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Analysis of surface formation of rotary ultrasonic milling of quartz glass based on nano-indentation experiment

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Abstract

As an effective and efficient way of machining in hard–brittle materials, rotary ultrasonic milling(RUM) has many unique advantages. In this research, machining and nano-indentation tests had been undertaken in order to obtain the material removal mechanisms and transformational rules of quartz glass, and the machined surface roughness and the three-dimensional morphology were analyzed according to the detection results deriving from laser confocal microscope. The influence law and the machining mechanism of feed speed, depth of cut with and without ultrasonic on the machined surface quality were discussed. The material removal mode nearby the final formed surface deriving from combination of ultrasonic vibration and depth of cut plays an key role in the formation of machined surface quality in milling process. This research work could provide some process foundation for rotary ultrasonic face milling of quartz glass.

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Keywords: Rotary ultrasonic milling; quartz glass; surface roughness; surface topography

Introduction

Quartz glass has high temperature resistance, low expansion coefficient, thermal shock resistance, high chemical stability, excellent performance, and is widely used in chemical industry, electronics, metallurgy and national defense and other industrial fields. Therefore, the traditional processing methods not only have low processing efficiency but also accompanied with serious tool wear, broken collapse, chipping and other issues, Rotary ultrasonic

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milling is a complex machining mode of diamond milling tool with high frequency strike along with axial ultrasonic vibration and feed milling motion. Its material removal method is the superimposition of high-frequency vibration, slip, plow and abrasion effects by diamond abrasive grains. The milling parameters such as spindle speed, feed speed, depth of cut and ultrasonic amplitude will have obvious impacts on the final workpiece surface quality. Rotary ultrasonic milling has excellent processing capacity for such hard and brittle materials to provide efficient and effective solution.

In recent years, many researchers have studied and printed many new theoretical and experimental results of RUFM[1, 2]. And the focus on this processing method is changing from the macroscopical surface quality to some microcosmic descriptions of materials removal mechanism. Lv[3] demonstrated that the cutting force of RUFM is obviously decreased and it can also change the ratio of brittle and plastic. Gong[4] studied the grains' motion trail on the side and gave the equations for the trace of motion of one grain. Zhang[5] found ultrasonic vibration-assisted scratch (UVAS) can reduce scratch loads and improve the plastic removal proportion comparing traditional scratching of sapphire. Liu[6] built up a cutting force model for rotary ultrasonic milling of brittle materials. In this paper, nano-indentation and rotary ultrasonic milling are used to study the material removal mechanism of quartz glass at micro/nano scale and the effect of ultrasonic amplitude on the actual depth of cut.

Experimental details

Fig. 1. The tool with its 1000X photos and the nano indenter

The equipment for nano-indentation test is MTS NANO G200 nano-indenter and the RUFM experiments were taken by the DMG ULTRASONIC 80 eVo linear five-axis machining center with Φ6 electroformed diamond hollow flat end mill. The size of abrasive grain is 76μm. The VK-X100 / X200 laser scanning confocal microscope was used to measure the surface roughness, and the micro-morphology at 1000 magnification and ultrasonic cleaning was carried out before the test experiences.

Table 1. Experiment parameters of RUFM and CM

Test Variables	Basic Processing Parameters n=3000r/min a_e=1.4mm								
a_p（mm）	0			0.002			0.02		
F（mm/min）	1000	1400	1800	1000	1400	1800	1000	1400	1800

Discussions on the material removal mechanism

In order to analyzed the changing mechanism of the materials' properties for quartz glass with low depth of cut during the rotary ultrasonic face milling, the nano-indentation test was carried out to understand the material removal mechanism of the quartz glass at the nanometer and the micron scale. Fig. 2 shows the surface morphology obtained by the nano-indentation experiment. The range of nano-indentation depth varies from 0.5μm to 1.8μm. According to the indentation image, it can be seen that the quartz glass shows obvious plastic deformation at the edge of the indentation with 1.8μm, indicating that the plastic domain of quartz glass can be processed in a certain depth of cut.