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FEMTOSECOND LASER TEXTURING EFFECT ON ABRASIVE WEAR OF CEMENTED CARBIDE TOOLS

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Abstract. *The objective is to investigate the femtosecond laser texturing effect on abrasive wear of cemented carbide tools. Micro-abrasive wear tests were performed with the fixed ball configuration, on non-textured and textured rake faces. A SiC abrasive slurry with concentration of 0.52 gSiC/cm³H_2O and counterbody made of AISI 52100 hardened steel ball, with 25.4 mm in diameter, were used. Ball rotational speed and normal load were kept constant during the tests, 37.6 rpm and 1.25 N respectively. The output variable used in this study is the wear coefficient. Among the three microtexture patterns evaluated, the micro-grooves on Rake face 2 and 3 have shown potential for improving tribological performance, since there was a wear coefficient reduction, about 13.7% and 24.5%.*

Keywords: *texturing, femtosecond laser, cemented carbide tool, micro-abrasion, wear coefficient.*

1. INTRODUCTION

The manufacture of objects exists since the beginning of civilization, in ancient societies manufacturing started with wooden spears, clay and stone artifacts. Currently, with all the technological evolution, ways of transforming raw materials into finished products are more complex and have vast market availability of different materials and processes (Trent and Wright, 2000; Kalpakjian and Schimid, 2009; Groover 2010). According to Kalpakjian and Schimid (2008), the manufacturing sector corresponds to about one third of the gross national product of the industrialized countries and metal cutting is a part of it.

Metal cutting may be defined as a manufacturing process in which a thin layer, called chip, is removed from the workpiece by the cutting tool action (Trent and Wright, 2000; Machado *et al.*, 2015). Therefore, cutting tools have great economical and technical importance to the process as well as to the finished product. Thus, the tool manufacturing market has suffered through the decades from the periodic necessity of technological innovation to attend demand where productivity is the prime factor (Trent and Wright, 2000; Suarez, 2012).

In the past, the metal cutting market had evolved due to the emergence of cement carbide as the new material for cutting tools. This material, manufactured by powder metallurgy process, has the ability to combine mechanical strength, wear resistance and toughness, making it excellent for metal cutting applications (Machado *et al.*, 2015).

Advanced manufacturing techniques have been used to extend the tool life and ensure productivity, promoting reduction of wear and friction coefficient on the chip-tool contact. Applying coatings on cutting tools is a common technique that confers wear resistance by hardening the surface, lower friction, finish aesthetics and protection against oxidation (Diniz *et al.*, 2004; Shaw, 2005; Neves *et al.*, 2006; Zhang *et al.*, 2015). However, new manufacturing techniques, such as laser surface texturing (LST), are emerging as an alternative proposal to improve tribological performances. Segu *et al.* (2013), Shum *et al.* (2013), and Youqiang *et al.* (2013), were successful in their tribological tests after applying LST on their samples. Moreover, Zhang *et al.* (2015) and Barbosa *et al.* (2015) had success carrying machining tests out for finishing and medium conditions, respectively, with texturing cutting tools.

The ultrashort pulse lasers, such as femtosecond laser (10^{-15} s of pulse length), are recent laser technology that is characterized by pulses of very brief duration, shorter than the thermal vibration period of the lattice, and by not allowing thermal diffusion occurrence on the material. This enables the ablation of textures with almost no heat-affected zones or re-solidified layers, thus preserving the surrounding properties. Furthermore, the ultrashort pulses duration creates very elevated intensities that promote higher nonlinear interaction with the matter, resulting in extremely localized ablations in addition to being non-selective, i.e., any kind of material can be machined with the same laser, with narrow dimensions (Liang *et al.*, 2003; Kawasegi *et al.*, 2009; Wang *et al.*, 2010; Samad *et al.*, 2012).

Therefore, the aim is to investigate the femtosecond laser texturing effect on abrasive wear coefficient of cemented carbide tools.

2. EXPERIMENTAL PROCEDURE

Triangular uncoated cemented carbide tools, grade P, were textured using femtosecond laser technology. The texturing was carried out on the rake face of the inserts with a Ti:Sapphire laser, Femtopower Compact Pro HR/HP model by Femtolasers. Three different patterns of parallel micro-grooves; with distance between grooves (pitch) of 65, 95 and 145 μm; were ablated using 7 μJ energy; 30 fs laser pulses, wavelength centered at 775 nm; at 4 kHz repetition rate; and feed velocity of the laser beam at 6 mm/min. Each micro-groove model received one pass of laser surface treatment, except the last one, which received two passes. The micro-texture patterns were schematized (Fig. 1) and their characterization was defined by interferometry (ZeGage/Zygo) (Tab. 1.)

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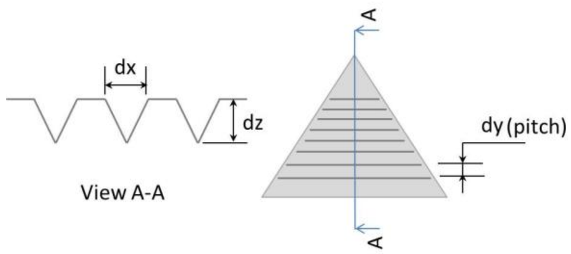

Figure 1. Schematic configuration of micro-texture pattern on rake face of cemented carbide tool.

Table 1. Dimensional characteristics of micro-texture patterns.

	dx (width) - [μm]	dz (depth) - [μm]	dy (pitch) - [μm]
Non-textured rake face (reference)	-	-	-
Rake face 1	30	25	65
Rake face 2	30	25	95
Rake face 3 (two passes of laser)	45	42	145

T66 Micro-Scale Abrasion Tester was used to perform the micro-abrasive wear tests, with fixed ball configuration on the rake face of the cemented carbide tools for the different surface conditions described in Tab. 1. Abrasive slurry was used with the concentration of 0.52 $gSiC/cm^3H_2O$ and applied as drops on the surface of the rotating ball at a standard rate of 12 drops/min. In addition, a counterbody of AISI 52100 hardened steel balls with a 25.4 mm of diameter was also used. The ball sliding direction was perpendicular to the micro-groove texture patterns. The test conditions were kept constant according to Tab. 2. The tests were interrupted at every 7.8 m of sliding distance and the wear craters were then examined by optical microscopy.

Table 2. Micro-abrasive wear test conditions.

Ball rotation speed – n	36.7 rpm
Normal load – N	1.25 N
Sliding distance – S	46.8 m
Time test – t	156 s (2.6 min)
Number of repetitions	3

The output variable considered was the wear coefficient (K), estimated according to the Archard wear law (Rutherford and Hutchings, 1996; Yahya and Todd, 2012), following Eq. (1).

(1)

where b is the wear crater diameter, R is the ball (counterbody) radius, S is the sliding distance and N is the applied load.

3. RESULTS AND DISCUSSION

Figure 2 shows the surface topography of the textured rake faces detected by Talysurf CLI 1000 profilometer. Qualitatively, three different texturing patterns can be seen evenly arranged on the surfaces. Rake face 1, Fig. 2 (a), presents the smallest distance between micro-grooves (pitch); Rake face 3, Fig. 2 (c), has the largest pitch and Rake face 2, Fig. 2 (b), has intermediary ones. V-shaped it was also observed for all textures. The larger and deeper micro-grooves were produced with two passes of the laser, as observed in the third pattern.

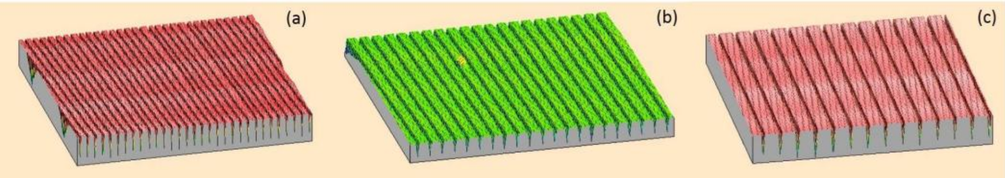

Figure 2. Surface topography of textured rake faces. (a) Rake face 1, (b) Rake face 2 and (c) Rake face 3

The typical wear craters, produced after the micro-scale abrasion tests, are shown in Fig. 3. The overall crater diameters produced were used to estimate the wear coefficient along the tests (Rutherford and Hutchings, 1996; Trezona *et al.*, 1999; Yahya and Todd, 2012). It can be observed that textures remain after the micro abrasion tests.

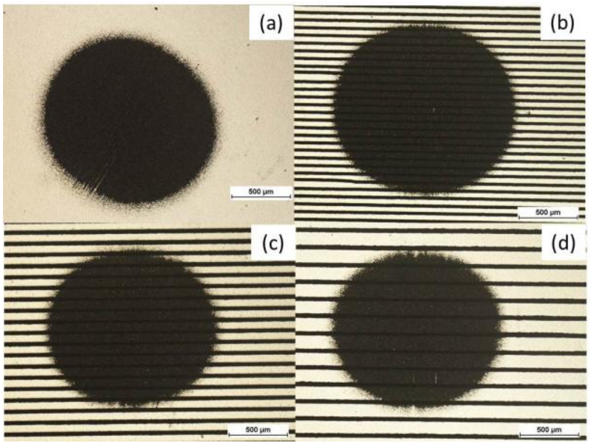

Figure 3. Optical micrographs of the last wear crater produced after the micro-abrasive wear tests. (a) Non-textured rake face (reference), (b) Rake face 1, (c) Rake face 2 and (d) Rake face 3.

Figure 4 presents the wear coefficient behavior as a function of the test time. Only Rake face 1 curve showed wear coefficient behavior above the reference; that is, the surface with micro-groove pattern 1 provided greater wear coefficient than the Non-textured rake face. Notwithstanding, texture patterns 2 and 3 (Rake face 2 and 3) showed better tribological tendency due to their lower wear coefficients (below the reference curve).

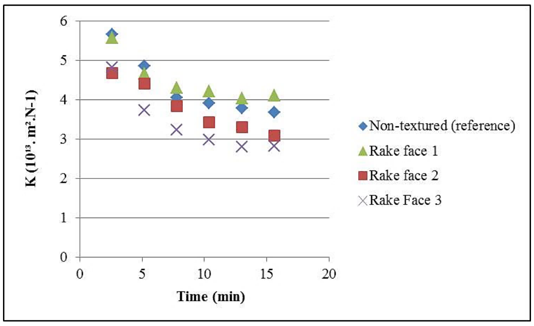

Figure 4. Wear coefficient (K) as function of the test time. N = 1.25 N and n = 36.7 rpm

According to Lozzer (2008), Gava (2010) and Marques *et al.* (2011) steady state behavior occurs when the test variations are smaller than 7%, and this is achieved for the three last test points as can be observed in Fig. 4. Therefore, the average wear coefficient was calculated and shown in Tab. 3.

Table 3. Average wear coefficient.

Nomenclature of tests	$K_{average}$ (m²/N)	Standard deviation
Non-textured (reference)	3.80	±0.09
Rake face 1	4.12	±0.07
Rake face 2	3.28	±0.14
Rake face 3	2.87	±0.09

Table 3 results were plotted in graph form (Fig. 5) to improve visualization and comparison of the averages and standard deviations of wear coefficients of the assessed rake faces.

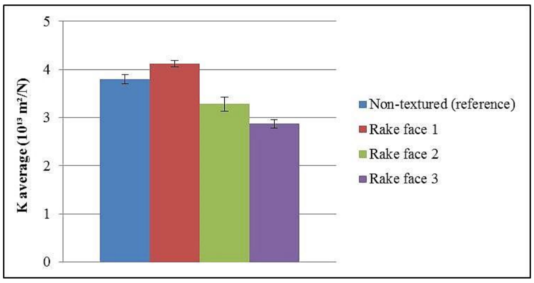

Figure 5. Average wear coefficient ($K_{average}$) to different texture surface patterns.

Wear coefficient results (Fig. 4, Tab. 3 and Fig. 5) showed potential by improving tribological performance for two kinds of microtexture patterns on Rake face 2 and Rake face 3, since there was reduction of the $K_{average}$, about 13.7% and 24.5%, respectively, i.e., the lower k the greater the wear resistance of the surfaces evaluated. It was observed that among the textures with the same depth and width, it can exist a minimum distance between the micro-grooves (pitch); to which the texture responds positively to tribological behavior by providing wear coefficient reductions (texture pattern on Rake face 2).

According to Suarez (2012), smaller spacing can weaken the textures since they do not resist to brittle fracture during the contact, increasing friction and consequently wear. By decreasing the spacing between grooves, the texture may become too sharp which causes the wear to increase, this occurs mainly when the body is harder than counterbody. On the other hand, when reducing contact area between body and counterbody, friction and wear decreases, as announced by Hutchings (1995), and as it can be noted from the comparison between the Non-textured rake face and Rake faces 2 and 3. It suggests that there was a geometric effect on micro-grooves patterns, in respect to pitch, width and depth, contributing to the improvement of wear resistance and possible friction coefficient.

Shum *et al.* (2013), carried out laser surface texturing (Nd:YAG) on M2 high speed steel to improve the wear resistance of DLC coating, applied after the laser surface treatment. They observed the lowest friction coefficients and wear rate at 10% of dimple density, with variations of 2 up to 30%, i.e., the larger density, the closer the textures are. By increasing the dimple density to above 10%, they noted higher friction coefficients and wear rates than the non-textured samples (reference). The same characteristics were observed when the diameter of dimples was altered. Therefore, with the appropriate dimensions and dimple density it was obtained a reduction of 20% in friction and nearly 52% in wear rate, during the reciprocating sliding-wear test under the oil lubricate condition. For dry conditions, similar results were obtained by Youqiang *et al*. (2013). They performed laser surface texturing on Si_3N_4/TiC ceramic by Nd:YAG pulsed laser. Micro-grooves, with wavy and linear forms, varying in their spacing characteristics, were tested in a ball-on-disk tribometer, being the ball material an AISI 440C, and compared together with a smooth surface. They observed that the wavy groove samples showed the lowest friction coefficient and wear rate. However, by increasing the spacing between grooves, the results get closer to the reference ones (non-textured).

4. CONCLUSIONS

For the micro-abrasive wear tests, three different micro-grooves patterns textured on the rake face of cutting tools were confronted with a non-textured one. From it was concluded that microtexture patterns on Rake face 2 and 3 improved the wear resistance in about 13.7% and 24.5%, respectively. The results also suggest that a geometric effect can contribute to improve tribological behavior for a minimum pitch value of above 65 μm.

5. ACKNOWLEDGEMENTS

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