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Deterministic fabrication of surface micro-step features using a facet diamond cutting tool

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Abstract
In this paper, a facet diamond cutting tool was specially designed and used to generate near-right-angle shape structures with mirror surface finish on both sides. A focused ion beam (FIB) was used to modify the tool cutting edge locally to improve its sharpness and straightness. The tool cutting performance was evaluated through a series of cutting trials on brass substrate under various cutting conditions, i.e. depths of cut (ranged from 5 µm to 20 µm) and feedrate (ranged from 3 µm/rev to 20 µm/rev). A Taylor Hobson CCI 3000 was used to evaluate the form accuracy and surface roughness of the machined micro step features. The results show that the surface machined under the feed rate of 3 µm/rev have the best surface finish as compared with the surfaces machined under other tested feedrates. The cutting tool was futher used to generate two clydlindrical micro steps with step heights and widths being 20 × 20 µm and 15 × 15 µm respectively. Twelve micro steps of each design were continuously generated to reflect the repeatability of this method. The measurement results were analysed by MountainsMap with results showing that the designed micro step features were successfully generated on brass surface. The dimensional deviation ratio of step heights and widths are all less than 4.5%, which well demonstrated the fleasiblity of the proposed method on surface micro structuring.

Keywords: Nanometric cutting, functional surface, micro steps, facet diamond cutting tool

1. Introduction

Fabrication of functional micro/nanostructured surfaces has drawn great interest in recent years due to their applications in diverse research fields including optics and electronics, solar energy, cell biology, bioengineering and medical science [1-2]. Diamond machining including diamond turning, micro milling, fast-tool-servo and fly cutting plays a key role in the fabrication of structured surfaces. Due to the inherent limitations such as machining errors induced by tool cutting edge radius and the motion errors of machine tools, the fabrication of micro steps having near-right-angle straight shoulders remains challenge, especially for micro step features having several micros step height but requiring mirror surface finish.

Diamond turning using FIB shaped micro cutting tools has provided an alternative way on micro maching. Recently, even nanoscale multi-tip single crystal diamond cutting tools have been developed to the fabrication of micro/nanostructures by directly replicating micro/nano structures pre-fabricated on the tip of diamond tools onto work substrate surfaces [3-4]. However, the difficulties on tool geometrical design and fabrication, and the tool wear (especially for small deminsion of cutting tool tips) significantly affect the wide application of this technique [5]. There remain challenges to use this method for scale-up fabrication of high aspect-ratio micro features.

This paper reports the research progress on the surface structuring of micro step features having near-right-angle using a special designed facet diamond cutting tool. A series of nanometric cutting trials on brass substrates (under 12 different cutting conditions) were carried out to to fully explore the nanomanufacturing capability and the advance of this technique. The focus will be on the influence of operational parameters on the surface quality and dimensional accuracy of machined micro steps.

2. Experimental design and setup

2.1. Experimental design

The nanometric face cutting of an brass bar (diameter = 30 mm) were conducted on a diamond turning machine (Precitech Nanoform250). The geometrical design of the facet diamond cutting tool and the fabricated samples are illustrated in figure 1. The facet diamond cutting tool has a reangular shape and three straight cutting edges. The measurement results of the left and right angle are 88.25 and 87.75 degree, respectively. The tool tip width is 2 mm with include angle being 0°. A FIB was used to modify the cutting tool locally to ensure the cutting edge sharpness (clearance angle 10°, rake angle 0°) and the near-right-angle shape on both sides of the tool.

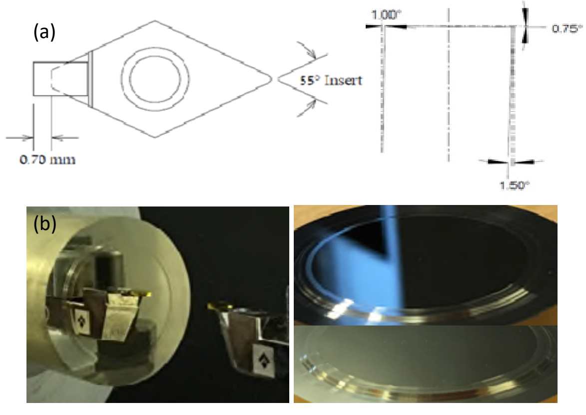

Figure 1. (a) The geometrical design of the facet diamond cutting tool and (b) the nanometric cutting setup and fabricated samples.

2.2.Experimental plan for surface structuring

Before surface structuring using the facet cutting tool, a flat surface was firstly prepared by face diamond turning using two normal diamond cutting tools: one diamond tool for roughing cutting and another controlled waviness cutting tool was used to generate the surface with mirror finish (Sa < 3 nm). The cutting fluid (CLAIRSOL 330 special kerosine) was applied in these steps.

The facet diamond cutting tool was then used to generate micro steps on the flat brass surface. To achieve the mirror surface finish, the Taguchi method has been used to find the optimal processing parameters. The tested processing parameters are listed in Table 1. The machined surface roughness was measured by a white light interferometer (Form TalySurf CCI 3000).

Table 1 Operational variables in face diamond turning trials

Depth of cut (μm)	Feed rate (μm/rev)	Cutting speed (m/s)
3	3	1.3
5	3, 5, 10, 20	1.3
10	3, 5, 7.5, 10, 20	1.3
15	3	1.2
20	3	1.2

3. Results and discussions

3.1. Effects of processing parameters

Figure 2 sumarise the machined surface roughness against the processing parameters. It is found that the surface roughness increase with the increase of depth of cut and feedrate. However, the variation of surface roughtness (Ra) machiend under the tested depth of cuts (feedrate kept at 3 μm/rev) are all less than 2.7 nm. The feedrate tends to dominate the surface roughness when the depth of cut is equal or less than 10 μm (figure 2(b)). Therefore, the feedrate of 3 μm/rev and the depth of cut being 5 and 10 μm were selected as the processing parameters for the fabrication of two cylindracal micro steps.

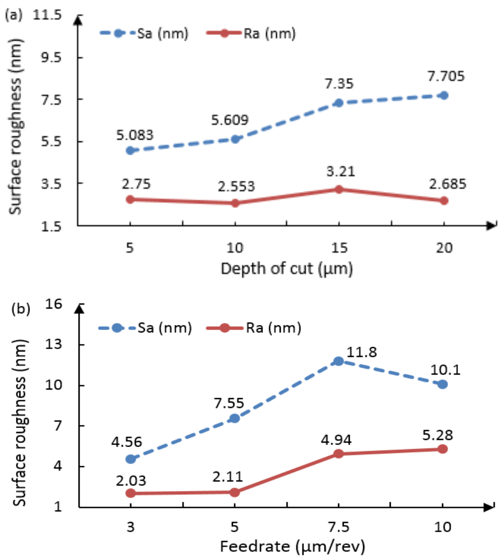

Figure 2. The machined surface roughness against: (a) depth of cut while the feedrate kept at 3 μm/rev; (b) feedrate while depth of cut kept at 10 μm.

3.2. Fabrication of cylindrical micro steps

Two clydlindrical micro steps with different step heights and width, 20 × 20 μm and 15 × 15 μm were then fabricated using the optimal processing parameters. For every single micro step, two cutting passes were used to generate the designed step heights. Twelve micro steps for each design were continuously generated to demonstrate the repeatability of this method. The measurement results were analysed by MountainsMap.

As shown in figure 3, micro steps features have been continuously generated on the brass surface with mirror surface finish achieved on both sides of the steps (only the steps in one field of view are shown in figure 3). Detailed analysis on the step width, step height and the surface roughness are shown in figures 4 and 5. The analysed results indicate that the dimensional deviation ratio of step heights and widths are all less than 4.5%, which well demonstrated the fleasiblity of the proposed method on surface structuring.

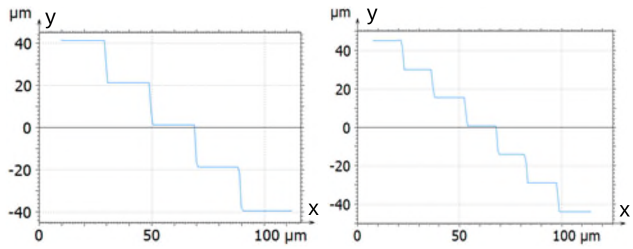

Figure 3. Cross-sectional view of machined micro step features 20 × 20 μm (left) and 15 × 15 μm (right)

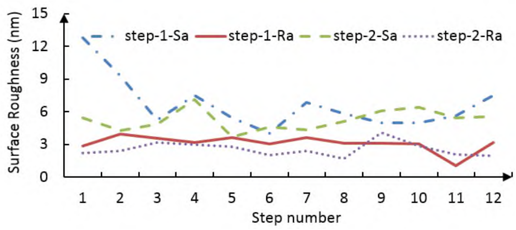

Figure 4. The surface roughness of machined micro steps

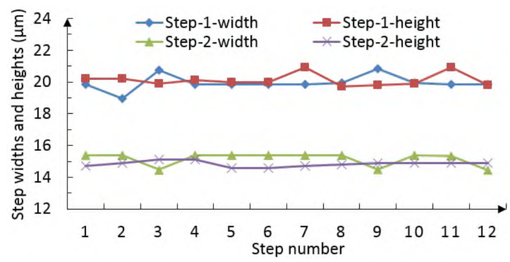

Figure 5. The analysis of micro step heights and step widths

4. Conclusions

A systermatic experimental research work has been conducted to investigate the diamond turning of surface micro step features using a facet diamond cutting tool. Near-right-angle shape structures with mirror surface finish on both sides have been successfully generated on brass surfaces under optimal processing parameters. The results indicate that diamond machining using proper shaped cutting tools provide an effective way for surface micro structuring.

References

[1] E. Brinksmeier, R. Gläbe, and L. Schönemann 2012*CIRP J. of Manuf. Sci. Technol.***5** 1-7

[2] Z. Tong, X. Jiang, X. Luo, 2016 *Current Nanoscience* **12** (999): 1-1

[3] Z. Tong, X. Luo 2014 *Appl. Surf. Sci.* **321** 495-502

[4] Z. Tong, X. Luo, J Sun, Y Liang and X. Jiang 2015 *Int J Adv Manuf Technol.* **80** (1): 699-710

[5] Z. Tong, X. Luo 2015 *Appl. Surf. Sci.* **347** 727-735