LASER TEXTURED COATED TOOLS USED IN TURNING PROCESS

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Abstract. *The tribological system in a conventional machining process is characterized by high pressure on the tool's surfaces. High forces applied over small areas generate pressures that can reach Giga Pascal. High temperatures are also developed at the cutting areas, and the combination of high pressures and high temperatures are responsible for many headaches of the production engineers and tool makers. Therefore it is important to study the chip-tool interface and always consider the forces (or pressures) and temperatures involved. These studies are responsible for technological advances such as high performance cutting fluids and tool coatings, looking for decreasing the friction coefficient and enhancing tool lives. Using a dedicated texture over the rake face of the tool it is possible to modify the tribological phenomenon occurring under high speeds at the chip-tool interface. A new proposal with this target is the modification of the tool surface topography in a controlled manner, using Laser technology, that allows to alter the topography of the tool surface, without altering it's mechanical properties. This work aims to evaluate the performance of laser textured tools in turning process and compared with non textured commercial tools. The workpiece material was the AISI 1050 carbon steel. Chip breaker and flat cemented carbide tools triple coated with* $TiCN\text{-}Al_2O_3\text{-}TiN$ *by the CVD process were textured using Nd-YAG Laser. The surfaces of the tools were studied using 3D topography analysis and a Scanning Electron Microscope – SEM before the machining test. It was varied the cutting speed using two different environments (dry and flood cooling). The machinability was evaluated by the cutting force and visual analysis of the wear on the rake face of the tool. The laser textured tools presented different effects on the cutting force, depending on the environments (dry or flood cooling). This work therefore attempts to contribute to this new research area and to provide important technical information for further support this new technology.*

Keywords*: Laser texture, Cemented Carbide, Flood Cooling Environment.*

1. INTRODUCTION

The high productivity always has been a target for the industry. Nowadays manufacturers with high standards of technologies assume the entire control of the market.

In machining process a high number of manufactured parts with high productivity are possible increasing the cutting parameters, specially cutting speeds, feed rates and depths of cut. Increasing the cutting parameters, however, may affect accuracies and surface roughness of the components and therefore must be done with care. The use of high cutting parameters has motivated not only new researches and developments of new machines, but it has also encouraged the appearance of new tools involved in the process. Presently high and ultra-high speed machining (HSM and UHSM) are terms normally used in machining environment, but they can only have success when using an adequate cutting tool (Machado *et al*., 2009).

New tool materials have been introduced in the market to attend the demand for the frequent higher mechanical loads involved in the chip formation processes. The performance of these materials are generally quantified by tool lives, material removal rates, cutting forces, power consumption, surface finishing, flexibility of application, and machining costs (Trent and Wright, 2000)

One fraction of the machining costs involves the tool price divided by the number of parts that can be produced with each tool, thus many researchers focus their work aiming to improve the tool life and consequently adding value to the tool.

Several techniques have been efficiently tried when looking for improvements in tool lives; the most popular is the use of coatings normally having multi layers of hard materials with high wear resistance, low friction coefficient and different thermal properties; cutting fluids are also widely used for the same target, allowing even higher cutting speeds (Yuhara, 2000).

In conventional machining process the chip-tool contact area are divided in two regions, the sticking and the sliding zones, the sizes of which depends on the machining parameters, the workpiece material properties and the surface characteristics of the tool (Trent and Wright, 2000). When the topography of the tool surfaces is modified the tribological phenomena change, varying the loads acting on the rake face and consequently altering the contact area (Kawasegi *et al*., 2008). The cutting tool's surface topography can be modified altering it´s texture.

A strategy for surface texturization with promising results is the laser technique which has been widely used to produce micro-holes or textures in a controlled manner (Low *et al*., 2001).

The micro cavities are produced by material melting or ablation when a laser beam is focused point by point of the tool surface. The micro cavities sizes mainly depends of the variation of parameters related to the laser-material interaction (beam power, intensity distribution, pulse form and pulse duration) (Neves *et al*., 2006).

High accurate detaching of material with less thermal affected zones is obtained when used ultra short pulses (nano-seconds) (Dumitru *et al*., 2005).

Several studies have showed the laser texturing being a good alternative to improve the tool life. Arroyo (2009) studied the use of laser for texturing cemented carbide substrate before deposition of $TiCN/Al_2O_3/TiN$ coatings by MT-CVD process. He showed that laser treatment produced a surface with stronger adhesion comparable to that of commercial tools pretreated by micro-sandblasting.

Viana (2009) also showed advantages in milling of cast iron using laser textured inserts before coating. Scratch and indentation tests showed the higher coating adherence of them when compared with conventional tools.

Etsion (2009) studied internal combustion engines performance when surfaces of the cylinders were laser textured. He found that partially textured surfaces enhanced power of the engines.

When applied in cemented carbide inserts with the aim of preparing the surface to receive coatings the laser beam promotes ablation of the cobalt present in the substrate surface of the tool leaving uncovered the hard grains of WC and generating a controlled roughness that improves the adhesion of the coated layer (Li *et al*., 2002).

The present research does not aim to apply laser texture before coating but to evaluate the influence of laser texturization over coated tools in machining. *Nd:YAG* short pulsed high frequency laser is used to modify the coated insert topography via controlled ablation, changing the tribological system at the chip-tool interface. These tools were used in turning of AISI 1050 mild steel with the cutting force being measured and compared with coated commercial inserts.

2. METHODOLOGY

Turning of AISI 1050 mild steel was used to compare the machinability in terms of cutting force of laser textured and commercial coated tools. A Kistler 9265B dynamometer was used to determine the cutting force under several cutting conditions. In order to characterize the topography of the tools SEM analysis were done in the tool's surfaces.

2.1. Workpiece Characterization

The workpiece material was a cylindrical bar of AISI 1050 carbon steel with, 54 mm of diameter and 500 mm long. The microstructure was analyzed in two areas of the cross section of the bars, schematically shown in Fig. 1. The Figure 2 shows the microstructures of these samples taken at the core and near the surface of the cylindrical bars.

The measured hardness gradient was correlated to the microstructure. It was determined that the bars surface exceed a hardness level of 221 HV for recrystallization to a fine grain size, while the bars core are hardened to a level of 212 HV for grain growth.

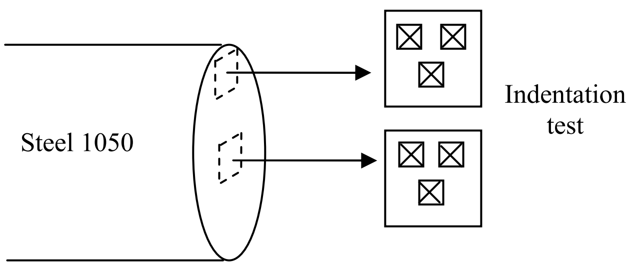

Figure 1 – Location of the samples for hardness and microstructure tests of the work material.

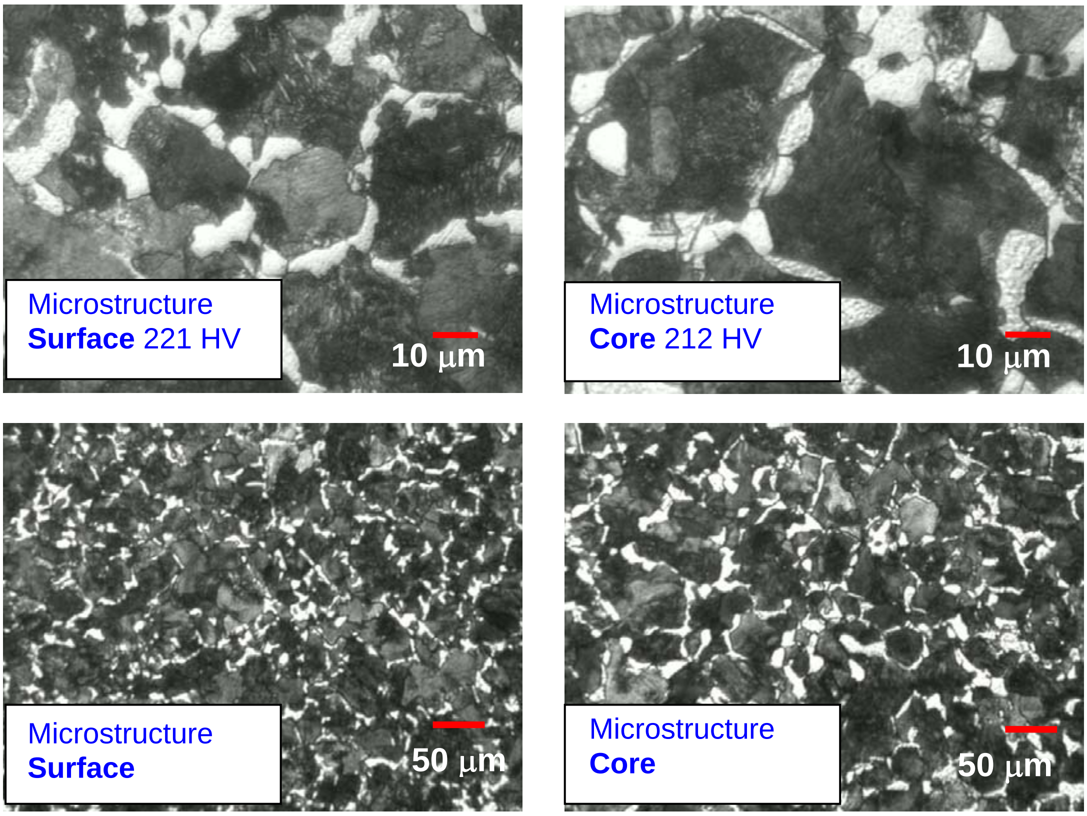

Figure 2 – Microstructure near the surface and at the core of the work material bars with different magnifications.

2.2. Tools Characterization

The inserts used were SPMR 120308 grade 415 (chip-breaker) and SPUN 120308 grade 3005 (flat) P25/K20 manufactured by Sanvik do Brasil S.A. The same laser texture was applied for the two types of the tools, the texturing was carry out at IEAv-CTA using a Nd:YAG laser, with intensity of 2.37×10^{8} W/cm^2, the pulse time was 82 ns, frequency of 10 kHz and focus beam diameter of 93 μm at normal atmosphere, for both of the tools.

The textured area was 12x12 mm^2 using a galvanometric head in line with the beam. The scanning was realized in a sequence of parallel lines at a fixed velocity of 50 mm/min and 0.03 mm lateral shift. All the tools were characterized by laser interferometer and scanning electron microscope. Fig. 3 illustrates the scanning methodology for texturing.

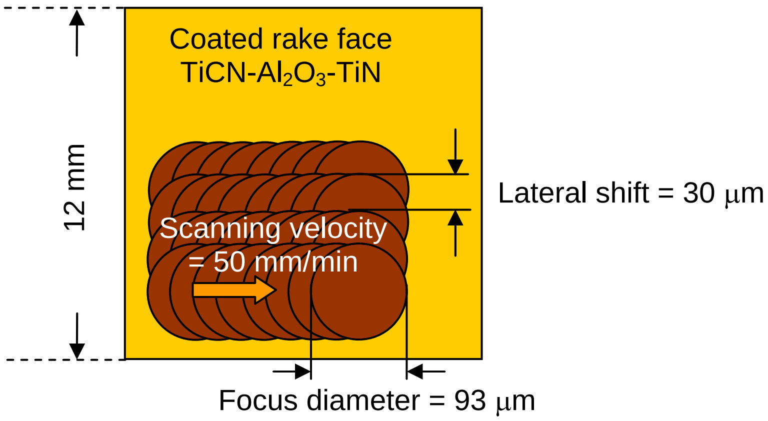

Figure 3 – Illustration of the texturing methodology for flat and chip-breaker tools.

After the laser scanning, tridimensional analyses of the treated and conventional tool surfaces were done by laser interferometer, Fig. 4 shows the resulted color map topography of the conventional and textured tools (flat and chip-breaker tools).

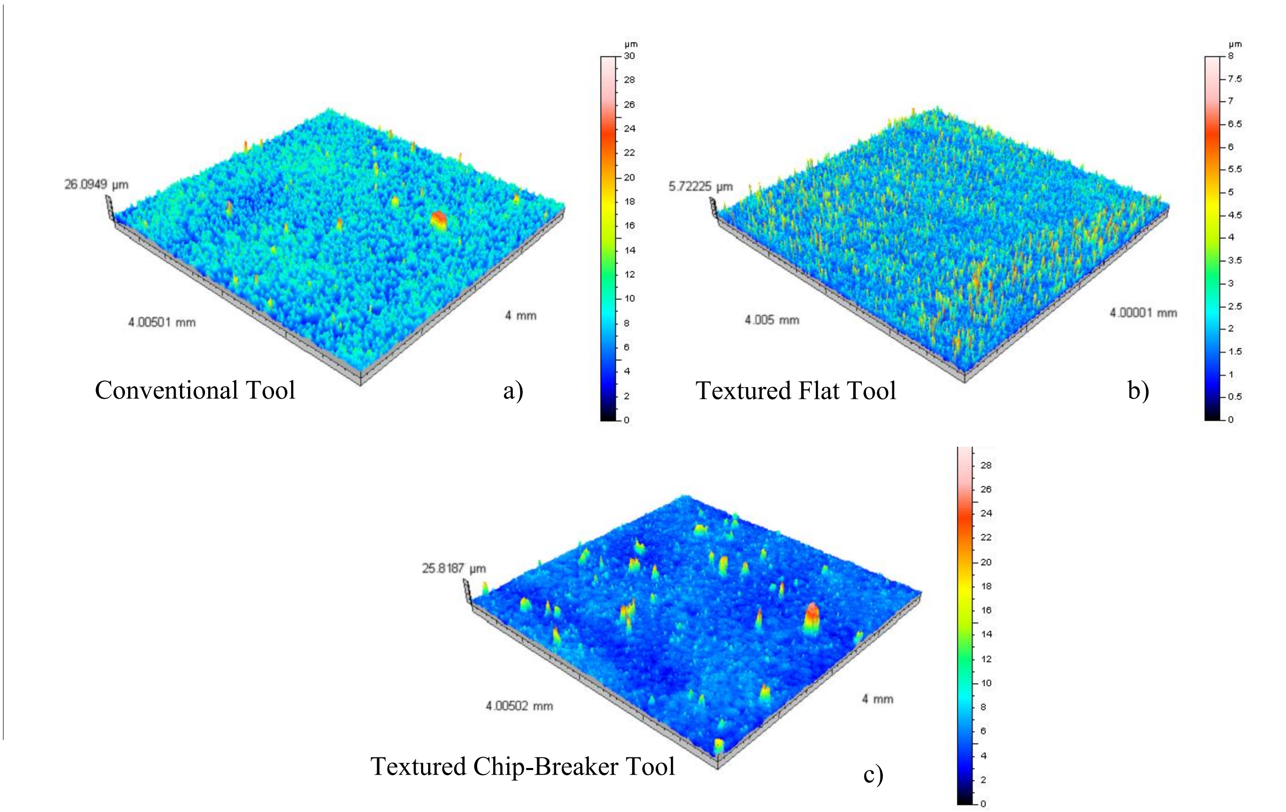

Figure 4 – Three-dimensional topography a) Conventional, b) Flat Textured and c) Chip-breaker Textured Tools.

The topographic analysis illustrates the distribution of peaks and vales through 4mm^2 of the rake face of the tool. In Fig. 4(a) it is observed and homogeneous topography with heights of the peaks varying between 9 to 10 µm. Fig. 4(b) shows a less rough surface where the difference between peaks and vales is about 5 to 6 µm, with a homogeneous distribution. Finally, Fig. 4(c) shows a heterogeneous topography, showing isolated peaks of 22 µm height and a most part with smooth areas with peaks varying between 4 and 6 µm. This type of analysis shows typical characteristics of the surface and gives ideas of load capability (Etsion, 2002), suitable volume to fluid and debris store (Costa, 2005), as well as wear resistance capability. The results of three dimensional roughness parameters are shown in Tab. 1.

Table 1 – Roughness parameters of tools surface.

Micrometer Scale Measures	S_a	S_q	S_p	S_v	S_t	S_{sk}	S_{ku}	S_z
Conventional Tool	1.28	1.80	19.57	6.51	26.09	2.15	15.96	24.62
Flat textured Tool	0.33	0.49	4.34	1.37	5.72	2.20	14.05	5.61
Chip-Breaker Textured Tool	0.84	1.55	20.74	5.07	25.82	5.66	56.74	25.06

Where:

$\mathbf{S_a}$ = Arithmetic Mean Deviation of the Surface.
$\mathbf{S_q}$ = Root-Mean-Square (RMS) Deviation of the Surface.
$\mathbf{S_p}$ = Maximum height of summits.
$\mathbf{S_v}$ = Maximum depth of valleys.
$\mathbf{S_t}$ = Total height of the surface.
$\mathbf{S_{sk}}$ = Skewness of the Topography Height Distribution.
$\mathbf{S_{ku}}$ = Kurtosis of the Topography Height Distribution.
$\mathbf{S_z}$ = Ten Point Height of the Surface.

Fig 5, illustrates the Scanning Electron Microcopy photos of the tool's rake faces, where the laser effect over the fine coated layers can be seen.

In Fig. 5(a) the SEM of chip-breaker textured tool and in Fig 5(b) the flat textured tool. The SEM shows a grey scale pictures, where the dark zones indicate the presence of elements with a low atomic number, in this case Aluminum as identified by the EDX graphics. At point 1 in Fig. 5(a) the detachment of the external coating layer of TiN, lets uncovered the sub-layer of (Al_2O_3). Points 2 and 3 in the Fig. 5(a), the light grey zone indicates the presence of titanium from the external coating layer.

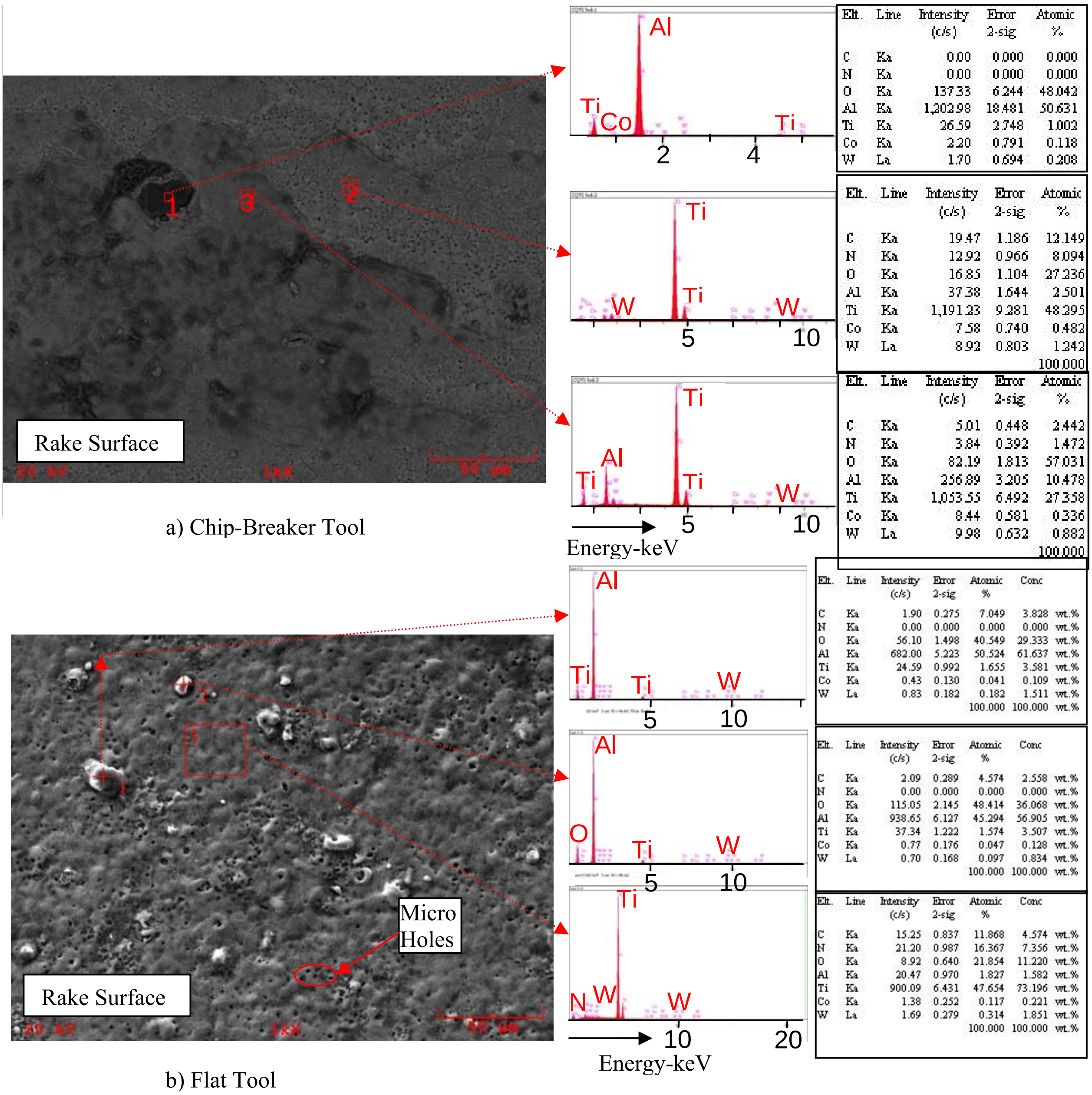

Figure 5 – View of the rake face and EDX composition analysis after laser texturing: (a) Chip-breaker tool; (b) Flat tool.

Fig. 5(b) shows a less affected surface if compared with Fig. 5(a), the large percentage of the surface shows a light grey color, indicating the presence of titanium with high energy level, from the external coating layer. It also shows several dark points, consequence of gases explosions which let micro holes throughout the titanium nitride layer.

2.3. Force Measurement System

To measure the cutting force a Kistler dynamometer model 9265-B was used, fixed at the main table of the lathe as shown in Fig. 6. A CSBPR 2525 M12 toolholder was fixed to the piezoelectric platform with 50 mm in balance following the dynamometer manufacturer recommendation. It was also used an analogic/digital data acquisition board PowerDAQ model NI USB DQPad-6251 Pinout 1.25 MS/s, with sampling rate of 1 kHz. The digital signals were managed using a virtual instrument programmed in LabView 6.0 software from National Instruments. For these tests, only one cutting edge of the tool was used for each tool tested, the Fig. 7 shows the rake face of the tools at the end of the test.

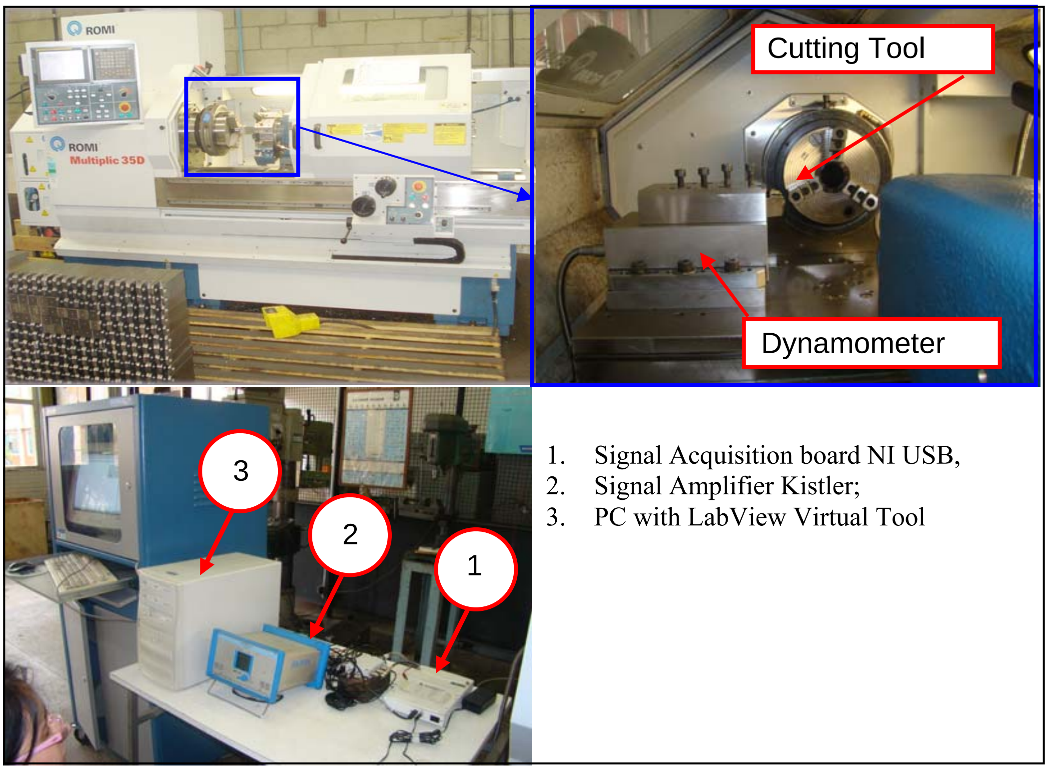

Figure 6 – Force measure acquisition system.

2.3 Experimental Design

In order to analyze the behavior of the textured tools at different chip flux velocities, the cutting speed was varied from 10 m/min up to 400 m/min with the feed rate fixed in 0.2 mm/rev and the depth of cut in 1 mm for chip breaker tools and 2 mm for flat tools. Two lubri-cooling atmosphere of cut, Dry and flood coolant were tested. Tab. 2 summarizes the tests carried out.

Table 2 – Experimental tests design

TEST		**CUTTING SPEED [m/s]**		**CUTTING TOOL**	**DEPTH OF CUT [mm]**
1	**10**	400	60	Commercial Chip-breaker	1
2	**11**	350	50	Textured Chip-Breaker	1
3	**12**	300	40	Commercial Flat	2
4	**13**	250	30	Textured Flat	2
5	**14**	200	20	**LASER PARAMETERS**	**ENVIRONMENT**
6	**15**	100	10	Spot Beam = 93 μm Lateral Shift = 30 μm Intensity = 2.37×10^8 W/cm^2 Scanning Vel. = 50 μm Frequency = 10 kHz Pulse Time = 83 ns	Dry
7		90			
8		80			Flood Coolant (360 L/h)
9		70			

High depth of cut was used in flat tools to help the chip-breaking. It was helpfully to analyze the effect of the texture when large chip-tool contact areas are used.

3. RESULTS

A visual inspection of the tools surface shows different colors from the laser treated tools. The chip-breaker tools suffering high ablation rate of material if compared to the flat tools. This phenomenon could be explained by the high influence of slight variations in the surface geometry of the tools, which can also be affected by the surface roughness, that strongly changes the laser absorption coefficient. The higher this absorption coefficient the higher the input of energy for material ablation.

Figure 7 shows the results of cutting force measurements when the cutting speed was varied, it must be considered that the depth of cut was the double when used flat tools. Each point in the graphic represent the average value from 5 seconds of signal acquisition using an acquisition rate of 1kHz, the dispersion of the signal was less than 8N and could not be represented in the graph.

It is clear that the texture enhanced the cutting force under dry cuts for the chip-breaker tool. However, when a cutting fluid is applied the effectiveness of the texture in anchoring the lubricant and reducing cutting forces is evident, as expected. The use of cutting fluid was also very effective, in both types of tools, when smaller wear is observed on the tool´s surface at the end of the tests with flood cooling.

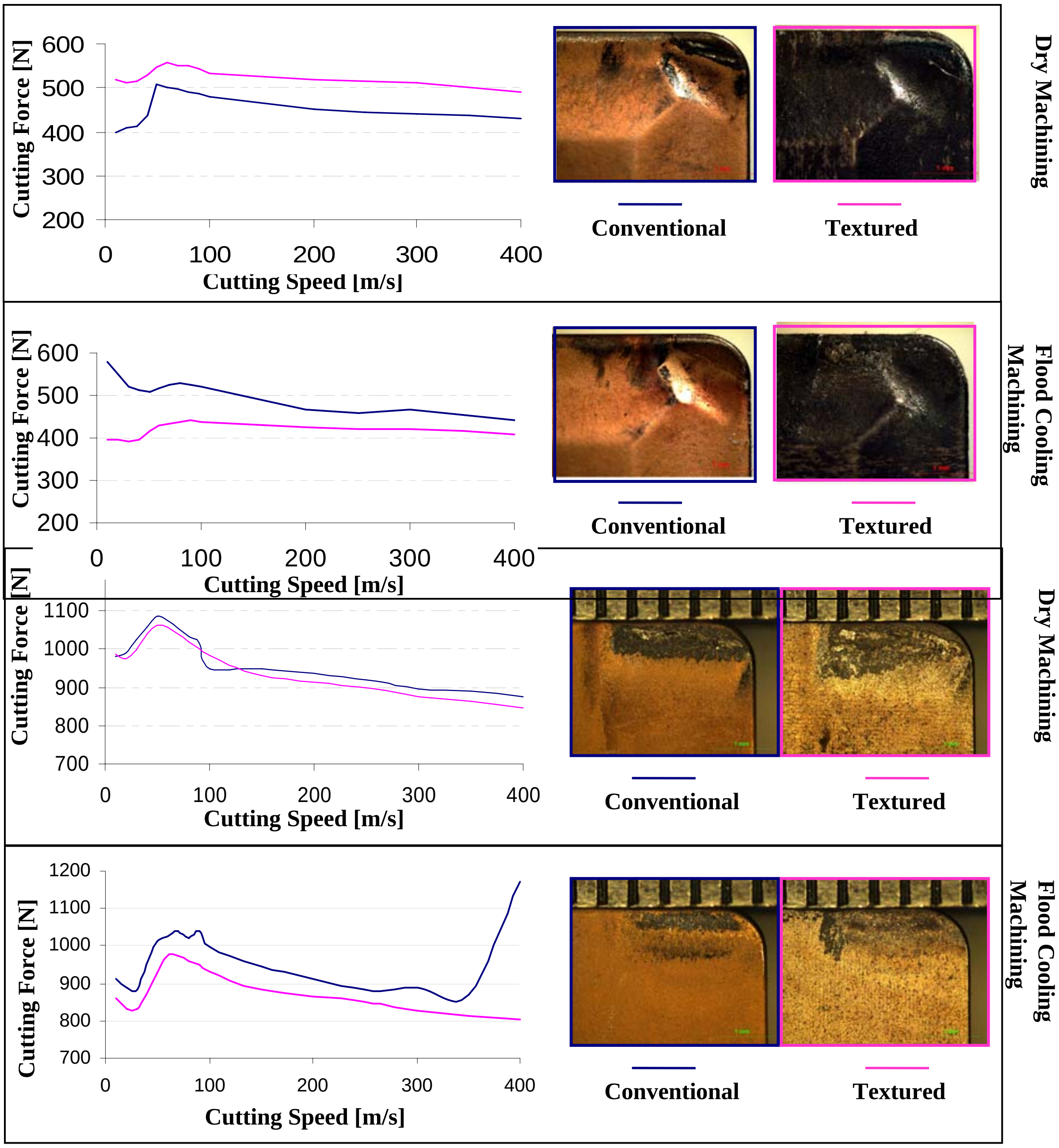

Figure 7 – Behavior of the cutting forces a) Chip-breaker dry cutting, b) Chip-breaker flood coolant cutting, c) Flat dry cutting, d) Flat flood coolant cutting.

4. CONCLUSIONS

The proposed new textured tools introduce topography variations on the tool´s surfaces, changing the complex tribological system during chip formation. In dry cuttings the textures act hindering chip motion and hence increased the cutting force. When a cutting fluid was applied the textured tools showed lower cutting forces because it provides cavities for fluid retention and the lubricity of the cutting area is raised, facilitating chip formation.

5. ACKNOWLEDGEMENTS

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