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Laser texturing of tungsten carbide tools: the effects on tribological performance when machining Ti-6Al-4V alloy

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Abstract
The research aims at evaluating the performance of laser textured (various arrays of dimples and grooves) tungsten carbide inserts when dry turning Ti-6Al-4V alloy. The tribological characteristics of the textured surfaces produced on equivalent carbide blocks were initially assessed using multi pass scratch tests. Pronounced smearing of material was prevalent at the textured regions with a lower friction coefficient (~16-60% reduction compared to other textured patterns) measured within the dimple patterns with a higher density of micro-holes. In the machining trials, lower tangential and axial cutting forces of up to 10% and 50%, respectively were obtained in certain trials when employing the textured tools, together with reduced built-up layer formation on the rake surface compared to the untextured inserts. Additionally, lower workpiece R_a and S_a (by up to 34% and 26%, respectively) were recorded in the majority of trials involving the textured inserts in contrast to the untextured tools.

Keywords: Laser texturing; scratch test; cutting force; tool wear; surface roughness; Ti-6Al-4V.

1. Introduction

Machining of titanium alloys is often characterised by poor tool life, in particular edge chipping, adhesive wear and premature tool breakage due to several inherent material properties such as low thermal conductivity, low modulus of elasticity, and high chemical reactivity [1]. In order to reduce the cutting temperature and its adverse effects on resulting workpiece surface integrity, use of flood or high pressure cutting fluid environment is typically recommended. However, owing to the environmental issues in using cutting fluids and their health implications, recent trends are fostering the use of minimum quantity lubrication (MQL) or even dry machining. Dry machining is typically associated with the application of coated (PVD or CVD) tools that have been routinely used by the industry. In contrast, despite reported benefits of surface structured/textured tools in terms of cutting force, temperature and tool life, as reported in the literature, the technology is still rarely used and has not been taken up by cutting tool manufacturers or industry till date.

Kümmel et al. [2] employed different laser-produced micro-dimples and channels on tungsten carbide (WC) tools when dry turning AISI 1045 steel. Compared to untextured inserts, reduced wear on the rake and flank surfaces was observed on tools with the micro-dimples, whereas superior workpiece surface finish was obtained when cutting using the micro-channel textured inserts, albeit with greater wear levels. Several researchers have evaluated the use of laser textured WC tools, in combination with solid lubricant coatings, such as MoS_2 [3], MoS_2 (80%) mixed with gear oil (20%) [4] and Zr/WS_2 [5] for the machining of Ti-6Al-4V alloy. Reported benefits include reduction in friction coefficient and an increase in tool life by 10-30% [3], a decrease in chip-tool contact area, cutting temperature [4] and a lower cutting forces by up to ~60% [5].

Despite reported advantages of the laser textured tools in terms of improved frictional properties and reduced cutting forces/temperatures, a systematic machinability study correlating its underlying tribological aspects has yet to be carried out. The present research aims to investigate the effects of different laser textured patterns on the tribological and machining performance of uncoated tungsten carbide tools when dry turning Ti-6Al-4V alloy.

2. Experimental methodology

2.1. Laser surface texturing of WC blocks and inserts

Five different laser textured patterns, comprising dimples and grooves, were produced on WC blocks using a MOPA-based Yb-doped fibre nanosecond laser source (1064 nm wavelength). Out of these, four patterns were generated on SNMA 120408 turning inserts. The dimples were created in a triangular and square arrangement while the grooves were aligned parallel and perpendicular to the principal cutting edge, see Fig. 1.

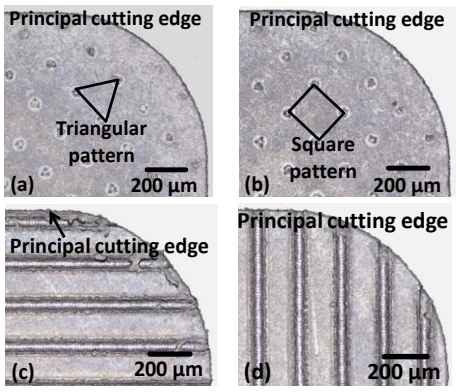

Figure 1. Dimples in (a) triangular and (b) square pattern with Grooves (c) parallel and (d) perpendicular to the principal cutting edge

2.2. Scratch tests

Sliding tests were performed on a CSM Instruments, i.e. a Revetest® scratch tester. An AISI 316L pin with 10 mm diameter and a polished hemispherical shaped tip was loaded against the textured WC blocks. The multi pass scratch tests were performed under dry conditions using a normal load of 20 N and a relative sliding speed of 10 mm/min. The sliding distance was 10 mm with 5 passes on each track. The friction coefficient and the acoustic emissions were continuously recorded in all of the tests.

2.3. Turning trials

A Ti-6Al-4V bar was turned dry on a Dean Smith and Grace 1910 manual lathe using both textured and untextured SNMA inserts at a cutting speed of 45 m/min, a feed rate of 0.1 mm/rev and depth of cut of 0.5 mm. Each trial was carried out with a new cutting edge for a total duration of 60 s with cutting forces recorded using a KISTLER 9263 piezoelectric dynamometer at periodic intervals of 20 s intervals followed by tool flank wear and workpiece surface roughness measurement. Tool wear was measured using a Wild M3Z tool makers' microscope. The pre- and post-machining conditions of the tools were analysed using an Alicona G5 InfinteFocus microscope. The average linear roughness, R_a and the average areal surface parameter, S_a of the machined surfaces were also measured using the Alicona after each machining interval.

3. Results and discussion

3.1. Scratch tests

The depths and diameters of the dimples were in the range of 10-13 µm and 23-26 µm respectively; while the depths and widths of the grooves varied between 7-8 µm and 40-45 µm, respectively. Brittle heat affected zone (HAZ) was generated on dimple side walls as a result of laser patterning as seen in Fig. 2(a). The scratch tests on the patterned surfaces typically exhibited pronounced smearing of material at the recast layer region towards the periphery/edge of the dimples and grooves, see Fig. 2(b).

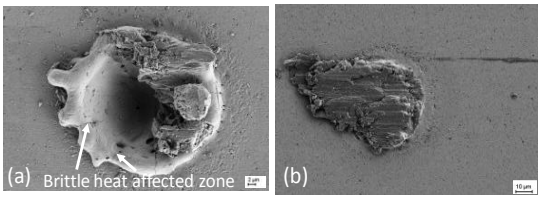

Figure 2. SEM of dimples showing (a) HAZ and (b) material transfer

The sliding tests revealed that friction coefficient typically increased with the number of scratch passes on each track. A higher density of dimples generally resulted in the lowest friction, whereas larger size of dimples exhibited the most stable friction conditions.

3.2. Turning trials

Figure 3 shows the tangential (F_z), axial (F_x) and radial (F_y) forces recorded after machining for 20, 40 and 60 s. Laser textured tools typically exhibited lower F_z and F_x (by up to 10% and 50% respectively), particularly during the first 20 and 40 s of machining, however this effect was not as prominent after cutting for 60 s due to the comparable level of tool wear. The typical rise in force with machining progression was possibly due to the built-up edge/layer (BUE/BUL) formation on the tool rake face that resulted from the adhesive wear when dry turning with uncoated WC tools. A marginally lower BUL formation was observed on all textured tools, compared to the untextured counterpart, see Fig. 4(a) and (b). This can be attributed to the shorter chip-tool contact length on the textured rake surfaces.

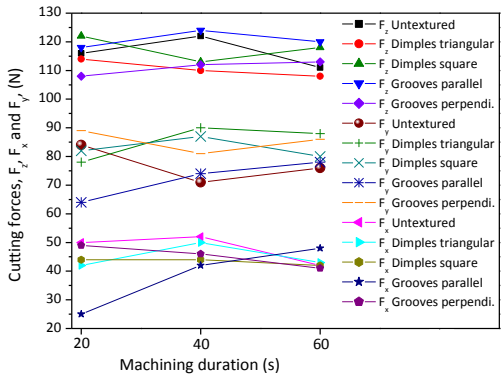

Figure 3. Three components of cutting force recorded during the trials

The use of patterned inserts also generally rendered a lower workpiece surface roughness with maximum reduction in R_a and S_a by up to 34% and 26%, respectively when using dimple textures in a triangular fashion.

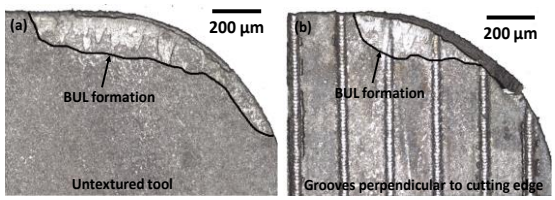

Figure 4. BUL formation on the tool rake faces after 60 s of machining

4. Conclusions

The tribological phenomena in terms of material adherence and transfer were different during the scratch tests and machining trials. In the turning tests, chip-tool contact conditions were more severe and the weak ridges of the dimples were easily removed. Furthermore, chip flow and wear debris distribution had an influence on the recorded cutting force data which was typically lower during the first 20 and 40 s of machining with the textured tools. A marginally lower BUL formation was also observed on all textured inserts compared to the untextured tools, which resulted in a lower workpiece R_a and S_a in the majority of trials conducted with the textured tools.

Acknowledgements

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