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Cutting edge damage in grinding of cemented carbides micro end mills

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ABSTRACT

Micro mills are widely applied in the micro manufacturing and mainly fabricated using the grinding method. Cutting edges have significant influences on the performance of micro mills such as the micro mill life and machining quality. In this paper, the cutting edge damage mechanisms in the grinding of cemented carbides micro mills are investigated. The micro end mills grinding experiments are carried out and the cutting edge maximum edge damage width and surface roughness of the end teeth flank are measured. The results show that the micro fractures and micro cracks are generated in the cutting edge following micro pits in the grinding surface. The grain size and composition of cemented carbides have significant impacts on the damage of the cutting edge. The maximum edge damage width increases with the increase of Co binder content and WC grain sizes. However, a better flank quality with less micro pits is obtained as the reduction of Co binder content and grain size of WC.

1. Introduction

Micro mills are widely applied in micro manufacturing such as MEMS, biotechnology and aerospace. Micro milling an effective way to produce more complex three-dimension geometries micro products in a wide range of materials [1]. Unlike traditional cutting, the micro machining characteristics are affected by micro mill edge radius [2]. When the depth of cut is equal to the damage width of tool cutting edge, the size effect occurs during the cutting process easily. However, in order to obtain high accuracy miniaturized parts, the depth of cut of micro milling often is needed to be less than 1 μm in some micro products manufacturing. Under this condition, the cutting edge and surface damages of micro mill have significant impacts on the tool life and machining quality. Thus, the tool surface and cutting edge are crucial to the quality of micro mills products.

For a long micro mill life and good machining quality, the fabrication of micro mills requires a precision manufacturing process. Cemented carbides are often selected as micro tool material, because it can be used to machine a large variety material and be fabricated to a complex tool easily. However, due to the limitation of the carbide grains size and sintering technique, the sharp tool is difficult to be processed [3]. Therefore, a great challenge still exists in micro milling manufacture to achieve high quality and precision micro milling tools. As a main method, grinding is often used to fabricate high precision micro mills for the high material removal efficiency and high machining accuracy. For instance, 10 μm diameter single edge helical micro end mills of cemented carbides have been fabricated using grinding method [4]. During the grinding process of micro tool, the cutting edge and surface quality of micro mills is strongly affected by the tool material property. Ohmori et al. [5] reported cemented carbides can be stably removed in ductile mode during the micro tools grinding, and they found the surface characteristics of micro tool exert extremely strong effects on mechanical strength of the tool. Zhan et al. [6] found the grain size of tool material is the most influential parameter on the grinding quality of micro mill, followed by grinding wheel grain size, feed rate and grinding speed. Furthermore, in traditional tool grinding, Denkena et al. [7] found the grinding quality of the cutter mainly depends on the cutter material removal mechanism which is significantly influenced by the cutter material grain size. Among these reports, during the fabrication process of micro mill, the micro cracks and micro fracture are often generated in cutting edge of micro mill, and micro pits are often generated in mill surface due to the property of tool material. The existence of the cutting edge micro fractures and micro cracks affects the strength of the mills significantly. However, few studies investigated the cutting edge damages in the fabrication of micro tool, and especially the effects of grain size and composition of cemented carbides on the cutting edge damages of micro mill are unclear.

In the last several years, great progress research has been made in the effects of the grain size and composition of cemented carbides on the quality of cemented carbides grinding. For instance, Hegeman et al. [8] reported the cemented carbides grinding removal behavior depends on the ratio between the abrasive grains sizes and the WC grains sizes, and the surface roughness depends on WC grains size and small grains

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size produces high surface roughness. Zhang et al. [9] found the surface generation mechanism of cemented carbides high speed grinding is material plastic deformation WC/Co grain dislodgement and WC grains crush. Liu et al. [10] demonstrated the material removal mechanism of cemented carbide presents ductile mode, semi-brittle mode and brittle mode with increase of depth of cut in the groove grinding. Yang et al. [11] discussed a deformed/damaged thin layer which contains fragmented carbides and micro cracks together with high compressive residual stresses are introduced during the grinding process of WC-Co cemented carbides. However, most of above studies investigated the traditional grinding of cemented carbides. The micro grinding of the cemented carbides tool material is rarely investigated. The cutting edge damage mechanism of the cemented carbides micro tools grinding are still unclear.

Herein, the micro mills of cemented carbides grinding experiments are carried out. The grinding morphology of the micro end mills surface are observed, and the maximum edge damage width of cutting edge and end teeth flank surface roughness of the mills are measured. The effects of grain size and composition of cemented carbides on the quality of micro mills are investigated. The cutting edge and surface damage mechanism in the grinding of cemented carbides micro end mills are discussed.

2. Experimental procedures

The micro end mills experiments are carried out on a six axes CNC tool grinding machine (CNS7d, by Makino Seiki Co., Ltd.) as shown in Fig. 1. During the grinding process, the mill shank is clamped to make the mill axis coincide with A-axis, and the mill could move along U-axis and Y-axis and rotate around W-axis. While the grinding wheel moves along X-axis and Z-axis. The resolution of the machine in X-axis, Y-axis and Z-axis are 0.0001 mm. The position precision of the grinding machine in X-axis, Y-axis and Z-axis are 0.0035 mm, and repositioning precision the grinding machine in X-axis, Y-axis and Z-axis are 0.0015 mm. Based on the above grinding method, the simulation software MSPS of Makino Seiki grinding machine is used to simulate the motion of the grinding procedure before the experiments.

The same geometries of micro helical end mills are fabricated with diameter 0.5 mm, helix angle 30°, rake angle 3° and relief angle 12° during the grinding experiments (Fig. 2) . The main cutting edge is formed by the peripheral rake face and peripheral flank face. The peripheral rake face and peripheral flank face rough grinding parameters are depth of cut a_p=20 μm, feed rate f=800 mm/min and grinding speed v=24 m/s, and the finish grinding parameters are a_p=4 μm, feed rate f=400 mm/min and grinding speed v=24 m/s. Meanwhile, the end teeth geometries rough grinding parameters are depth of cut a_p=20 μm, feed rate f=200 mm/min and grinding speed v=24 m/s, and the finish grinding parameters are a_p=4 μm, feed rate f=20 mm/min and grinding speed v=24 m/s. The resin bonded diamond grinding wheel (2000#) (Henan UN Whirlwind Diamond Co., Ltd) and grinding oil are used in the experiment. The single bevel grinding wheel (1) with diameter 135 mm and edge angle 45° is used to fabricate the peripheral rake face, the peripheral flank face and the end teeth gash. The single bevel grinding wheel (2) with diameter 100 mm and edge angle 45° is used to fabricate the end teeth flank face. Each experiment is repeated three times. The cemented carbides with different grain sizes and composition including K55SF, DK450UF, DK500UF and DK120UF (GUHRING Co., Ltd.) are adopted during the experiment. The mechanical property of different grain sizes and composition cemented carbides tool materials are shown in Table 1.

The fabricated micro mills are cleaned using ultrasonic cleaning machine before measuring. The surface roughness Ra of micro mills end teeth first clearance is measured using optical profiling system (Wyko NT1100, Veeco Co., Ltd.), and the maximum edge damage width Rk of micro mills cutting edge in rake face is also measured by scanning electron microscopy (SEM, FEI Quanta 650FEG).

3. Results and discussion

3.1. Cutting edge damage mode in grinding of micro mills

The grinding defects of the fabricated micro end mills are shown in Fig. 3. It could be found that the damages of the micro mill are mainly manifested as micro fractures and micro cracks in the cutting edge, and micro pits and cracks in the grinding surface. There are many plastic scratching grooves and feed masks in feed direction and micro pits and micro cracks randomly distributed in the grinding surface (Fig. 3). Some WC grains are broken in the cutting edge and the broken WC grains can be observed in micro fractures of cutting edge. Regular shape organization structure is found in the micro fracture of the cutting edge, which indicates some WC particles are broken in the cutting edge. It could be seen from the micro fractures that the WC grains are pulled out from the WC/Co or WC/WC boundaries in the cutting edge (Fig. 3(b)). It indicates that the micro cracks and micro fractures of the cutting edge tend to propagate twisting around the boundaries of WC/Co or WC/WC. In order to evaluate the cutting edge damage of the micro mill, the maximum edge damage width Rk is defined as shown in Fig. 3(d). It also can be seen that there is a thin deformed layer made of fragmented and plastic deformed WC particles from the fracture cross-section of the mills cutting edge tip. The deformed layer becomes denser with the WC particles breakage and plastic deformation during grinding process. The cutting edge damages of the micro mills significantly affect the strength of the mills.

Cutting edge tip fracture of micro mill is one of the most significant damage effects on the performance of micro mill. Unreasonable select of grinding parameters and tool material defects will lead to the cutting

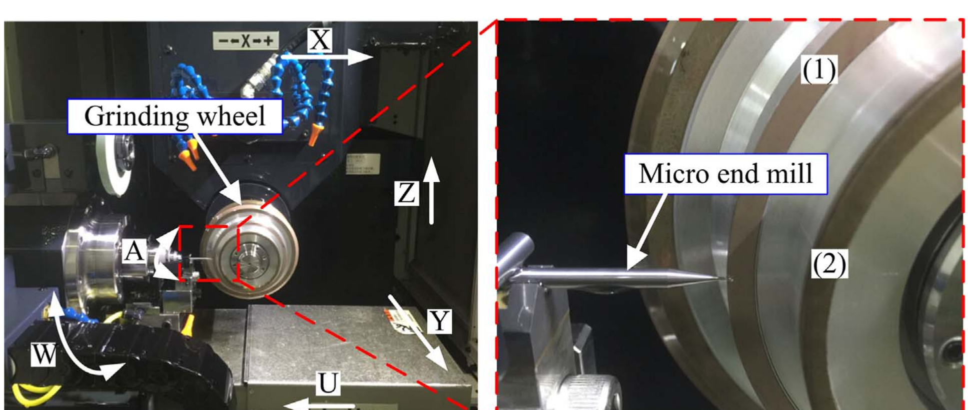

Fig. 1. Micro end mills grinding experiment setup.