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Cutting mechanism and performance of high-speed machining of a titanium alloy using a super-hard textured tool

Yongsheng Su[a,b,*], Liang Li[b], Gang Wang[a], Xiangqiang Zhong[a]

[a] School of Mechanical and Automotive Engineering, Anhui Polytechnic University, Wuhu 241000, China
[b] College of Mechanical and Electrical Engineering, Nanjing University of Aeronautics & Astronautics, Nanjing 210016, China

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ABSTRACT

The study investigates the anti-friction and anti-adhesion effects of micro-textured super-hard polycrystalline diamond (PCD) tools in high-speed machining of a titanium alloy, Ti6Al4V. The experimental results indicate that the friction coefficient can be dramatically reduced by increasing the cutting speed. PCD tools with micro-grooves resulted in less friction during cutting in the absence of lubrication than both un-textured and textured tools with various lubrication condition. It was found that the adhesion area on the rake face of the PCD tool during high-speed cutting can be dramatically reduced by adding micro-grooves near the main cutting edge. It was shown that the maximum width of chip adhesion was reduced by 23.6% on the micro-grooved tool compared to that on the un-textured tool. Furthermore, the results confirmed that TiC can be formed on the surfaces of PCD tools as a bonding layer, which is of significance to revealing anti-friction performance of tool-chip interface. Together, these results show that the directional distribution of the micro-grooves on the tool, the actual tool–chip contact area, the effect of micro-grooves on trapping tiny debris and the TiC bonding layer play important roles in improving tool performance.

1. Introduction

Technology for high-speed cutting has been increasingly used for various cutting applications because of its excellent advantages compared to other techniques. However, rapid tool wear limits the cutting speed that can be used for machining titanium alloys and high-temperature alloys. Therefore, studies to develop anti-friction and anti-adhesion approaches for the high-speed machining process are of great significance for increasing the tool life.

Various methods have been used to reduce tool wear, including the application of cutting fluids [1] and tool-coating materials [2,3], the use of new materials in the construction of the cutting tool itself, and the optimization of the structure and angle parameters of the cutting tool [4]. With recent advancements in machining technology, there are now strict requirements regarding efficiency, energy consumption, and environmental impact. Thus, there has also been interest in developing green cooling and lubrication for improving cutting-tool performance, including liquid nitrogen, high-pressure cooling and minimum-quantity lubrication (MQL) [5–7].

In recent years, many studies have shown that the use of textured tools can also reduce the cutting friction and improve the anti-adhesion and anti-wear properties of the tool, thus improving tool performance and increasing the tool life [8–11]. Many other studies [12–21] have also shown that textured tools can be used to reduce the cutting friction, minimize tool wear, and extend the tool life. Hence, it is considered that the best cutting performance can be achieved through the use of surface textures combined with the lubrication.

Cemented carbide is the material that is most commonly used in cutting tools. But, the cemented carbide tools and many other conventional tools have shorter tool life in high speed machining of difficult-to-cut materials. Own to the remarkable anti-friction and anti-wear performance of PCD tools, there are some reports on machining of titanium alloys using PCD tools [22–24]. However, little information has been reported about textured super-hard PCD tools for high-speed cutting of difficult-to-machine materials. Thus, the objective of this study is to characterize the anti-friction and anti-adhesion properties of PCD tools with and without micro-grooves under different cutting conditions and to understand the mechanisms underlying these characteristics. We expect that these findings will contribute to further efforts toward improving tool life.

* Corresponding author.
E-mail address: sysh@ahpu.edu.cn (Y. Su).

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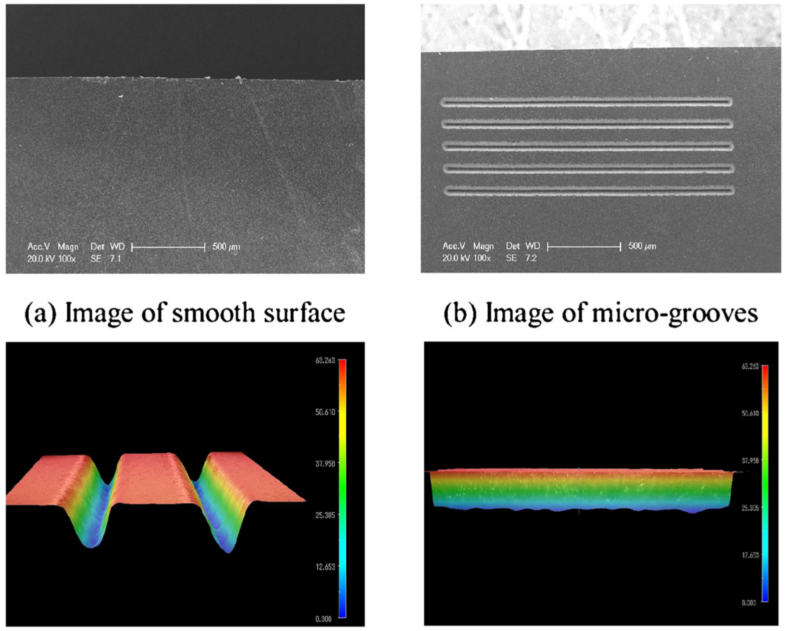
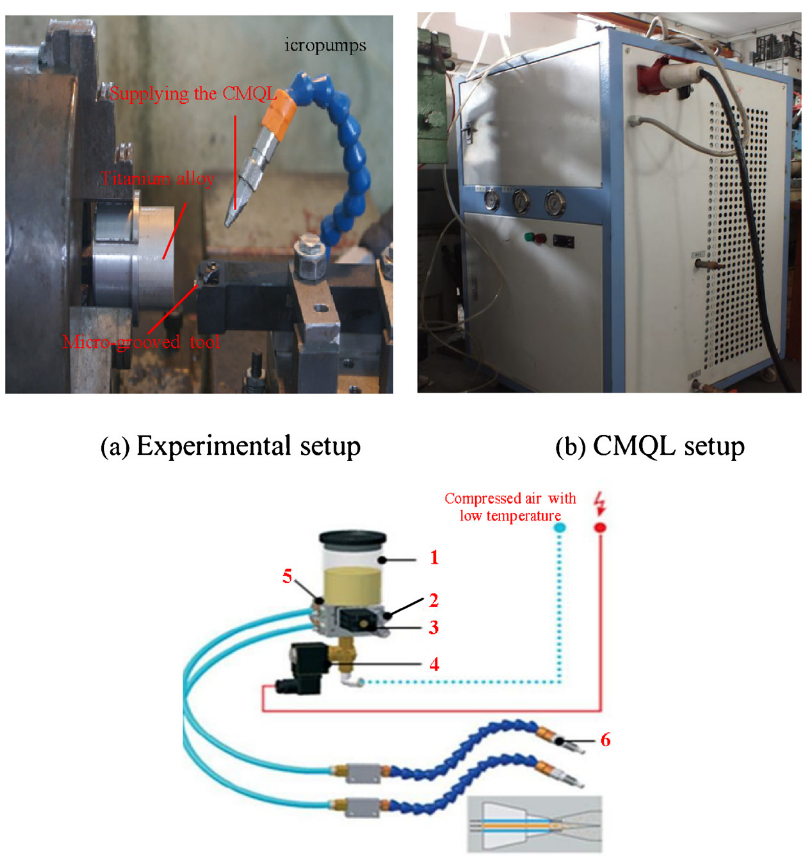


(a) Image of smooth surface (b) Image of micro-grooves

(c) Image of a cross-section (d) Image of micro-grooves bottom

Fig. 1. SEM and optical images of the micro-grooved tools.



(a) Experimental setup (b) CMQL setup

(c) Schematic sketch of the CMQL setup

Fig. 2. Experimental setup and CMQL setup (1-Lubricant reservoir, 2-Control buttons of lubricant flow, 3-Pneumatic pulse generator, 4-General air solenoid valve, 5-Micropumps,6-Nozzle).