THE INFLUENCE OF TERNARY COATING (Ti-C-N) ON SURFACE FINISH OF AISI 4340 STEEL AND AA6262-T6 ALUMINUM AFTER TURNING

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Abstract. *The use of single and multi-layer coatings produced by PAPVD (Plasma-assisted physical vapour deposition) has allowed tungsten carbide tooling to become more versatile and competitive. Nowadays, topographic parameters analysis has been the most realistic proceeding to evaluate the surface finish in workpieces for different and strategic applications. This work is focused on the monitoring topographic parameters (amplitude, functional,…), by profilometry, in two tribological systems: (WC-Co/Ti-C-N) against AISI 4340 hardened and tempered steel and (WC-Co/Ti-C-N) against AA 6262-T6 aluminum under real machining condition (cutting speed 200m/min, feed rate 0,25mm/rev and depth of cut 1,0mm) The results indicated that, in general, the best surface finishes were observed in turning of both materials with coated cutting tools when compared with a tribological systems: uncoated tool / AISI 4340 and uncoated tool / AA 6262-T6 used for comparative analysis.*

Keywords*: topographic functional parameters, coatings, ternary coating, AISI 4340 steel, AA 6262 T-6 aluminum*

1. Introduction

Ti-C-N processed by PAPVD (Plasma-assisted physical vapour deposition) 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, since the 90´s this coating is used mainly for metal cutting operations (turning, milling and drilling) providing high metal removal rates (Prengel et al, 2001; Jindal et al, 1999; Lim et al, 2001 and Imbeni et al, 2001). Ti-C-N coating forms at high temperatures, dense, highly, adhesive protective graphite layer (Bull et al, 2003). Best mechanical properties, such as higher hardness and lowest coefficient of friction of these protective layers have been reported for different tribological systems (Batista et al, 2002; Paldey, et al 2003 and Imbeni et al 2001). 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 present a direct influence on tool life and workpiece surface finish.

Recently, the measurement of surface topographic has involved in two promising directions: precision measurement and three-dimentional 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. (Stout, 1993).

Three-dimensional parameters for characterizing of surfaces have not been standardized, 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 their correlation with performance (Stout, 1993).

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 studying of the influence of ternary coating (Ti-C-N) on topographic parameters when submitted in different tribological systems: (WC-Co/Ti-C-N) against AISI 4340 quenchend and tempered steel and (WC-Co/Ti-C-N) against AA 6262 T-6 aluminum under typical machining condition.

2. Experimental procedure

The experimental work was carried out at both the Machining and Automation Laboratory and Tribological Coatings Laboratory of the University of Minas Gerais, Brazil. The experimental work was divided into following steps: machining tests, cleaning of machined samples and topographic mapping (methodology, results and discussion).

2.1. Machining Tests

First of all, single-layered Ti-C-N coating (average thickness of 3,0 μm) was produced in a TECVAC IP35L equipment produced by electron beam evaporation. The coating deposition temperature was within the range from 669 to 715K.

Bars of AISI 4340 (± 30 HRc) and AA 6262-T6 aluminium 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°.

The machining tests were carried out on a CNC lathe (5,5kW and 3500rpm maximum rotational speed). The cutting condition was established after preliminary machining trials: cutting speed (v_c) = 200m/min, feed rate (f) = 0,25mm/rev and depth of cut (a_p) = 1,0mm. The tests were conducted without cutting fluid and two replicates for each condition were performed. For each condition a new cutting edge was used.

2.2. Topographic Analysis

Quantitative 3-D 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 (10 x 10) 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 1 shows the profilometer and detail about measurement (topographical mapping).

Figure 1. Profilometer and details of topographical mapping

Quantitative and comparative analysis of surface finish in both workpieces was established in a criterious methodological. Figure 2 shows the optimized steps for this purpose.

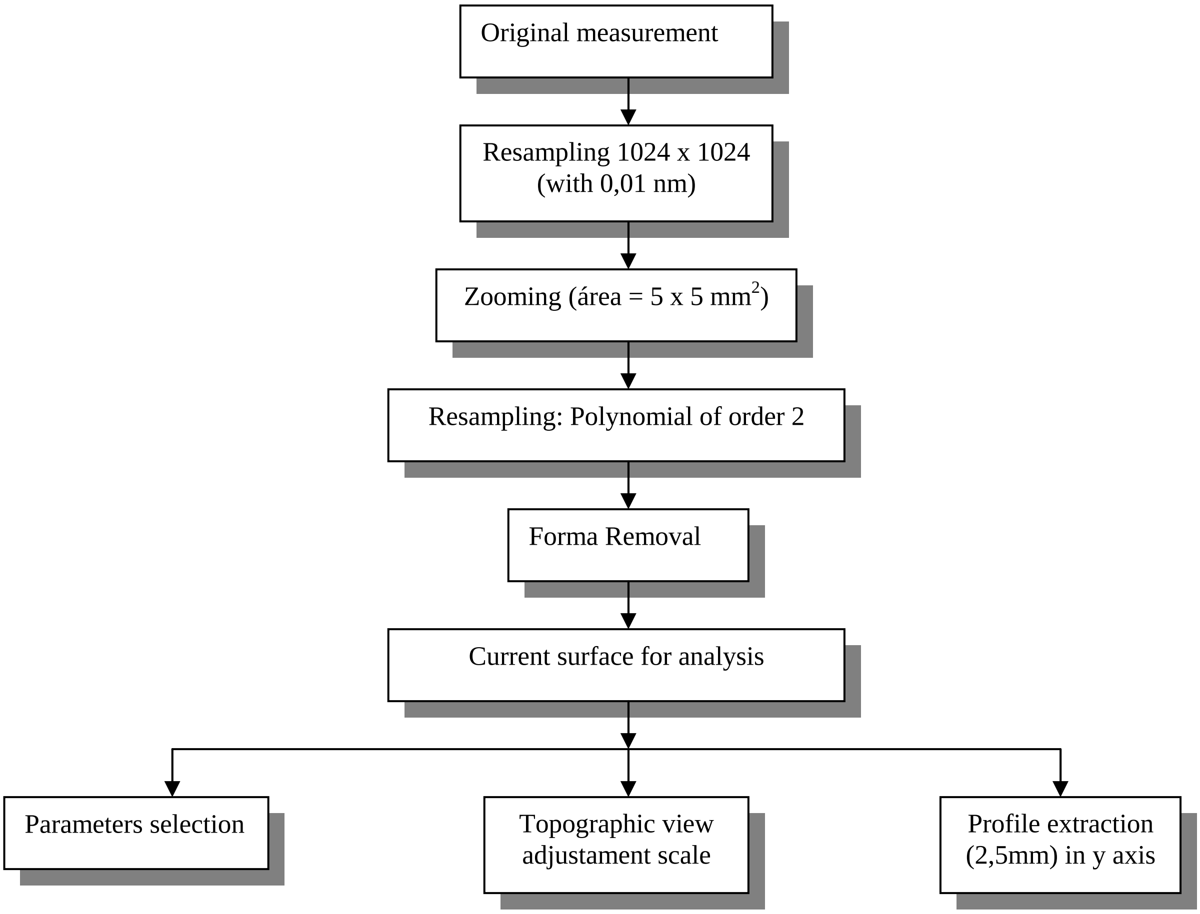


Figure 2. Blocks diagram for qualitative and comparative analysis

3. Results and discussion

Table 1 shows the main parameters of the 3D topography analysis used to describe the amplitude and height distribution properties: S_a, average roughness; S_q, root-mean-square deviation; S_{sk} and S_{ku}, skewness and Kurtosis of the surface height distribution. The functional parameters S_k, S_{pk} and S_{vk} (similar to R_k parameters from DIN 4776) were also analyzed. All selected parameters was obtained through minimal square plane. The position of this reference plane is determined with the use of MOUNTAINS MAP EXPERT Software (Version 3.0.8) in the current surface for analysis (Fig. 2). A tribological system constituted with an uncoated carbide tools/workpieces was considered for comparative analysis.

Table 1: Topographic parameters chosen for comparative analysis

Parameters	**(WC-Co) against AISI 4340**	**(WC-Co/Ti-C-N) against AISI 4340**	**(WC-Co) against AA 6262-T6 aluminum**	**(WC-Co/Ti-C-N) against AA 6262-T6 aluminum**
S_a (μm)	2,5	1,89	3,03	2,92
S_q (μm)	2,94	2,18	3,5	3,9
S_k (μm)	5,97	3,69	6,36	4,8
S_{sk} (μm)	0,526	0,549	0,436	0,508
S_{ku} (μm)	5,12	3,12	3,83	2,76
S_{vk} (μm)	0,245	0,503	2,7	3,54
S_{pk} (μm)	3,62	1,71	0,299	0,285
S_{bi}	0,686	1,04	0,0725	0,106
S_{vi}	1,75	3,78	1,62	1,64

In general, when using the Ti-C-N coated cemented carbide the amplitudes parameters (S_a, S_q and S_k) were less than the values obtained with uncoated (WC-Co) tool for both work materials (AISI 4340 and Aluminium 6262 T6). Ti-C-N coating forms at high temperatures a protective graphite layer (Bull et al, 2003). Best mechanical properties, such as higher hardness and lowest coefficient of friction of protective layers in ternary coatings have been reported for different tribological systems (Batista et al, 2002; Paldey, et al 2003 and Imbeni et al 2001). 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.

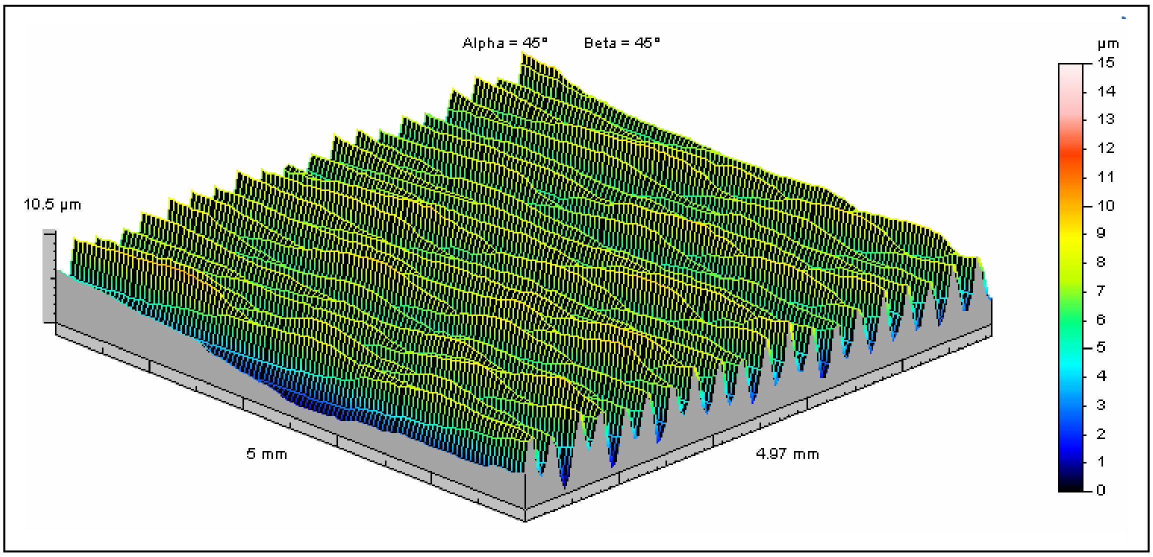
Skewness of topography height distribution ($S_{sk} > 1$) was registered in both tribological systems was observed This occurrence may indicate the presence of spikes peaks on the surface which could quickly wear away in contact with another surface in different engineering applications. The kurtosis of the topography height distribution S_{ku} characterises the spread of the height distribution. For the tribological system (WC-Co)against AISI 4340 this topographic parameter (more than 3) indicated than this surface have not a Gaussian distribution of peaks and valleys, however, for the pair (WC-Co/Ti-C-N) was observed value around to 3. It means that the systems studied possess a Gaussian surface with a symmetric and normal surface height distribution (peaks and valleys). This fact is very important because represent a relative control of surface finish. This control is very important for several mechanical contacts.

For the functional parameters analysis: reduced valley depth (S_{vk}) and reduced summit heigh (S_{pk}) was used indexes rather S_{bi} and S_{vi}. This is mores easy to realize intelligent control or comparative analysis for manufacturing process and functional properties of surfaces. For example, it is more easily understood that a functional property is good if an index is large or small.

Surface bearing index (S_{bi}) and valley fluid retention index (S_{vi}) are related to strategic requirements for machined surfaces in different applications. A larger surface bearing index (S_{bi}) indicates a good bearing property and a larger valley fluid retention index (S_{vi}) indicates a good retention in the valley zone similar the plateau honed surface. Both index parameters are calculated like a extend the Rk parameters set established in DIN 4776 (Stout, 1993). For the machining of the AISI 4340 the best results were observed when used coated cemented carbide (Ti-C-N) indicating the best conditions for bearing and fluid retention application.

For the tribological system (WC-Co) against Aluminum 6262 T6 the S_{ku} parameter was observed value around to 3.was indicating that the surface have a Gaussian distribution of peaks and valleys.

Functional topographic parameters indexed (S_{bi}) and (S_{vi}) for the tribological systems: (WC-Co) against AA 6262-T6 aluminum and (WC-Co/Ti-C-N) against AA 6262-T6 aluminum showed the most value for Sbi only. This fact suggest that the surface finish obtained after machining with coated cemented carbide tool (Ti-C-N) is the most indicated for application were surface bearing property is required if compared. For this workpiece material the topographic parameters may be related with the thermal properties of workpiece. Figure 3 to 6 shows the topographic view considered for analysis and bidimensional profile extraction for all systems studied.. This profile was extracted in 2.5mm (y axis). Profile extraction (WC-Co/Ti-C-N) / Alumínio 6262-T6 showed valley widest. This occurrence can be relationed with higher cutting temperature in the machining attributed the expansion coefficient and conductivity thermal of aluminum (approximadely 15 times higher than the steel). These results indicate that the selection of a coated cemented carbide tool with Ti-C-N is very important with correlationed surface finish and performance required: such as bearing and fluid retention.



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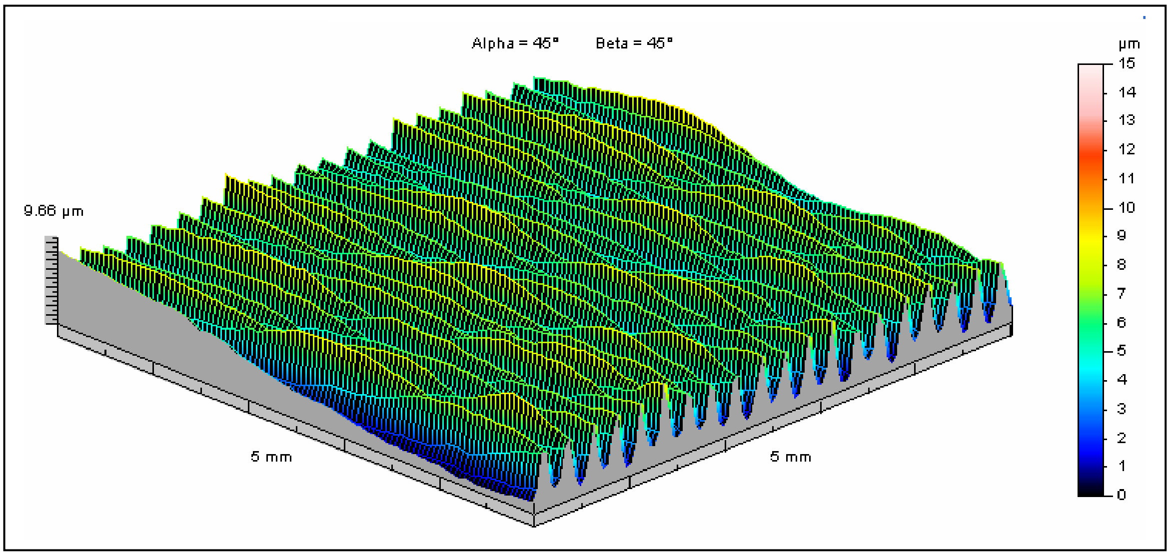

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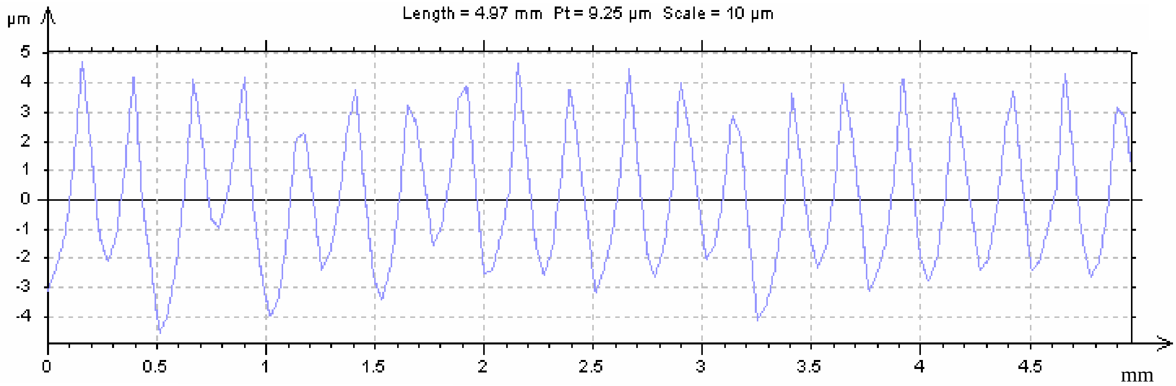
Figure 3. Topographic view: (a) WC-Co / ABNT 4340 and (b) (WC-Co/Ti-C-N) / ABNT 4340



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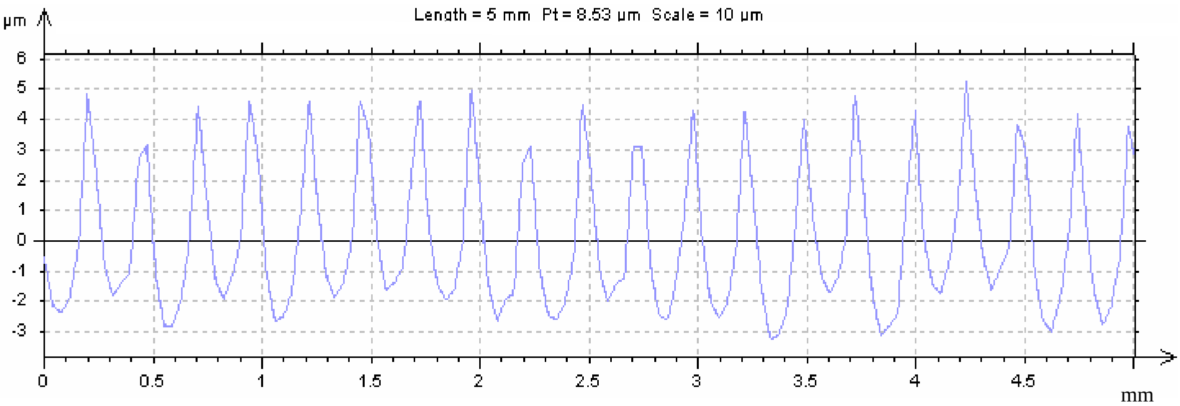

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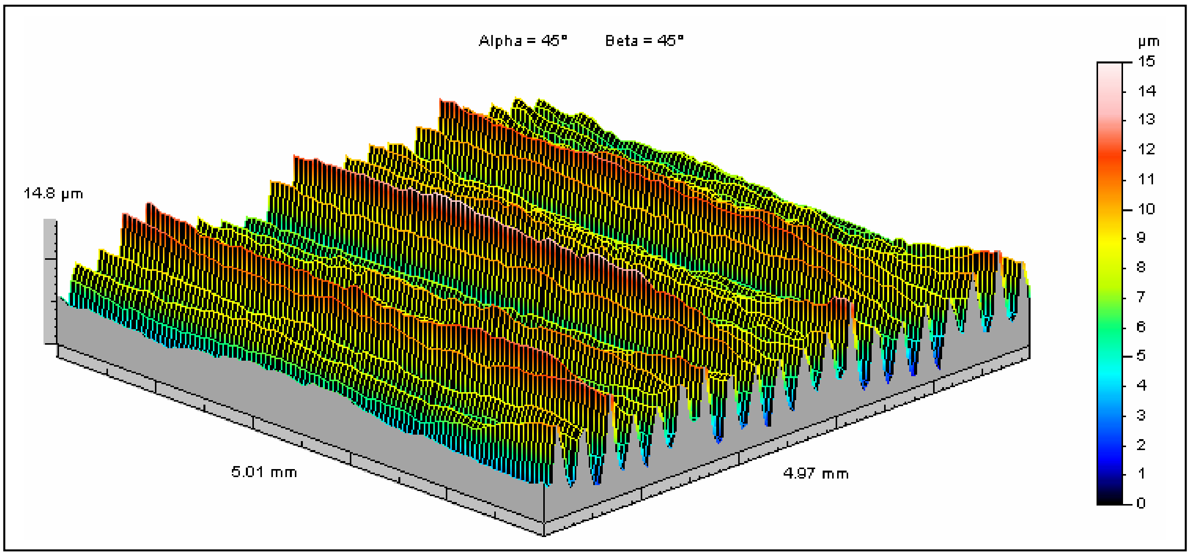
Figure 4. Profile extration: (a) WC-Co / ABNT 4340 and (b) (WC-Co/Ti-C-N) / ABNT 4340



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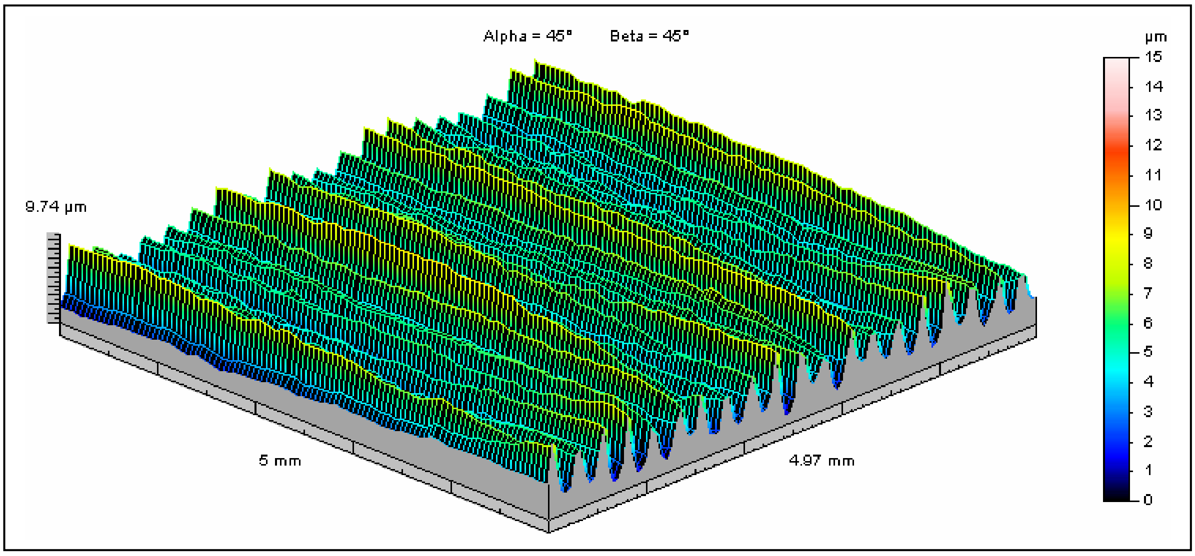

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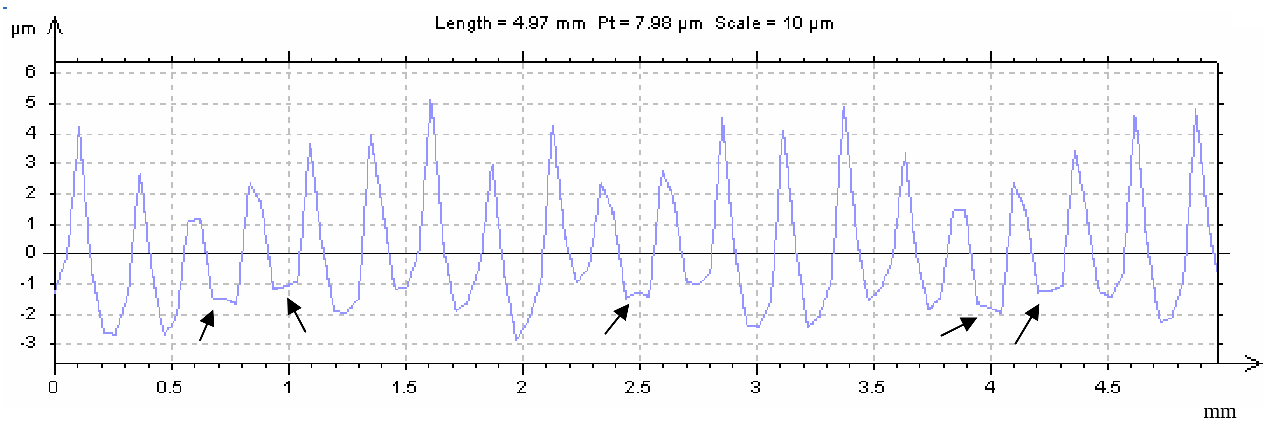
Figure 5. Topographic view: (a) WC-Co / Aluminum 6262 T6 and (b) (WC-Co/Ti-C-N) / Aluminum 6262 T6



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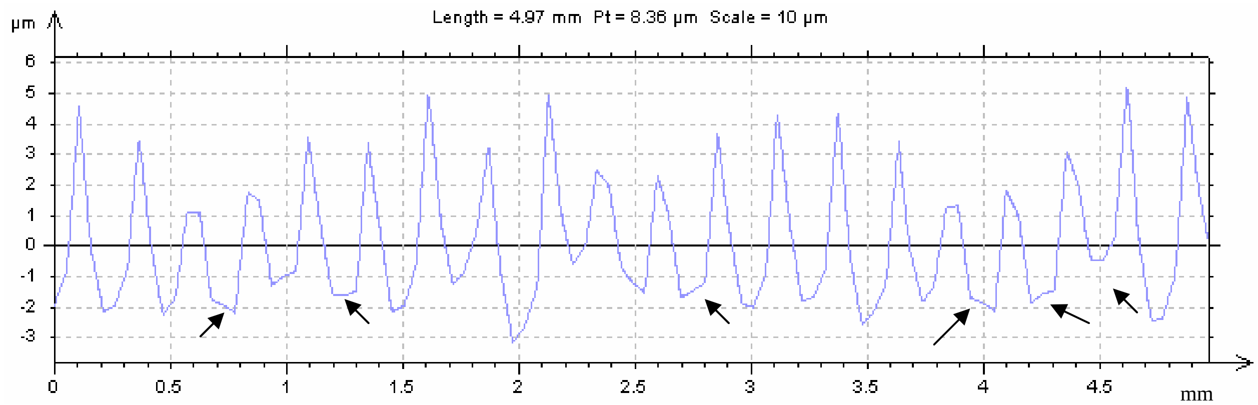

(b)

Figure 6. Profile extration: (a) WC-Co / Alumínio 6262-T6 and (b) (WC-Co/Ti-C-N) / Alumínio 6262-T6

The results indicated that, in general, the best surface finishes were observed after turning both materials with coated cutting tools This study reveals that in engineering applications, many surfaces are produced aiming to present selected specific functional properties such bearing, sealing and lubrificant retention capabilities. Depending on the functional requirements, these surfaces may be designed to possess specific topographic features that are beneficial to the intended application. In machining process the use of coated cemented carbide tools give good topographical parameters for this purpose. This study is not concluded yet. It is intended to investigate others tribological systems, others machining operations, others coatings, others cutting parameters. A problem with functional characterization is that the engineering requirements for surfaces are numerous, and are still not fully understood and documented. There also exist a knowledge gap between features which should be specified by designer and those can be generated by manufacturing process.

4. Conclusions

The following conclusions can be showed:

- In both tribological systems amplitudes parameters (S_a, S_q and S_k) studied presented less than values for the when used coated cemented carbide with Ti-C-N if compared with uncoated (WC-Co) tool.
- In both tribological systems was observed skewness of topography heigh distribuition (S_{sk}) more than a unit. This occurrence may indicate the presence of spikes peaks on the surface which could quickly wear away in contact with another surface in different engineering applications.
- The kurtosis of topography height distribution S_{ku} (around 3) indicated a Gaussian surface with symmetric and normal surface height distribution and normalized (peaks and valleys) except for the tribological system (WC-Co) against AISI 4340. This fact is very important because represent a relative control of surface finish.
- In accorder the S_{bi} and S_{vi} index the machining of the AISI 4340 with coated cemented carbide (Ti-C-N) shows the best results for bearing and fluid retention applications.
- For tribological systems (WC-Co) against AA 6262-T6 aluminum and (WC-Co/Ti-C-N) against AA 6262-T6 aluminum was observed the most value for S_{bi}. This fact suggest that the surface finish obtained by machining with coated cemented carbide tool (Ti-C-N) is the most indicated for application were surface bearing property is required.
- The profile extraction for the tribological systems: (WC-Co) against AA 6262-T6 aluminum and (WC-Co/Ti-C-N) against AA 6262-T6 aluminum valley widest. This occurrence can be relationed with higher cutting temperature if considered the machining of AISI 4340 steel and expansion coefficient and conductivity thermal of aluminum (approximately 15x more than the steel).

5. Acknowledgements

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7. Responsibility notice

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