VOL. 11, NO. 18, SEPTEMBER 2016 ISSN 1819-6608

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

EFFECT OF CUTTING SPEED ON BIO-CORROSION OF AISI 316L STAINLESS STEEL

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ABSTRACT

Stainless steel of AISI 316L type (SS316L) has been widely used as metallic biomedical implants material because of it offers good characteristics, including high mechanical properties and biocompatibility, and relatively low cost. However, its machinability an issue, with relation between cutting parameters and surface roughness is of interest to be considered. Related to this, its corrosion behavior related to cutting parameters also needs to be taken into consideration due to its application in implants. This study investigates the biocorrosion behavior of AISI 316L stainless steel which was machined by face milling at different cutting speeds. The cutting speeds were 100, 300 and 500 m/min while feed rate and depth of cut was kept constant. Initial assessment was done on the surface roughness of the face milled samples, with initial hypothesis that the surface roughness should be constant for all cutting speeds, with Ra to be within 0.8 - 1.2 µm. Biocorrosion test was then performed on the samples by Potentiodynamic Polarization Test under a simulated body fluid (SBF) electrolyte. It was found that although similar surface roughness is expected, the cutting speed affected the surface roughness in which the surface roughness tended to be inversely proportional to the cutting speed. Samples machined at the highest cutting speed was observed to have smooth surface with less defects, such as pits and grooves, compared to samples machined at lower cutting speeds. Related to this, the corrosion behavior of the AISI 316L stainless steel was also affected by the cutting speed during its face milling where the corrosion rate is inversely proportional to the cutting speed.

Keywords: metallic implant, face milling, cutting speed, surface roughness, surface characteristic, corrosion behavior.

INTRODUCTION

Accidents involving vehicles such as cars, motorcycles, and buses and etc. show increasing trend every year, with bone fractures as one of the major problems. A considerable percentage of these fractures are too complex to medicate externally and the preferable solutions require bone fixation by using bone implants [1].

Stainless steel, in particular of 316L type is widely used as medical implants because of their relatively low cost, excellent biocompatibility, high strength, and reasonable chemical stability. Some of these positive characteristics come from the formation of a stable passive layer on its surface, making them highly corrosion resistant [2 - 4]. However, 316L stainless steel still has problems in clinical uses related to their corrosion behavior, in which it sometimes corrodes excessively when implanted [5]. It is unavoidable that metals experience electrochemical dissolution with different extent when exposed to human body which consists of an ample amount of fluids, minerals such as chlorides, amino acids, and proteins. Such corrosion leads to concerns about leaching of harmful metallic ions into the body [4]. Hence, corrosion behavior of the stainless steel is of primary importance especially when subjected to human body environment.

Bio-corrosion is described as corrosion behavior in medical implant that is exposed to and is influenced by biological environment in human body [6]. It has been considered as one problem for durability of implants for prolonged use in human body. This is related to the release of metal ions which may cause various deleterious phenomena, inciting allergies (metal allergy), adverse physiological effects, toxicity, and carcinogenicity [3, 7]. Besides that, a large amount of released metal ions also could be harmful to human health and may eventually lead to severe complications and failure of the implant system [7]. Therefore, bio-corrosion of implant materials is a significant topic in biomedical applications.

In processing the stainless steel into implants, machining is a commonly used process. The quality of a machined component is becoming more important due to the increasing demand for high performance, longevity, and reliability. This is especially the case for manufacturing process of implants. These demands can be met by producing good surface integrity of the machined surface which includes fine surface roughness. Machining is usually performed to produce near net shape or as finishing process. When machining is used as finishing process, the range of expected surface roughness value, Ra, is typically between 0.75 – 1.5µm [8]. Theoretically, surface roughness is a function of the tip radius of the cutting tool and also the feed rate. Nonetheless, we have identified that it is also a function of other machining parameters, such as cutting speed and depth of cut as well as other machining conditions. In this study, we are interested in analyzing the effect of cutting speed to the surface roughness. Further, related to the intended application of the stainless steel as implants material, the effect of cutting speed to the corrosion behavior of the stainless steel is also of interest.

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METHODOLOGY

The workpiece material was an AISI 316L stainless steel (ASSAB Steel, Malaysia). Sample preparation was done first by removing oxide layer on the bulk samples' surface by milling. The main experiment was then conducted by face milling process using Mazak 410A-II CNC milling machine. Cemented carbide inserts (Kennametal) were used as the cutting tool in this machining process. After the oxide layer was moved, the substrate was subjected to milling process at three different cutting speeds, i.e. 100, 300, and 500 m/min. The cutting speeds and other machining parameters (e.g. feed rate and depth of cut) were selected from the cutting tool's manufacturer to obtain the surface roughness of 0.8 - 1.2 μm. After the machining, the samples were cut to make blocks of 10 mm x 10 mm x 10 mm. Five samples per cutting speed were prepared. The surface roughness of the samples was measured using portable surface roughness tester machine. After that, surface characterization was conducted by using Scanning Electron Microscopy (SEM) and followed by corrosion testing using Potentiodynamic Polarization Test. The polarization test was carried out to study the corrosion behaviour of the AISI 316L stainless steel in simulated body fluid (SBF). The equipment consists of a three-electrode cell assembly with corroded 0.402 cm^2 surface areas per sample. The SBF used in this study was saline solution that was prepared by mixing sodium chloride in distilled water. The electrochemical cell with three electrodes was connected to VersaSTAT Instrument Potentionstat and VersaSTAT software was controlled by computer to measure the polarization curves of samples.

RESULTS AND DISCUSSION

Surface roughness

Considering the face milling was done at the same feed rate and using the same type of cutting tool, it was expected that the surface roughness to be similar, within the value of Ra between 0.8 and 1.2 μm. The results as shown in Figure-1 showed that the surface roughness values were within the expected range. However, it was found that there is tendency that the increase in cutting speed reduces the surface roughness.

Although not as expected, the trend that the surface roughness is inversely proportional to cutting speed is in agreement with previous work [9]. However, in the reference, there was no satisfactory explanation on why the phenomenon occurred.

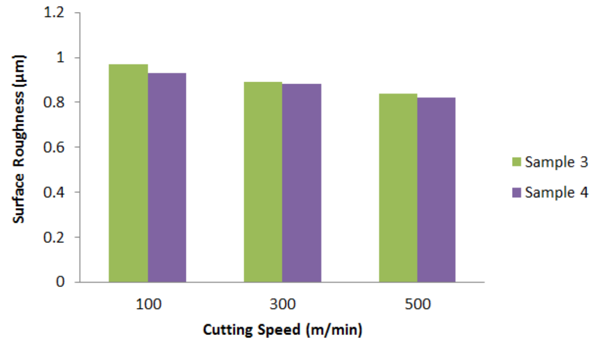


Figure-1. Surface roughness versus cutting speed for two selected samples

Surface morphology

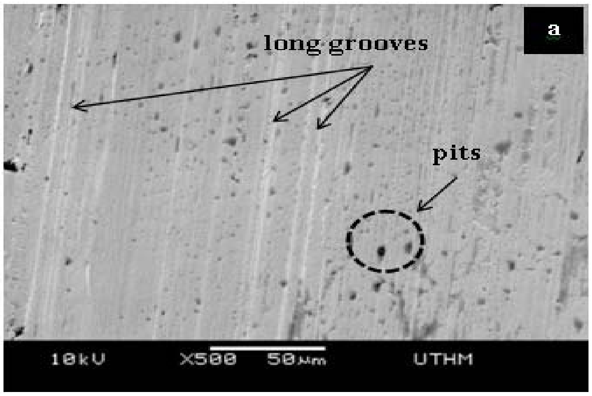
Figure-2 represents the surface of machined samples under observation using Scanning Electron Microscopy (SEM) with 500x magnification to assess the surface morphology. The machined surface consists of long straight grooves as the feed marks and of ridges in between the grooves from the tool's rubbing action. This is typical on surface of machined steel [9]. The machined surface produced at cutting speed of 100 m/min shows pits. For surface produced at higher cutting speeds, the presence of pits was fewer. There was less clear differentiation between feed marks and ridges at surfaces produced by high cutting speeds. From these, the finer surface produced at higher cutting speed was likely due to less defects on the machined surface. Such fewer defects might be the result of machining at higher temperature induced by higher cutting speed.

Corrosion behavior

Bio-corrosion test in order to observe the corrosion behavior on the AISI 316L stainless steel using Potentiodynamic Polarization Test resulted in polarization curves as shown in Figure 3. The curves could then be processed to extract the corrosion potential, corrosion current density, and corrosion rate, as shown in Table 1.

The results showed that there is apparent difference in corrosion rate for the AISI 316L stainless steels machined at different cutting speeds. Generally, corrosion rate is lower for samples produced at higher cutting speeds. Possible reasons for this include the less surface area for samples produced at higher cutting speeds. Referring to the morphology, pits were more in existence for samples machined at low cutting speed. Also, referring to the surface roughness, there is good chance that lower surface roughness (which is produced at high cutting speed) means less surface area. Another possible reason is there were less peaks on the surface of the samples produced at higher cutting speeds. It is known that peaks are the sites prone to corrosion attacks. The higher the cutting speed, the less obvious the difference between feed marks and ridges, which means the peaks (and also the valleys) were less in sharpness and/or fewer in number.

VOL. 11, NO. 18, SEPTEMBER 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences



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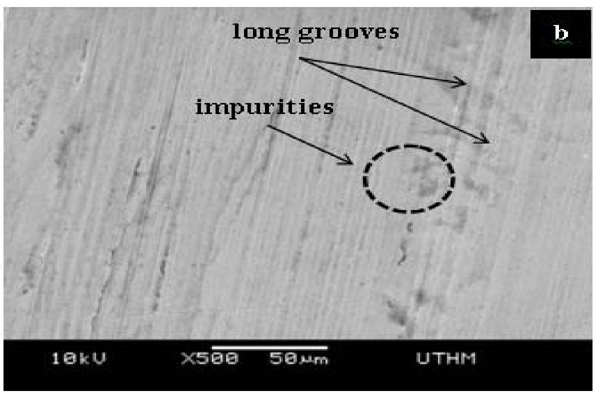

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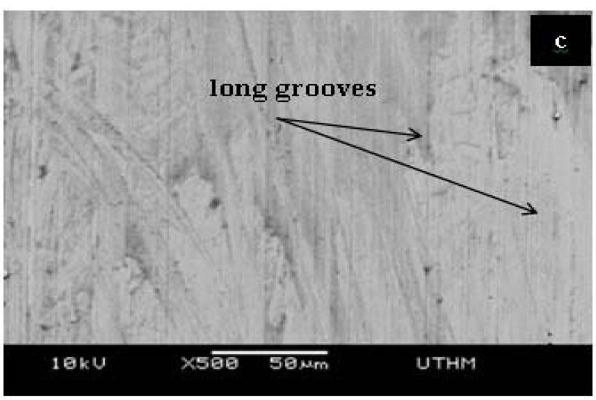
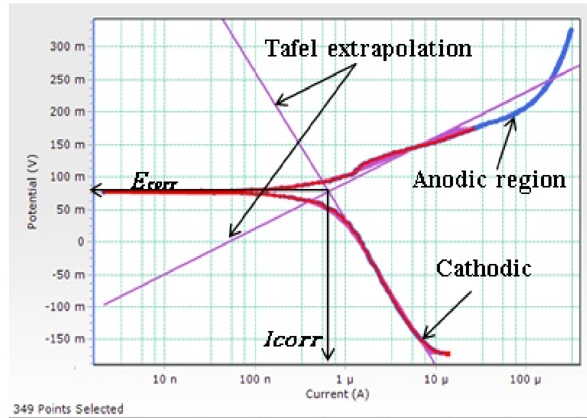


(c)

Figure-2. The surface microstructure examined by SEM with cutting speed: (a) 100m/min, (b) 300m/min, (c) 500m/min.

Aside from the surface area and presence of peaks, the tendency of pitting or crevice corrosion when the steel was exposed to chloride containing solution can also be the factor for the corrosion rate [10]. Moreover, they also mentioned that the chloride concentration also will cause pits nucleation. Besides, the pits produced from low cutting speed will provide chances of fast initiation to pitting corrosion and cause the corrosion rate increased.



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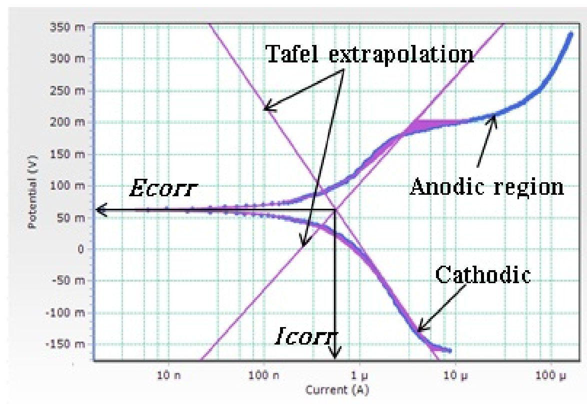

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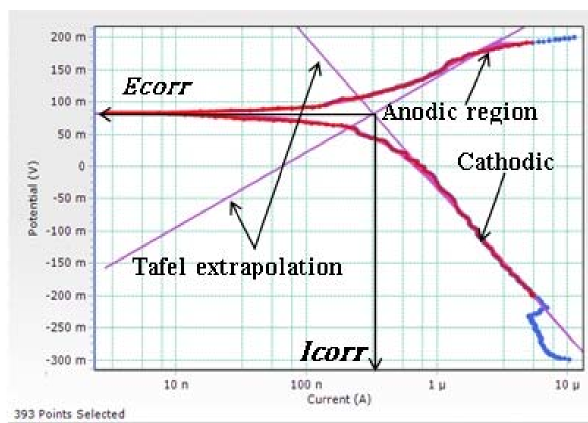

(c)

Figure-3. Tafel extrapolation at polarization curves of three cutting speed: (a) 100 m/min, (b) 300 m/min, (c) 500m/min.

From Figure-4 which shows the surface morphology after the potentiodynamic polarization test, the corrosion product on the surface was not apparent. It was as expected considering the high corrosion resistance nature of stainless steel.

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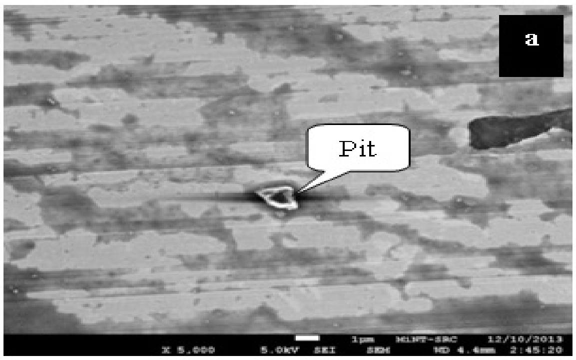
Table-1. Polarization parameters for 316L SS with different cutting speed.

Cutting speed, V (m/min)	Corrosion Potential, E_{corr} (mV)	Corrosion Current Density, I_{corr} (mA/cm²)	Corrosion Rate, R_M (μm/year)
100	77.498	654.329	37.920
300	62.723	564.968	32.741
500	82.440	325.464	18.861



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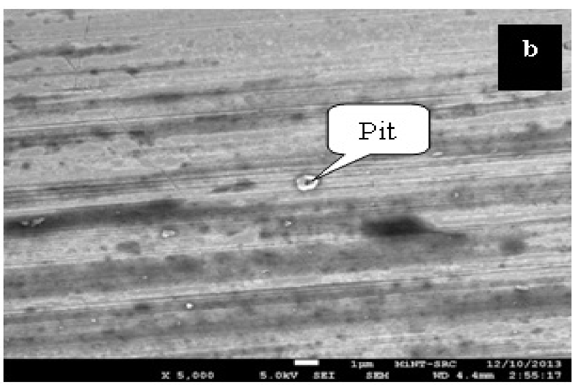

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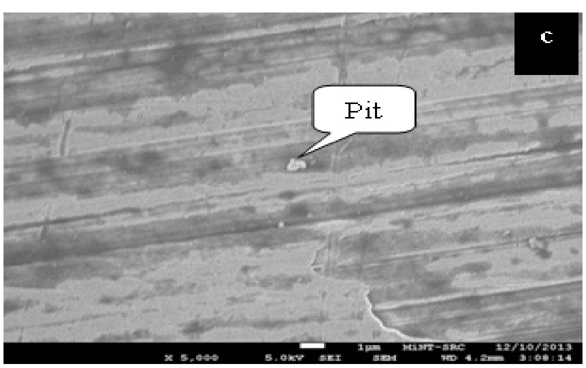

(c)

Figure-4. The surface microstructure examined by SEM after potentiodynamic polarization test. The mark area was the pit initiations occur at the surface with cutting speed at (a) 100 m/min, (b) 300 m/min and (c) 500 m/min.

Considering the values of corrosion rate which went down with increasing cutting speed, one can observe that the value is still not exhaustive. Further work is still needed to determine the cutting speed which can result in the lowest corrosion rate on face milled AISI 316L stainless steel.

CONCLUSIONS

An AISI 316L stainless steel was machined by face milling at different cutting speeds of 100, 300 and 500 m/min while keeping other machining parameters constant. The following conclusions can be summarized:

(i) Assessment on the surface roughness of the face milled samples shows that surface roughness of Ra = 0.8 - 1.2 μm was obtainable using the set machining parameters.
(ii) There was tendency that the surface roughness is inversely proportional to the cutting speed.
(iii) Samples machined at the high cutting speeds showed smooth surface with less defects compared to samples machined at lower cutting speeds.
(iv) The corrosion rate is inversely proportional to the cutting speed.

Overall, the result was encouraging in which corrosion rate can be affected by the cutting speed. Further work is still needed to provide better explanation on why the phenomena reported here occur. The next stage recommended is to determine the optimum cutting speed which can best suppress the corrosion rate.

ACKNOWLEDGEMENTS

Financial supports from the Research Acculturation Grant Scheme (RAGS) (vot R030) in Universiti Tun Hussein Onn Malaysia and Ministry of Higher Education, Malaysia through Fundamental Research Grant Scheme in Universiti Teknologi Malaysia (No. 4F285) are acknowledged.

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