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Development of micro-texture patterns of cemented carbide cutting tools to improve cutting performance

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Abstract

Micro texture on cutting tool inserts obtained via laser micro-machining has recently emerged as an environment friendly method to reduce adhesion on the tool's rake face and to improve friction conditions during machining. However, these benefits are strictly correlated with a correct design and behavior of the texture to be replicated on the tool surface. This paper reports an experimental study of developing an array of dimples on both rake and flank of commercial, cemented carbide cutting inserts using a picosecond laser source. Experiments of orthogonal dry cutting on E235 steel tubes were performed using textured and untextured tools to evaluate the improvements obtained. The improvements achieved were assessed in terms of cutting force and their impact on cutting performances. A predictive finite element model was developed to optimize the design of the dimples, to be replicated onto the rake surface of the tool.

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Keywords: Cutting tool; micro-scale texture; picosecond laser; dry cutting; cutting force.

1. Introduction

In recent years, functionalization of tool surfaces via laser texturing has been an emerging topic related to production engineering. Proper texture design can have several benefits on the cutting performance as well as in terms of cutting forces, chip adhesion, friction coefficient and machined surface quality especially in dry cutting, where the aim of environmental sustainability leads the process toward severe thermo-mechanical conditions. In these terms, Xing. et al. [1] investigated three types of laser surface textures (linear, circular and rectangular) generated on the rake face of cemented carbide tools by performing orthogonal dry cutting tests on 6061 aluminum alloy tubes. Their results showed an improvement in cutting performance under specific cutting speeds compared to the non-textured tools. Kawasegi et al. [2] found a decrease in friction at the tool-chip interface when cutting A5052 aluminum with tools with micro- and nanotextures on the rake face. They also observed a decrease in the cutting forces. Obikawa et al. [3] and Sugihara and Enomoto [4] stated that textures parallel to the cutting edge on the tool rake face were effective in reducing the cutting force as compared to perpendicular ones. Further and extensive works emphasized the improvements in cutting performance that textured tools can exhibit. These are related to the change in the chip flow [5], enhancing in anti-adhesion and wear resistance [6] or to the decrease in friction coefficient [7].

Although there have been many studies on the effects of geometry on the cutting performance of textured tools in

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machining, they mainly focused on grooves generated at a given distance from the cutting edge.

Throughout this work, a study on the influence of different texturing strategies in terms of machining process stability have been evaluated. Textures were replicated via laser ablation on both side (rake and flank) of a series of commercial carbide tools, starting from their connecting edge. A numerical simulation was performed to compare the experimentally detected forces during cutting tests. Effects of different types of textures were then compared.

2. Material and Methods

2.1. Tools under investigation

A set of commercial cemented carbide tools were used to perform the texturing campaign. They are 60° uncoated carbide triangular inserts used for turning of cast iron and heat resistant alloys. Inserts are characterized by a manufacture grade of H13A, by a rake angle of 9° and a main clearance angle of 11°. These tools have a flat rake face with no chip breaker to facilitate texture replication. Different patterns of textures were created via laser ablation to evaluate the influence of the texturing strategy regarding the stability of the turning process. Table 1 summarizes their characteristics. Twelve inserts in total have been textured while two inserts were left in the commercial state (i.e. not-textured, NT1 and NT2). The strategies have foreseen the realization of rectangular in shape dimples with nominal dimension 30x60 µm (FBD1 and FBD2) as well as micro stripe grooves with a rectangular cross-section which extends in the parallel direction (∥) to main cutting edge (WW1 and WW2) or in the orthogonal (⊥) direction (GG1 and GG2). The width of these kind of groove was chosen of 30 µm with a pit of 75 µm. Two inserts (GR1 and GR2) were instead textured in both rake and flank side by grids by combining the previous pattern of grooves with rectangular cross section. In these cases, width and spacing were unchanged. Combined texturing strategies were also examined based on the previous considerations (WG1, WG2, GW1 and GW2).

Table 1 Developed texturing strategies. NT stands for "Not-Textured".

Tool name	Groove direction respect to the cutting edge (rake face)	Groove direction respect to the cutting edge (flank)
NT1, NT2	-	-
FBD1, FBD2	-	-
GR1, GR2	-	-
WW1, WW2	//	//
GG1, GG2	⊥	⊥
WG1, WG2	//	⊥
GW1, GW2	⊥	//

The textured area had a length of 5 mm and a width of 3 mm and was kept unchanged passing through the different patterns, instead, the target depth to be reached in the different texturing strategies has been set at around 20 µm. This depth was chosen to limit the adhesion phenomena between tool and chip with the aim to preserve the texture during machining. The morphology of the developed textures is summarized in Fig. 1.

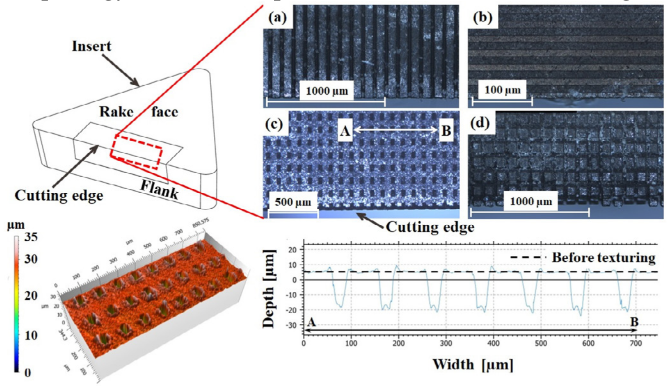

Fig. 1. Surface micrographs of the four types of micro-texture replicated on the inserts. In the enlarged figure: rake face textured with: (a) GG1-GG2; (b) WW1-WW2; (c) FBD1-FBD2 and (d) GR1-GR2 strategy.

2.2. Laser texturing

Laser ablation process was used to produce microscale textures on the cemented carbide tools. A picosecond laser source (EKSPLA, Mod. Atlantic 50) was used to texture both rake and flank of cutting inserts. The laser amplifier operated at the green wavelength (532 nm) by producing ultrashort pulses with a duration in the order of 10 ps. An appropriate optical path ensures the achievement of a focused beam diameter of ~ 10 µm, evaluated at $1/e^2$ intensity. A square working area by side of 39 mm is ensured thanks to a Raylase Superscan IV galvanometric scanner coupled with an 80 mm F-theta lens.

Preliminary tests were conducted to evaluate the response of the cemented carbide tools to the green wavelength interaction. The aim of this phase was also to obtain a pulse overlap of 5 µm corresponding to a laser spot overlap of 50% of the whole surface. These tests allowed to calibrate, and optimize, the laser parameters to achieve a precise regular grooves formation thus preventing the formation of recast materials and providing a homogeneous distribution of energy on the area under texturing. The texturing campaign was performed with faster rate and heat-affected zones didn't occur. The laser adopted parameters are summarized as follow: pulse frequency 400 kHz; pulse duration 10 ps; average output power 0.44 W; pulse fluence 1.4 J/cm^2; pulse energy 1.1 µJ; marking speed 1 m/s and 14 as the number of passes on each groove.

2.3. Evaluation of the effective texture dimension

The textured tools were cleaned in an ultrasonic bath in a solution containing isopropanol. A structured light profiler (Confosurf, Mod. Confovis GmbH) coupled with an optical microscope (Nikon, Mod. Eclipse LV150) were used to evaluate the effective achievement of dimension by the dimples and their in-depth development.

2.4. Numerical simulation

The numerical procedure was developed using a FE model of the machining process. In particular, 2D plane-strain simulations have been performed using SFTC Deform 2D® software. The workpiece material was modelled as a plastic body and divided into 15000 elements. The average element edge length on the surface was less than 10 µm using a mesh window to define finer elements located around the cutting edge and along the machined surface. The cutting tool was defined as a rigid body and divided into 2500 elements. For sake of simplicity, the surface was modelled according to the laser treatment just on the rake face since materials do not flow on the tool flank. The global heat transfer coefficient with the environment was established between the workpiece and cutting tool and it was set equal to 10^5 kW/(m^2 K) according to literature suggestions [8]. The shear model was used for friction setting the shear factor m = 0,82 [9].

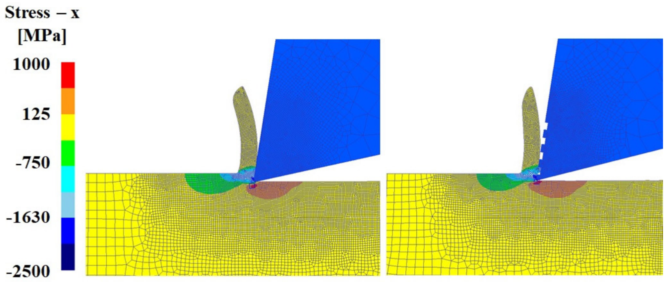

Fig. 2. Numerical model of the cutting process. On the left: NT insert.; on the right WW tool.

2.5. Cutting test

The orthogonal cutting operations were conducted on a CNC MAZAK (Mazak, Mod. QuickTurn Nexus 220-II CNC). high-speed CNC turning center. The experiments involved tube specimens cut at feed rate of 0.05 mm/rev and at 150 m/min of cutting speed. The cutting length was set at 10 mm. Cutting parameters were selected based on industrial applications and cutting tool manufacturer's recommendation. The workpieces were E235 steel tubular cylinder with 50 mm outer diameter, 1.5 mm tube thickness and 40 mm length. The tests were executed without any lubricant at the tool-chip interface. Cutting and thrust force, i.e. F_x and F_z, were measured by using a six-components piezoelectric dynamometer (Kistler© 9257). The experimental setup of the cutting process is illustrated in Fig. 3.

All the different texturing strategies were tested randomly over time and in their succession so as not to have external influences on the results due to ambient conditions.

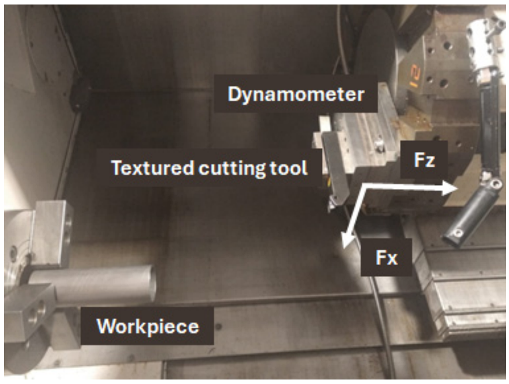

Fig. 3. Experimental setup for tube cutting.

3. Results

3.1. Effect of texture strategy on the stability of machining

Both cutting force and thrust force measured by the dynamometer during the experiments for the whole combinations of textured insert are shown in Fig. 4.

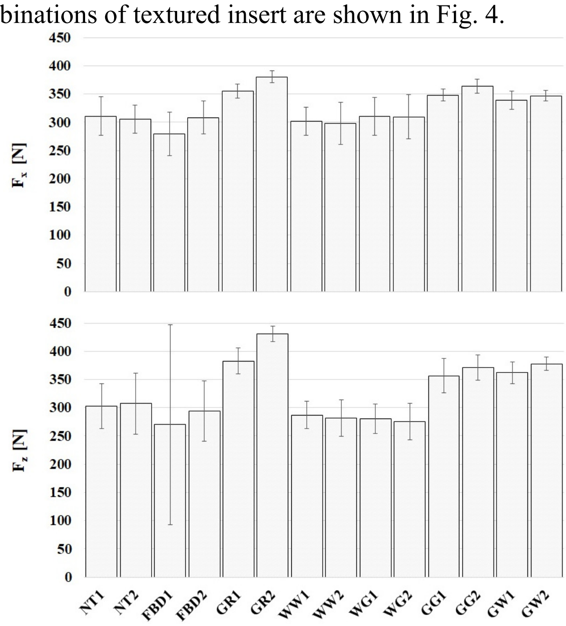

Fig. 4. Comparison of the average cutting forces for NT and textured inserts. The error bars indicate standard deviation of the cutting forces measured in the steady state.

The results show no significant changes between NT inserts and FBD specimen. By observing the GR1, GR2, GG1 and GG2 it is possible to see the effect of texture strategy on the cutting and thrust force which are increased by an amount of 20% in GG1 and GG2 textured tools. Specimen GR2 reaches instead the maximum value of the cutting force. The remaining inserts show intermediate conditions comparable to the NT tool. These increases in force are related to the change in contact area. In fact, it should be noted that the true representation of the friction behavior in the tool-chip contact zone involves not only purely sliding contact region but also sticking phenomena on the rake face of the tool. A change in sticking region results in a change in friction and so the cutting forces. The effect of the sliding region could instead be considered independent in terms of the true contact region [10], [11]. By increasing the contact area and working in dry condition, the chip flow will be more hindered and therefore the higher the friction. However, this effect is not found in WW1 and WW2 samples. In these cases, the texture acts as an obstacle towards the chip, interrupts it and forms the built-up edge. Instead, analysing the standard deviation values, it is possible to see a significant decrease passing from the NT1 and NT2 to the GG1, GG2, GR1 and GR2. This reduction indicates better chip accommodation along with more stable cutting forces as visible in Fig. 5. Therefore, machining, in the absence of friction, benefits in terms of process stability thanks to this texturing strategy.

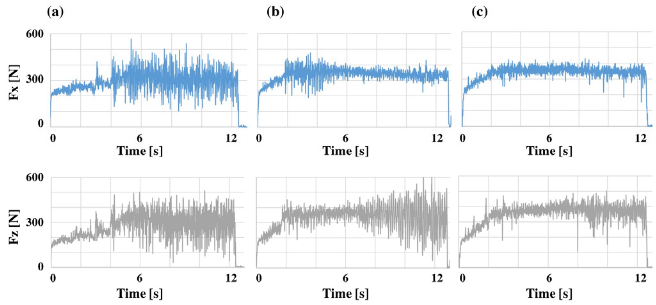

Fig. 5. Changes in cutting forces during dry cutting. Proceeding by columns: (a) NT; (b) GG1; (c) GR1.

3.2. Comparison of numerical evaluations

Fig. 6 plots the comparison in terms of F_x component for the non-textured tool and the WW1 insert. As main outcome, neglecting the initial zone where the tool is in incipient cutting conditions and encounters low resistance, it is possible to observe how the expected forces approach the value detected by the dynamometer during the cutting tests.

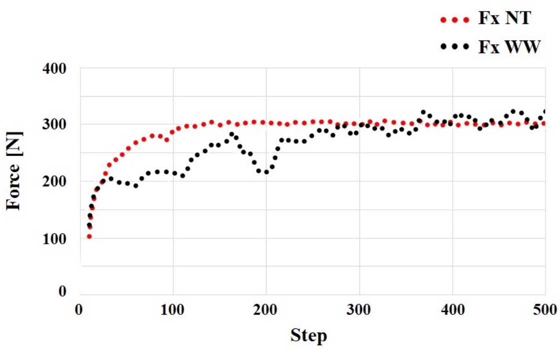

Fig. 6. Comparison of numerical evaluations in terms of F_x component.

Conclusions

This paper studied the effect of different micro-textures at the rake face as well as the flank of carbide uncoated cutting inserts on the performance in machining E235. Through the orthogonal dry cutting experiments, thrust and cutting forces were measured from the dynamometer. A FE model was developed to predict the behavior during turning operations of textured inserts. Rake face was inspected after machining. The GR1 and GR2 tools have been shown to be the most effective in improving the cutting performances ensuring lower fluctuation in forces compared to other strategies. Similar trends are also found in textured insert with rectangular in shape grooves which extends in the orthogonal direction respect to the cutting edge. Instead, WW1 and WW2 inserts while showing a slight reduction in force components, they have presented built-up edge formation. So, an increasing in adhesive effects occurred in these inserts. Further works will investigate the overall effect of the textures replicated on tool surfaces with no distance from the cutting edge also by means of contact length estimation and evaluations of the improvement of anti-adhesion properties at different values of cutting speed.

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