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Cutting performance of micro-textured polycrystalline diamond tool in dry cutting

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ABSTRACT

This study investigates the performance of micro-grooved polycrystalline diamond (PCD) tool in dry machining of Ti6Al4V titanium alloy. Regular micro-groove array was successfully fabricated on the rake face of PCD tools by a fiber laser. The effect of the micro-grooved PCD tools and the untextured PCD tools on cutting force, average friction coefficient, and anti-adhesion was studied in detail. It is found that better tribological properties of the tool–chip interface can be achieved by the micro-grooved PCD tools compared with that of the untextured PCD tools even under dry cutting conditions. Furthermore, the action mechanism of the micro-grooved PCD tools on the friction behaviors has been discussed and revealed by the tool-chip contact length, direction of micro-grooves, and formation of TiC.

1. Introduction

Titanium alloy has been widely applied in numerous fields because of its significant advantages compared with other materials. The cutting process of Ti6Al4V titanium alloy, the most common difficult-to-machine material [1,2], can cause chips to adhere severely to the surface of cutting tools and lead to rapid tool wear. Therefore, improving the friction behaviors of the tool-chip interface is critical to improving the cutting efficiency, delaying the cutting tool life, and saving processing cost.

Researchers have found that the non-smooth surface texture of some animals or plants can play a part in reducing friction resistance, surface wear, and anti-adhesion during long-term natural selection [3–6]. Various sizes and types of surface texture have been designed, fabricated, and widely applied in many fields such as anti-friction, anti-wear, anti-vibration, and anti-adhesion [7–11]. Research on bionics and surface texture tribology shows that the tribological properties can be changed by applying surface texture, which can provide a novel way of improving the friction behaviors.

Surface texture has been widely applied in cutting tools for improving the tribological properties at home and abroad. Arulkirubakaran et al. [12] fabricated three types of micro-grooves on the surface of cemented carbide tools by wire-EDM, and the experiments on turning of titanium alloy were carried out by micro-grooved cutting tools, in which the direction of micro-grooves was parallel to the flow direction, perpendicular to the flow direction, and cross pattern. Results showed that the textured tools with lubricant can effectively reduce the actual contact area, friction coefficient, cutting force, and cutting temperature compared with that of the untextured tools, and the textured tool with micro-grooves perpendicular to the flow direction shows excellent anti-friction behaviors.

Denget al. [13] fabricated micro-holes with MoS_2 solid lubricants on the rake face and flank face of cemented carbide tools. The results of dry cutting of hardened steel showed that the micro-holed tools with MoS_2 solid lubricants can reduce significantly the cutting forces compared with that of the untextured tools.

Denget al. [14] also studied the effect of WC/Co carbide tools with different shapes of micro-grooves on cutting performance in dry cutting process. It was found that the tools with elliptical grooves filled with MoS_2 solid lubricants demonstrated the smallest cutting force, cutting temperature, and friction coefficient.

Sugihara and Enomoto [15] developed micro-stripe grooves on the flank face of cemented carbide tool, and milling experiments on steel materials revealed that the cemented carbide tool with micro-stripe grooves with cutting fluid can significantly reduce the flank wear. Enomoto and Sugihara [16] studied the effect of cemented carbide tool with nano/micro textures on the improvement in anti-adhesive properties during cutting of aluminum alloys, and their results indicated that the chip adhesion on the tool rake face can be

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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

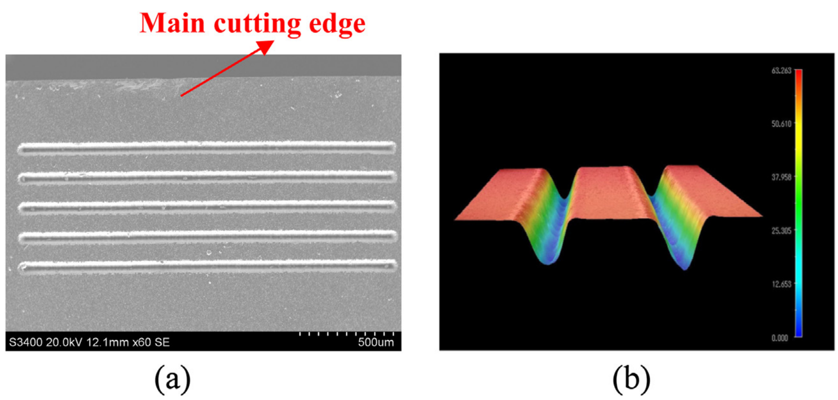

Fig. 1. SEM and optical topography of developed polycrystalline diamond tools with micro-grooves: (a) SEM topography of micro-groove array, (b) optical topography of micro-groove cross-section.

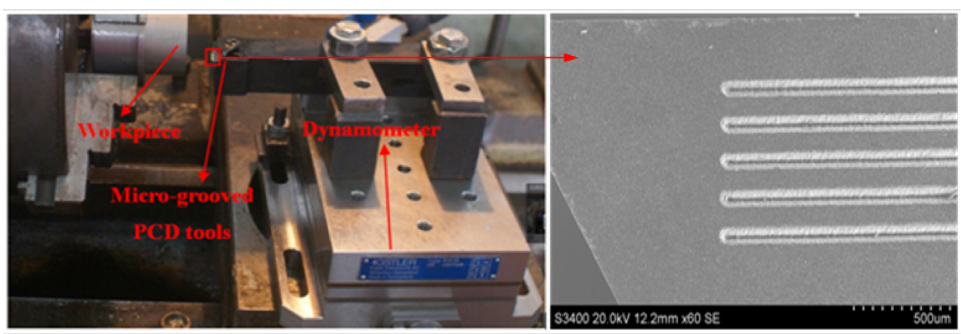

Fig. 2. Experimental setup of orthogonal cutting.

significantly reduced by the nano/micro textures under wet cutting conditions.

Lei et al. [17] studied the effect of micropool-lubricated tungsten carbide tool in cutting of mild steel on performance, and results showed that the micropool-lubricated tool can effectively reduce the cutting force and tool-chip contact length. Qi et al. [18] studied the on orthogonal cutting of Ti6Al4V using micro-textured tool, and results indicated that the micro-texture combined with lubricant can effectively reduce the cutting force, cutting temperature, improve anti-adhesion and anti-wear.

The performance of micro-textured tool in machining of Ti-6Al-4V has been investigated by Finite Element Method [19–21], and results indicate that the micro-textured tools can effectively reduce the cutting force, cutting temperature and tool-chip contact length.

Presently, majority of the results show that textured tools can improve tribological properties compared with that of untextured tools under lubrication conditions; most of the textured tools are cemented carbide materials, and the workpiece materials mainly include carbon steels and aluminum alloys [22–26]. However, little information has been reported on machining of difficult-to-cut materials by micro-textured PCD tool without any lubricant.

In this study, the micro-grooved PCD tools are fabricated by a fiber laser and applied in the cutting process of Ti6Al4V titanium alloy. The effects of the micro-grooved PCD tools and the untextured tools on the friction behavior are studied under dry cutting conditions.

2. Experimental

The cutting tool material is the PCD (Table 1). Different kinds of the micro-grooved PCD tools with the micro-groove array parallel to the main cutting edge are fabricated by the fiber laser (YLP-1-100-20-20-RG). The processing parameters of the fiber laser are as follows: scanning speed = 2 mm/s, pulse repetition rate = 20 kHz, average output power = 12 W, defocusing distance = −0.6 mm.

The micro-groove images are measured and examined by a digital microscope (Leica DVM5000) and a scanning electron microscope (SEM; S-3400N), respectively. Fig. 1(a) shows the SEM topography of the micro-groove array on the rake face of the PCD tool, and optical images of the micro-groove array are shown in Fig. 1(b). Fine size, shape, and arrangement of micro-grooves array can be obtained by the fiber laser. The micro-groove width of the top surface is apparently larger than that of the bottom surface, and a profile of a cross-section of a micro-groove resembles a parabola.

The workpiece material is the Ti6Al4V titanium alloy in this study. The outside diameter and inside diameter of the workpiece are 50 and 46 mm, respectively. Experiments of orthogonal cutting of the Ti6Al4V titanium alloy are carried out by the untextured PCD tools and the micro-grooved PCD tools on a lathe under different cutting speeds.

The rake angle and clearance angle of the untextured PCD tools and micro-grooved PCD tools are 6° and 11°, respectively. The following cutting parameters are adopted in this study: