfer to other parts from the implant [7].

Stainless steel has been used in dentistry for almost a century. The first stainless steel used in dentistry for implantation steel consisted of 18wt% Cr, 8wt%Ni which was stronger than steel and corrosion resistant. Later the properties of stainless steel were improved by addition of Molybdenum (Mo), which was known as type 316. Then the reduction of carbon (C) content from 0.08wt% to 0.03wt% improved corrosion resistance of stainless steel which was named as type 316L [8].

Titanium alloy (Ti-6Al-4V) has been widely used in dentistry applications due to their good biocompatibility and fatigue strength. But these alloys are subjected to certain limitations. These alloys release metal ions into bloodstream, which cause tissue sensitivity in around the implantation. Studies have shown that the presence of vanadium produces oxides that are dangerous to the human body. So the toxicity of vanadium had led to studies of other dental biomaterials that can replace Ti-6Al-4V [9].

The most important factor for any biomaterial is evaluated by its corrosion behaviour. So the first step in the development of new biomaterials is to evaluate the corrosion parameters and check biocompatibility by in-vitro MTT assay or test. The corrosion behaviour of the biomaterials mainly depends on protective passive film. So for determining passive film composition of in-vitro corrosion test is carried out [10].

RESEARCH ELABORATIONS

Both SS316L and Titanium Alloy (Ti-6Al-4V) dental implant materials were used to evaluate their corrosion behaviour by using electrochemical corrosion studies. The composition of the materials was tested by using optical emission spectrometer BAIRD DV6. The composition of the materials used is depicted in Table 1.

The experiment was carried out using a three electrode cell system. The reference electrode is referred to as the saturates calomel electrode and the counter electrode is made of platinum wire. Hanks balanced salt solution having a pH of 7.2 was selected as corrosion medium to match the physiological human body environmental conditions. The physical composition of hanks balance salt solution is given in Table 2. The test was carried out for about 3 hours at 37°C. In this experiment the open circuit potential parameter and electrochemical impedance spectroscopy measurement were measured.

Table 2. Composition of hanks balanced salt solution.

Components	mg/L
Calcium Chloride (anhydrous)	140
Magnesium Chloride	100
Magnesium Sulphate	100
Potassium Chloride	400
Potassium Phosphate	60
Sodium Bicarbonate	350
Sodium Chloride	8000
Sodium Phosphate (dibasic)	48
D-Glucose (Dextrose)	1000

RESULTS OR FINDINGS

Open Circuit Potential (OCP) Measurements Method

Open circuit potential (OCP) is the easiest method to study the corrosion behaviour of materials. The formation of the film on the implants in the solution can be studied and potential can be plotted as a function of time. Increase in potential shows the formation of film and steady state potential shows that the film is protective and decrease in potential results shows dissolution of film or no film formation or break in the film.

Figure 1 represents the measurements of SS316L and Ti-6Al-4V OCP in HBSS measured for 3 hours at 37°C. The performance of corrosion can be evaluated from the analysis of OCP measurements. From the results obtained, graphs were plotted for time versus potential for SS316L and Ti-6Al-4V. The curves represent a continuous rise in potential and thus reveal a film formation. The curves clearly run parallel to each other and are quite similar. The corrosion potential (E_{corr}) is increasing and reaches a maximum of 0.147 for SS316L and 0.108 for Ti-6Al-4V. It is

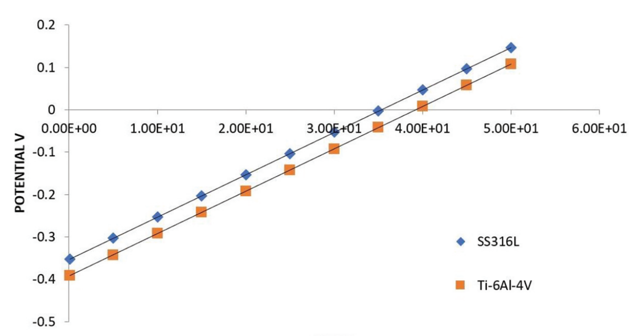

Figure 1. OCP measurements of SS316L and Ti-6Al-4V in HBSS measured for 3 hours.

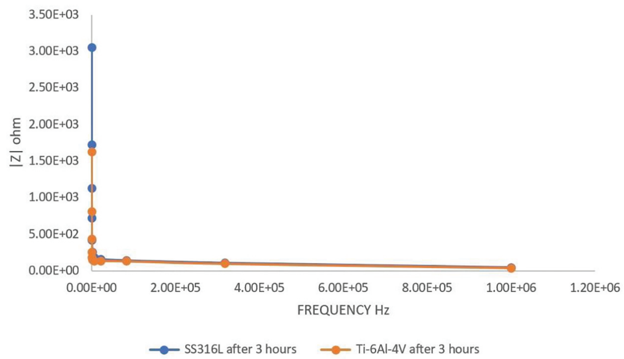

Figure 2. EIS measurements of SS316L and Ti-6Al-4V in HBSS measured for 3 hours.

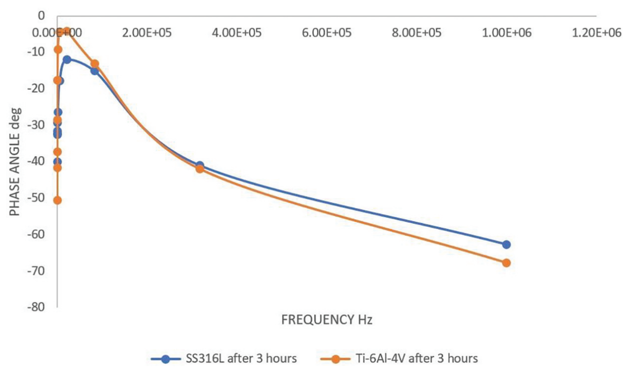

Figure 3. EIS measurements of SS316L and Ti-6Al-4V in HBSS measured for 3 hours.

seen that the corrosion potential (E_{corr}) is more for SS316L. Hence it can be evaluated that SS316L exhibits superior corrosion performance than Ti-6Al-4V in hanks balanced salt solution.

Electrochemical Impedance Spectroscopy (EIS) Measurement Method

The most effective method to study corrosion behaviour is the electrochemical impedance spectroscopy measurement method, where the response of the material is subjected to corrosion is applied by a small amplitude signal which depends on the frequency of the signal. The behaviour of impedance of a specimen can be expressed as Bode plots of impedance modulus |Z| which represents as a function of frequency and phase angle.

Figures 2 and 3 represent the EIS measurements of SS316L and Ti-6Al-4V in HBSS measured for 3 hours at 37°C. Bode plots are plotted for frequency versus current Z and frequency and phase angle for SS316L and Ti-6Al-4V. From above graphs, we can observe that the region of higher frequency |Z| tends to be constant as the phase angle decreases to zero for increasing frequencies. The impedance results indicate formation of a passive layer on both materials SS316L and Ti-6Al-4V which resists corrosion. The film formed consists of a higher impedance inner barrier layer which is responsible for protection of surface from corrosion and a lower impedance outer porous layer which facilitates osseointegration. The maximum corrosion resistance of SS316L was 3.06E+03 and for Ti-6Al-4V was 1.63E+03. Hence it can be evaluated that SS316L exhibited better corrosion resistance than Ti-6Al-4V placed in hanks balanced salt solution.

CONCLUSION

The electro-chemical corrosion technique used in this study provides the following conclusions. It was evaluated that SS316L exhibited better corrosion performance than Ti-6Al-4V and indicated presence of film formation. The EIS results exhibited that the film formed is a two-layered oxide which consisted of an inner barrier layer that has high impedance which is responsible for protection of surface from corrosion and an outer porous layer that has lower impedance which leads to osseointegration. The results also showed that the corrosion potential (E_{corr}) was increasing and reached a maximum value of 0.147 and 0.108 for SS316L and Ti-6Al-4V, respectively. Hence the study revealed SS316L exhibits better corrosion properties than Ti-6Al-4V to overcome problems encountered with vanadium.

CONFLICT OF INTEREST

All authors have "NO" potential conflict of interest.

AUTHOR CONTRIBUTIONS

All authors have carried out this research work and agree to be accountable for the content of the work.

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