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Texturing of metal surface by using vibration-assisted microcutting

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Abstract

Improving surface functions by introducing surface texture is of great interest in various fields. However, the current fabrication processes for surface textures are mainly dependent on the MEMS technologies, that require complicated and multistage facilities, thus are extremely costly. Therefore, alternative patterning methods need to be developed to meet the increasingly high demand from manufacturing industries. In the beginning, the vibration-assisted microcutting was performed to fabricate a surface texture composed of periodical concavo-convex nanopatterns, anticipating the texture mould fabrication for duplicating antireflective surfaces. In the experiment, a pure copper plate was cut by an acute triangular pyramidal diamond indenter tip vibrated by a piezo actuator in the cutting depth direction with an amplitude and a frequency of 2.1 μm and 5 kHz, respectively. As a result, a textured surface with numerously inverted pyramidal impressions surrounded by pileups was almost successfully fabricated. The average dimensions of impressions are around 300 nm in height and less than 1 μm in pitch in the cutting and feed directions, respectively.

Surface texture; vibration-assisted cutting; impression; pileup; diamond indenter tip

1. Introduction

Improving surface functions by introducing surface texture is an important issue in various fields [1]. For example, the moth-eye is well known as an antireflective surface, and such a function has been applied to the commercial products including solar cells. However, the current fabrication processes for such antireflective surfaces are mainly dependent on the MEMS technologies based on the photolithography. Such processes are complicated, time consuming and expensive. Thus, inventing alternative patterning methods, which are more concise, economic and precise, is the key to solving such problems.

Taking those into consideration, a part of the authors has examined the microcutting with a microfeed for enhancing the photocatalytic surface function [2]. Consequently, an improvement in the hydrophilicity, which is one of the photocatalytic functions, has been achieved due to an increase in the real surface area. Still, finer surface texture is necessary for reducing the surface reflectivity. Hence, the vibration-assisted microcutting using the microvibration in the cutting depth direction was introduced. It was confirmed that the proposed fabrication method is beneficial for fabricating textured surfaces composed of numerously inverted pyramidal impressions with several μm deep and wide [3].

This paper presents the results obtained through the vibration-assisted diamond microcutting experiment conducted on a pure copper plate in order to fabricate finer surface texture by applying a smaller feed and a higher frequency, anticipating the texture mould fabrication for duplicating antireflective surfaces.

2. Experimental Procedures

Figure 1 shows (a) experimental setup on a 3-axis (X, Z, C) NC (numerical control) lathe system equipped with an FTS system, (b) vibration-assisted cutting method and (c) scanning electron micrograph of cutting tool tip, respectively. In the experiment, a 3-axial (X, Z, C) simultaneous NC control machine tool (reorganized version of ULG-100A made by Toshiba Machine Co., LTD) was used for the fabrication of microcutting grooves on the workpiece (see Fig. 1(a)). At the same time the cutting tool was vibrated in the direction of the cutting depth using an FTS (fast tool servo) system (NS6141 made by Nano Control Co., LTD) as shown in Fig. 1(b). A triangular pyramidal diamond indenter tip for micro-hardness tester was used as a cutting tool to fabricate the microgrooves with a few μm or smaller deep and wide (see Fig. 1(c)). The three edge angle and the initial tip radius were 90 deg. and around 100 nm, respectively.

A confocal laser scanning microscope (OLS4000 made by Olympus Co.) was used for measuring the fabricated surface texture.

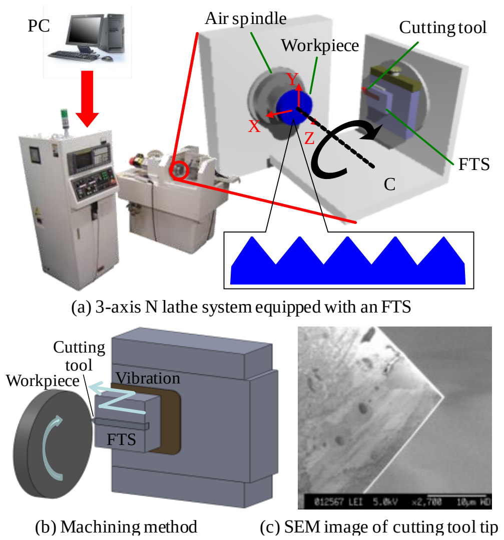

Figure 1. Experimental setup, machining method and cutting tool

Table 1 Vibration assisted cutting conditions

Workpiece	Pure copper plate
Cutting tool	Monocrystalline diamond
Three edge angle	90° (Cube corner indenter)
Initial edge radius	0.1 μm
Tool rake	One of the three edges
Average cutting depth (set)	2 μm
Cutting speed	4.2 mm/s
Feed	1 μm/rev
Vibration frequency	5 kHz
Vibration amplitude (set)	2.1 μm
Environment	MQL (Plant oil)

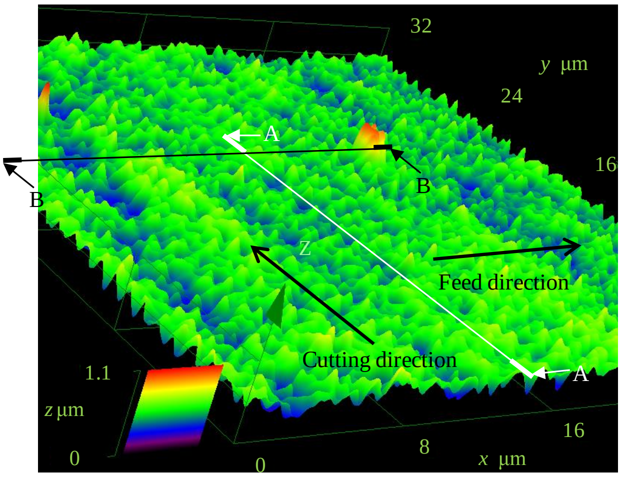

Figure 2. 3-D image of textured pure copper surface (32 μm x 32 μm)

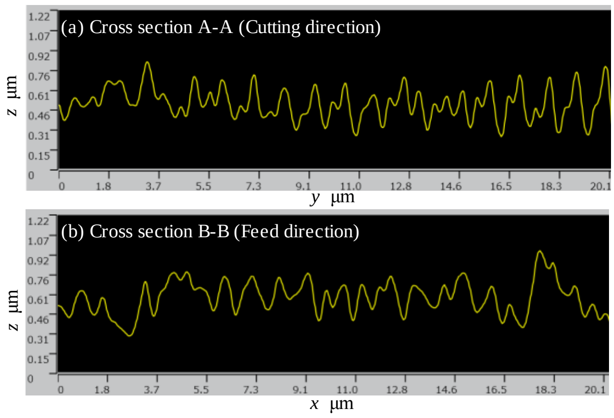

Figure 3. Cross-section A-A and B-B shown in fig. 2

3. Results and discussion

The initial workpiece surface was finished by the microcutting with the same cutting tool as used in the following texturing. In that case, one of the three faces of the indenter was used as the tool rake. The depth of cut, the feed and the cutting speed were 3 μm, 1.25 μm/rev and 0.6 m/s, respectively. As a result, the roughnesses in the initial workpiece surface became 0.17 μm and 0.036 μm in Rz and Ra, respectively.

The vibration-assisted microcutting conditions for surface texture formation are listed in Table 1. Both the average depth of cut and the vibration amplitude are around 2 μm. On the other hand, the feed/pitch is 1 μm, which is half of the cutting depth. Therefore, there are no uncut regions under the present machining conditions.

Figure 2 indicates a 3-D image of the fabricated surface texture measured by a confocal laser scanning microscope. From fig. 2, it is apparent that a surface texture composed of numerously inverted pyramidal impressions surrounded by pileups were successfully fabricated on the pure copper plate, although it is difficult to recognize apparent inverted triangular pyramidal shape. Each impression is systematically arranged in both the cutting and the feed directions. There remain some small cutting chip particles on the textured surface, because extremely small cutting chip particles were generated in the process of the vibration-assisted microcutting by using the vibration in the cutting depth direction. The waviness with a few hundreds μm amplitude reflecting the initial surface is also seen. This waviness is one of the future tasks to be solved.

The cross-sectional profiles along both the cutting and the feed directions are shown in figs. 3(a) and (b), respectively. From figs. 3(a) and (b), it is observed that each interval between adjacent two impressions becomes 980 nm and 960 nm respectively, in the cutting and the feed directions. Consequently, both of them have come to sub μm, which is the same order as the wavelength of the visible light even though further downsizing is still necessary. It is also understood that the maximum height of irregularities has become around 300 nm from figs. 3(a) and (b). The size of the individual impressions is smaller than that of the achievement gained through the machining of micropatterns such as holograms by other researchers [4]. Although the target application is totally different and more precise evaluation of each impression's geometries is still necessary. The maximum height of irregularities is remarkably smaller than the setting value of the vibration amplitude. If we anticipate an application of the fabricated texture patterns to the texture mould for duplicating antireflective surfaces, solving this kind of strange phenomenon will also be one of the future tasks as well as decreasing all the intervals between adjacent two concavo-convex patterns.

4. Conclusion

In order to develop an alternative simpler technique to fabricate the texture mould for duplicating antireflective surfaces, the vibration-assisted microcutting was conducted on a pure copper plate by vibrating a diamond indenter in the cutting depth direction with an amplitude and a frequency of a few μm and several kHz, respectively. As a result, a textured surface composed of inverted pyramidal impressions were almost successfully fabricated. The average dimensions of impressions are around 300 nm in height and less than 1 μm in pitch in both the cutting and feed directions, respectively. Although precise evaluation of each impression's geometries is still necessary. It is also confirmed that further decreases in both the cutting speed and the feed are still needed to obtain an antireflective surface.

Acknowledgement

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