TOPOGRAPHIC FUNCTIONAL PARAMETERS IN MACHINING OF AISI 4340 STEEL WITH COATED CEMENTED CARBIDE TOOLS

R. F. Ávila
Department of Mechanical Engineering,University of Minas Gerais, Brazil
Institute Factory of the Millennium
rfavila1@yahoo.com.br

B. R. P. Candido
Department of Metalurgical Engineering,University of Minas Gerais, Brazil
romanus_23@yahoo.com.br

G. C. D. Godoy
Department of Metalurgical Engineering,University of Minas Gerais, Brazil
gcgodoy@uaivip.com.br

A.M. Abrão
Department of Mechanical Engineering,University of Minas Gerais, Brazil
Institute Factory of the Millennium
abrao@ufmg.br

Abstract. *Topographic parameters analysis has been the most realistic proceeding to evaluate the surface finish in workpieces for different applications such as automotive and aeronautic industries. This work is focused on the studying of topographic functional parameters of AISI 4340 hardened and tempered steel after maching with coated cemented carbide tools. For this purpose, continuous turning tests were performed on a C.N.C. lathe (3500rpm and 5,5kW) in real conditions (cutting speed: 200 and 400m/min, feed rate 0,08 and 0,16mm/rev and depth of cut 0,5mm). First of all, ternary coating (Ti-C-N and Ti-Al-N) were produced on cemented carbide tools (WC-Co (6%)) by Plasma-assisted physical vapour depositio with approximately 3,0μm thickness. Topographic parameters were evaluated by Profilometry for all tests (tribological and cutting conditions). A tribological system (uncoated tool / AISI 4340) was used for comparative analysis. In general, the best results were observed when used coated cutting tools. Results were analysed by index functional topographic parameters (S_k, S_{pk}, S_{vk}, S_{bi} and S_{vi}). These parameters have been a direct relationship with fluid retention, abrasive wear and sliding conditions.*

Keywords*: topographic functional parameters, coatings, profilometry, turning, AISI 4340 steel*

1. Introduction

Ternary coatings have become extremely important to several and strategic industrial applications such as automotive and aeronautic industries. This coating is thermodynamically metastable and posses high microhardness value, high oxidation stability, low thermal conductive and relatively low coefficient of friction against steel (Paldey et al, 2003; Hultman, 2000 and Karlsson et al, 2000). Because of these remarkable advantages, this coating is currently used mainly for metal cutting operations (turning, milling and drilling) since the 90´s providing high metal removal rates (Prengel et al, 2001; Lim et al, 2001 and Imbeni et al, 2001).

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).

Three-dimensional 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, topography geometry and functional behaviour in a fundamental way. There are limited information about these parameters and theirs correlation with performance (Stout, 1993).

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. 1 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).

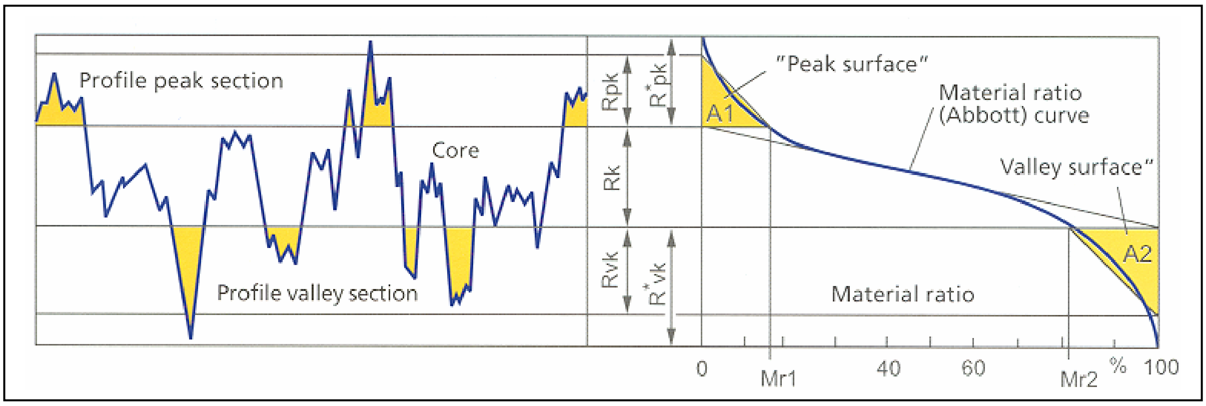


Figure 1. Functional parameters: R_k family functional parameters (Mummery, 1992)

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 Rvk, because this value is decisive for the oil retaining volume Vo.

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

These surfaces are by nature three-dimensional, and should therefore be treated by 3D analysis instead of 2D which, nonetheless, is still the most common method in industry today. Three-dimensional characterization of surface topographies is 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. One possibility is to optimize the sampling strategy and minimize the measured area (Olson et al, 1994). This operation can be difficult since knowledge about the actual surface is needed and some parameters are directly proportional to the sampling interval.

This work is focused on the monitoring topographic functional parameters of AISI 4340 hardened and tempered steel after maching with coated cemented carbide tools under real conditions of machining.

2. Experimental procedure

The experimental work was carried out at the Machining and Automation Laboratory 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 topographic mapping (methodology, results and discussion).

Bars of AISI 4340 (± 30 HRc) with 76,2mm diameter and 280mm 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 (3500rpm and 5,5kW) in real conditions Table 1 shows the cutting conditions chosen after preliminary machining tests. All conditions were used in the turning of AISI 4340 steel with coated cemented carbide tools: (Ti-C-N) and (Ti-Al-N).

Table 1: Optimized cutting conditions for machining tests

conditions	cutting speed (m/min)	feed rate (mm/rev)	depth of cut (mm)
1	400	0,08	0,5
2		0,16	
3	200	0,08	
4		0,16	

First of all, ternary coatings (Ti-C-N and Ti-Al-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.

Quantitative topographic surface measurements were conducted 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. The primary parameters set proposed in the Second Workshop on the Characterization of Surfaces in 3-D (Stout, 1993) involving 14 parameters was used for describing topographic features. Figure 2 shows details about measurement (topographical mapping).

Figure 2. Details of topographical mapping

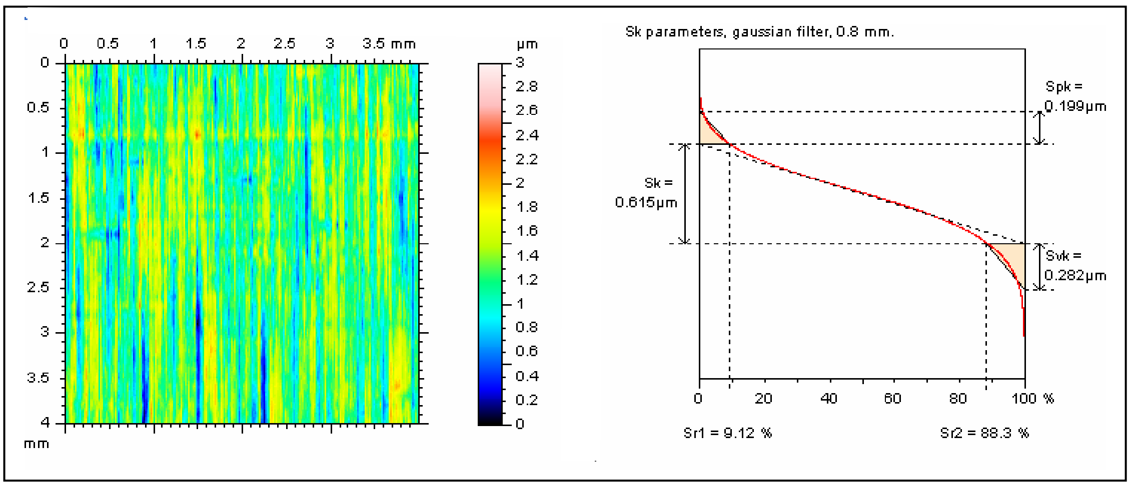
After 3-D surface measurements in both workpieces was established in criterious and optimized methodological for a quantitative and qualitative analysis. Main steps were:

- 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 (adjustment of scale: 3 and 7 for conditions 1,3 and 2,4 respectively),
  - Parameters selection: functional parameters (S_k, S_{vk} and S_{pk}) and functional index parameters (S_{bi} and Sv_i)was obtained with the use of MOUNTAINS MAP EXPERT Software (Version 3.0.8).
- Comparative analysis: (S_k, S_{pk}, S_{vk}) for condition (1 and 3) and (S_{bi} and Sv_i) for all conditions (table 1).

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.

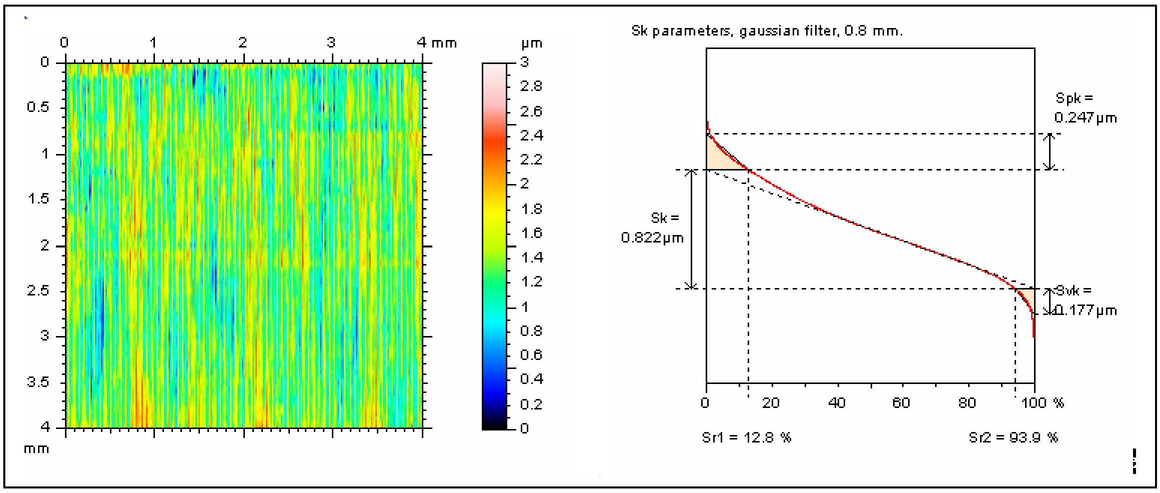
3. Results and discussion

Figures 3 to 6 shows the current surface, graphical study of S_k parameters (conditions 1 and 3)



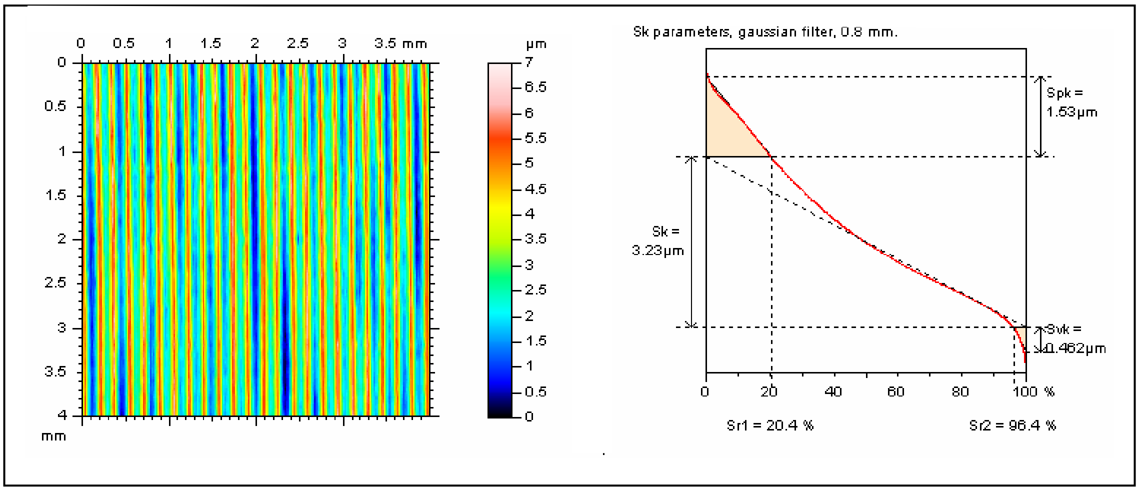
(a) (b)

Figure 3. (a) current surface and (b) graphical study of S_k parameters (Ti-C-N – condition 1)



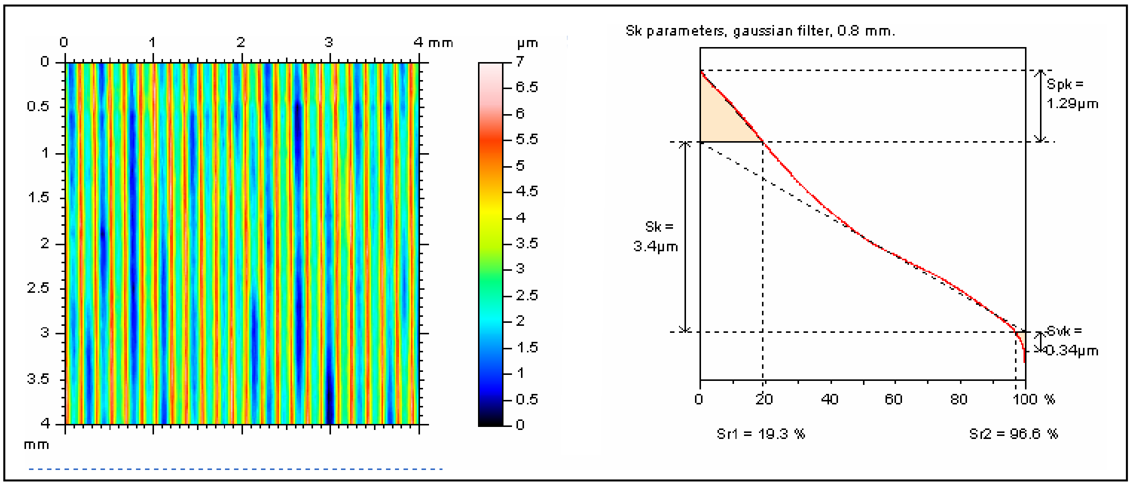
(a) (b)

Figure 4. (a) current surface and (b) graphical study of S_k parameters (Ti-Al-N – condition 1)



(a) (b)

Figure 5. (a) current surface and (b) graphical study of S_k parameters (Ti-C-N – condition 3)



(a) (b)

Figure 6. (a) current surface and (b) graphical study of S_k parameters (Ti-Al-N – condition 3)

First analysis indicated that the functional parameters (S_k, S_{pk} and S_{vk}) give different results when used in the same cutting conditions by coated cemented carbide cutting tools (Ti-Al-N and Ti-C-N coatings). 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 case best results were considered when smaller R_{pk} are obtained. Considering this purpose, the surface finish obtained after machining with coated cemented carbide tools (Ti-C-N) given the best results for the condition 1.(Ti-Al-N) coatings given the best results for condition 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).

Have been reported Ti-Al-N and Ti-C-N coatings form at high temperatures, dense, highly, adhesive protective Al_2O_3 and graphite layers in different tribological systems (Paldey et al, 2003; Bull et al, 2003; Batista et al, 2002; Hultman, 2000; Karlsson et al, 2000 and Stappen et al, 1995). Best mechanical properties, such as higher hardness and lowest coefficient of friction of these protective layers. 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.

In practical is more easily understood that a functional property is good if an index is large or small. Figures 7 to 10 show the results obtained.

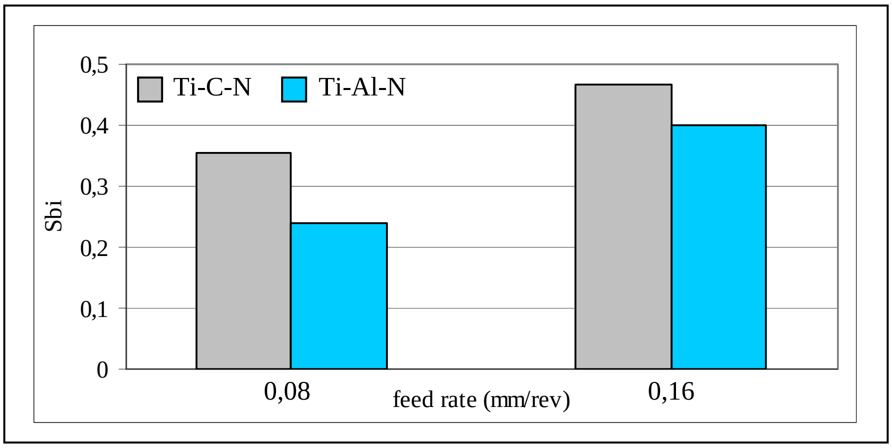


Figure 7. Functional index parameter S_{bi} (cutting speed = 400m/min and depth of cut = 0,5mm)

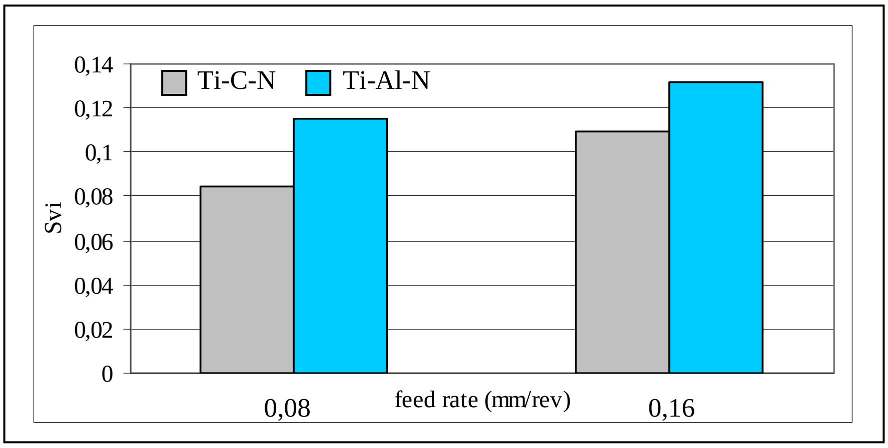


Figure 8. Functional index parameter S_{vi} (cutting speed = 400m/min and depth of cut = 0,5mm)

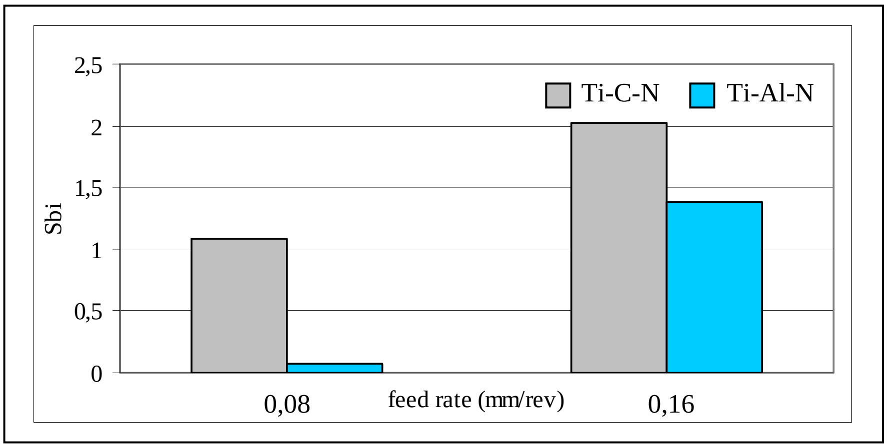


Figure 9. Functional index parameter S_{bi} (cutting speed = 200m/min and depth of cut = 0,5mm)

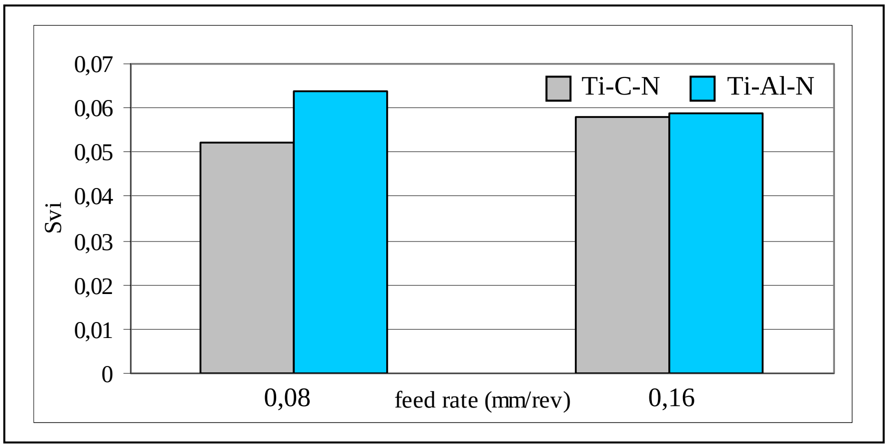


Figure 10. Functional index parameter Sv_i (cutting speed = 200m/min and depth of cut = 0,5mm)

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).

Both index parameters were influenced by conditions of machining (Tab. 1). In this study was observed larger Sbi values when increased the feed rate (400m/min and 200m/min) in both 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 ternary 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. 7 and Fig. 10). Ti-Al-N shows the best performance when fluid retention is the main objective required (Fig. 8 and Fig. 10) except in the cutting condition 4 (Tab. 1 and Fig. 10: feed rate of 0,16mm/rev) when both coatings showed the same value for this parameter.

4. Conclusions

Results of this study constitute a first investigation. Little differences obtained for the same cutting conditions suggest that this methodology has been improved in future steps. 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. The main conclusions for this first step were:

- Functional parameters (S_k, S_{pk} and S_{vk}) give different results when used in the same cutting conditions by coated cemented carbide cutting tools (Ti-Al-N and Ti-C-N coatings);
- 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-C-N coated cutting tools (Fig. 7 and Fig. 9);
- Ti-Al-N, in general, showed the best performance (larger S_{vi}) for fluid retention (Fig. 8 and Fig. 10) except in the cutting condition 4 (Tab. 1).

5. Acknowledgements

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