Effect of Uric acid Level on the Corrosion Behavior of SS 316L and Co-Cr-Mo Used in Implant Applications

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ABSTRACT

In this study electrochemical behaviors of SS 316L and Co-Cr-Mo alloys were studied using electrochemical method by potentiostat in simulated body fluid (SBF) at pH=7.4 and 37ºC in absence and presence of 7 and 12 g/dL uric acid which causes arthritis. Corrosion parameters for two implants were calculated which include corrosion potentials (E_{corr}), corrosion current densities (i_{corr}), cathodic and anodic Tafel slops (b_c & b_a), polarization resistance (R_p) and corrosion rates (C_R).

Increases uric acid in human body gives decreasing in corrosion rate for SS 316L because of formation organometallic complexes between acid molecules and released metal ions, but an increase in corrosion rate for Co-Cr-Mo alloy because of low affinity of cobalt ions to formation organometallic complexes. General comparison between two implants shows that the Co-Cr-Mo alloy has lower corrosion rate than SS 316L in the same conditions due to Cr content. This means that using Co-Cr-Mo alloy better than SS 316L as bioimplant.

Keywords: Corrosion in human body, Uric acid, Surgical implants.

تأثير مستوى حامض اليوريك على السلوك التأكلي للصلب المقاوم للصدأ 316L وسبيكة Co-Cr-Mo المستخدمة في تطبيقات الزروع الجراحية

الخلاصة

في هذه الدراسة تم دراسة السلوك الكهروكيميائي للفولاذ المقاوم للصدأ 316 وسبيكة الكوبلت-كروم-موليبدينوم باستخدام الطريقة الكهروكيميائية مستخدمين المجهاد الساكن عند اس هيدروجيني 7.4 ودرجة حرارة 37 مئوية بغياب ووجود نسبتين من حامض اليوريك بالجسم والمسؤول عن حصول

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التهاب المفاصل. تم حساب العديد من متغيرات التاكل لكلا المزروعتين وتضمنت جهود وكثافات تيار التاكل وميول تافل الكاثودية والانودية بالاضافة الى حساب مقاومة الاستقطاب ومعدل سرعة التاكل.

وقد بينت الدراسة بان ارتفاع نسبة حامض اليوريك الى 7 و12 غرام لكل 100 مل تقود الى نقصان معدل سرعة التاكل للفولاذ المقاوم للصدأ بسبب تكون المعقدات العضوية المعدنية بين جزيئات الحامض وايونات المعدن المتحررة، اما سبب الزيادة في معدل سرعة تأكل سبيكة الكوبلت-كروم-مولبيدينوم بسبب ارتفاع نسبة حامض اليوريك فيعزى الى الالفة القليلة للكوبلت لتكوين المعقدات العضوية المعدنية. ان المقارنة العامة لسلوك كلا المزروعتين تشير الى ان سبيكة الكوبلت-كروم-مولبيدينوم تمتلك معدل تأكل اقل من الفولاذ المقاوم للصدأ عن القياس في نفس الظروف والمعزى الى محتوى الكروم في كلا السبيكتين. وهذا يعني بان استخدام سبيكة الكبلت-كروم-مولبيدينوم افضل من استخدام الصلب المقاوم للصدأ كمزروعة جراحية.

INTRODUCTION

The implantation of foreign bodies is sometimes necessary in the modern medical practice. However, the complexes interactions between the host and the can implant weaken the local immune system, increasing the risk of infections. Therefore, it is necessary to further study these materials as well as the characteristics of the superficial film formed in physiologic media in infection conditions in order to control their potential toxicity due to the release of metallic ions in the human body[1].

Gout has a strong male predominance, with an estimated 2% prevalence in men over age 30 years[2] and a peak incidence in the fifth decade of life among men[3].

Gout is rarely seen in premenopausal women but can be found in postmenopausal women. The prevalence of gout is higher in African Americans than in whites[4], and gout prevalence overall appears to have increased in recent decades[5]. Other risk factors for gout include older age, obesity, taking certain medications (e.g., diuretics), and consuming purine-rich food and alcohol. Alcoholic beverages not only increase urate production but also decrease urate elimination via the kidney. Beer has the highest purine content of the alcoholic beverages and confers the highest risk for developing gout.

However, wine does not increase the risk of developing gout. Interestingly, a recent study by Choi et al. [6] indicate that consuming purine-rich vegetables had no correlation with gout development and increasing dairy intake decreased gout incidence. Hyperuricemia is defined as a serum uric acid level greater than 6.8 mg/dL. Baseline uric acid level is higher among men (5.1 ± 1.0 mg/dL) than among women (4.0 ± 1.0 mg/dL)[7]. When the limit of solubility of monosodium urate in plasma is exceeded, urate crystals precipitate. Urate crystals are phagocytosed by neutrophils, which subsequently release potent inflammatory mediators, such as tumor necrosis factor-α, interleukin-1, and interleukin-6. These inflammatory mediators are responsible for systemic effects (eg, fever, leukocytosis) observed during an acute attack of gout.

There are many studies about the corrosion of implants in human body fluid by using electrochemical methods include potentiostatic measuring, auger spectroscopy, and impedance spectroscopy in addition to use scanning electron microscope and X-ray spectroscopy to identification the protective and type of corrosion that can be occur [8-14]. On other hand, Lee Ann O. Bailey et. al. studied the quantification of cellular viability and inflammatory response to stainless steel alloys[15].

The establishment of quantitative tests of biocompatibility is an important issue for biomaterials development. Therefore, Lee Ann O. Bailey and co-worker developed an in vitro model to measure the pro-inflammatory cytokine production and in this study investigated the cellular responses induced by nitrogenated and 316L stainless steel alloys in both particulate and solid form. Fluorescence microscopy and flow cytometry were used to probe the viability of the population [15].

This work presents a study of the corrosion resistance of AISI 316L stainless steel and Co-Cr-Mo alloys in aerated simulated body fluid (SBF) which was employed as working solution at 37 ^oC, the pH was adjusted to 7.4 in order to reproduce normal body in presence of uric acid with two levels 7mg/dL and 12mg/dL. Corrosion resistance was measured by means of electrochemical method using potentistat.

MATERIALS AND PROCEDURE

The used materials in this study were SS 316L and Co–Cr–Mo alloy and the chemical composition are shown in Table (1 and 2) respectively. The human body fluid (SBF) prepared by dissolved tables of Ringer's solution, which obtained from (Germany), in 300 ml of distilled water and then heated until adjusted the pH at 7.4 value. This solution used after cooling at room temperature and then heated to 37^oC for corrosion test using water bath.

To perform corrosion test, SS 316L was cutting to cylinder shape with diameter of (5 mm) and height of (10 mm), while Co-Cr-Mo alloy was cutting to cubic shape with dimensions of (1×1 mm), mounting by using 2X-QB hot mounting using phenolic resin in mold and heated up to 140^oC under pressure of 3500 – 4000 psi. For 5 – 10 minutes. Suitable provision was made on one side for electrical contact.

The mounted specimens were ground with SiC emery papers in sequence on 120, 180, 220, 320, 500, 800, 1000, and 1200 grit to get flat and scratch- free surface. The specimens were polished using polish cloth and alpha alumina 0.05µm and 0.1 µm then washed with distilled water. The polished specimens were degreased with acetone trichloroethylene and cleaned in the same solution. The degreased specimens were washed with deionized water, dried and kept in a dissector over a silica gel pad and used for electrochemical investigation.

Potentiostatic and cyclic polarization measurements were carried out with Autolab with Nova software. Electrochemical measurements were performed at a scan rate 3 $mV.sec^{-1}$. Polarization experiments were started when the rate at which open circuit potential (E_{ocp}) changed was less and more 200mV. Electrochemical standard cell with three electrodes was used, the first was working which represents the SS 316L or Co-Cr-Mo alloys, the second was auxiliary electrode (Pt electrode), and the third was saturated calomel electrode (SCE) as a reference electrode which was connected with electrochemical cell by Luggin capillary. All experiments performed in science of Malaysia University.

Table (1) Chemical composition of Stainless Steel 316L Obtained by XRF.

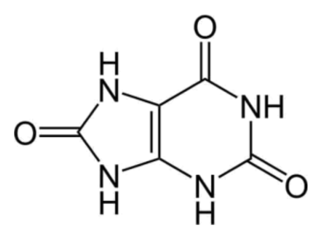
Element	*C*	*N*	*Mo*	*Ni*	*Mn*	*Cr*	*S*	*P*	*Si*	*Fe*
Wt%	*0.03*	*0.05*	*3.00*	*12.0*	*1.50*	*16.0*	*0.01*	*0.03*	*0.75*	*66.33*

Table (2) Chemical composition of Co – Cr – Mo alloy obtained by XRF.

Element	*Cr*	*Mo*	*C*	*Si*	*Co*
Wt%	*28.0*	*6.00*	*0.35*	*1.00*	*Remained*

RESULTS AND DISCUSSION

Corrosion is an important process since it contributes to the release of ions into the body. Different articulating surfaces have been used to find combinations that result in less corrosion, and therefore, less release of ions into the body [16]. Uric acid (or urate) is a heterocyclic compound of carbon, nitrogen, oxygen, and hydrogen with the formula $C_5H_4N_4O_3$ as shown below may be increase to high concentration in the human body.



Figures (1) to (3) show the polarization curves of SS 316L and Co-Cr-Mo alloys in simulated body fluid (SBF) in absence and presence uric acid with two concentrations (7 and 12 g/dL) at pH=7.4 and 37°C respectively. These curves indicate the cathodic reaction region (lower section of the polarization curve ***ab***) which represents the reduction of oxygen and hydrogen according to the following reactions:

$$O_2 + 2H_2O + 4e \rightarrow 4OH^- \quad , \quad 2H^+ + 2e \rightarrow H_2 \qquad \text{…. (1)}$$

And $$O_2 + 4H^+ + 4e \rightarrow 2H_2O \qquad \text{…. (2)}$$

In addition to anodic reaction region (upper section of the curve ***bc***) which represents the oxidation of metals in implants as shown below:

$Fe \rightarrow Fe^{2+} + 2e$, $Ni \rightarrow Ni^{2+} + 2e$, $Cr \rightarrow Cr^{3+} + 3e$, $Mo \rightarrow Mo^{3+} + 3e$

The results of corrosion parameters which shown in Table (3) indicate that Co-Cr-Mo alloy has nobler corrosion potential (E_{corr}) than SS 316L alloy, also lower corrosion current density (i_{corr}). Therefore Co-Cr-Mo alloy has more corrosion resistance (R_p) and lower corrosion rate (C_R) than SS 316L alloy.

The data of corrosion potentials, corrosion current densities and Tafel slopes (b_c and b_a) obtained from linear polarization using M lab software program, but the corrosion rate and corrosion resistance calculated using the following equations[17,18,19]:

$$C_R(mm/y) = 3.271\frac{e}{\rho}i_{corr.} \quad \ldots (3)$$

Where C_R *(mm/y)*: corrosion rate in millimeter per year, *e*: equivalent weight of alloy (gm), and ρ: density of alloy (gm/cm^3).

$$R_p = \frac{b_a b_c}{2.303(b_a + b_c)i_{corr}} \quad \ldots (4)$$

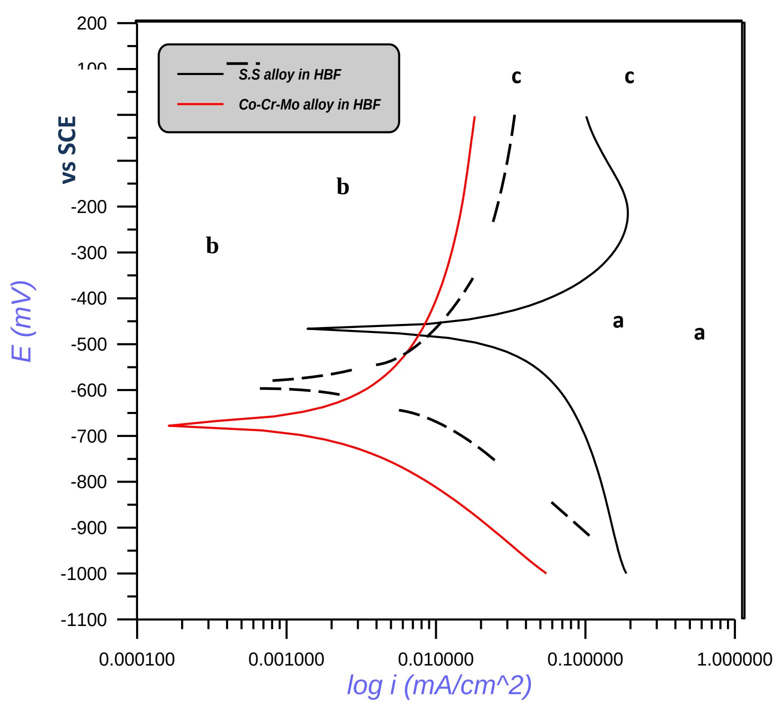


Figure (1) Potentiodynamic curve of SS 316L and Co-Cr-Mo alloys in simulated HBF.

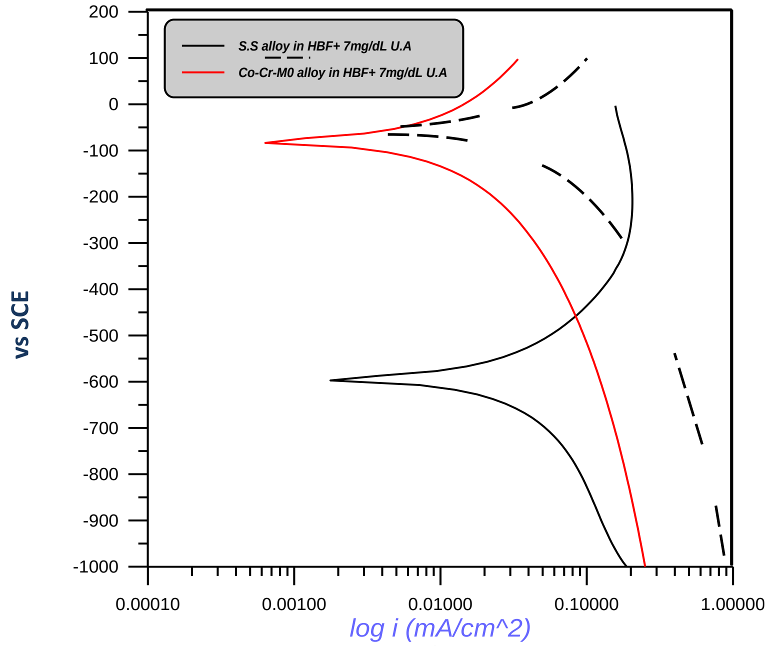


Figure (2) Potentiodynamic curve for SS 316L and Co-Cr-Mo alloy in simulated HBF in presence of 0.7 g/L uric acid .

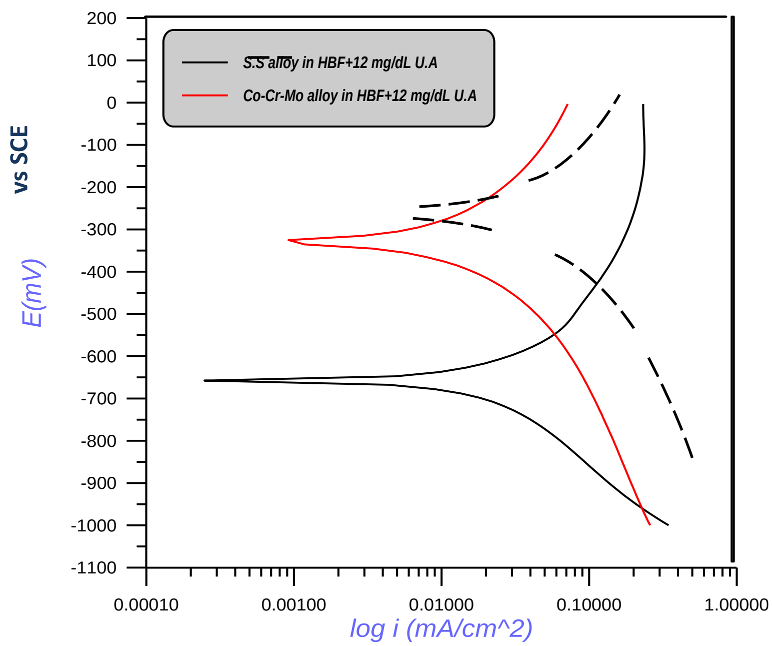


Figure (3) Potentiodynamic curve for SS 316L and Co-Cr-Mo Alloy in simulated HBF in presence of 1.2 g/L uric acid.

Table (3) Corrosion parameters of SS 316L and Co-Cr-Mo alloys in Ringer's solution (SBF), corrosion potential (E_{corr}), corrosion current density (i_{corr}), cathodic & anodic Tafel slopes (b_c&b_a),polarization resistance (R_p), and corrosion rate (C_R) in the absence and presence of uric acid with two concentrations at pH=7.4 and temperature 37ºC.

Alloys	*Medium*	*$-E_{corr}$ (mV)*	*i_{corr} ($A.cm^{-2}$)*	*$-b_c$ ($mV.dec^{-1}$)*	*b_a*	*R_p ($\Omega.cm^{-2}$)*	*C_R (mm/y)*
SS 316L	SBF only	437	1.693 e^{-5}	075	333	5.229 e^{2}	1.752 e^{-1}
	SBF+7g/dL uric acid	579	5.817 e^{-6}	057	128	4.288 e^{2}	6.017 e^{-2}
	SBF+12g/dL uric acid	650	6.129 e^{-6}	09	133	6.741 e^{2}	6.34 e^{-2}
Co-Cr-Mo	SBF only	677	6.311e^{-7}	101	07	4.859 e^{3}	6.946 e^{-3}
	SBF+7g/dL uric acid	066	3.652 e^{-6}	092	157	1.731 e^{3}	3.977 e^{-2}
	SBF+12g/dL uric acid	327	3.484 e^{-6}	109	111	1.507 e^{3}	3.794 e^{-2}

Effect of increases uric acid on electrochemical behavior of SS 316L indicates that presence of uric acid (7 and 12 g/dL) shift corrosion current potential to active direction and the corrosion current density value became lower, also cathodic and anodic Tafel slopes (b_c & b_a) were lowered indicating the decreases in corrosion rate values as shown in Table (3).

The presence of uric acid with two concentration shift the corrosion potential of Co-Cr-Mo alloy toward noble direction, but increases the corrosion current density and anodic Tafel slop. From general comparison between behaviors of SS 316L and Co-Cr-Mo alloy, can be seen that the corrosion rate for Co-Cr-Mo alloy was better than SS316L.

Clinicians should be aware of the possibility of implant-related immune activation when patients develop symptoms of arthritis after receiving implants. Diagnostic testing by tumor necrosis factor (TNF) -release assay could be a diagnostic tool in these patients, although comprehensive studies are needed to test the validity of this method of diagnosis in broader populations. The arthritic complaints were alleviated in the case patient following removal of the implant [20].

In Co based alloy, cobalt is transported from tissue to the blood and eliminated in the urine within 48h, while chromium builds up in the tissues and red blood cells [21]. The only ion taken up intracellular by red blood cells following corrosion of alloy is Cr^{6+}, which is then rapidly converted to Cr^{3+}. When comparison the Cr wt% between two implant can be observed that Cr content in Co-Cr-Mo alloy is the most, therefore the last alloy become more resistance than SS 316L.

Morais et al. [22] found that chromium and nickel are retained in bone marrow. Nickel is very small and has a low affinity for blood cells. Cobalt binds to both red blood cells and white blood cells. Although only very small quantities of Cr^{3+} bind to cells, Cr^{6+} binds very strongly to red blood cells and white blood cells [23].

While Eddie et al. [24] studied cobalt complexes as antiviral and antibacterial agents through Co^{2+} complexes containing N,O donor ligands (CTC), which used as class of drugs were performed using a rabbit eye model infected with Herpes simplex Virus type 1 (HSV-1) and all complexes inhibited HSV-1 replication in vitro with as little as 5µg/ml required for strong antiviral activity.

CONCLUSIONS

In this work, corrosion behavior of SS 316L and Co-Cr-Mo alloys were studied in presence of uric acid in human body, and the conclusions drawn from this study Co-Cr-Mo alloy has less corrosion rates than SS 316L in the same condition due to chromium content which is builds up in the tissues and red blood cells. While cobalt is transported from tissue to the blood and eliminated in the urine within 48h and cobalt binds to both red blood cells and white blood cells and iron form organometallic complexes.

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