The Influence of Porosity on Corrosion Attack of Austenitic Stainless Steel

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Abstract. Porous metals also known as metal foams is a metallic body having spaces or pores through which liquid or air may pass. Porous metals get an attention from researchers nowadays due to their unique combination of properties includes excellent mechanical and electrical, high energy absorption, good thermal and sound insulation and water and gas permeability. Porous metals have been applied in numerous applications such as in automotive, aerospace and also in biomedical applications. This research reveals the influence of corrosion attack in porous austenitic stainless steel 316L. The cyclic polarization potential analysis was performed on the porous austenitic stainless steel type 316L in 3.5% NaCl solution. The morphology and the element presence on the samples before and after corrosion attack was examined using scanning electron microscopy (SEM) and energy dispersive x-ray (EDX) respectively to determine the corrosion mechanism structure. The cyclic polarization potential analysis showed the result of (E_{corr}) for porous austenitic stainless steel type 316L in the range of -0.40v to -0.60v and breakdown potential (E_{b}) is -0.3v to -0.4v in NaCl solution.

1. Introduction

Porous metals and cellular structure are artificial metals that have pores in their bodies and having large volume of porosities. The interesting combination properties of porous metals are availability to maintain their mechanical properties at higher temperatures, lightweight while be able to be strong and stiff, capability of absorbance in energy, vibration and sound, and great thermal conductivity. Porous metals are essentials for a wide range of industrial technologies includes filters, electrodes, catalysts, heat exchanger and excellent for medical devices such as implants[1,2]. With an advanced in medical technology nowadays, porous metals has been applied in biomedical application such as in orthopaedic, dentistry, surgical instruments, cardiovascular surgery, and neurosurgery[3]. Thus, it is important to produce the porous metals that have high porosity and excellent in mechanical properties to provide synergy effect between implant and the bones to avoid implant loosening to happen[4].

Metals such stainless steel, cobalt-base alloys, and titanium-base alloys have been successfully used as biomaterials implants due to their excellent characteristics such as ability to provide good mechanical properties, high corrosion resistance and biocompatibility. Research has proved that stainless steel was widely used to fabricate implants due to their ability to withstand significant loads,
fatigue resistance, high fracture toughness and corrosion resistance [5]. SS316L have the low carbon content in their composition and able to produce passive layer (chromium oxide) to protect from corrosion attack. Since, corrosion attack on stainless steel become a serious problem due to possibility of implant to sudden falling continuous exposed of extracellular tissue fluid after implanted may exposed the human body to contamination of corrosion. The surface of the implant will interact with the surrounding environment of human body which contains water, complex organic compounds, dissolved gasses will trigger chemical reactions to cause implant degradations. In addition, the reaction between SS316L implant will release Fe, Cr and Ni ions and lead to allergens and carcinogens which harmful to human body[6].

It has been reported that pitting and crevice corrosion attack are the main reasons of the failure of SS316L implant. Pitting corrosion happened when passive film on SS316L breached and exposed the surface for another corrosion attack due to existing surrounding of tissue fluid and serum. Not only pitting, crevice corrosion may also happen between bone plate and screws made from SS316L such as between the heads and the countersink holes [6]. Previous researchers has established that; fabricate porous metal by using stainless steel type 316L exhibited poor corrosion resistance because of porous surface geometry[7]. However, there are lacks of study in corrosion attack of porous metal for biomedical applications especially for implant. Advanced in medical technology clearly demand for porous metal as an implant. Therefore, continuing research are essential for better understanding of how corrosion mechanism on porous metal and could continue the manageable implant failure in medication[6].

The aim of this research is to study the effect of corrosion attack on porous SS316L. The cyclic polarization potentiodynamic analysis has been performed to the porous SS316L in the 3.5% NaCl solution. The morphology of the porous SS316L before and after performing cyclic polarization potentiodynamic analysis was investigated by using scanning electron microscopy (SEM). The element presence to the porous SS316L before and after cyclic polarization potentiodynamic analysis was is determined by energy dispersive x-ray (EDX).

2. Methodology
As per received porous SS316L was used represent as implant material. The preparation starts with cutting the samples into size 2cm length with an exposed area 2.5cm². The cyclic polarization potentiodynamic analysis was carried out with the working electrode (SS316L) in 3.5% NaCl solution at room temperature. By using potentiostat apparatus the scan rate has been set to 0.25 mV/s. The NaCl solution was prepared by diluting 35 gram of NaCl particles with 1000ml distilled water. The potentiodynamic cyclic polarization analysis was repeated to get statically acceptable results. The characterization of the morphology before and after performing cyclic polarization potentiodynamic analysis of the porous SS316L samples was evaluated by using Hitachi Scanning electron Microscopy while the energy dispersive x-ray was performed to study the element present to the samples.

3. Result and Discussion

3.1 Potentiodynamic cyclic polarization analysis
Figure 1 presents the result of CPP of porous SS316L. The cyclic polarization potential curve in all solutions are shifted in positive hysteresis may be subjected to the susceptibility to pitting corrosion happen to the samples in NaCl solution. The corrosion potential (E_{corr}) of porous austenitic stainless steel type 316L are in the range of -0.40V to – 0.60V in NaCl solutions. Previous studies claim that, the austenitic stainless steels with higher chromium, molybdenum, nickel, and nitrogen exhibit higher E_{corr} value and improved the pitting corrosion resistance[8]. The breakdown potential (E_b) of porous SS316L are in the range of -0.30V to -0.40V in NaCl solution. E_b is where potential starts to slow down at increasing current. This is where the passive film starts to breach and exposed stainless steel for another corrosion attack.
3.2  Morphology analysis of porous austenitic stainless steel type 316L

Figure 2 shows the SEM micrograph with the magnification of 500x and 1000x of the samples surface morphology before performing cyclic polarization potentiodynamic test. The surface of porous SS316L was polished using sand paper with the grit size of 600, 800 and 1000 in order to obtain the clear view of pores before performing corrosion test. From Figure 2(a) and 2(b), it can be seen that the fine pores already exist in sample before the corrosion test was performed. The size of the pore approximately to 6µm and can be categorized as micropores and the structure of the pore can be see clearly at the SEM micrograph with magnification 1000x.
Figure 3 shows the SEM micrograph of the samples before and after performing cyclic polarization *potentiodynamic* analysis. *It can see from the Figure 3(b) that parallel corrosion pits form on the surface of the samples after corrosion test.* Pitting holes starting to enlarge and become local anodic which creates another corrosion to happen.

![SEM micrograph of the samples before and after performing potentiodynamic cyclic polarization test](image)

Figure 3(c) shows the EDX spectrum of the samples after performing corrosion test. Figure 3(d) displays the focus area of EDX analysis which pitting holes on the samples surface formed. As mentioned, SS316L rich with the element iron (Fe) and from the EDX analysis, the element of iron (Fe) was dominated on SS316L surface samples. The element of carbon (C) recorded highest value and signify the standard of carbon content in SS316L. However, the high amount of carbon element can be neglected due to the use of carbon electrode during performing potentiodynamic cyclic polarization analysis.

Figure 4 shows the SEM micrographs with the magnification of 100x surface of SS316L before performing corrosion test and after corrosion attack in 3.5% NaCl solution. Figure 4(b) displays the formation of branching and clustered crystallite structures on the surface of the porous SS316L. The corrosion product form in irregular structure at the SS316L surface after the testing. The same structure also obtained by previous researcher that study the corrosion behaviour of self-ligating and conventional metal bracket [10]. Figure 4(c) presents the EDX spectrum for the focus area that displays on Figure 4(d) which branching and clustered crystallite structure was formed in the surface of the sample after corrosion test. The element of iron is the highest element in the composition followed by sodium (Na), carbon and chloride (Cl).
Figure 4. SEM micrograph of the sample a, b) before and after performing potentiodynamic cyclic polarization test, c) EDX spectrum of the samples, d) branching and clustered crystallite structures on the sample surface.

Figure 5 compares the SEM micrograph for the surfaces structures of the samples before and after performing potentiodynamic cyclic polarization analysis. As shown in Figure 5, the particles of corrosion product appear on the surfaces of the samples after corrosion test. Figure 5(c) provides the EDX spectrum of the samples that consist of the particles. The iron element dominates the composition of the samples compare to other element followed by chromium (Cr) content that sufficient into the composition of the samples. Generally, austenitic stainless steel consists of different composition such as chromium, molybdenum, nickel, and etc. These contribute to galvanic effect. Galvanic is the effect from the two different of metal combine together, and exposed to the oxidize atmosphere and then start to corrode and produce the galvanic effect. Moreover, the other elements such nickel and chromium that consist in austenitic stainless steel will react and produce the oxide layer with the aim of increasing resistance to stainless steel [10].
Figure 5. SEM micrograph of the sample a,b) before and after performing potentiodynamic cyclic polarization test, c) EDX spectrum of the samples, d) particles of corrosion product appear on the sample surface.

4. Conclusion
Cyclic polarization potentiodynamic analysis successfully performed in order to study the corrosion attack to the porous SS316L. From the result, the anodic polarization curve recorded the result of \( E_{corr} \) for porous SS316L in the range of -0.40v to -0.60v and breakdown potential \( E_b \) is -0.3v to -0.4v in NaCl solution. From the SEM observation, there are three types of formation happen to the surface due to corrosion includes the in line formation of corrosion pits, the formation of branching and clustered crystallite structure, and the formation of the particles of corrosion product. Based on EDX analysis, the dominant element in the composition of the porous SS316L after performing cyclic polarization potentiodynamic analysis is iron and followed by chromium and carbon. It can be conclude that, the pore structure and morphology of the porous austenitic stainless steel type 316L influence the corrosion attack.

5. References
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