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Investigating the influence of built-up edge on forces and surface roughness in micro scale orthogonal machining of titanium alloy Ti6Al4V

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ABSTRACT

The edge geometry of cutting tools directly influences the chip formation mechanism in micro-mechanical machining, where the edge radius and uncut chip thickness are in the same order of magnitude. An uncut chip thickness that is smaller than the cutting edge radius results in a large negative rake angle during machining, and built-up edge formation then affects the mechanics of the process. In this study, micro-scale orthogonal cutting tests on titanium alloy Ti6Al4V were conducted to investigate the influence of built-up edge formation on the machining forces and surface roughness. Cutting edges in these tests are engineered using wire EDM technique to have an edge radius of around 2 μm and clearance angles of 7° and 14°. It is observed that machining process inputs (uncut chip thickness, cutting speed, and clearance angle) affect the size of the built-up edge, which in turn affect the process outputs. It is observed that built-up edge formation protects the cutting edge from flank and crater wear under micro machining conditions and the influence of built-up edge on the surface roughness varies depending on the cutting speed and uncut chip thickness. Our findings also indicate a close relationship between the minimum uncut chip thickness and the mean roughness depth (R_z) of the machined surface. The minimum uncut chip thickness is found to be around 10% of the edge radius in the presence of built-up edge.

1. Introduction

Mechanical micro machining is defined as the machining of precision parts made out of a wide range of engineering materials with complex surfaces (Dornfeld et al., 2006). A solid understanding of the mechanics of cutting at the micro scale is crucial in building predictive models and controlling the quality of micro parts. A commonly observed phenomenon which appears during continuous chip formation is built-up edge (BUE) and it is known to affect surface roughness and tool wear. A BUE consists of material layers which are deposited onto the tool surface, changing the tool geometry and, hence, the mechanics of the process. A stable and thin BUE is known to protect the cutting edge (Kalpakjian and Schmid, 2010). Small uncut chip thicknesses machined with tools having a comparable edge radius creates suitable conditions for BUE formation in micro scale machining. Gaining a better understanding of the influence of BUE on process outputs have resulted in an increased interest in machining research.

Due to the micro cutting tool fabrication process and tool material grain size limitations, the edge radius cannot be easily decreased without sacrificing the strength of the tool, which in turn affects the chip formation process and the surface quality of the machined workpiece. Weule et al. (2002) showed the importance of edge roundness when tungsten carbide micro end mills are used to machine ferrous materials. Woon et al. (2008) studied the interaction between uncut chip thickness and edge radius using experimental and finite element based techniques when micro machining AISI 1045. They showed the edge radius acting like a negative rake angle and found that a constant stagnation point on the tool exists for a large range of uncut chip thickness values. However, in an earlier study, Waldorf et al. (1999), studied ploughing

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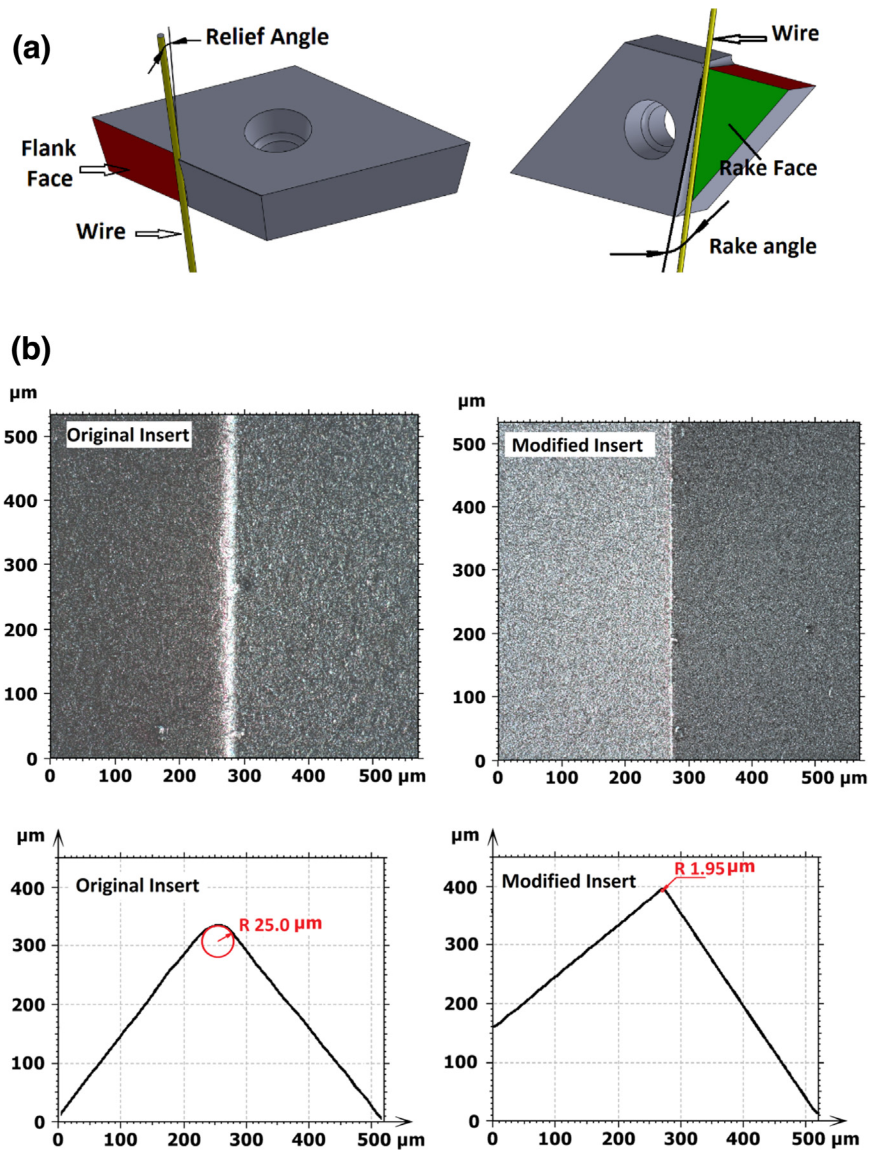

Fig. 1. (a) Schematic of wire-EDM processing to obtain required rake and clearance angles, (b) Edge radius measurement of the insert after edge preparation.

Table 1
Experimental conditions.

Initial Cutting Edge Radius	Clearance Angle	Uncut Chip Thickness	Cutting Speed (m/min)
1.95 µm	7–14	0.2–0.4–0.6–0.8–1 µm	30–47–62–78

Table 2
EDX analysis of surface on the tool.

Insert Surface before machining	Analysis of BUE	Insert Surface after Cleaning
Co %5.19 W %94.81	Al %5.66 Ti %82.82 V %3.46 Co %0.59 W %7.48	Co %4.65 W %93.95

models during orthogonal cutting and found that a stable built-up model described experimental observations better than a stagnation point model. Fang and Dewhurst (2005) used slip line field analysis to predict the size of the built-up edge during machining. Karpat and Özel (2008) also presented a slip line field based approach for machining with round edged tools, including built-up edge. Karpat (2009) considered the influence of cutting edge radius including built-up edge during micro scale machining and studied the effect of fracture on machining outputs. Childs (2013) developed a finite element model to predict built-up edge formation during machining of steel by integrating a damage model. Some preliminary results on simulating built-up edge during micro scale machining were also presented in Childs (2013). A detailed investigation of how built-up edge influences micro scale machining is the aim of this study.

In micro scale machining, the cutting tool edge radius and the amount of material being cut are in the same order of magnitude. There is a value of uncut chip thickness after which continuous chip formation ceases. This critical value is defined as minimum chip thickness, which is known to be a function of the tool material, cutting edge radius, and workpiece material (Ikawa et al., 1992). Lucca et al. (1991, 1993) indicated the importance of the sliding and ploughing at the tool workpiece interface due to edge radius of the tool during ultra precision machining conditions. Kim et al. (2004) analyzed the periodicity of forces during micro milling and identified the transition between non-cutting and cutting regimes near