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3D Finite Element Modeling Based Investigations of Micro-Textured Tool Designs in Machining Titanium Alloy Ti-6Al-4V

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Abstract

Surface texturing on cutting tools is considered a potential improvement to the tool performance both in dry machining with use of solid lubricants and in wet/cryogenic machining. This paper presents investigations on the effects of micro-textured tool designs that include grooves that are parallel, perpendicular, and diagonal to the main cutting edge as well as with pitted and diagonal pitted forms in the case of dry cutting titanium alloy Ti-6Al-4V by using 3D Finite Element modelling based simulations. The results include predicted forces, stress, temperature, and wear rate distributions which possess certain advantages of micro-texture tool designs.

Keywords: Cutting Tool; Finite Element Method; Surface Texturing; Titanium Alloy

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1. Introduction

Textured surfaces had been reported to enhance the tribological performance between the parts having frictional contacts by reducing the friction and improving their wear resistance. In machining, the use of micro textured cutting tools was found to reduce friction between the tool and chip eliminating the use of lubricants or enabling solid lubricants to be places in dry machining applications, and providing micro pools for lubricants on the tool-chip

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interface in wet machining applications as wells as providing improvements on debris entrapment and extended tool life. Micro textured cutting tools are expected to be more efficient than traditional cutting tools, especially with cutting applications such as titanium alloys that are experiencing high friction, intense adhesion, and built-up edge development due to work material's chemical affinity and low thermal conductivity. The textured surface on the cutting tool contributes to improved machinability by reducing overall apparent contact area, and consequently, lower tool wear, reduced cutting forces and temperatures can be achieved.

The influence of tool textures was investigated for different materials in the literature. Kawasegi et al. [1] investigated the effect of perpendicular, parallel, and crossed pattern nano-textures and micro-textures on the performance of dry and wet cutting aluminum alloys. It was found that reduction in cutting forces for perpendicular tool is the highest, while the parallel and crossed pattern tools showed similar results to the non-textured tools. Koshy & Tovey [2] investigated the effect of the distance between the cutting edge and first groove for a parallel grooved tool during cutting of steel material. These findings were interesting as it was found out that the friction angle is minimal when the ratio between the distance to the feed rate is about 2 to 3 times. The effect of groove orientation was studied by Xie et al. [3] by considering 45° diagonal and perpendicular textures on cutting titanium alloy Ti-6Al-4V. The diagonal grooved tool wear rate was lower than parallel tool. However, the shear angle was higher than perpendicular and non-textured tools. The parameters of parallel textures effect on cutting forces and friction were investigated by Yang et al. [4] where cemented carbide tools were used during dry and cryogenic cutting of titanium alloy Ti-6Al-4V. Per their findings, over many tool designs, minimum cutting forces were achieved when using a textured tool with groove depths of 29 µm, widths of 59 µm, spacing of 53 µm, and 250 µm. It was also found that cutting forces while using parallel textures for dry and cryogenic cutting are slightly lower than non-textured tools, while the reduction in friction coefficient (μ) was high for cryogenic cutting (from $\mu=0.5$ to $\mu=0.37$) and reasonable for dry cutting ($\mu=0.5$ to $\mu=0.41$). Kim et al. [5] studied the effect of perpendicular grooved tool on turning AISI 52100 steel for different feed rate values, where a reduction in cutting forces, tool wear, and friction coefficient was high at low feed rate values. There are other work have been reported about the performance of micro-textured cutting tools in various machining applications.

There are various ways by which the micro/nano-textures can be fabricated on the tool rake face including; i) laser micro-machining based texturing [1, 7, 8, 9], ii) micro-electrical discharge machining (EDM) based texturing [2, 6], iii) micro-grinding based texturing [3], iv) focused ion beam machining based texturing [10], among others. Micro-EDM had provided high precision (up to 5µm) and low surface roughness. It was previously used in tool texturing in [2], and with high frequency vibration assistance in [6]. This fabrication method was reported as efficient and reasonable in terms of machining time.

The laser machining is a widely used fabrication method for surface texturing. Using laser texturing, Lei et al. [7] fabricated dimple patterns having 70 µm diameter on tungsten carbide (WC/Co) tool inserts using a femtosecond laser, and Kümmel et al. [8] fabricated dimples, parallel, and perpendicular micro-textures having a size of 50 µm and depth 20 µm on tungsten carbide (WC/Co) tool rake face. Xing et al. [9] also fabricated parallel, perpendicular, and wavy grooves on micro scale and nano scale on Al_2O_3/TiC ceramic insert. The micro-texture groove width was about 40–50 µm, the depth was about 45–50 µm, the spacing was 150 µm and nano-texture groove width was about 350–400 nm, the depth was about 120–150 nm, and the spacing was about 750 nm.

The current work aims to investigate the effect of micro-texture tool designs that are found in literature on stress and temperature distributions, cutting forces, and tool wear during machining of titanium alloy Ti-6Al-4V using Finite Element Simulations.

2. Tool designs

In this paper, five designs for micro-texture were identified from the literature to investigate their contribution to the cutting process compared to the non-textured tool. The five designs were selected because they are feasible to be fabricated on tool surfaces and had been previously used on cutting tools. The use of texture at the cutting edge was found to increase the cutting forces and tool edge wear [2]. The distance between the first texture and cutting edge is set to the feed value. All five tool micro-texture designs, shown in Figure 1, have feature width (w) of 50µm, spacing or pitch (p) of 100 µm, and a distance (d) of 100 µm from the cutting edge. The area of rake face falling between the cutting edge and parallel nose radius centre line is shown in Table 1.