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Experimental study of fiber laser surface texturing of polycrystalline diamond tools

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ABSTRACT

Micro-grooves and micro-holes with different geometrical characteristics were fabricated on the surface of the polycrystalline diamond (PCD) tools by the fiber laser surface texturing. The effect of the processing parameters on the dimensions of micro-textures was investigated. In general, the dimensions of the micro-textures (e.g., width, diameter and depth) were reduced with a higher scanning speed, pulse repetition rate and a lower average output power. For both micro-grooves and holes, their dimensions are significantly affected by different defocusing distance. The maximum depth can be achieved when the defocusing distance is around −0.8 mm. Furthermore, the sidewall topography of the micro-grooves was also studied, where the quality can be improved by a larger average output power or a lower scanning speed. Based on the experimental results, an optimization of the processing parameters can effectively control the micro-texture dimensions as well as improve their surface qualities on the PCD tools.

Introduction

High speed machining technology has been widely used in metal cutting due to its remarkable advantages compared with conventional machining such as improving productivity, decreasing thermal deformation and cutting force, etc. However, cutting tools have shorter tool life and lower cutting efficiency when applied for difficult-to-cut materials [1–3]. The rapid wear of cutting tools is one of the key issues for high speed machining of difficult-to-cut materials. Therefore, it is greatly significant to improve wear resistance on the tool-chip interface, which causes cutting heat, thermal deformation and the rapid wear of tools. Several methods like cutting fluid, fluid supply, Minimum Quantity Lubrication [4], surface coating [5,6] and finishing have been developed to improve the tribological properties of the tool-chip interface. However, the extensive usage of cutting fluid seriously contaminates the environment and increases the cost [7,8]. Also, the development of new coating materials is difficult.

The solid or liquid lubricants are sometimes required in practical use to improve the tribological properties of the tool-chip interface, but it is not easy to directly supply these lubricants to the actual frictional interface. Biomimetic tribology researches suggest that non-smooth surface texture can effectively reduce friction resistance and improve wear resistance and anti-adhesion [9,10], which give a new research direction that surface texture will be applied to the cutting tools. Researches were found that cutting tools with micro-textures can effectively improve the tribological properties of the tool-chip interface such as wear resistance [11,12], anti-adhesion [13,14], cutting force, cutting temperature and the friction coefficient [15,16].

This improvement could be attributed to the effect that the micro-textures are playing a role as reservoirs, which can trap wear debris, store solid or liquid lubricants and generate hydrodynamic pressure [17–20]. Furthermore, it may be owing to reducing actual contact length and forming lubricating film on the tool-chip interface [21–23]. These researches revealed that the shape of texture has a significant influence on the friction behavior and the wear resistance. Therefore, it is of great significance to study the surface texture topography of the cutting tools to obtain desired dimensions and quality. Various kinds of methods were used for fabricating the micro-textures including electrical discharge machining [24], electrochemical machining [25–27], abrasive jet machining [28], LIGA technology [29], laser texturing [30–33], etc. However, little information has been reported on the fabrication of the micro-textures on the surface of the PCD tools by the fiber laser. Compared with the other processing methods, the laser texturing has many obvious advantages such as rapid fabrication, no pollution, the excellent control of the shape and size of the micro-textures, etc. In recent years, the fiber laser texturing [34,35] has already been used in many research fields owing to the advantages of high beam quality, high efficiency, compact structure, high stability and high reliability. The type of laser can also provide a wide choice of pulse durations, pulse repetition rates and peak powers. The laser can operate safely under industrial shock, vibration, dust and humidity in the temperature range from 0 °C to 50 °C.

In this paper, the fiber laser was used to fabricate micro-grooves and micro-holes on the surface of PCD tools. The comparative investigations

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Table 1
Properties of PCD tools.

Density (g/cm^3)	Grain size (μm)	Young's modulus (GPa)	Poisson's ratio	Thermal conductivity (W/(m·K))	Compressive strength (GPa)	Transverse rupture strength (GPa)	Fracture roughness (GPa·m$^{1/2}$)	Knoop hardness (GPa)
3.85	10	900	0.086	560	7.6	0.96	7.31	50

of different geometrical characteristics and topography were carried out to determine the impact of the processing parameters on the micro-grooves and micro-holes. The work can contribute to the optimization on the dimensions and topography of micro-textures, with which the tool-chip interface may present better tribological properties.

Experimental details

The PCD (CTB010) was selected as the experimental material in this study (Table 1). A fiber laser (YLP-1-100-20-20-RG) was used to fabricate the micro-grooves and micro-holes on the surface of PCD tools. The focal length and scanning field of the scanner lens (FL-Y50 F100) are 100 mm and 50 × 50 mm^2, respectively. The experimental data and surface topographic images of micro-textures were measured and characterized by a digital microscope (Leica DVM5000) and a scanning electron microscope (S-3400N). The processing parameters for fabricating micro-grooves and micro-holes are listed in Table 2.

Experimental results and discussion

Optical images (Fig. 1 (a) and (b)) and SEM topography (Fig. 1(c) and (d)) of micro-grooves and micro-holes on the surface of the PCD are shown in Fig. 1. It can be seen that a fine shape of micro-textures can be obtained by a fiber laser. The width or diameter of top surface is apparently larger than that of the bottom surface. In this paper, the recorded width or diameter of micro-textures is the entry width or diameter on the surface of polycrystalline diamond.

Influence of scanning speed on micro-textures

Fig. 2 shows the enlarged SEM morphology of micro-textures under different scanning speed. As seen in Fig. 2(a) and (b), the width of micro-grooves was reduced when the scanning speed was increased from 0.5 mm/s to 10 mm/s and the diameter of micro-holes was reduced when the scanning speed was increased from 2 mm/s to 20 mm/s.

Furthermore, it can be observed that the sidewall quality of the micro-grooves and micro-holes is effectively improved under a lower scanning speed (Fig. 2(a) and (c)).

Fig. 3 illustrates the influence of scanning speed on the two kinds of micro-textures under different scanning speed. As shown in this figure, the depth, width and diameter of micro-textures were reduced with the scanning speed ranging from 0.5 mm/s to 6.5 mm/s.

Influence of pulse repetition rate on micro-textures

Fig. 4 shows the enlarged SEM morphology of micro-textures under different pulse repetition rate. According to the experimental results, the width of micro-grooves was significantly decreased when the pulse repetition rate was increased from 20 kHz to 50 kHz, and the diameter of micro-holes was reduced with the when the pulse repetition rate was increased from 50 kHz to 90 kHz.

The influence of pulse repetition rate on micro-grooves and micro-holes is shown in Fig. 5. It indicates a decreasing trend for the width, diameter and depth of micro-textures when the pulse repetition rate was varied from 50 kHz to 90 kHz and 20 kHz to 60 kHz for the micro-grooves and the micro-holes, respectively.

Influence of average output power on micro-textures

Fig. 6 shows the enlarged SEM morphology of micro-textures under different average output power. It can be seen that the width and diameter of micro-textures were significantly increased when the average output power was increasing, and the sidewall of the micro-grooves was smoother with an average output power of 11 W compared to that of 6 W.

Fig. 7 shows the influence of average output power on micro-grooves and micro-holes. As shown in this figure, the width, diameter and depth of micro-textures were increased when the average output power was changed from 4 W to 9 W and 10 W to 16 W for the micro-grooves and micro-holes, respectively.

Influence of defocusing distance on micro-textures

Fig. 8 gives the SEM morphology of micro-textures with increasing defocusing distance. It indicates that the width and diameter of micro-textures firstly increased and then decreased when the defocusing distance was increased.

The enlarged SEM topography of micro-textures under different defocusing distance is shown in Fig. 9, where the width or the diameter of the micro-textures was greatly reduced when the defocusing distance ranged from −0.8 mm to −1.2 mm or 0.8 mm to 1.2 mm. While the defocusing distance was excessively increasing towards the positive direction or negative direction, the depth of micro-textures was significantly reduced (Fig. 9(b), (d), (f) and (h)).

Fig. 10 shows the influence of the defocusing distance on micro-grooves and micro-holes. It can be seen that the depth of micro-grooves and micro-holes was basically decreased with the defocusing distance ranging from −0.8 mm to 1.2 mm. The maximum depth of the two micro-textures can be achieved when the focus is around 0.8 mm below the material surface. And it was found that the depth of micro-textures was deeper with a negative defocusing distance than that of the positive one within the range from −0.8 mm to 1.2 mm. From these results, it was obviously observed that the minimum width and diameter of micro-textures can be obtained around 0 mm.

Table 2
Processing parameters for fabricating micro-grooves and micro-holes.

Repeat number	Average output power (W)	Scanning speed (mm/s)	Pulse repetition rate (kHz)	Defocusing distance (mm)	Types
100	8	0.5 to 6.5	30	−0.5	Micro-grooves
100	15	0.5 to 6.5	80	−0.5	Micro-holes
100	10	2	50 to 90	−0.5	Micro-grooves
100	15	2	20 to 60	−0.5	Micro-holes
100	4 to 9	1	30	−0.5	Micro-grooves
100	10 to 15	1	80	−0.5	Micro-holes
100	10	2	30	−1.2 to 1.2	Micro-grooves
100	15	2	40	−1.2 to 1.2	Micro-holes