STUDY OF SURFACE FINISH OF ALUMINUM ALLOYS IN TURNING WITH COATED CERAMIC CUTTING TOOLS

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Abstract. *Single and multi-layer coatings produced by PAPVD (Plasma-assisted physical vapour deposition) have allowed tungsten carbide tooling to become more versatile and competitive. Nowadays, surface finish has been studied in different materials, techniques and strategic applications such as automotive industry. In general, ceramic coatings exhibit high microhardness value, high oxidation stability, low thermal conductive and relatively low coefficient of friction against different materials. In particular two last properties and conditions can result in the best surface finish.This work is focused on the study of the influence of ceramic ternary coatings on roughness parameters (in particular: functional parameters), in the following systems: (WC-Co/Ti-N) and (WC-Co/Ti-C-N) against AISI AA 6262-T6 aluminum under real turning condition (cutting speed, feed rate and depth of cut mm). For this investigation was considered cylindrical and conical geometries. Results indicated that, in general, the best surface finishes were observed in turning of work piece when used coated cutting tools if compared with a tribological systems: coating tools / AA 6262-T6 and uncoated tool / AA 6262-T6 used for comparative analysis. In particular, functional parameters that have been an important relation with: retention and maintenance lubrificant films, sliding and wear conditions.*

Keywords*: coatings, surface finish, aluminum alloys, tribological systems*

1. INTRODUCTION

Binary and most recently ternary coatings Ti-N and Ti-C-N processed by PAPVD either as mono or multilayer have become extremely important to several and strategic industrial applications such as automotive and aeronautic industries. These coatings are thermodynamically metastable and posses high micro hardness value, high oxidation stability, low thermal conductive and relatively low coefficient of friction against steel and several materials for different applications in the metal-mechanical industries. Because of these remarkable advantages, these coatings are currently used mainly for metal cutting operations (turning, milling and drilling) since the 90´s providing high metal removal rates (Paldey et al, 2003; Hultman, 2000 and Karlsson et al, 2000)

Parameters for characterizing of surfaces have not standard, yet. Basically, these parameters are classified in the following categories: amplitude parameters, spatial parameters, hybrid parameters and functional parameters (area/volume and properties). A key problem in surface related research is choosing parameters that characterize surface properties in such way that they correlate with surface formation mechanisms, geometry and functional behaviour in a fundamental way. There are limited information about these parameters and theirs correlation with performance (Stout, 1993).

Recently, the measurement of surface topographic has involved in two promising directions: precision measurement and three-dimensional measurement. The industries that will benefit from the introduction of an integrated approach to three-dimensional data collection included: aerospace, automobile, machining tool manufacture, electronics, communication, metal working, materials and medical engineering. Nowadays, , the development in nanotechnology will make increasing use of such a standard both in terms of surface produced and in terms of the use of high precision manufacturing machine for use in this important industry (Stout, 1993). Fig. 1 demonstrates that one parameter, such as the average roughness R_a, even so, very used in metal mechanical industries does not distinguish of the correct form an manufactured surface has been considered the relation between process and applications of products.

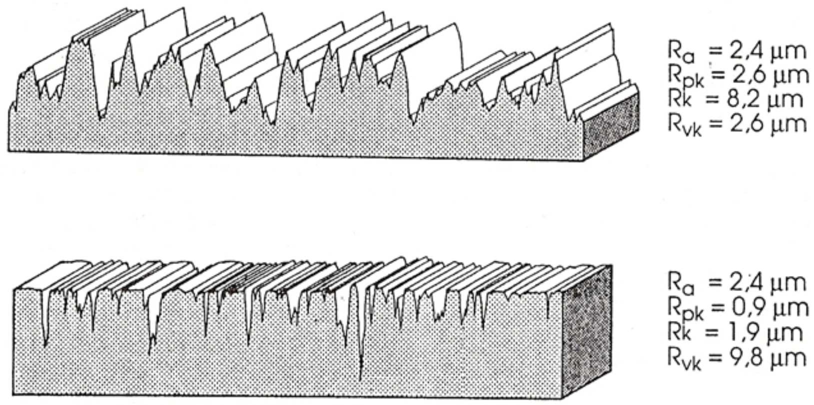


Figure 1. Comparison of the parameters: R_k family functional parameters (Mummery, 1992)

For this case, both surfaces have the same R_a values. The upper surface has large peaks, small valleys and a very open roughness core. In contrast, the lower surface has very small peaks, a tight roughness core and large valleys. The $R_{k,}$ R_{pk} and R_{vk} each others, such as V_o values clearly describe and quantify the surface characteristics.

The functional parameters: core roughness depth (S_k), reduced summit height (S_{pk}) and reduced valley depth (S_{vk}) are maintened in according with the R_k family parameters showed in Fig. 2 set defined in DIN 4776 to topographical analysis without any modification of the algorithm except for (i) employing the surface bearing area ratio instead of the profile bearing length ratio and (ii) using surface filtering instead of corresponding profile filtering (Gaussian filter). Although the surface bearing area ratio is proposed here to be scaled according to the RMS (Root Minimal Square) deviation rather than the maximum peak to valley height, it does not have any influence on the algorithm defined in DIN 4776. It is recommended that the R_k parameters be renamed as S_k parameters (Mummery, 1992).

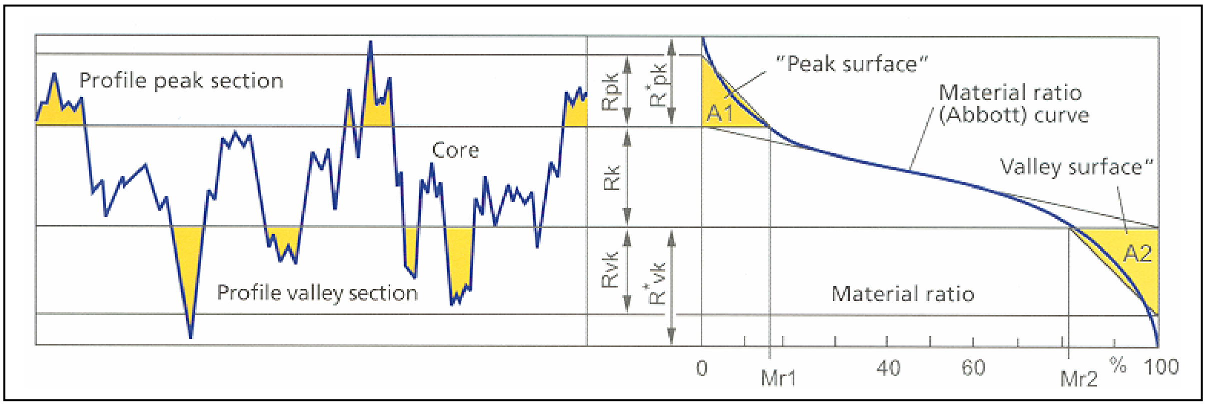


Figure 2. Functional parameters: R_k family functional parameters (Mummery, 1992)

The R_k value with the associated parameters serves primarily for functional evaluation of plateau-type surfaces, like those desired when honing cylinder liners and those resulting from the fine processing of ceramic pieces. R_k= core roughness depth R_{pk} = reduced peak height (stands for the start-up characteristics) R_{vk} = reduced valley depth (determines the oil retaining volume) The Material ratio parameters are calculated from the digital 2-fold Gaussian filtered R_k profile. In the designing stage, low values are sought for R_{pk} and much larger ones are sought for R_{vk}, because this value is decisive for the oil retaining volume V_o.

Engineering surfaces are created by a large variety of manufacturing processes, each resulting in a unique profile and/or topography, designed to fulfill given functional demands such as friction, wear resistance and oil retaining capacity.

These surfaces are by nature three-dimensional, however analysis instead of 2D which, nonetheless, is still the most common method in industry today. 2D studies and three-dimensional characterization of surface are increasingly recognized as the most adequate method for obtaining a better understanding of the functional performance of surfaces and a better control of their manufacturing (Davis et al, 1990). The disadvantage of the 3D technique is that it takes time (normally an hour) to perform these measurements with a stylus instrument and required cost with equipment.

This work is focused on the monitoring 2D parameters when used coated cutting tools if compared with a tribological systems: coating tools: Ti-N and Ti-C-N / AA 6262-T6 and uncoated tool / AA 6262-T6 used for comparative analysis. For this purpose was considered R_k families parameters (2D), that have been an important relation with: retention and maintenance lubrificant films.

2. EXPERIMENTAL PROCEDURE

The experimental work was carried out at the Machining Laboratory (University of Juiz de Fora / CTU) as well as at the Tribological Coatings Laboratory of the University of Minas Gerais, Brazil. The experimental work was divided into following steps: machining tests, cleaning of workpieces after that bidimensional and topographic mapping (methodology, results and discussion).

Bars of Alluminum Alloy AA 6262 T6 with 76,2mm diameter and 200mm long were used as work materials. ISO grade K10 cemented carbide inserts with geometry ISO SNMA 120408 (without chip breaker) was used as substrate. The inserts were mounted on a tool holder code PSDNN2525-M12. Thus, the following angles were obtained: cutting edge angle χ_r = 45°, included angle ε_r = 95°, cutting edge inclination angle λ_s = -5°, rake angle γ_o=-6° and clearance angle α_o = 6°. Continuous turning tests were performed on a C.N.C. lathe (4000rpm and 7,5kW) in real finish conditions Table 1 shows the cutting conditions chosen after preliminary machining tests and Figure 3 some details of machining test.

Table 1: Optimized cutting conditions for machining tests

Tribological systems	cutting speed (m/min)	feed rate (mm/rev)	depth of cut (mm)
WC-Co/aluminum	600	0,04	0,5
WC-Co/Ti-N/aluminum		0,12	
WC-Co/Ti-C-N/aluminum			

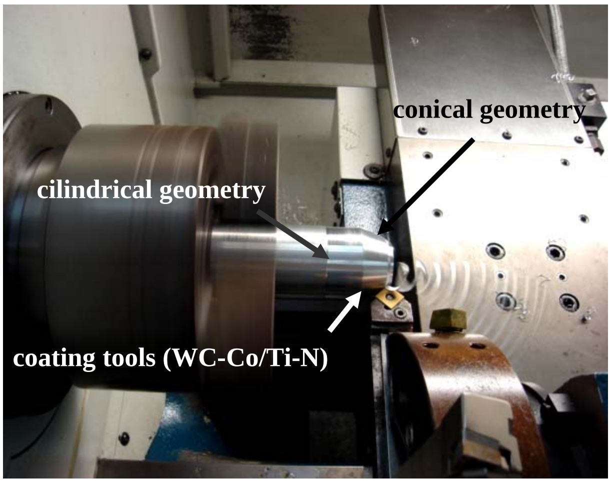


Figure 3. Some details of machining tests: geometries

First of all, ternary coatings (Ti-N and Ti-C-N) were produced on cemented carbide tools (WC-Co (6%)) by Plasma-assisted physical vapour deposition (TECVAC IP35L equipment produced by electron beam evaporation) with approximately 3, 0μm thickness. The coating deposition temperature was within the range from 669 to 715K.

The Rockwell-C hardness test was employed to evaluate the adhesion of the coatings. The principal advantage of this method is that it is easy to use, even in an industrial environment. A conventional Rockwell hardness test was performed using loads of 588N and 980N for each coating. The damage pattern around the imprint was evaluated at the optical microscope (magnification of 200 times). Standard damage pictures were used to classify the adhesion into six classes as presented in Figure 4.

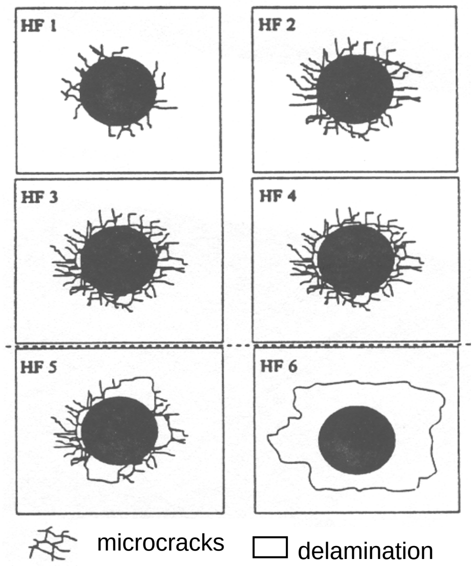
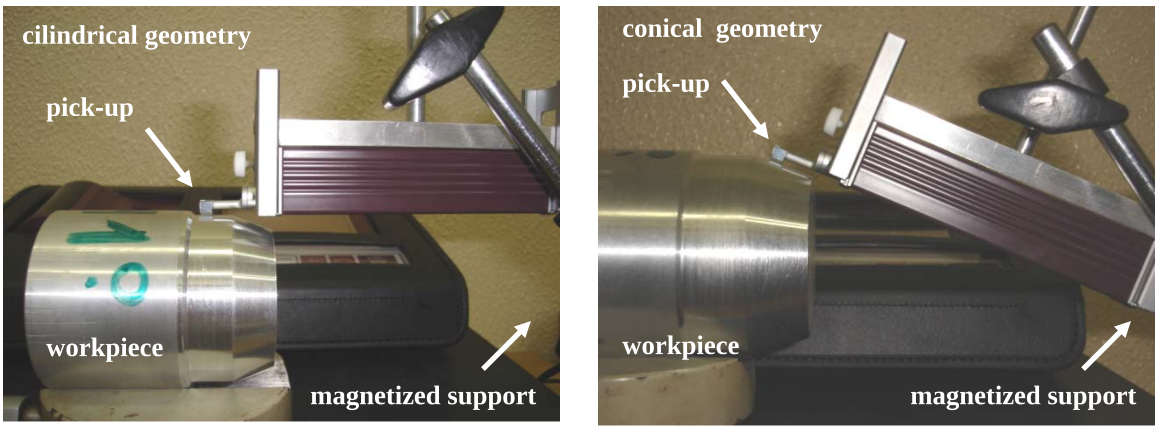


Figure 4. Standard damage picture in Rockwell-C adhesion test (Heinke et al, 1995)

Quantitative bidimensional parameters were conduced on a rugosimetro Surftest SL-301. For this step was chosen the standard DIN 4776, profile R, length of 4,0mm, λ_c (cut-off) of 0,8mm, scanning speed of 0,50mm/s. R_k family functional parameters were obtained for cylindrical and conical geometries. Figure 5 (a) and (b) shows details about measurement.



(a) (b)

Figure 5. Details of bidimensional scanning: a) cylindrical geometry and b) conical geometry

Quantitative topographic surface measurements were conducted for the cylindrical geometry obtained for the following tribological systems WC-Co/Ti-N/aluminum and WC-Co/Ti-C-N/aluminum. In this step was considered the cutting conditions optimized for cylindrical geometry (cutting speed of 600m/min, feed rate of 0,04mm and depth cut of 0,5mm) on a Hommelwerke stylus-based profilometer with a TKU 300 pick-up (stylus tip radius of 2 µm and cone angle of 60º). The size of the sampling area was (8x8) mm^2 and a sampling interval of 55.0 µm at a scanning speed of 0.50mm/s was chosen. Values for surface bearing index (S_{bi}) and valley fluid retention index (S_{vi}) were obtained in this step. Figure 6 shows main details about measurement.

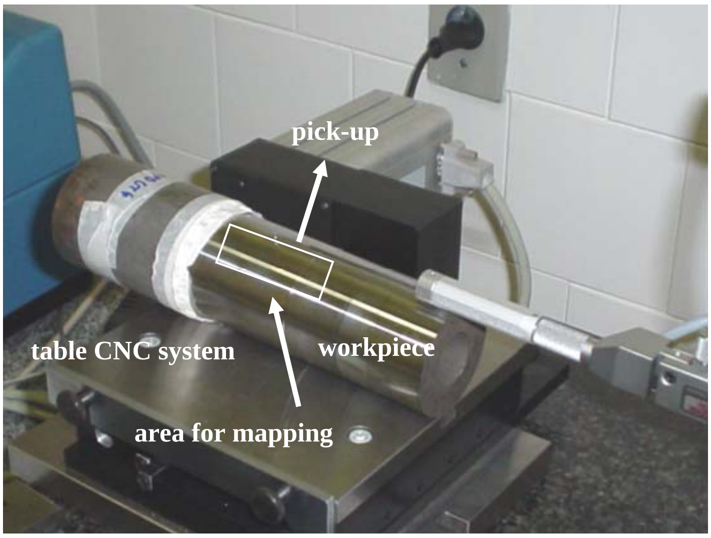
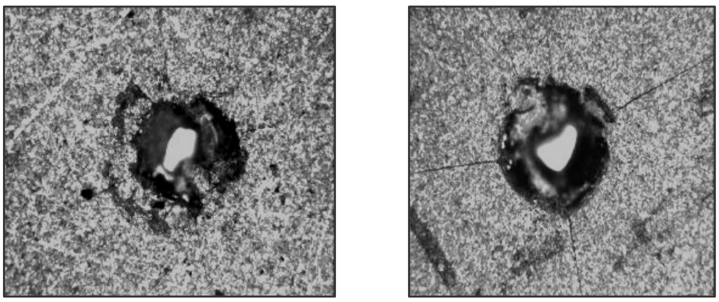


Figure 6. Details of topographical mapping

After 3-D surface measurements in both workpieces was established in criterious and optimized methodological for a quantitative and qualitative analysis. Main steps were resampling: new Z resolution and spacing (1024 x 1024 and 0,01nm); zooming (area: 4 x 4 mm^2); resampling: Polinomial of order 2; form removal; current surface (Gaussian filter, 0,8mm) - topographic view (adjustament of the scale), parameters selection: functional parameters (S_k, S_{vk} and S_{pk}) and functional index parameters (S_{bi} and Sv_i) obtained with the use of MOUNTAINS MAP EXPERT Software (Version 3.0.8) and comparative analysis for the cutting conditions (S_{bi} and Sv_i). At present moment, this experimental procedure was the best optimized for minimal error conditions. All values were obtained in a topographic surface and the "Minimal Square Plane" was used like a reference for all results.

3. RESULTS AND DISCUSSION

The experimental work was divided into three phases: firstly, a procedure for coating characterization was carried out covering the following aspects: Rockwell-C adhesion test, machining tests were performed and surface analisys. Figure 7 shows the results obtained for Ti- N and Ti-C-N coatings in the Rockwell-C adhesion test using two loads (588 and 980 N).



(a) (b)

Figure 7. Rockwell C adhesion test: a) WC-Co/Ti-N and b) WC-Co/Ti-C-N

According to the standard damage pictures shown in Figure 7, both coatings under study showed good qualitative results for the adhesion tests classified as standard damage HF1 – HF4. In such away, firstly a problem with possibly occurrence of delamination during machinig test was discarded.

Table 2 show the main results obtained after machining process for different conditions established on preliminary tests (cutting speed of 600m/min and feed rate 0,04mm/rev and 0,12mm/rev) for cylindrical and conical geometries.

Table 2: R_k parameters family obtained for bi dimensional analysis: cylindrical geometry

	feed rate 0,04mm/rev			**feed rate 0,12mm/rev**		
Functional parameters	**WC-Co**	**Ti-N**	**Ti-C-N**	**WC-Co**	**Ti-N**	**Ti-C-N**
R_a (µm)	0.39	0.39	0.85	0.70	0.94	0.89
R_{pk} (µm)	0.68	0.30	0.28	0.85	0.28	0.39
R_{vk} (µm)	0.50	0.49	1.82	2.10	1.31	3.26
R_k (µm)	1.04	0.87	2.38	3.43	2.06	2.75
V_o	0.0030	0.0060	0.0099	0.0042	0.0105	0.0150

Table 3: R_k parameters family obtained for bi dimensional analysis: conical geometry

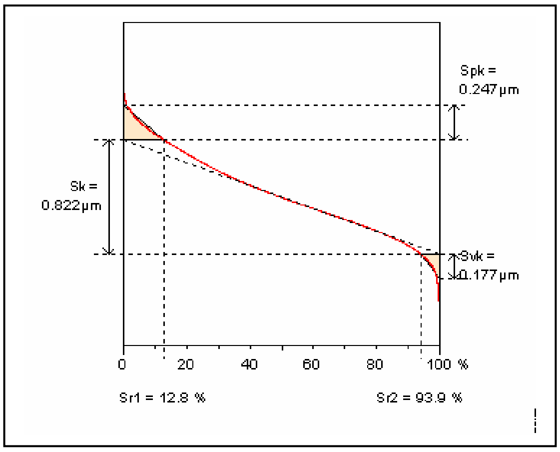
	feed rate 0,04mm/rev			**feed rate 0,12mm/rev**		
Functional parameters	**WC-Co**	**Ti-N**	**Ti-C-N**	**WC-Co**	**Ti-N**	**Ti-C-N**
R_a (µm)	0.40	0.38	0.71	0.52	0.67	0.75
R_{pk} (µm)	0.94	0.66	0.55	0.64	0.48	0.39
R_{vk} (µm)	0.72	1.10	1.93	0.64	0.74	0.89
R_k (µm)	1.37	1.33	2.52	1.79	2.76	2.36
V_o	0.0024	0.0061	0.0084	0.0028	0.0077	0.0089

First analysis indicated that the functional parameters (R_k, R_{pk} and R_{vk}) give different results when used in the same cutting conditions with uncoated (WC-Co) and coated cemented carbide cutting tools (Ti-N and Ti-C-N).

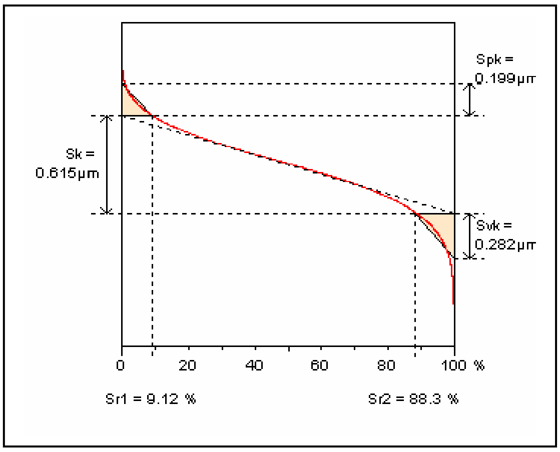
This fact suggests that the selection of the coating has got an influence about the surface finish for different and strategic applications in engineering, for example (V_o). V_o, the oil retention volume is a quantity derived from the R_k parameters family. For example: oil retained by a cylinder bore surface after it has been scraped by a piston ring (Hutchings, 1992). In this study the biggest R_{pk} were obtained when used uncoated cutting tools in both geometries and cutting conditions. These values have got a reverse relation between Vo see tables 2 and 3. This fact may have a relation with different performance when both ceramic coatings are submitted in high mechanical and thermal solicitation (typical in this machining process). Considering the workpiece material (aluminum), this material has got a conductive thermal approximately fifteen each bigger than the steel, in general. This fact suggests modification on surface finish: roughness parameters and dimensional control when used uncoated and coated ceramic cutting tools in machining process.

Best mechanical properties, such as higher hardness and lowest coefficient of friction of these protective layers (Paldey et al, 2003; Bull et al, 2003; Batista et al, 2002; Hultman, 2000; Karlsson et al, 2000 and Stappen et al, 1995). These properties are critical to machining processes because they increase the resistance to thermal and mechanical shocks, reduce the cutting forces and facilitate the chip removal from the work zone. These advantages have got a direct influence on tool life and workpiece surface finish. Have been reported that ceramic coatings, in general, form at high temperatures a dense, highly, adhesive protective Al_2O_3 and graphite layers in different tribological systems.

Figures 8 (a) and (b) shows the current surface, graphical study of S_k parameters (cutting speed = 600m/min, feed rate = 0,04mm/rev and depth cut of 0,5mm)



(a)



(b)

Figure 8. a) graphical study of S_k parameters (Ti- N) and b) graphical study of S_k parameters (Ti-C-N)

In practical is more easily understood that a functional property is good if an index is large or small. Figures 9 and 10 show the results obtained when realized topographical analysis for a cylindrical geometry, in this case was considered the coated cutting tools.

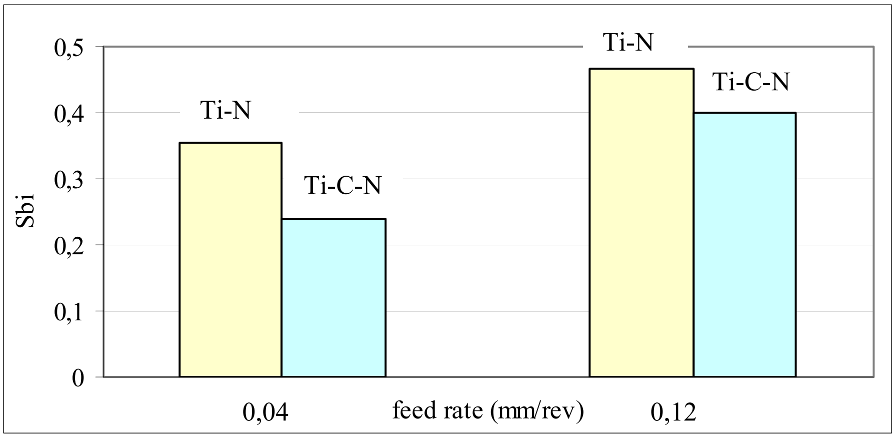


Figure 9. Functional index parameter S_{bi} (cutting speed = 600m/min, and depth of cut = 0,5mm)

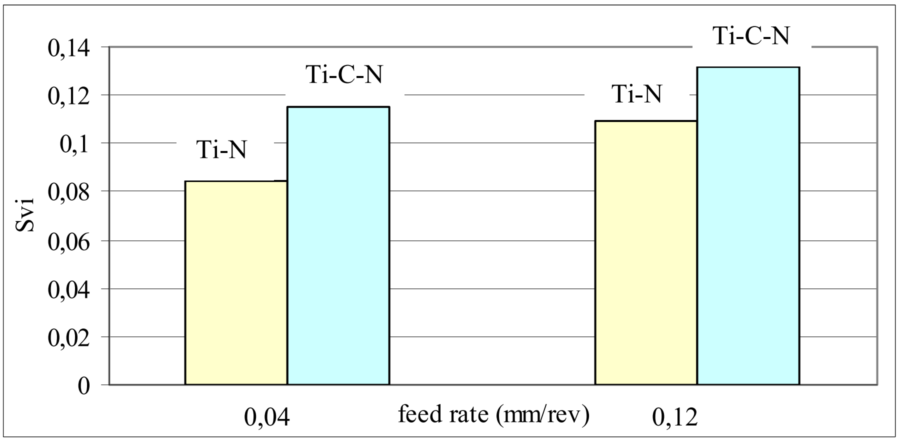


Figure 10. Functional index parameter S_{vi} (cutting speed = 600m/min and depth of cut = 0,5mm)

Surface bearing index (S_{bi}) is the ratio of the RMS deviation over the surface height at 5% bearing area. A larger surface bearing index indicates a good bearing property. For a wide range of engineering surfaces, this index is between 0.3 and 2. When a surface experiences unworn to worn, this index increases. Valley fluid retetion index (S_{vi}) is the ratio of the void volume of the unit sampling area at the valley zone over the RMS deviation. A larger S_{vi} indicates a good fluid retention in the valley zone (Stout, 1993; Ohlsson, 1994).

Both index parameters were influenced by conditions of machining (Tab. 1). In this study was observed larger S_{bi} values when increased the feed rate (0,04mm/rev and 0,12mm/rev) for the same cutting speed. In general, the S_{bi} index values is between 0,3 and 2. This fact suggests that surface finish accommodate a wide range of engineering applications (Stout, 1993).

Different values these index parameters were obtained when used different ceramic coatings. These facts suggest that the chosen of coating is strategic for special applications when required special surface finish in design. In general the best results for bearing property was obtained when used the coated cemented carbide with Ti-C-N in all cutting conditions tested (Fig. 9). Ti-C-N shows the best performance when fluid retention is the main objective required (Fig. 10). These results confirm the values obtained for R_{pk}, R_{vk} and V_o (tables 2 and 3).

4. CONCLUSIONS

Results of this study constitute a first investigation. Others parameters and the methodology have been improved in future steps for the same tribological analysis. The main conclusions for this first step were:

- Functional bi and topographical parameters (R_k, $R_{pk,}$ R_{vk} and V_o) give different results when used in the same cutting conditions by uncoated and coated cemented carbide cutting tools (Ti -N and Ti-C-N coatings) for different geometries;
- The selection of the coating has got high influence about the surface finish for different and strategic applications in engineering, for example fluid retention and bearing property,
- Ceramic coatings have a relation with different performance (surface finish) when both are submitted in high mechanical and thermal solicitation (typical in this machining process);
- Best results for bearing properties (larger S_{bi}) were observed for Ti- N coated cutting tools (Fig. 9);
- Ti-C-N, in general, showed the best performance (larger S_{vi}) for fluid retention (Fig. 10).

5. ACKNOWLEDGEMENTS

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6. REFERENCES

Batista J. C. A., Godoy, C., Buono, V. T. L. and Matthews, A., 2002, "Characterisation of duplex and non-duplex (Ti, Al)N and Cr-N PVD coatings", Materials Science and Engineering, A336, pp.39 – 51.

Bull, S. J., Bhat, D. G., Staia, M. H., 2003, "Properties and performance of commercial TiCN coatings Part 2: tribological performance", Surface and Coatings Technology, Vol 163 – 164, pp.507 – 514.

Davis, E.J., Stout, K.J., Sullivan, P.J., 1990, "The scope of three dimensional topography", Industrial Metrology 1.

Hultman, L., 2000, 1991 "Thermal stability of nitride thin films", Vaccum, Vol.57, pp. 1 – 30

Hutchings, I. M., Tribology – Friction and Wear of Engineering Materials, Mettalurgy and Materials Science Series, 273 p.

Karlsson, L., Hultman, L., Johansson, M. P., Sundgren, J-E., Ljungcrantz, H., 2000, "Growth, microstructure and mechanical properties of arc evaporeted TiC_xN_{1-x} ($0 \le x \le 1$) films", Surface and Coatings Technology, V. 126, 1– 14.

Mummery, L., 1992, "Surface texture analysis the handbook", 106 pages.

Ohlsson, R., Rose´n, B-G, Pulkkinen, T., Jonasson, M., 1994, "Practical considerations when measuring 3D surface roughness", Exploitation Problems of Machines 29 (3-4 (99–100)).

Paldey, S. and Deevi, S. C., 2003, "Single layer and multilayer wear resistant coatings of (Ti, Al)N: a review", Materials Science and Engineering A342, pp. 58 – 79.

Prengel, H. G., Jindal, P. C., Wendt, K. H., Santhanam, A. T., Hegde, P. L. and Penich, R. M., 2001, "A new class of high performance PVD coatings for carbide cutting tools", Surface and Coatings Technology, Vol. 139, pp. 25 - 34.

Stappen V. M., Stals, L. M., Kerkhofs, M. and Quaeyhaegens, C., 1995, "State of the art for the industrial use of ceramic PVD coatings", Surface and coatings Technology 74 –75, pp. 629 - 633.

Stout, K. J., "The development of methods for the characterization of roughness in three dimensions", 1993, Commission of the European Communities, Report EUR 15178 EN, ISBN 0 7044 13 13 2,.

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