A Study of Cutting Strategy on Surface Microstructural Changes in Ultra-precision Raster Milling of Aluminium Alloy

S.To*, S.J. Zhang, C.F. Cheung and W.B. Lee
State Key Laboratory in Ultra-precision Machining Technology, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong SAR, China
** mfsto@polyu.edu.hk*

Abstract

Ultra-precision raster milling (UPRM) is an advanced manufacturing process for machining non-rotational symmetric freeform surfaces with nanometric surface roughness without the need for any subsequent polishing. Due to different cutting mechanics, the UPRM process is very dependent on cutting strategies (up-cutting and down-cutting) as compared with ultra-precision diamond turning and conventional milling. In this paper, the power spectral density (PSD) are used to analyze the characteristics of the cutting forces with different cutting depths. The effect of the high frequencies changes, and the contribution rate is gradually reducing with the increment of depth of cut, which means that the cutting chips will become softer based on the temperature increment from cutting forces, due to soft phase absorbs one part of imposed strain.

1 Introduction

Ultra-precision machining has been developing rapidly in the manufacture of optical components and laser mirrors with a surface roughness of a few nanometers. The success of the technology relies on high precision machine tools, advanced control systems, laser metrology and single crystal diamond tools. Ultra-precision raster milling is recognized as one of the most important machining technologies to manufacture precision parts with a surface finish of a few nanometers[1]. Over the past decades, the surface integrity of the diamond turned surface has absorbed much scientific and public attention, but the microstructure changes is a little. The properties depend on the micro-structural changes, which are determined by a many factors, including the cutting tool, feed rate, cutting speed, lubricants, as well as the metallurgical properties of the surface before and after machining or different cutting depth. There has been a limited amount of research on the effect of ultra-precision machining on the material properties from micro-structural changes.

In this paper, the Al6061 are selected for this study, and the cutting force data is measured and analyzed by using a power spectrum (PS) techniques[2-4]. The micro-structural changes are studied by X-ray diffraction (XRD) with different cutting depth. It has been shown that the effect among the microstructure, surface quality and different cutting depths.

2 Experimental procedures

In this study, the polycrystalline aluminum alloy Al6061 was used. A series of face cutting tests were performed on each of the specimens with a diameter of 12.7mm. All cutting tests were performed on a five-axis CNC ultra-precision lathe under the same cutting conditions. The cutting conditions were tabulated in Table 1.

Table 1. Cutting condition

Spindle speed (rpm)	3000
Feed rate (mm/min)	20
Tool rake angle (o)	0
Tool nose radium (mm)	1.49533
Front clearance angle (o)	5
Cutting depth (μm)	0 1 5 10 20 50

XRD is the prime tool used in this paper as it has been found to give detailed and systematic information on the phase precipitation occurring at the machined surface. XRD results provide information on the changes in preferred crystallographic textures caused by machining. An X-ray diffraction examination will be carried out on specimens using a Philips X-ray diffractometer with nickel-filtered Cu Kα radiation, λ = 1.5406 at a scanning speed of 1 degree per minute. A range of diffractions will be selected from 35-47 degrees to achieve strongest X-ray diffraction. The main cutting force and thrust cutting forces were measured by a Kistler 9252A piezoelectric force transducer mounted directly under a tool post purposely made for the study. The force signals captured from the force transducer was pre-amplified by a charge amplifier, and the analogue voltage output was recorded and digitized by a digitizing oscilloscope (Tektronix TDS744A).

3 Results and discussion

3.1 Microstructure changes on machined surface

Fig.1 shows the X-ray diffraction of Al6061 with different cutting depths, and the range of the diffraction angle 2θ is from 35° to 47°. From Fig.1, the 2θ of one between dual-peaks increases and other reduces, so the *d*-spacing changes a little with increment of the cutting depth, but when the cutting depth is above 10μm, the *d*-spacing changes obviously. The α (111) is increasing with the cutting depth increasing, and synchronously the dual-peaks appear, because the cutting depth becomes more and more, and the peaks from recrystallization become relatively stronger, and the same is the α(200). The A_2 is precipitating from A_1 and the B_2 from B_1. When the cutting depth is increase, the microstructure is changed significantly. And the distance between dual-peaks, A or B, respectively, will increase with the increment of the cutting depth, and it can indicate that the residual stress increases, simultaneously.

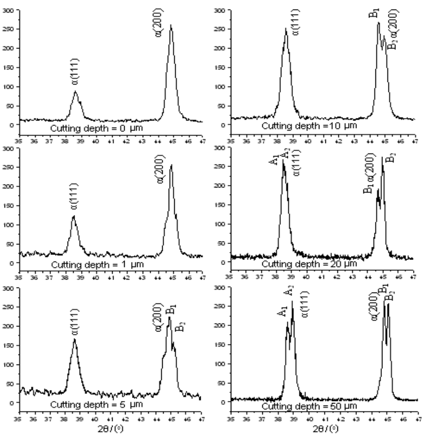

Fig.1 XRD of Al6061 with different depth of cut.

3.2 Analysis of power spectrum density

Fig.2 shows the increasing of the cutting depth, the cutting forces are increasing. In the first stage that the cutting depth is around less than 2.5μm, main cutting force is more than thrust cutting force, in the second stage that the cutting depth is about from 2.5 to 12.5μm, main cutting force is less than thrust cutting force which is mainly from material swelling, and in the final stage that the cutting depth is around more than 12.5μm. From the analysis above, it indicates that, when machining influence between two kinds of cutting forces will change with the cutting depths and also means that in the second stage, the uniform chips cannot form but in the third stage the uniform chips can form.

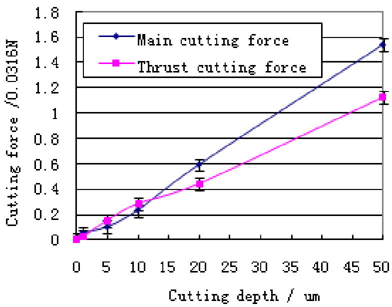

Fig.2 Cutting force with different cutting depths

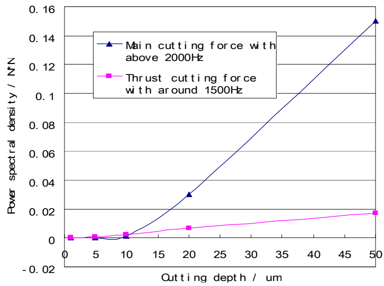

Fig.3 Max PSDs with different cutting depths

Fig.3 shows that, when the cutting depth is more than 12.5μm, the power spectral density is further more than that less than 12.5μm. The range is from 1μm to 10μm, the PSDs with the frequencies around 1500Hz are more than with those above 2000Hz, and reversely when above 10μm.

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