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Surface quality for rotary ultrasonic milling of quartz glass employing diamond ball end tool with tool inclination angle

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Abstract

Nowadays, quartz glass is widely used in many industry fields. The machined surface quality is an important issue in the ultrasonic milling of quartz glass with diamond ball end tool. This paper analyzed the movement characteristics of the engaged cutting abrasive particles and investigated the effects of spindle rotation speed, feed speed, width of cut, and depth of cut on the machined surface topography and surface roughness. Also, comparisons of machining effects with and without ultrasonic were carried out. In general, application of ultrasonic vibration needs to cooperate with other process parameters to give play to the advantages of RUM, and ultrasonic function could not necessarily improve the formed surface. Comparing with conventional milling, reasonable selection of process parameters could decrease the machined surface roughness under the premise of achieving a high materials removal rate for RUM.

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Keywords: surface quality; rotary ultrasonic milling; quartz glass; diamond ball end tool; inclination angles

1. Introduction

Because of its exceptional properties, quartz glass is extensively applied in optical instruments, semiconductors and precision equipments[1-3]. Multi-axis milling could be used in the manufacture of complex components in manufacture field[4]. Rotary ultrasonic machining of hard and brittle materials with diamond cutters are effective

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process technology to achieve higher materials removal rate[5]. By coupling the related technical elements, machining of complex parts made of hard and brittle materials could be achieved by multi-axis rotary ultrasonic milling with the diamond cutters.

Some studies have been reported on the surface quality and machining mechanism when machining hard and brittle materials. Arif et al. [6] proposed an prediction model identifying the critical conditions by analyzing the relation between subsurface damage depth and radial depth of cut during machining for generating a crack-free surface for milling of brittle material. Radial depth of cut significantly affects the machined surface condition with or without crack. Karpat[7] analyzed the interaction between the cutting edge radius and material removal deriving from ductile fracture, and found that the properties of workpiece material are related with the uncut chip thickness. Shao et al.[8] predicted surface roughness by a physics-based model for grinding of ceramic materials, and surface roughness is expressed as a function of parameters of the wheel, material properties, and process conditions.

Although some investigations about the machining phenomenon and mechanism for machining of hard and brittle materials have been done, special analysis of the tool inclination angles effects induced in the rotary ultrasonic milling (RUM) and conventional milling without ultrasonic (CMWU) with diamond ball end tool is still needed. This paper focused on the effects of process parameters on the machined surface topography and surface roughness with tool inclination angles for RUM and CMWU.

2. Experimental settings

Based on the previous experimental results, it is found that the surface topography and surface roughness is ideal under positive lead 20°when the interaction angle between tool axis vector and the normal direction of the machined point was 20°for rotary ultrasonic milling of quartz glass. The tool inclination angle was fixed at lead 20° in the experiments, as is shown in Table. 1 and Table. 2. The fundamental parameters are n=10000r/min, F=2000mm/min, a_e=0.15mm, and a_p=0.03mm. The ultrasonic amplitude was set as 10% for the experiments from Exp No.1 to Exp No.4, while the experiments from Exp No.5 to Exp No.8 were carried out without ultrasonic vibration. The machining field and detection equipment is shown in Fig. 1. The ultrasonic vibration frenquency is 42430Hz, and the radius of the diamond ball end tool customized by Effgen (Model:6D76-714782.01-151214G2) is 5.003mm which is calculated from the four times measured data by using the cutter measurement instrument on the machine tool. The machined surface is detected by laser scanning confocal microscope (Model:VK-X100/X200). The machined surface topography is measured under 200 times magnification to view wider field containing more surface features, while surface roughness is measured under 1000 times magnification in order to obtain more accurate surface roughness values.

The tool inclination angles mainly consist of tilt angle and lead angle[9, 10]. The lead angle is introduced by rotating the tool axis about the Y direction, as is shown in Fig. 2. The positive lead angle is defined as rotating the tool axis in counterclockwise direction seeing from the positive direction of y-axis (negative cross-feed direction), while the negative lead angle is the inverse intersection angle[11].

Table 1. Process parameters for rotary ultrasonic milling (RUM) of quartz glass (down milling).

Fundamental parameters		*tilt*0°	*lead*20°	n=10000r/min	F=2000mm/min	a_e=0.15mm	a_p=0.03mm	*UA* percent 10%
ExpNo.1	Variable n/(r/min)	3000	5000	7000	9000	11000	13000	
ExpNo.2	Variable F/(mm/min)	600	1000	1400	1800	2200	2600	
ExpNo.3	Variable a_e/mm	0.05	0.1	0.15	0.2	0.25	0.3	
ExpNo.4	Variable a_p/mm	0.015	0.02	0.025	0.03	0.035	0.04	

Table 2. Process parameters for conventional milling of quartz glass without ultrasonic (CMWU) (down milling).

Fundamental parameters		*tilt*0°	*lead20°*	n=10000r/min	F=2000mm/min	a_e=0.15mm	a_p=0.03mm	*UA* percent0
ExpNo.5	Variable n/(r/min)	3000	5000	7000	9000	11000	13000	
ExpNo.6	Variable F/(mm/min)	600	1000	1400	1800	2200	2600	
ExpNo.7	Variable a_e/mm	0.05	0.1	0.15	0.2	0.25	0.3	
ExpNo.8	Variable a_p/mm	0.015	0.02	0.025	0.03	0.035	0.04	