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Investigation of Femtosecond Laser Texturing in Cemented Carbide Cutting Tools

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Abstract

The aim of this work is to characterize uncoated cemented carbide tools textured byfemtosecond laser and to investigate the influence of texturing on the cutting tool in machining.Thus, parallel micro-grooves were machined on the rake face of uncoated cemented carbide inserts at 100, 200, 300 and 400 µm from the cutting edge using aTi:Sapphire laserset for15 µJ, 30 fs pulsesemission centered at 775 nm and at 4 kHz of repetition rate. The cutting forces were monitored along the semi-orthogonal turning of austenitic stainless steel (V304UF) for textured tools and compared with non-textured ones (reference).The cutting conditions were kept constant. The results showed reproducible grooves with meanwidth and depth of 35±3 and 32±6 µm, respectively;a reduction of 27.6% in the machining force for textured tool at 200 µm from the cutting edge and lower surface roughness for textured tools at 200 and 300 µm when compared with reference ones.

Keywords:Texturing; Femtosecond laser; Cemented carbide tools; Machining force; Surface roughness

1. Introduction

Considering thatthe global market of cutting tools moves billions of dollars per year and the exponential evolution of the metalworking industry in recent decades, it is observed that productivity has become decisive forthe world competitiveness. Therefore, the toolmakers industry regularly needs to innovate technologicallyto meet market demand. Thus, any research that aims to improve the cutting tool design adds value and / or reduces costs (Trent; Wright, 2000; Dedalus Consulting, 2011).

Based on machining theory, it is known that the rake face of cutting tools is subjected to high compressive stresses and plastic strain during machining. These conditions favor metallic bonding at the chip-tool interface and influence the cutting forces, cutting heat and wear mechanisms in the cutting tools (Trent; Wright, 2000; Shaw, 2004;Xie et al., 2013).

Recently, laser texturing on cutting tools has been studied as an alternative to control tribological behavior on tool-chip interface in order to reduce the friction (Xie et al., 2013). It has been shown as a significant technique for changing the surface topography to improve the adhesion of coatings; retain cutting fluid; or reduce the contact area between chip and tool (Kawasegi et al., 2009; Sugihara; Enomoto, 2009).

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In the last decade, the ultrafast laser (pulselength shorter than 10^{-12} s) has attracted great interest as a new possibility for micromachining due to its ability to produce very high peak power intensity in a short time(Samad et al., 2012). Many studies have shown femtosecond laser (10^{-15} s) advantages over the long pulses, including preserving theproperties of surrounding material; accurate ablation threshold;high repeatability; efficiency and highly precise control of the ablationgeometry with minimal heat affect zone (HAZ).In addition, femtosecond pulse promotes a nonselective ablation, which allows the machining of all types of material with the same laser(Liang et al., 2003; Samad et al., 2012).

Therefore,the aim of this work is to characterize uncoated cemented carbide tools textured by femtosecond laser and to investigate the influence of texturing in medium machining test.

2. Experimental Procedure

Triangular uncoated cemented carbide tools, BA55, by Brassinter/BRA were textured with femtosecond laser technology. The texturing was carried out on the rake face ($A\gamma$) of inserts with Ti:Sapphire laser, Femtopower Compact Pro HR/HP model by Femtolasers/AUT, with 30 fs laser pulses, emission centered at 775 nm, with 4 kHz repetition rate and 15 µJ energy. The laser beam was focused with a lens of focal length of 38 mm.

The textures designcomes from a previous study, in which a specific contact area between chip and tool, called seizure region, was determined. At the time, the main cutting force was also measured for tool-workpiece pair. From the literature (Ezugwu; Pashby, 1992; Shi et al., 2005; Oliveira et al., 2008), it was possible to estimate the rupture strength of tool material.Thus, from the elemental equation,$\sigma=F/A$ (stress is force divided by area), the critical area was determined and the maximum number of grooves (texture) were put inside this contact area, without reachingthe material rupture strength.

Four texture models were micro-cut with a distance from the main cutting edge: at 100, 200, 300 and 400 µm, with distance between grooves of 95, 65, 60 and 60 µm, respectively.The texture was carried out parallel to cutting edge, with feed velocity of laser beam of 3 mm/min. The ablation area was 2.5 mm^2, which corresponded 2.5 mm in the depth of cut direction and 1 mm in the feed direction.

The characterization of textures was performed by scanning electronic microscope (TM3000, Hitachi/JAP) and by laser interferometer (ZeGage, Zygo/USA).

Semi-orthogonal turning tests were carried out with textured and non-textured (reference) tools, which had geometry TPUN 16 03 04, assembled on a tool-holder CTGPR 2525 M16 by Sandvik/BRA, allowing a cutting geometry with 0° inclination angle (λs), 6° rake angle (γ_0) and 91° side-cutting edge angle (K_r). The workpiece material was an austenitic stainless steel (V304UF) by Villares Metals/BRA, see Table 1. A conventional turning machine, S-30 by Romi/BRA, with 8 HP and 1800 rpm was used to perform the tests. The cutting conditions were kept constant in vc = 156 m/min (cutting speed), f = 0.205 mm/rev (feed),ap = 2 mm (depth of cut) and Lf = 10 mm (feed length).

The output variable of the machining test was machining force (F_R), which resultantsfrom three orthogonal force components (Fc = cutting force,Ff = feed force and Fp = passive force), which were used to compare the results of textured tools with reference ones (non-textured). Cutting forces were monitored with the aid of a piezoelectric dynamometer 9265B/9441B model, conditional signal 5070A 11100 and analysis software DynoWare 2825A1-2, both Kistler/CHE. Surface roughness was measured for Zeiss/GER roughness tester, Handysurf E-35B model, with cut-off 0.8 mm, according to ISO 4288:1996.

Table 1. Chemical composition of V304UF [w%]

C	Si	Mn	P	S	Cr	Ni	Fe
0.08	1.00	1.85	0.06	0.03	18.00	9.00	70.00

3. Results and Discussions

3.1. Textures characterization

The characterization of textures was made by microscopy and interferometry. Figure 1 shows images of four texture models manufactured by femtosecond laser. In these SEM images there were no signals of melting material along the surface micro-cut, or other kind of flaws, such as cracks or spalling.

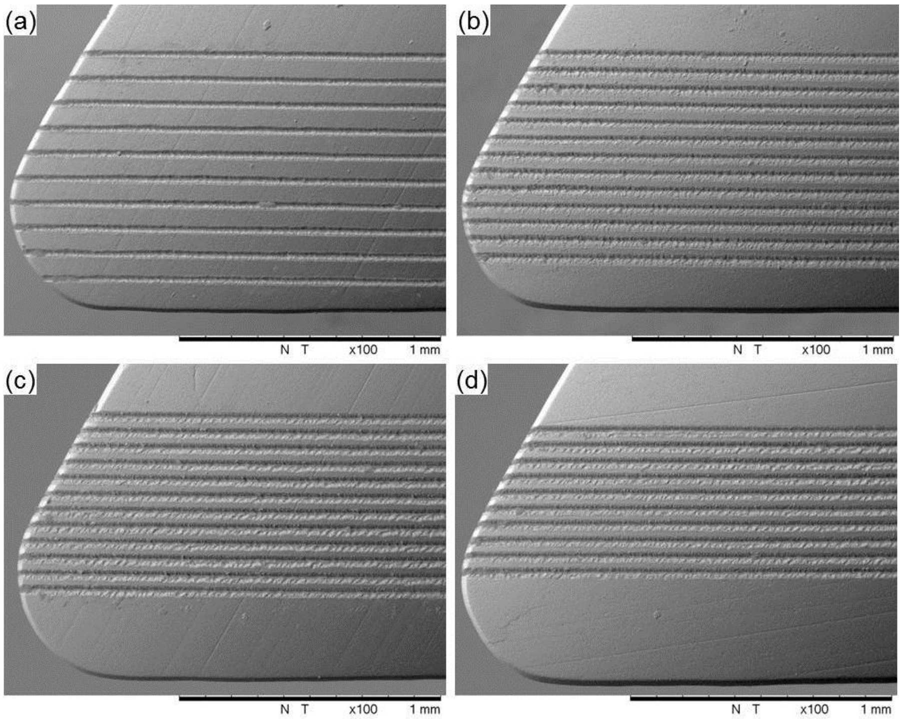

Fig. 1. Microscopic characterization of texture models used from cutting edge. (a) At 100 µm; (b) At 200 µm; (c) At 300 µm; (d) At 400 µm.

Figure 2 shows an interferometry image of the texture model at 200 µm. It is a representative image of form and dimension of grooves for any kind of texture model, since laser parameters were kept constant. The interferometric characterization allowed evaluating the “v”form grooves produced andthe reproducibility of the laser used, as for their width and depth.

Data from the interferometry analysis are shownin Table 2, which presents mean values of width and depth of grooves for each texture model fabricated; besides an average of all width and depth points for comparison. The standard deviations of the table are rather small, including the global average of all points. The width has a narrower deviance, while the depth has a bit wider one, probably due to the laser intensity variations caused by plasma formation in focus. According to (Kawasegi et al., 2009; Samad et al., 2012), ultrashort pulse lasers, as the femtosecond one, provide micromachining with low damage to the piece and nearly accuratedimensions. Due to its brief pulse duration, shorter than the thermal vibration period of the lattice, the heat affect zone (HAZ) is minimized; furthermore, it has elevated intensity which, aided by the precision CNC table, allows a localized ablation and nonlinear with matter.

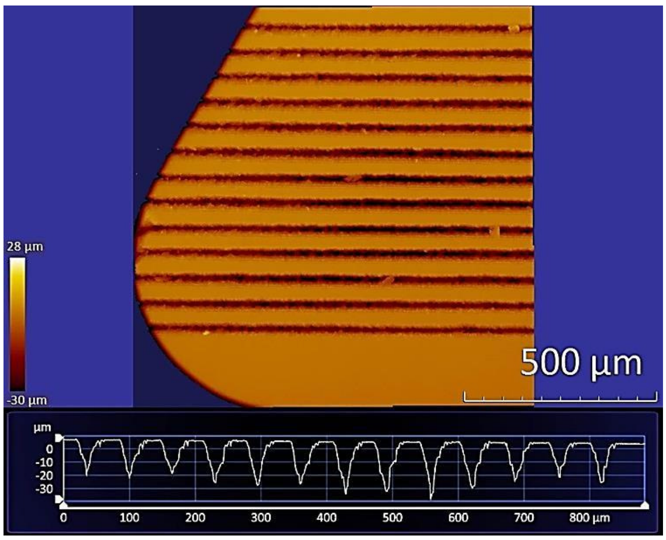

Fig. 2.Representation of Interferometric characterization.

Table 2.Width and depth of grooves.

	Average Values [µm]				
	100 µm	**200 µm**	**300 µm**	**400 µm**	**Global Average [µm]**
Width	29.72±1.27	37.03±0.99	37.00±1.27	36.19±1.87	35.21±3.26
Depth	30.11±4.02	33.75±7.51	33.87±4.35	29.33±5.17	31.99±5.76

3.2. Machining application

Figure 3 shows practical machining results with textured tools and non-textured ones (reference). It presents the texture models influence over the machining force (F_R),resultant from the cutting force(Fc), feed force (Ff) and passive force (Fp) components. It shows the mean values of machining force for textured tools lower than the reference. The best performance was reached by the model at 200 µm. A 27.6% decline in (F_R) was observed, due to a reduction mainly in (Fc) and (Ff) components of 24.5 and 38%, respectively, as can be seen in Table3.

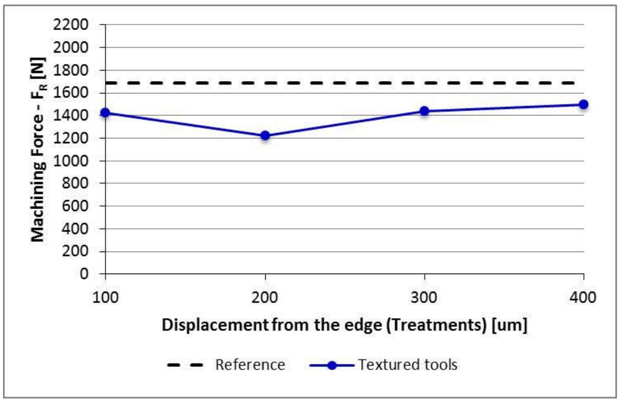

Fig.3. Texture models influence over machining force (F_R).

Table 3. Average values of cutting forces.

	Cutting forces components			
Texture models	Fc [N]	Ff [N]	Fp [N]	F_R [N]
Reference	1460.65	783.65	328.34	1689.80
100 µm	1144.11	761.73	363.99	1424.68
200 µm	1102.44	486.24	213.75	1224.12
300 µm	1281.32	583.22	287.83	1436.93
400 µm	1320.92	647.09	267.56	1495.04

Kawasegi and co-workers (2009) textured cemented tools by femtosecond laser. They observed a more effectivereduction for Ff and Fp components than the Fc one, when turned in CNC machine aluminum alloy (A5052), in finishing cutting conditions (vc = 60 m/min; f = 0.1 mm/rev and ap = 0.2 mm), using minimum quantity lubrication (MQL). Zang and co-workers (2015) textured their cemented tools by Nd:YAG laser. They also turned in finishing conditions (f = 0.1 mm/rev and ap = 0.3 mm), but AISI 1045 in conventional lathe, with microtextured tools, coated with TiNAl, in dry and lubricated conditions. The most interesting results happened at vc = 200 m/mim. Fp, Ff and Fc decreased 33, 34.7 and 21.2%, respectively, in lubricated condition; while in dry condition, the force components reduced by 2-8%. Xie and co-workers (2013) microtextured cemented tool using a diamond wheel. They found great reduction in Fc, turning in medium condition (vc = 39 m/mim; f = 0.3 mm/rev and ap = 1 mm) titanium alloy (Ti-6Al-4V), in CNC machine and in dry condition. Therefore, when it is compared to the literature results, the textures made in femtosecond laser showedto be very successful, since they were tested in medium cutting conditions, dry and in conventional lathe. Besides, the results show that there is a texture optimum positioning on the rake face ofcutting tool.

Figure 4 shows the rake face of cutting tool after the machining tests.In general, textures were observed to resist the cuttings forces largely. Spallingis verified in thenose radius of tools,which can be managedin the future, but does not hinderthe main objective,that is, to show the machining force reduction. Only in the model at 400 µm from the main cutting edge can some fracture be verified in the middle of texture.

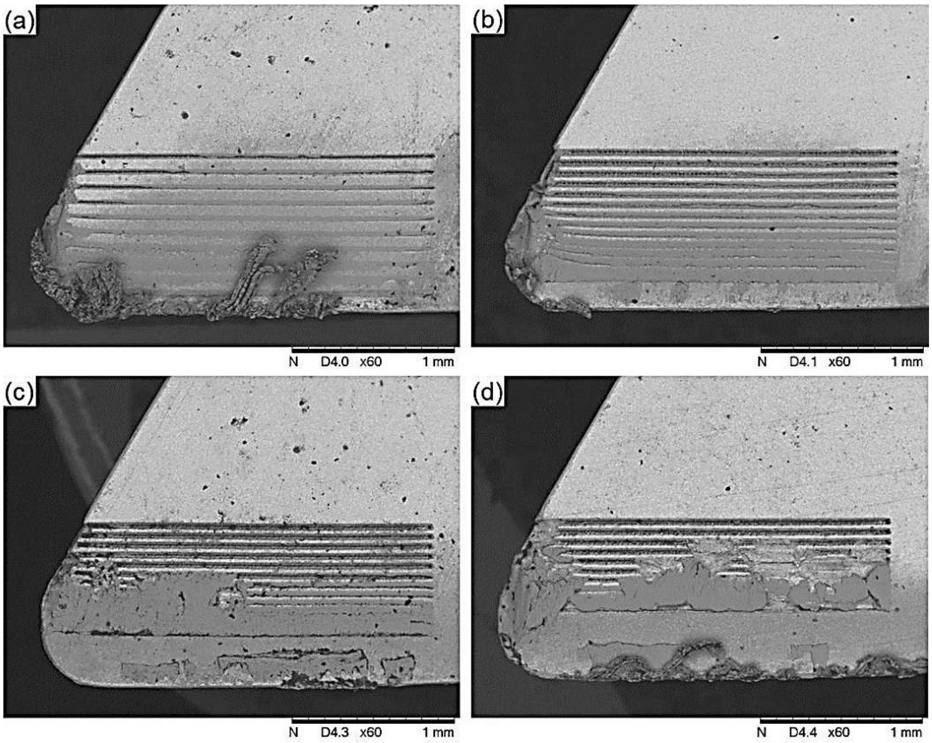

Fig. 4. Rake of cutting tools after machining tests.

Figure 5 presents an EDS analysis that was able to identify the main elements of stainless steel adhered on the rake face of cutting tool. As Trent and Wright (2000) pointed out, in metal cutting, it is inevitable to have seizure condition and intermittent one (with slip-stick motion of chip), in chip-tool contact area. However, the texture caused tribological changes at the chip-tool interfacethat was evidenced by cutting forces reduction. The images suggest there is material of workpiece anchoring inside the grooves and chip sliding over the material anchored. Therefore, the hypothesis of reduction of seizure (stick) in the intermittent region (peripheral or sliding region) of the chip-tool contact may be considered to explain the cutting forces reduction.

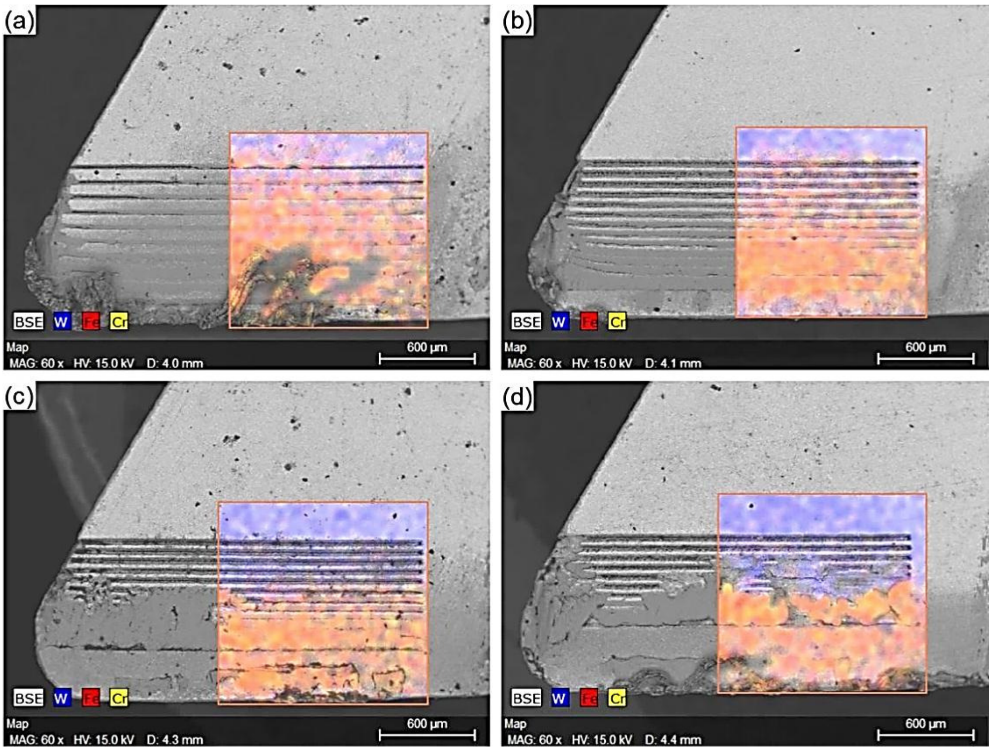

Fig. 5. Evidence of workpiece material adhered on the rake face of cutting tool by EDS analysis.

Figure 6 shows roughness surface results about Ra and Rz parameters. Ra is the average absolute deviation of the roughness irregularities from the mean line over one sampling length. It is the mostly used roughness parameter for general quality control, giving a good general description of height variations. Whereas the International ISO defines Rz as the difference in height between the average of the five highest peaks and the five lowest valleys along the assessment length. It is more sensitive to occasional high peaks or deep valleys than Ra (Gadelmawla et al., 2002).

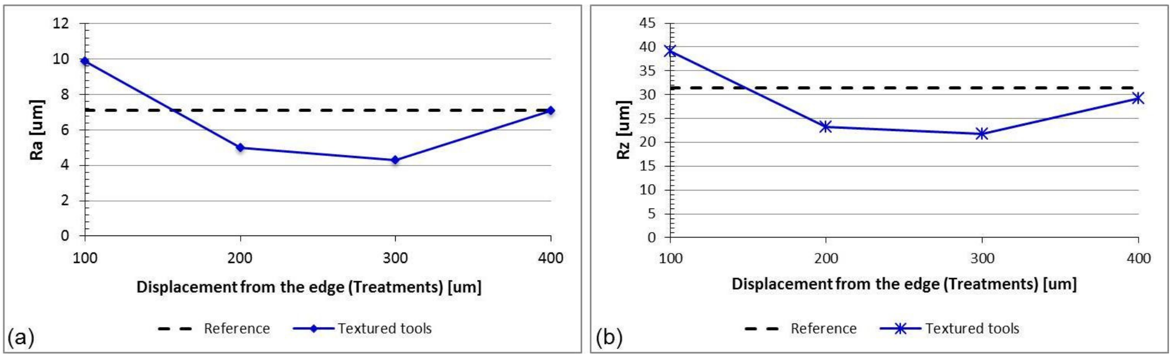

Fig. 6. Roughness surface. (a) Ra parameter; (b) Rz parameter

Surface roughness also followed the tendency to reduce with the displacement of texture, so that at 200 and 300 µm, the values of Ra and Rz got below the reference. For Ra, the reduction was 29.3 and 39.2%, while for Rz, 26.1 and 30.7%, respectively. As texture tended to anchor machined material, at 100 µm, this anchoring possibly disturbed the cutting in the space between the clearance face and the machined surface. The following observations aid to justify this condition. In Figure 4 (a) a large amount of material can be seen to haveadhered to the nose radius of the insert; besides, in Table 2, the passive force (Fp), defined in the direction of shank of tool-holder and perpendicular to machined surface, was larger than the reference. It can also be noted that the more distant the texture is from the cutting edge, the more it approaches to the reference condition.

4. Conclusions

Femtosecond laser showed to be a reproducible tool to texture micro-grooves with narrow dimensions and controlled harm on the rake face of cemented cutting tools.Machining results showed a reduction by 27.6% in the machining force for texture tool at 200 µm from the cutting edge. Besides, surface roughness showed asimilar tendency for textured tools at 200 and 300 µm.

Acknowledgements

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References

Trent, E.M., Wright, P.K., 2000. *"Metal Cutting"*, Ed. Butterworth-Heinemann, London, United Kingdom, p. 446.

Dedalus Consulting, 2011, Cutting Tools: World Markets, End-Users & Competitors: 2010-2015 Analysis & Forecast, p. 500.

Shaw, M.C., 2005. *"Metal Cutting Principles"*, 2ndEdition. Oxford University Press, New York, p. 651.

Xie, J., Luo, M.J., Wu, K.K., Yang, L.F., Li, D.H., 2013. Experimental study on cutting temperature and cutting force in dry turning of titanium alloy using a non-coated micro-grooved tool. International Journal of Machine Tools & Manufacture, Vol. 73, pp. 25-36.

Kawasegi, N., Sugimori, H., Morimoto, H., Morita, N. and Hori, I., 2009. Development of cutting tools with microscale and nanoscale textures to improve frictional behaviour. Precision Engineering, v. 33, pp. 248-254.

Sugihara, T.; Enomoto, T., 2009. Development of a cutting tool with a nano/micro-textured surface – Improvement of anti-adhesive effect by considering the texture patterns. Precision Engineering, 33, pp. 425-429, 2009.

Liang, W.L.; Ngoi, B.K.A.; Lim, L.E.N.; Venkatakrishnan, K.; Hee, C.W., 2003. Micromachining of circular ring microstructure by femtosecond laser pulses. Optics & Laser Technology. v.35, pp. 285-290.

Samad, R.E., Machado, L.M., Junior, N.D.V. and Rossi, W., 2012. Ultrashort Laser Pulses Machining, in *"Laser Pulses – Theory, Technology, and Applications"*.InTech., pp. 143-174.

Ezugwu, E.O., Pashby, I.R., 1992. High speed milling of nickel-based superalloys. Journal of Materials Processing Technology, 33, pp. 429-437.

Shi, X.L., Shao, G.Q.,Duan, X.L.; Yuan, R.Zh., Lin, H.H., 2005. Mechanical properties, phases and microstructure of ultrafine hardmetals prepared by WC-6.29Co nanocrystalline composite powder. Materials Science and Engineering A, 392, p. 335-339.

Oliveira, F.A., Lopes, A.C., Fernandes, J.C., Sacramento, J., Valente, M.A., 2008. Fracture behaviour of a new submicron grained cemented carbide. Ciência&Tecnologia dos Materiais, v. 20, n. 1/2, pp. 52-59.

International Organization for Standardization. ISO 4288:1996 Geometrical Product Specifications (GPS) - Surface texture: Profile method - Rules and procedures for the assessment of surface texture.

Zhang, K., Deng, J., Xing, Y., Li, S.,Gao, H., 2015. Effect of microscale texture on cutting performance of WC/Co-based TiAlN coated tools under different lubrication conditions.Applied Surface Science, 326, pp. 107-118.

Gadelmawla, E.S., Koura, M.M., Maksoud, T.M.A., Elewa, I.M., Soliman, H.H., 2002. Roughness parameters. Journal of Materials Processing Technology, 123, pp. 133-145.