Proceedings of 10th International Conference on Precision, Meso, Micro and Nano Engineering (COPEN 10)
December 07 – 09, 2017, Indian Institute of Technology Madras, Chennai – 600 036 INDIA

Investigations on Surface Morphology Micro-milling of Ti-6Al-7Nb Alloy for Biomedical Application

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Abstract

Titanium-Niobium (Ti-Nb) based alloys predominantly used as an implant material in Bio-medical field due to its unique characteristics such as non-toxicity, better Osseo-integration and high strength to weight ratio. The objective of the present work is to investigate surface morphology in micro-milling of Ti-6Al-7Nb alloy in order to analyze the effect of cutting conditions on surface texture. Response surface methodology based experiments were carried out based on process variables include spindle speed, feed rate and depth of cut on Arithmetic Average Surface Roughness (Ra). Micro slot of size of 500 µm produced for a length of 10mm using Tungsten Carbide flat end mill cutter under dry cutting condition. Surface morphology study was carried out and surface damages were analyzed using Scanning electron microscope. Various damages include micro particle deposition, over lapping grooves and micro burr were observed at the machined area. It is observed that, cutting conditions of spindle speed 12000 rev/min, feed 110 mm/min and depth of cut 105 µm yields minimum surface damage include micro particle deposition and grooves formation.

Keywords:Micro-milling, Ti-6Al-7Nb alloy, Average Surface Roughness, Surface Morphology

1. INTRODUCTION

The use of Titanium (Ti) and Ti alloys for medical and dental applications are increased dramatically in recent scenario. Ti and Ti alloys especially suitable for dental implants and prostheses due to their physical and chemical properties, Siddharth et al. [1]. Ondrejet al.[2] evidently reported that , the most important characteristic of dental implant made of biomaterials is the ability to create correct interaction between implant and bone tissue. Since most of the implant surface is in direct contact with bone tissue, shape and integrity has great influence on successful Osseo-integration. In order to increase the success rate of dental implants, research have focused on the control of surface properties such as morphology, topography, roughness, chemical composition, surface energy, residual stress, the existence of impurities and the presence of metallic and nonmetallic compounds on the surface. These properties have major impact on tissue response to the implant. Proper osseointegration and increasing or decreasing of healing time mainly depends on the surface properties of the implant. Xiong et al. [3] described various methods used to develop morphological structures of Ti implant surfaces for promoting bone ingrowth and fixation between implants and bone. Among them, powder/fiber/wire mesh metallurgical sintering, plasma spray processing and surface blasting are the widely used methods to modify surface topography of load-bearing Ti implant surfaces. These methods have adverse effects on mechanical properties due to the possibility of residual stress from high temperature process and stress concentrations at the interface between the porous layer and the substrates. Also, these methods generate irregular and random surface geometry.

Arithmetic Average Surface Roughness (Ra) generally plays an important role in wear resistance, ductility, tensile and fatigue strength for machined parts. Pedro et al. [4] performed a comprehensive study on the surface roughness of the machined surfaces and cutting parameters such as feed rate as well as machining strategies were varied to optimize micro milling. Dornfeld et al. [5] reviews some of the main drivers, developments and future requirements in the field of micro manufacturing as related to the machining process from the perspective of the recent research and development literature. Cuia et al. [6] described that commercially pure Ti and Ti-6Al-4V alloy have been used as surgical implant in the past years but some defects such as comparatively low strength and potential toxicity of Vanadium element limit their further applications. Ti-6Al-7Nb alloy with non-Vanadium, has gradually substituted pure Ti and Ti-6Al-4V. As α+β type alloy Ti-6Al-7Nb has moderate strength, high temperature plasticity and suitable to fabricate the complicated surgical implant. XuLi et al. [7] mentioned that the crystal structure and morphology of Ti-Nb alloys are sensitive to their Niobium (Nb) content. When Nb content is 5%, the acicular α crystal grain is observed. For Ti-Nb alloys, the increase of Nb content modifies the microstructure of Ti-Nb alloys significantly and decreases their compression elastic modulus. Liu et al. [8] discussed that chipload varies continuously during continuous engagement of a tooth in the cut and owing to the very small chip loads; the size effect plays a significant role. Surface quality reflects a set of properties include roughness, color, polarity and morphology, Kakaboura et al. [9]. Rama et al. [10] reveals that even though micro milling process have been well suited to manufacture implants with various surface morphologies, the effect of surface morphology on the long term biological compatibility and osseointegration has not been well established. Leo et al. [11] explain that micromachining is the fundamental technology to assuage the needs of the industries in terms of miniaturization in size. Leo et al. [12] performed an experimental investigation on micro end milling to analyze the impact of process conditions on surface roughness and machining time. Using genetic algorithm optimization for minimization of responses is carried out.

ISBN: 978-93-80689-28-9

2. MATERIAL AND METHODS

Ti is an optimum choice for many critical applications by virtue of merging various properties such as light weight, high strength-to-weight ratio, excellent mechanical properties, high corrosion resistance, biocompatible, non-toxic, long-lasting, better osseointegrated and long range availability. Titanium and its alloys play a major role as implant materials for a specific reason of rapid and proper osseointegration. The Ti-Nb based alloy enclosing 6%Al and 7%Nb (Ti-6Al-7Nb) is widely used as prosthesis material owing to its superior mechanical and biocompatibility properties. The recent study evidentially proves that appropriate structural and functional connection of the implant with living bone relies on the surface characteristics such as Ra of the implant. Usually implants are smaller in size with many micro features involved. Therefore micro milling is widely used as a manufacturing process for prosthesis to obtain the required micro features and surface characteristics. In real terms, there are manifold factors include cutting conditions, tool geometry, run- out, workpiece and tool material, vibration and chip formation impinge Ra to a greater extent. Control of convoluted micro end milling process and selection of pertinent cutting tool to meet the requirement for accuracy is an important issue.

High speed Computer numerical control machine with 18 kW power and maximum spindle speed of 18000 rpm was used for experimentation. Spindle speed, feed rate and depth of cut are chosen as the process parameters. Ra is taken as the response parameter. Design of experiment was done based on Response surface methodology approach and 20 experimental trials were carried out.The workpiece of size (50x50x3mm used for experimentation. The tool of size 500µm diameter made of Tungsten Carbide (WC) with a shank diameter of 6mm with a overall length of 55mm.All the experiments were conducted in dry condition. Slot of size 500µmwidth for a length of 10mm were machined based on the experimental trials and machined slot is shown in the figure 1.

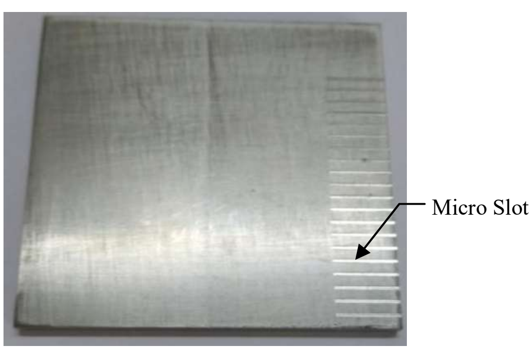

Fig 1 Ti-6Al-7Nb Alloy with Micro Slot Feature

Ra measurements were carried out using surface roughness tester for each slot. Ra heights are measured in micro inches or micrometers. Cutting conditions for each slot along with the response value is shown in Table 1.The graph representing surface roughness under various cutting conditions of experimental trial is shown in figure 2.

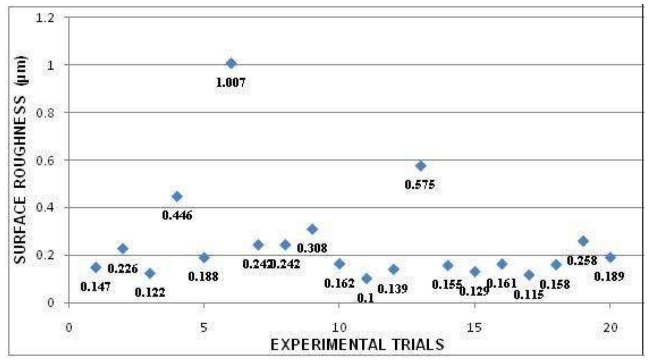

Fig 2 Observed Surface Roughness Results

Table 1: Experimental Results

Exp. No	Spindle Speed (rev/min)	Feed Rate (mm/min)	Depth of Cut (µm)	Surface Roughness Ra (µm)
1	14000	110	105	0.147
2	14000	110	60	0.826
3	14000	110	105	0.122
4	16000	100	150	0.146
5	12000	100	60	0.188
6	14000	110	150	1.007
7	16000	100	60	0.242
8	16000	120	150	0.242
9	14000	110	105	0.308
10	16000	110	105	0.162
11	12000	110	105	0.100
12	14000 Tool	110	105	0.139
13	12000	100	150	0.575
14	14000	110	105	0.155
15	14000	100	105	0.129
16	12000	120	60	0.161
17	14000	110	105	0.115
18	12000	120	150	0.158
19	14000	120	105	0.258
20	16000	120	60	0.789

3. RESULTS AND DISCUSSION

Morphology study of solid surfaces exposes their structure on a scale of nanometers (nm) to micrometers (µm). Surface morphology becomes the governing factor in a number of practical processes, including crystal growth, etching, machining etc. In developing aquantitative understanding of these processes, it is significant to understand the morphology of the surface. The surface profile was extracted from Scanning Electron Microscope (SEM).

The machined surfaces were examined to explore the surface irregularities produced during machining of Ti (Ti-6Al-7Nb) alloy at magnifications from 100xthrough SEM. Surface morphology of machined surface was obtained for each machined slots to perform a detailed study of the machined surface. The figures 3, 4 and 5 shows the surface generated under dry machining with different cutting conditions. The surface generated under dry machining for the cutting conditions speed 12000 rev/min, feed rate 110 mm/min, depth of cut 105 µm is shown in figure 3.

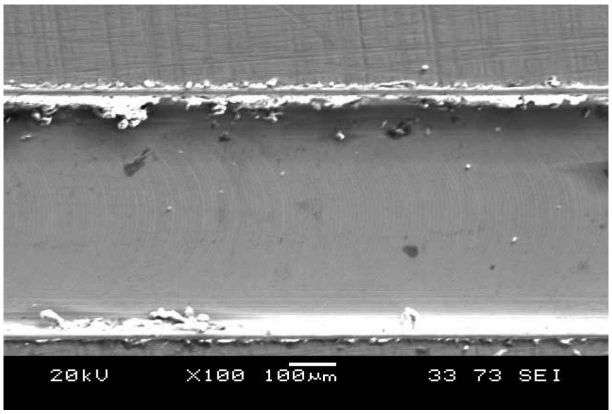

Fig 3 Surface Morphology of Cutting Condition SS= 12000 RPM, FR= 110 mm/min, DOC= 105 µm

Ra value for the slot generated by this cutting condition is 0.100 µm. Less amount of Ra value was observed under the specified conditions due to minimum surface defect. The macroscopic structure of the machined surface under various cutting conditions appeared to be smooth. When visualized using SEM many defects and irregularities were precisely found. The micro particle deposition and grooves formation are less when compared with other slots. It was observed that, the machining environment and cutting parameters influence the occurrences and magnitude of the defects on machined surface.

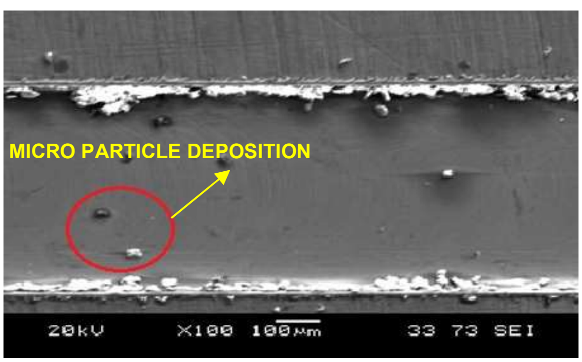

Fig 4 Surface Morphology for Cutting Condition SS= 12000 RPM, FR= 100 mm/min, DOC= 150µm

Figure 4 shows the surface morphology for the cutting conditions of spindle speed 12000 rev/min, feed rate 100 mm/min, depth of cut 150 µm. Ra value is found as 0.575 µm. Increase in roughness value when compared with the slot shown in figure 3 is due to the higher accumulation of micro particles. It depicts that micro particle deposition has greater influence on the Ra value.

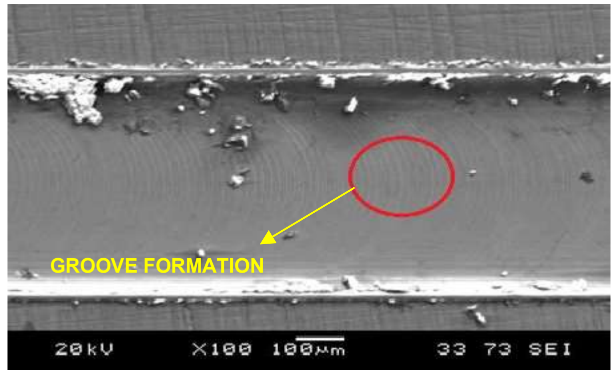

Fig 5 Surface Morphology for Cutting Condition SS= 14000 RPM, FR= 110 mm/mm DOC= 150µm

The surface morphology for cutting condition speed 14000 rev/min, feed rate 110 mm/min and depth of cut 150 µm is shown in figure 5. No damage on the surface like tear, laps, cracks were found. The Ra value for the slot generated by this cutting condition is 1.007 µm. It is noted that the surface defects in the bottom surface of the slot is very high and accumulation micro particles is to a greater extent. Specifically severity of groove formation is higher and it leads to the increase in roughness of the surface. Examination of machined surface of the workpiece by SEM provides clear evidence for certain cutting parameters. From figure 6 the important aspect to be noted is that as the depth of cut increases the Ra value is increased. The main reason behind the upsurge of Ra is higher accumulation of micro particles and high grooves formation is noted as the depth of cut is raised.

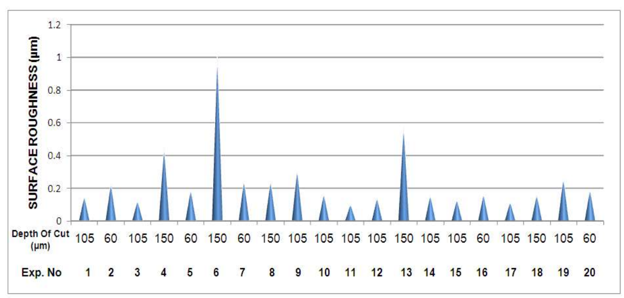

Fig 6 Surface Roughness Variation in Accordance with Depth of Cut

4. CONCLUSION

In this work investigations on surface morphology micro-milling of Ti-6Al-7Nb were performed. Analyses on the effect of cutting conditions on surface texture were carried out. Ra for each slot was measured and surface morphology study was performed and the following conclusions are drawn from the study.

- Observed surface defects are micro particles deposition, smeared materials, grooves, overlapping grooves and micro burr formation. The intensity of the defect varies according to the cutting conditions.
- From the results it is observed that, micro particle deposition and groves formation is higher when the depth of cut is

maximum at 150 µm for the chosen levels. This phenomenon causes increase in Ra as depth of cut increases.

- The ratio of depth of cut to the effective cutting edge radius has a great influence on the machining of both isotropic and anisotropic materials. Hence, a small change in the depth of cut significantly influences the cutting process.
- Consideration of microstructure, wear, tool nose radius, number of flutes and their effects on Ra can be carried as scope for future work.

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