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Investigations on Corrosion Behaviour in Micro-Milling of Biomedical Grade Ti-6Al-7Nb Alloy

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Abstract

Titanium (Ti) based alloy is extensively used in bio-medical field due to its unique properties that promotes osseo-integration. Present work deals with investigation on the effect of cutting conditions on corrosion resistance in micro-milling of Ti-6Al-7Nb alloy for enhanced biocompatibility. Experiments were carried out based on Taguchi L_9 Orthogonal array with selected process variables include Cutting Speed (v_c), Feed rate (f) and Depth of cut (a_p). Micro slot of size 700 µm for a length of 10 mm were made using high speed micromachining station under wet condition. Potentiostat setup with three electrodes and Simulated Body fluid (SBF) at 37^{o}C was used for corrosion resistance measurement and corresponding I_{corr} values were obtained from polarization curve.. I_{corr} values are found to be minimum at higher v_c and lower a_p conditions. From the study it is observed that Ti-6Al-7Nb alloy exhibits higher corrosion resistance under In-Vitro condition for enhanced biocompatibility for medical application.

Keywords: Biocompatibility, Corrosion resistance, Micro-milling, Ti-6Al-7Nb alloy.

1. Introduction

Titanium (Ti) is a non-cytotoxic element used for manufacturing biomedical implants. It is alloyed with many biocompatible elements like Tantalum (Ta) and Niobium (Nb) to reduce the young's modulus value (Mohamed et. al [1]). (Eisenbarth et. al [2]) described about replacement of Ti-6Al-4V with Ti-6Al-7Nb, due to the toxic nature of Vanadium (V) therefore V is replaced with Nb. Even after replacement, metallurgical and mechanical properties of Ti-6Al-7Nb alloy are similar to Ti-6Al-4V alloy. (Mobarak et. al [3]) investigated corrosion performance of Ti-6Al-7Nb alloy using Hank's solution and compared the results with Ti-6Al-4V alloy. Investigation results showed that Nb cations helped to increase resistance to corrosion by formation of TiO_2 film with less number of anion vacancies. (Assis et. al [4]) examined corrosion characteristics of Ti-6Al-4V, Ti-13Nb-13Zr and Ti-6Al-7Nb alloys by using Hank's solution and observed that, these Ti alloys had two oxide layers. A porous oxide film formed above barrier layer enhanced the corrosion characteristics. The porous layer of Ti–6Al–7Nb alloy increases the ability of osseointegration.

(Mohan et. al [5]) studied the development of TiO_2 layer formation on surface of Ti–6Al–7Nb alloy in electrolytic solution containing hydrofluoric and sulfuric acid. Variation in porous diameter of oxide layer was observed when there is a change in applied voltage. This nano structure helps in improvement of osteoblast cells attachment. (Kobayashi et. al [6]) evaluated the existence and growth of protective layer in Ti–6Al–7Nb alloy using anodic polarization and immersion test. It is inferred that, there is no sign of pitting corrosion. (Chrzanowski [7]) presented the influence of various surface treatment on topographical and corrosion properties on Ti alloy. The experimental results proved that, Ti-6Al-7Nb alloy possess superior corrosion resistance in SBF condition. (Carlos et. al [8]) experimentally investigated Ti-6Al-7Nb alloy under micro cutting conditions. The result shows that, the cutting quality can be improved by increase of v_c. It was also indicated that, spindle speed increment results minimization of heat generation on the tool. (Leo et. al [9]) performed a review on tool based micromachining process and mentioned the importance of surface characteristics for various micro part fabrication.

From the literatures it is observed that, Ti-6Al-7Nb alloy can be used as a biomaterial for medical implants. The human body is a highly corrosive environment, as a result it is mandatory to investigate the corrosion resistance of machined implant surface.

2. Materials and Methods

In this work Ti-6Al-7Nb is chosen due to its biocompatible properties and their availability. Taguchi experimental design has been incorporated and process variables include f, v_c and a_p are considered for the study of corrosion resistance. The workpiece of size 20×20 mm has been used for investigation. Micro milling experiments are carried out in CNC micromachining station. The machine is precision enough to produce micro feature with positional accuracy of ± 1 μm with high spindle speed capable of running up to 60,000 rpm. Tungsten carbide tool of size 700μm diameter with two flute end mill cutter is used for experimentation. Micro milling experiments were carried out under wet condition with mist cooling facility. Experimental setup is shown in figure 1.

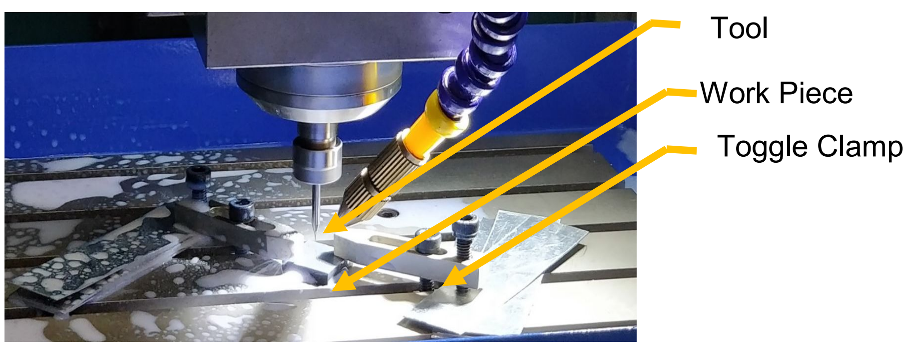

Fig. 1. Micro Milling Experimental Setup

Corrosion test was carried out with the help of potentiostat setup. It consists of a flat cell and three electrodes namely working electrode (work material), reference electrode (Silver (Ag)) and counter electrode (Graphite). In order to perform corrosion study, SBF is used for in-vitro study. The solution possess pH level of 7.4 ± 0.1 with acid-base. The test was carried out for an hour at temperature of 37±1.0ºC. Fresh solution is prepared for each trial and the potentiostat setup has been used for measuring corrosion resistance.

3. Results and Discussion

From potentio-dynamic study, Nyquist plot and Tafel plot were generated from experimentation. Tafel plot is used to identify rate of pitting and corrosion susceptibility by plotting relation between electric potential and current density. Further cathodic polarisation curve and anodic polarisation curve were extrapolated and their intersection point provides E_{corr} and I_{corr} values. E_{corr} value is open circuit potential of metal in a liquid environment and I_{corr} values influence corrosion rate. Electrochemical Impedance Spectroscopy (EIS) or Nyquist plot is used to find electrochemical impedance of Ti alloy. Electrochemical impedance is the response of an electrochemical system to an applied potential is complex in nature. Hence in Nyquist plot Z_{real} is plotted against $Z_{imaginary}$, in which impedance is measured as a function of frequency.

Table. 1. Experimental Results on Corrosion Resistance

Ex. No	Cutting Speed (m/min)	Feed Rate (mm/min)	Depth of Cut (µm)	E_{corr} mV	I_{corr} nAm^2
1	31.4	0.5	100	-174	688
2	31.4	1	150	-290	3250
3	31.4	1.5	200	-250	2130
4	39	0.5	150	-491	711
5	39	1	200	-477	2290
6	39	1.5	100	-288	1120
7	47	0.5	200	-299	961
8	47	1	100	-318	1860
9	47	1.5	150	-522	576

From Tafel plot, I_{corr} and E_{corr} values are obtained as shown in table 1. These values were further investigated to study effects of v_c, a_p and f on corrosion behaviour. The Tafel and nyquist plot for machining conditions of v_c=47 m/min, f=1.5 mm/min a_p 150 µm is shown in figure 3 (a) and (b). The I_{corr} value is obtained from the polarisation curve by cathodic branch of polarisation curves to corrosion potential were found to be 576 nA and -522 mV respectively. The resistance offered by material increases with respect to time and initial increment is due to formation of very thick oxide film on surface that leads to improvement of corrosion protection ability. The tafel and nyquist plot for cutting conditions of v_c=31.4 m/min, f=1 mm/min a_p=150 µm is shown in figure 4 (a) and (b). A sharp increase in current density at level of potentials above 0.0V (SCE) was identified. This suggests that oxide film is getting replaced gradually by a less protective passive film. The resulted passive film becomes stable approximately above 500mV (SCE). The formation of protective passive film is distinguished by i_{corr} value of 3.25 μAm^2.

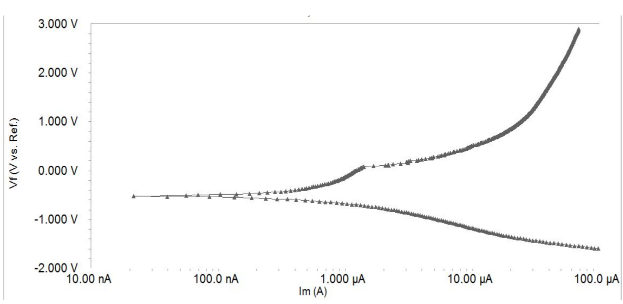

Fig. 3(a). Tafel Plot

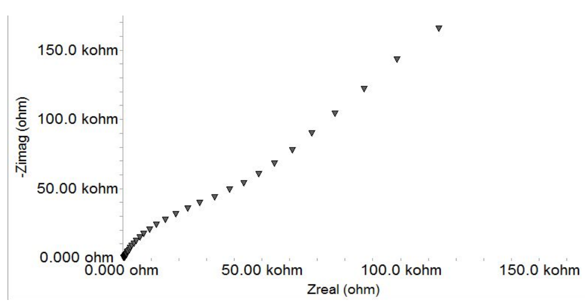

Fig. 3(b). Nyquist Plot

Fig. 3. Tafel and Nyquist Plot for Cutting Conditions of v_c= 47 m/min, f=1.5 mm/min a_p=150 µm

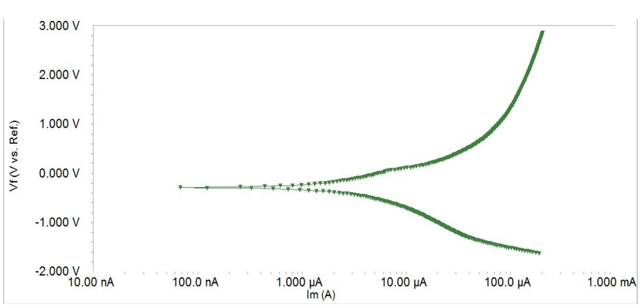

Fig. 4(a). Tafel Plot

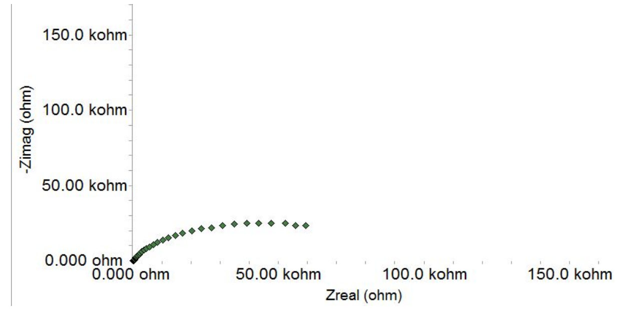

Fig. 4(b). Nyquist Plot

Fig 4: Tafel and Nyquist Plot for Cutting Conditions of a_p= 31.4 m/min, f=1 mm/min a_p=150 µm

3.1 Influence of Cutting Parameters on Response

The intearction of f, v_c and a_p on corrosion resistance were investigated. From corrosion study, it is observed thatl implants should have very less I_{corr} value inorder to have better corrosion resistance. It is identified that increment in v_c and decrease in a_p condition has major influence on corrosion resistance as shown in figure 5. It clearly shows that, a_p and v_c has significant effects on I_{corr} value. It is attributed by improvement in surface quality creates residual compressive stress within the subsurface i.e. chemical species adsorption resistance along with low roughness which prevents initiations of surface pores and twinning which were potential in influencing corrosion. It is inferred that, increase of v_c reduces micro particle deposition that promotes better surface finish attributing to improved corrosion resistance.

Fig. 5. Effects of v_c, f and a_p on Current Density (I_{corr})

4. Conclusion

In this work, an effort has been made to analyze the effect of micro milling cutting conditions on corrosion behaviour in Ti-6Al-7Nb alloy. I_{corr} and E_{corr} value for the cutting conditions were obtained from Tafel and Nyquist plot and the following conclusions are drawn:

- The potentio-dynamic polarization test shows that the influence of v_c and a_p on I_{corr} value is higher.
- The minimum value of I_{corr} obtained is 576 nA at v_c=47m/min, f=1.5mm/min.

- It is observed that at higher level of v_c, higher feed and lower a_p condition, the corrosion resistance of Ti-6Al-7Nb is found to be high under In-Vitro condition.
- Variation in process parameters influences the surface characteristics to a greater extent, which intern alters the corrosion resisting potential of surface.
- The EIS result proves oxide film formed on Ti-6Al-7Nb is submissive at initial time, after which, the curve indicates formation of a strong bi-layered oxide film.

From the investigation, it is inferred that, the machined surface characteristics have a great influence on the corrosion behaviour of Ti-6Al-7Nb alloy.

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