euspen's 15th International Conference & Exhibition, Leuven, Belgium, June 2015
www.euspen.eu

The novel method for tool life monitoring

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Abstract
To ensure a reasonably good precision on machining micro-lens arrays in ultra-precision machining, the tool life must be monitored without removing the single point diamond cutting tool from the tool-holder. In this paper, a method is presented to monitor the condition of tool nose radius. The prime objective is to spot when the tool starts to wear significantly. Initially, because of the good roundness of the tool nose, the wear is expected to be slow. However, when the roughness begins to deteriorate, the rate of wear will increase tremendously because of the friction induced adhesion occurred at localized zones sandwiched between the workpiece and the tool.

The method proposed in this paper aimed at identifying when the roundness is no longer smooth relative to the cutting conditions and to the workpiece materials used. The profile of quasi-circular channels, which were machined by single pass grooving, was measured by an optical profiling system. A model was proposed to assist in reconstructing the groove profile at the time the tool still remained in contact with this portion of the groove. By comparing the reconstructed profile with the measured profile, the effect of adhesion on deforming the profile could be estimated. In our experimental work on single point diamond machining of Aluminum 6061, no adhesion happened at the depth of cut between 1-1.5um while significant adhesion was observed when the depth of cut was larger than 2um. This inferred that the tool used in this work was no longer fit for machining with depth of cut beyond 2um but was still good enough to be used to perform shallow cutting.

Keywords: tool life, ultra-precision machining, micro-lens array

1. Introduction

Tool nose radius measurement is a common strategy in tool wear study. It is usually measured by the typical methods of SEM, FIB and AFM, which require removing the tool from the tool-holder. In continued ultra-precision machining, it is not practical to remove and recalibrate the cutting tool regularly, as the depth of cut is only a few microns. In this paper, a method was developed to monitor the tool nose roundness without removing the single point diamond cutting tool, and observe the effect of adhesion. Cai and Lee [1] found that the plastic strain ratios are bounded based on the Sach Model and the Taylor Models. Based on the study, a meso-plasticity model are proposed by Lee and Chan [2-4] to predict the force vibration of micro-cutting in ultra-precision machining. In a further study on the model in micro-cutting process, Wang et al. [5] examined the elastic strain effects on shear band formation and predicted the shear band occurred first in the free edge of chips instead of the tool tip. However, those models do not focus on elastic recovery in micro-cutting. In ultra-precision machining, the elastic strain fields (ESFs) can be accumulated and bouncy dynamically, which would affect cutting history.

In this paper, tool nose radius is used as datum to quantify elastic recovery without directly dealing with ESFs and quasi-circular channel arrays are generated by single pass grooving. If the deformation mode is purely plastic, the newly machined groove profile would trace the tool nose profile accurately and in circular shape. Nonetheless, the circular groove profile is deformed when elastic recovery occurs. Therefore, a model is developed to assist in unambiguously reconstructing the ideal circular channel from the rebounded one, two assumptions were made in the machining process: Firstly, before and after the grooving process, surface adjacent to the circular channel remains planar; Secondly, materials are not torn away from the workpiece because of adhesion against the diamond tool. Therefore, before and after elastic recovery, the total groove volume V(all) is remains constant.

2. Experimental setup

2.1. Machining

A series of straight-cutting experiments were conduced to generate a groove (Figure 1(b)) from 2 micrometer to 0 micrometer, with about 0.01 degree tapered slope as shown in Figure 1(e). The groove was machined by single point diamond turning tool (Figure 1(d)) on a four-axis CNC ultra-precision machine (Nanotech 350FG) as shown in Figure 1(a). The material of the workpiece was aluminum alloy 6061 and the size was about 10mm x 3mm x 3mm (L x H x D) (Figure 1(e)).

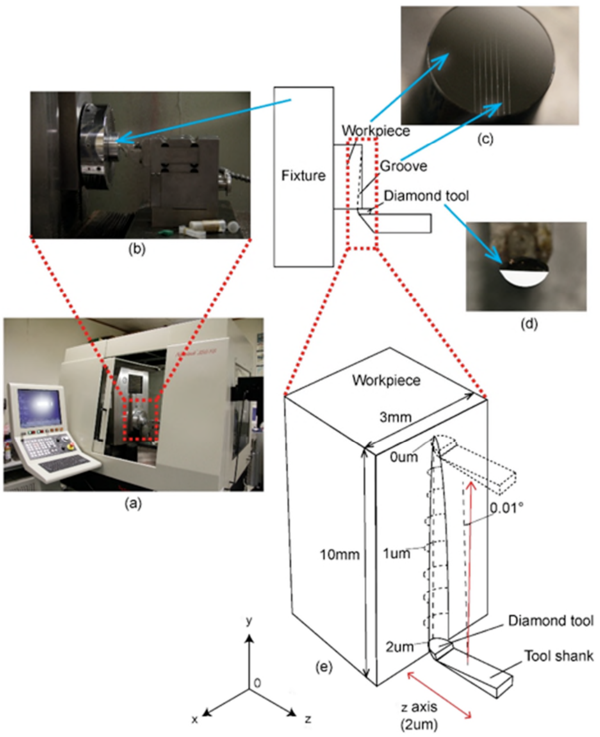

Figure 1. The schematic diagram of the straight-cutting experiments

2.2. Measurement

After the straight cutting process, the precision measurement of the machined groove was carried out by a non-contact Optical Profiling System (Wyko NT8000) for measuring surface topographies of the machined specimen with an effective magnification 20x. The stitched resolution was about 600x22000 pixels and the sample distance was about 480nm, as shown in Figure 2. 40 grooves cross section profile were extracted sequentially from the 3D profile.

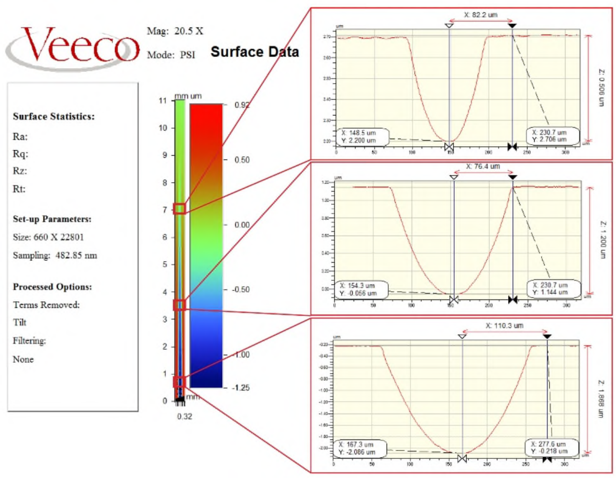

Figure 2. 2D profile of straight cutting groove

3. Results and discussion

Based on the microscopic examination of the disrupted flank edges of the channels and the tool condition, no significant tool wear was found to occur. Total 40 cross section groove profiles were aligned in Figure 3, the ratio of X and Y axis is scaled over. Different depth of cut were colored and labeled and the yellow color ideal tool radius was added for referencing. Attention should be cast on the flattened bottom (due to bounce back) and the disrupted flank edges (due to adhesion wear).

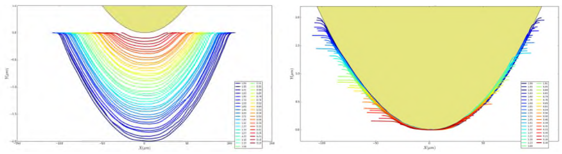

Figure 3. The 2D profile of the groove with different depth of cut

The relationship of measured groove area$^{2/3}$ ($S_M^{2/3}$) and depth of cut (DoC_M) was plotted in Figure 4, and the detailed calculation results are shown in Table 1. The observed relationship is reasonably linear and the estimated diamond cutting tool is 2.5mm.

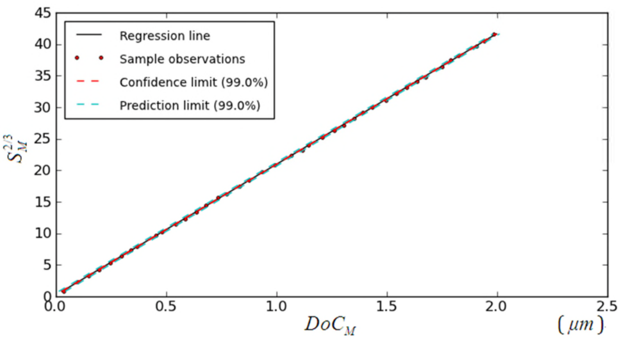

Figure 4. Relationship curves of $S_M^{2/3}$ and DoC_M

Table 1. Calculation results of data processing software

items	results
slope of regression line	20.73±0.08
Y intercept	0.22±0.09
standard deviation of linear regression residuals value	0.11
confidence interval	99%
T value	2.71
degree of freedom	38

4. Conclusions

Based on our experimental work, volume conservation rules apply reasonably well for cutting 6061 aluminum alloy with DoC between 1-1.5um. Through our proposed taper cutting and the tool radius measurement method, tool life can be monitored without being removed from the tool holder.

5. Acknowledgment

The authors wish to thank the Innovation and Technology Commission of HKSAR Government for the financial support of the research under the Project No. ITS/338/12.

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