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Effect of laser surface modification on the micro-abrasive wear resistance of coated cemented carbide tools

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ABSTRACT

The use of surface texturing on the rake face of a tool can modify the tribological phenomena present at the chip-tool interface. Many different wear mechanisms, including abrasive wear, occur at the tool during machining. The presence of hard phases in the workpiece material, as well as hard particles removed from the tool, can generate abrasive wear on the tool surfaces. The objective of this work is to study the abrasive wear resistance of micro-textured tools in comparison to conventional (commercial) cutting tools. Square cemented carbide inserts containing a three-layered coating (TiCN–Al_2O_3–TiN) were textured using two different linear patterns, perpendicular and parallel to the direction of the chip movement. Microabrasion and machining tests on both textured and commercial tools were carried out. Turning tests were carried out for ABNT/AISI 1050 steel under severe cutting conditions with overhead application of cutting fluid. In order to simulate the abrasive wear mechanism that can occur on the tool surface, a free ball microabrasion test was used under a suspension of silicon carbide particles and distilled water. The abrasive wear mechanisms were observed using SEM. The micro-scale abrasive wear resistance of laser micro-textured cement carbide tools was compared to untextured tools. For the turning tests, texturing increased the tool life, which was determined when the wear at the tool flank achieved a specified value. On the other hand, for the microabrasion tests, laser texturing resulted in a pronounced increase in the coating wear rate. This fact was connected to the decrease of coating hardness caused by laser texturing. Therefore, the increase of tool life in the turning tests was not related to a reduction of abrasive wear on the tool flank. Probably, it was caused by other tribological conditions that were not represented in microabrasion tests, for example: the presence of cutting fluid in the environment and elevated contact temperatures.

1. Introduction

Surface microtexturing can be used to change surface topography in order to improve the tribological behaviour. Surface engineering research has suggested that systematic patterning could lead to optimised behaviour, as a logical development of the more random texturing achieved through general finishing processes. This better tribological performance can be connected to different mechanisms, for example: under dry sliding conditions, the main effect is the removal of wear debris from the contact, while in lubricated contacts the microtexture can also influence lubrication mechanisms, leading to beneficial changes in friction and wear [1].

Kolvachenko et al. [2] investigated the effect of surface texturing of hardened steel discs (H-13) on lubrication regime transitions and on the load capacity of machine elements, showing variation of friction coefficient as a function of dimple shape and distribution.

Recently, surface texturing has started to be applied on machining tools. Lima et al. [3] used laser texturing before CVD and PVD coating of M2 tool steels to increase adhesion between coating and substrate. They found that laser texturing increased adhesion of PVD coatings when compared to conventional cleaning by grit blasting, although for CVD coatings no improvement could be detected. Good correlation was found between adhesion tests and machining tests, since PVD coated tools textured by laser in drilling tests of the ABNT 304 steel showed a large increase of the tool life when compared with conventional coated tools, whereas the performance of textured CVD tools was not improved. Viana and Machado [4] also found an increase of tool life due to previous texturing of coated M2 steel tools.

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Wu et al. [5,6] studied the effect of laser texturing of a tool rake surface on friction and wear. They filled the texture marks with molybdenum disulphide (MoS_2) and performed dry reciprocating ball-on-flat tests comparing textured to untextured cemented carbide samples. Their results showed that the presence of texture decreased the average friction coefficient up to 35% compared to untextured samples [5]. The counterbody wear volume also reduced with surface texturing [5]. These authors also performed dry machining tests using textured cement carbide inserts with different patterns on the rake surface. Again, they found that the presence of solid lubricant inside texture grooves reduced cutting forces and increased tool life [6].

Many different wear mechanisms have been identified on machining tool surfaces after machining. One of these mechanisms is abrasion. The presence of hard phases in the workpiece material, as well as hard particles removed from the tool, can cause abrasive wear. Grooves caused by such particles have been largely reported in the literature [3,7], in particular on the tool rake surfaces.

Microabrasion tests have been proving to be adequate to assess abrasive wear resistance of machining tools. Rutherford et al. [8] used microabrasion tests to evaluate abrasive wear resistance of PVD coatings deposited on M2 tool steels and its correlation with cutting tool performance in milling tests. Coated tools with six different single layers were tested: TiN (evaporation), TiN (sputtering), TiCN (evaporation), TiCN (sputtering), TiAlN (evaporation), and CrN (evaporation). A good correlation was found between coating abrasive wear coefficients obtained in microabrasion tests and flank wear, measured in milling tests.

Imbeni et al. [9] investigated abrasive wear resistance of multi-layered PVD nitride coatings (TiN, Ti_2N, TiCN and TiAlN) deposited on tool steels. The TiCN-based multilayer showed the highest microabrasion wear resistance due to its high intrinsic hardness. These results were compared flank wear measurements from high speed milling tests using C45 UNI 7845 steel plates as workpieces. However, in the milling tests, the TiN-based multilayer presented the highest flank wear resistance. To justify the discrepancy, the authors stated that the workpiece used in the milling tests was relatively free from abrasive precipitates and inclusions, and therefore the TiCN-based coated tools could not take advantage of their superior hardness.

In this work, the effect of surface texturing on the micro-scale abrasive wear resistance of cement carbide tools will be investigated. Additionally, the abrasive wear resistance will be compared with the durability (life time) of textured and tools in machining tests. This comparison aims to investigate if the mechanisms that affect the performance of textured tools in machining tests are related to the abrasive wear that occurs at the tool flank surface.

2. Experimental methods and materials

2.1. Characterisation of the samples

The samples used in this work were commercial cemented carbide inserts (WC-Co) containing a three-layered coating ($TiCN–Al_2O_3–TiN$) deposited by a CVD process – SPMR 120308 grade 415 P25/K20 manufactured by Sandvik do Brasil S.A. Their rake surface has a special chip breaker shape. The flat central part of the insert rake surface was used for the microabrasion tests.

In order to investigate the effect of microtexturing on the tribological behaviour of the inserts, they had their rake surface textured with different linear patterns, perpendicular and parallel to the direction of the chip movement. Texturing was carried out using a Nd:YAG laser, with intensity of $3.5 \times 10^7\ \mathrm{W\,cm^{-1}}$, pulse time of 100 ns, frequency of 10 kHz and focus beam diameter of approximately 100 μm. Fig. 1 presents the samples used in the microabrasion tests. The texture pattern detail, Fig. 1(c), was obtained using optical microscopy (OM).

A 3D laser interferometer, model UBM MESSTECHNIK MicroFocus, was used to assess the surface topography of the textured samples. Measurement densities of 1000 points and 100 points were used in the x direction in the y direction, respectively. The total measurement area was 3 mm (x direction) by 3 mm (y direction). The measuring rate was 300 points/s, using continuous measurement mode.

The coating layers were characterised using cross sections obtained by slow refrigerated cutting (Miniton-Struers®) and their thicknesses were measured using scanning electron microscopy (SEM).

Knoop tests were chosen to measure the microhardness of the multilayered coatings to reduce penetration depth. Microhardness tests were performed in ten different positions under a normal load of 490.3 mN (50 gf). This load was chosen to guarantee an indentation depth 10 times smaller than the coating thickness. For the textured samples, the microhardness was measured in the area between the laser texturing marks, indicated by arrows in Fig. 1(c), because the laser action removes the coating partially and therefore the main contact will occur on the higher areas between the laser path.

2.2. Machining tests

Machining tests in turning operation were carried out using a CNC Centur 35D lathe (manufactured by Industrias Romi SA) with a power of 15 kW. Cutting speed was set as 350 m/min. The workpiece was a ABNT/AISI 1050 carbon steel forged bar ($HV=212\ \mathrm{kgf/mm^2}$) with a diameter of 53 mm and a length of 500 mm. The flood cooling environment (flow rate of 4.2 L/min) was a vegetable based emulsion with 7% concentration. This fluid has lubricant and refrigerant characteristics. The machining parameters *feed rate* and *depth of cut* were kept constant at 2.5 mm/revolution and 2 mm, respectively.

Tool performance during turning was evaluated using a maximum acceptable flank wear of 600 μm, as proposed by ISO 3685 standard. The flank wear was measured using an optical microscopy (OM) and image analyser software, Image Pro. When that limit is achieved, the volume of removed material (VRM) is calculated using Eq. (1). More wear-resistant tools will be able to machine larger volumes of material from the workpiece before achieving this limit. Eq. (1) presents the calculated volume as a function of the machining parameter *length cut* (*Lc*) and of the workpiece dimensions: *initial diameter* (*ID*) and *final diameter* (*FD*):

$$VRM = \frac{\pi Lc}{4}\left(ID^2 - FD^2\right) \tag{1}$$

In order to investigate the influence of the texture on the tool wear, the textured inserts were positioned in two different ways according to the chip flow: (a) laser marks perpendicular to the chip flow (PP) and (b) laser marks parallel to the chip flow (PR). Results were compared to the wear of the untextured insert.

2.3. Microabrasion tests

Abrasive wear tests were carried out using a ‘free ball’ microabrasion tester [10]. In this method, a sphere of radius R is rotated against a specimen in the presence of fine abrasive particle slurry. Fig. 2 shows the schematic representation of the microabrasion test. In this variant of the experimental apparatus, the ball is driven by friction from a drive shaft against which it rests, and in which the