euspen's 16th International Conference & Exhibition, Nottingham, UK, May 2016
www.euspen.eu

Precision cutting of micro textured surface on implant of Ti alloy

Hirofumi SUZUKI [1, a], Mutsumi OKADA [1)], Eiji KATO [2)], Masahiro YAMADA [3)], Yosuke ITOH [4)], Koichi OKADA [4)]

[1] *Department of Mechanical Engineering, Chubu University*
[2] *Kato Clinic Implant Center*
[3] *Graduate School of Dentistry, Tohoku University*
[4] *NS Tool Co. Ltd*

[a] *Suzuki@isc.chubu.ac.jp*

Abstract
Ti alloy has been conventionally used for parts of air plane or chemical equipment, because it is tough and has low specific gravity, and has high anti-corrosion characteristic. Furthermore, the material is very flexible to human living body cells and there are few allergic reactions as a medical application. These characteristics of Ti alloy are most suitable for a dental implant or a total hip prosthesis, and recently a lot of Ti alloy has been used for many medical applications. Furthermore, generation of textured surface of several micron meter level on the dental implant of Ti alloy is extremely effective to improve the fusion characteristics of the living body cell from the recent dental studies. However, Ti alloy is a difficult to machine material, the tool wear is extremely high and precision texturing by cutting is very difficult. In this study, Ti alloy was face turned by some kind of tool materials such as single crystal diamond, cBN, tungsten carbide and CVD-SiC, and the tool wear characteristics and surface roughness changes were evaluated experimentally. Finally cutting tests of micro textured patterns were carried out by the fabricated micro cutting tool of polycrystalline cBN (PCBN) tool and feasibility of the micro tool for the texturing was studied.

Ti alloy, implant, texturing, micro cutting, biocompatible, tool wear evaluation, diamond tool, cBN tool

1. Surface texturing for Ti implant

Needs of implants made of titanium (Ti) alloy is recently increased because of its anti-corrosion characteristics and low allergic reactions. From the recent dental and medical reports [1], it is clarified that generation of micro textured surface on the dental implant of Ti alloy is extremely effective for improving of the fusion characteristics to the living body cell. Figure 1 shows a SEM image of surface textures on a sample of Ti implant. The pattern was fabricated by scanning of conventional laser beam and the width is 10-20 µm and the depth is about 5µm. However there are following problems. (1) Some debris are adhered on the surface, (2) Oxide layers remains on the Ti surface, and (3) The textured patterns are not regular. In order to overcome these problems mechanical cutting process with micro tool is required.

In this study, Ti alloy was cut by some kind of tool materials such as single crystal diamond, cBN, tungsten carbide and CVD-SiC, and the tool wear characteristics and surface roughness changes were evaluated experimentally.

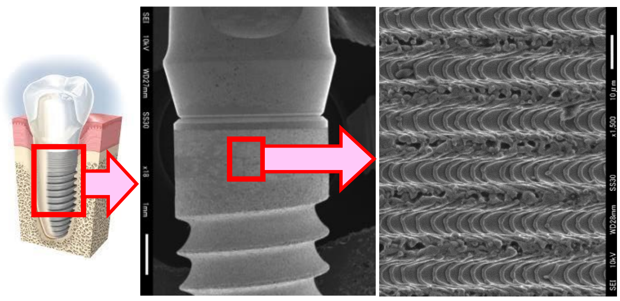

Figure 1. Surface micro texture of Ti implant.

2. Cutting experiment machine and method

In the fundamental study, the thin plates of Ti alloy are face turned at several feed rate by several kind of the tool to evaluate the tool wear and the face turned surface roughness is measured and the effects of cutting conditions on the machined surface quality are discussed. Finally, the actual surface textured Ti alloy is tested to cut and the form accuracy and surface roughness are measured and evaluated.

The Ti alloy plate was attached to a 3-axis (X,Y,Z) controlled ultra-precision machine as shown in **Fig. 2**. The workpiece spindle is an air-bearing spindle with the maximum rotational speed of 1,000 min^{-1}. The tool was actuated in X and Z-axes by the linear scale feedback system with 10 nm positioning resolution. In the cutting test, the workpiece was vacuum chucked onto the workpiece air spindle.

In the tool wear evaluation experiments, the tool shapes in each cutting process are transcribed to the acryl plane workpiece and this replica is measured by a non-contact type of laser probe scanner, the change of tool shape is measured, and the volume of tool wear is calculated as shown in **Fig. 3** [2].

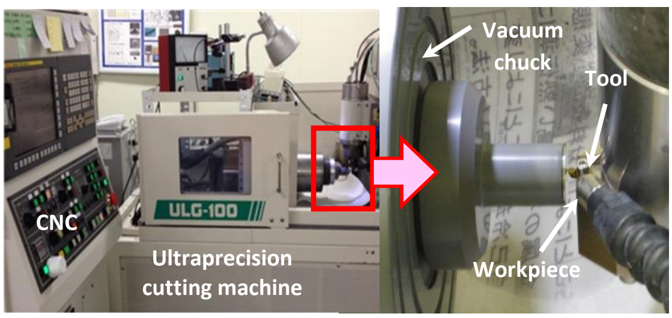

Figure 2. View of precision turning of Ti alloy.

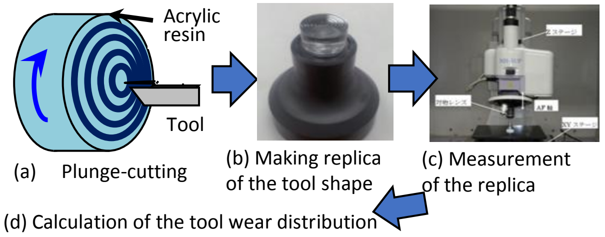

Figure 3. Evaluation method of the tool wears.

3. Experimental results

3.1. Tool wear evaluation

Cutting conditions are shown in Table 1. In the fundamental cutting experiment, Ti alloy disk of HV154 was tested. 4 kinds of tool materials of 1 mm edge radius were used and feed rate was changed in 0.5 - 10 mm/min in the radial position.

Table 1 Cutting conditions

Tool	Single crystal diamond	cBN	Tungsten carbide	CVD-SiC
Radius	1.02 mm	1 mm	1 mm	1 mm
Rake angle	-0.33 °	0 °	0.2 °	0.5 °
Relief angle	13.75 °	9.97 °	6.75 °	7.0 °
Workpiece	Ti alloy (JIS H 4650 Grade 2)			
Hardness	HV154.2			
Shape	Flat			
Dimension	Φ20 mm x 2 mm (Thickness)			
Rotation	1000 mm^{-1}			
Depth of cut	2 μm			
Feed rate	10, 5, 2, 1, 0.5 mm/min			
Cutting distance	2.39 km/cut			
Cutting number	1-64			
Coolant	Kerosene			

Changes of the tool edge shapes of 4 kinds are measured by the method as shown Fig. 3. Total depth of cut was changed in 0 - 128 μm. From these figures, tool wear ratios are calculated. In order to calculate the cutting efficiency of the tool, the tool wear ratio, r_t was defined as well as the grinding ratio by the next equation:

$$r_t = V_w / V_t \quad (1)$$

Where, V_w is the volume of the workpiece and V_t is the volume of worn tool. Changes of the tool wear ratio are shown in **Fig. 4**. The tool wear ratio of the cBN is highest.

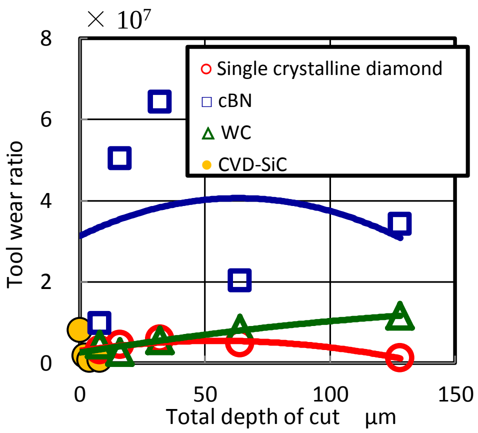

Figure 4. Changes of tool wear ratio of 4 tool materials.

3.2. Surface roughness

Surface roughness changes of the cut Ti alloy are shown in **Fig. 5**. Surface roughness increased with the total depth of cut. Surface roughness by cBN tool is smallest. The Red dotted line is theoretical surface roughness change of Rz=f2/(8R) and it is so small. In any tool, as the feed rate is higher, the surface roughness is better. It was because the cut Ti alloy was adhered on the tool when the tool feed rate was lower. Tool life was longest in case of cBN tool.

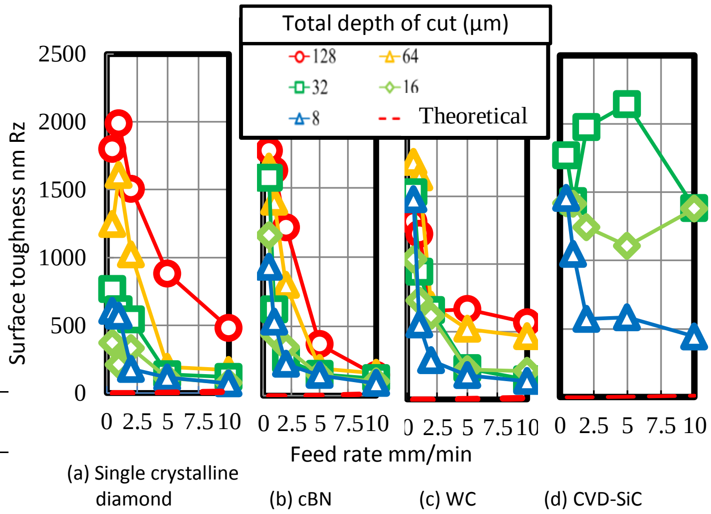

Figure 5. Change of surface roughness in each tool materials.

4. Micro texture cutting experiments

Finally, the actual surface textured Ti alloy is tested to cut by planing and the form accuracy and surface roughness are measured and evaluated. The tool WC is shown in **Fig. 6**. Width was 20 μm and depth of cut was 2 μm. Textured surface of Ti alloy by planing with WC tool and cut chips are shown in **Fig. 7**. Smooth texture was obtained.

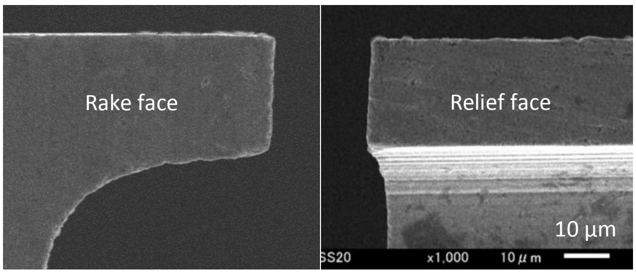

Figure 6. SEM images of WC tool for micro texture cutting.

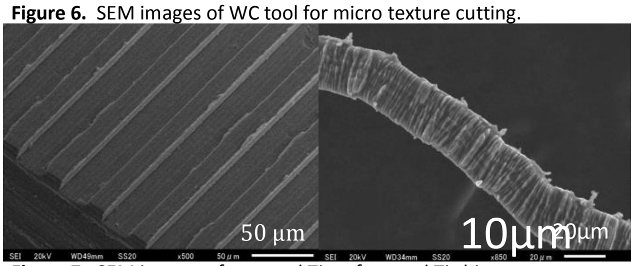

Figure 7. SEM images of textured Ti surface and Ti chip.

5. Conclusions

In this study, the Ti alloy was face turned to evaluate the tool wear and workpiece surface roughness, and finally the actual surface textured Ti alloy was tested to cut by planing, and the form accuracy and surface roughness were evaluated. From the experimental results, cBN tool and WC tools are suitable for generating textured surface.

References

[1] Timothy L Downing et al. 2013 Nature Materials **12** 1154
[2] Suzuki H, Okada M, Matsui S and Yamagata Y 2013 Annals of the CIRP **62** 59