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Built-up edge effects on process outputs of titanium alloy micro milling

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ABSTRACT

Built-up edge (BUE) is generally known to cause surface finish problems in the micro milling process. The loose particles from the BUE may be deposited on the machined surface, causing surface roughness to increase. On the other hand, a stable BUE formation may protect the tool from rapid tool wear, which hinders the productivity of the micro milling process. Despite its common presence in practice, the influence of BUE on the process outputs of micro milling has not been studied in detail. This paper investigates the relationship between BUE formation and process outputs in micro milling of titanium alloy Ti6Al4V using an experimental approach. Micro end mills used in this study are fabricated to have a single straight edge using wire electrical discharge machining. An initial experimental effort was conducted to study the relationship between micro cutting tool geometry, surface roughness, and micro milling process forces and hence conditions to form stable BUE on the tool tip have been identified. The influence of micro milling process conditions on BUE size, and their combined effect on forces, surface roughness, and burr formation is investigated. Long-term micro milling experiment was performed to observe the protective effect of BUE on tool life. The results show that tailored micro cutting tools having stable BUE can be designed to machine titanium alloys with long tool life with acceptable surface quality.

1. Introduction

Micro milling offers high flexibility in terms of its ability to create three-dimensional surfaces made from a variety of engineering materials. For example, micro milling is a commonly used process to produce micro molds, which are used in mass production of micro components [1,2]. The material removal in micro milling is realized by using micro end mills, which have defined cutting geometries. The micro end mills have diameters less than 1 mm. The influence of micro end mill diameter on the process outputs becomes significant as the tool diameter decreases. The cutting edge geometry and surface quality of the micro tool, together with the work material properties, have a direct influence on the quality of the manufactured parts [3]. Small diameters of micro end mills limit the maximum cutting speed during the process. In addition, feed values lower than the cutting edge radius results in rapid rounding of the cutting tool edge. When ductile materials such as steel, aluminum, and titanium alloys are machined, built-up edge (BUE) is observed on the cutting edges and it affects the process outputs and especially the surface roughness. An understanding of the interplay between tool wear, built-up edge, and surface quality for a given tool-work material pair is crucial for the successful application of the micro milling process. The work material is selected as titanium alloy Ti6Al4V due to its widespread use in practice [4–6].

The influence of BUE on machining has been considered mainly for macro scale machining processes [7–9]. However, the influence of BUE on the micro milling process has not been studied in detail. Thepsonti and Özel [10] observed BUE formation in micro milling of titanium alloy Ti6AL4V. Recently, Kovvuri et al. [11] and Wang et al. [12] studied the influence of BUE while machining 316L stainless steel and reported that BUE is mainly responsible for surface roughness deterioration in the finish micro milling process. They showed that when BUE is not present, theoretical surface roughness models yield acceptable predictions. Ucun et al. [13] and Aslantas et al. [14] both studied the finish micro milling operation and observed that coated tools minimize BUE and help improve surface roughness.

BUE affects the friction conditions at the tool-chip and tool-workpiece interfaces by acting like a cutting edge so that the cutting tool material is no longer in contact with the chip and the machined surface. Iwata and Ueda [15] studied machining of low carbon steel and observed that fracture behavior of the work material affects BUE formation and its adhesion to the tool. They reported that tool rake temperature between 350 and 500 °C provided the nec-

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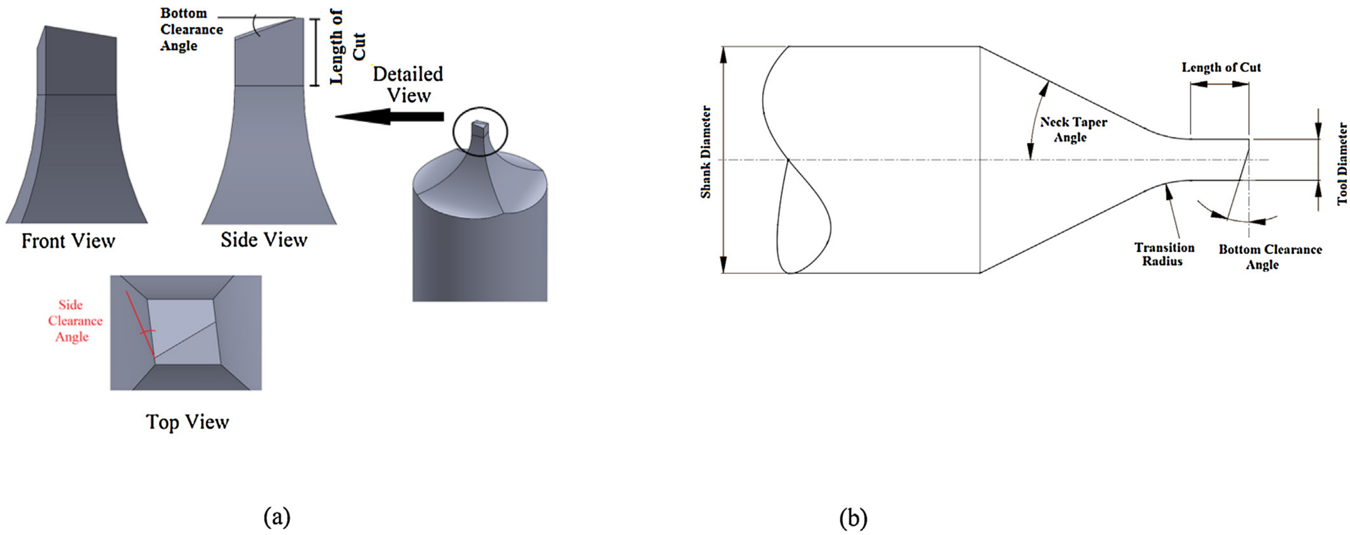

Fig. 1. (a) Geometry of the designed single edge cutting tool, (b) Design parameters of the tool.

essary conditions for BUE to adhere to the cutting tool surface. The influence of rake face temperature on the adherent layer was also observed by Mills et al. [16] while machining calcium dioxide low sulphur content austenitic stainless steel. Kümmel et al. [17,18] created dimples on the tool surface to promote BUE formation during macro scale turning operation. The dimples on the cutting tool surface increase BUE adhesion on the cutting tool, hence improving the tool life. Oliaei and Karpat [19] fabricated micro cutting tools using wire electrical discharge machining, which creates micro scale craters on the surface of the tool, which was also shown to promote BUE adhesion during machining. The protective effect of BUE was shown for micro turning process. In this study, this approach is carried out during micro milling of titanium alloy Ti6Al4V by fabricating micro cutting tools using wire electrical discharge machining (WEDM). The influence of BUE on the process outputs is investigated. The research question is whether tool design parameters and machining conditions can be adjusted to obtain a stable BUE that protects the cutting edge. This may be especially useful to increase material removal rate during micro milling operation.

Various techniques have been used to fabricate micro end mills in the literature [20,21]. End mills fabricated via electrical discharge machining (EDM) have been shown to work effectively on metal alloys and polycrystalline diamond [22–24]. The surface integrity and cutting edge radius are two important issues. Studies have shown that tailored micro end mills designed for specific machining cases yield comparable performance compared to conventional micro end mills [25]. Compared to conventional micro end mills, which are produced through grinding process to have helical flute geometry, these tools usually have straight edges, which improves the stiffness but limits the chip evacuation. The use of straight edges can be justified by considering the low depth of cut values in micro milling.

In this study, a single cutting edge micro end mill has been fabricated using wire electrical discharge machining. The influence of micro end mill surface quality and design parameters on the micro milling process has been investigated. A tool design for stable BUE formation was selected. The effect of BUE on the micro milling process outputs such as surface roughness and burr formation was investigated for the set geometry.

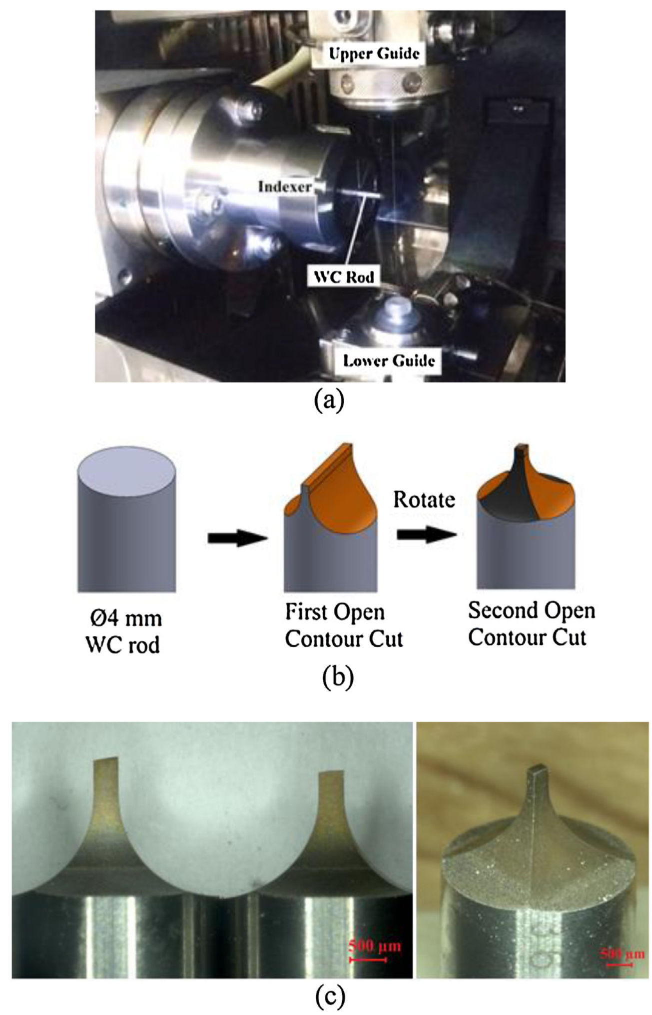

Fig. 2. (a) WEDM setup used for micro end mills fabrication, (b) Schematic representation of micro end mill fabrication process, (c) Fabricated single edge WC micro end mills.

2. Single edge micro end mill design and its fabrication

A novel single edge cutting tool geometry has been designed by considering the problems associated with tool runout in micro milling. In addition, a single-edge cutting tool provides a lower tooth passing frequency, which helps conduct experiments under a stable machining process. The solid model of the proposed cut-

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