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INFLUENCE OF NANOSTRUCTURED COATINGS ON SURFACE FINISH OF AISI 1047 STEEL[1]

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Abstract

Ternary coatings prepared by different deposition techniques were investigated in the past, in particular, Ti-Al-N and Cr-Al-N coatings. Both coatings have wear protection of cutting tools, dies, molds, and are used in the metalworking industry. The main purpose of this study was to investigate the influence of nanostrutured coatings of Ti_{1-x} Al_x N and Cr_x Al_{1-x} N on surface finish of AISI 1047 steel. The following steps: processing of ternary coatings on low ($x \leq 0.3$) and high Al content ($x \geq 0.7$), coatings characterization: chemical compositions and thickness by EDS and SEM cross-sections analysis respectively, testing under real cutting conditions and surface finish analysis by amplitude and functional parameters in accordance with JIS 2001 and DIN 4776. Coatings studied produced different results when processed into high and low Al content (%at).

Key words: Surface finish; Nanostructured coatings; Continuous cutting; AISI 1047.

INFLUENCIA DE REVESTIMENTOS NANOESTRUTURADOS SOBRE O ACABAMENTO SUPERFICIAL DO AÇO AISI 1047

Resumo

Revestimentos ternários preparados por diferentes técnicas de deposição foram investigadas no passado, em particular, Ti-Al-N e Cr-Al-N revestimentos. Ambos os revestimentos apresentam proteção contra o desgaste de ferramentas de corte, matrizes, moldes, e são utilizada na indústria metal mecânica. O principal objetivo deste estudo foi à investigação da influência da composição química (diferentes teores de Al) nos revestimentos de Ti_{1-x} Al_x N e Cr_x Al_{1-x} N sobre o acabamento superficial do aço AISI 1047 em corte contínuo. Desta forma foram cumpridas as seguintes etapas: processamento de revestimentos ternários em baixo teor ($x \leq 0,3$) e alto teor de Al ($x \geq 0,7$), caracterização dos revestimentos: composição química e espessura através de análise EDS e MEV, testes em condições reais de corte e de análise de superfície através de parâmetros de amplitude e funcionais Os revestimentos estudados proporcionaram diferentes acabamentos superficiais: quando processados em alto e baixo teor de Al (% at).

Palavras-chave: Acabamento superficial; Revestimentos nanoestruturados; Torneamento contínuo; AISI 1047.

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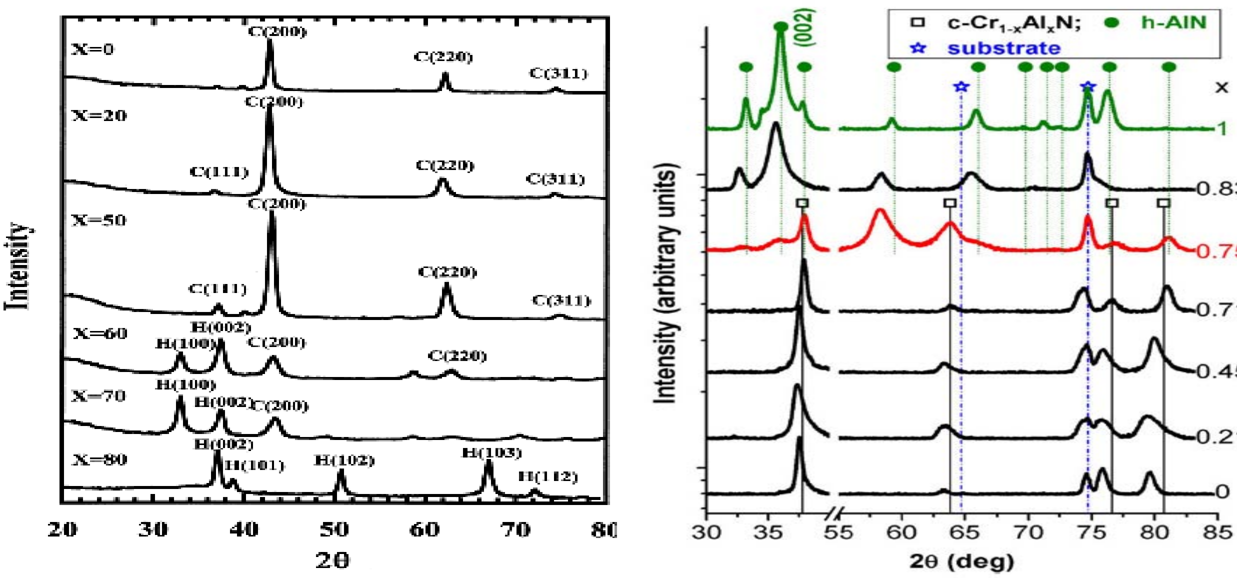
1 INTRODUCTION

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 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, and these coatings are currently used mainly for metal cutting operations (turning, milling and drilling) since the 90´s providing high metal removal rates.[1-3]

Researches show that ternary coatings Ti-Al-N and Cr-Al-N have different crystalline structures (single phase crystalline cubic structure, mixed phases - cubic and hexagonal structure and hexagonal structure) in according with the Al (% at.) content,[4-6] (Figure 1).



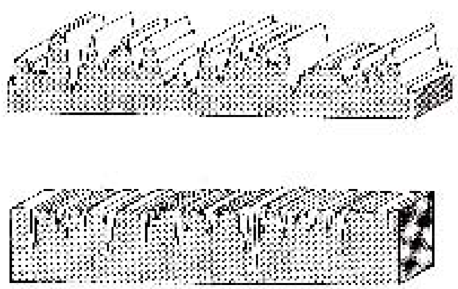
(a) (b)

Figure 1. XRD scans from as-deposited: a) $Ti_{1-x}Al_xN$ films[6] and b) $Cr_{1-x}Al_xN$ coatings on steel substrates.[4]

Studies show that ternary coatings Ti-Al-N and Cr-Al-N exhibit different friction coefficient against steels in sliding tests.[7-12] Such findings gave rise to the purpose of this study in order to investigate the performance of nanostructured coatings, considering the influence of Al (%at.) content in coatings on the surface finish by parameters of roughness.

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.[13]

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.[13] (Figure 2) 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.



Ra	2,4 μm
Rpk	2,6 μm
Rk	8,2 μm
Rvk	2,6 μm
Ra	2,4 μm
Rpk	0,9 μm
Rk	1,9 μm
Rvk	9,8 μm

Figure 2. Comparison of the parameters: R_k family functional parameters.[14]

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 (Figure 3) 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.[13]

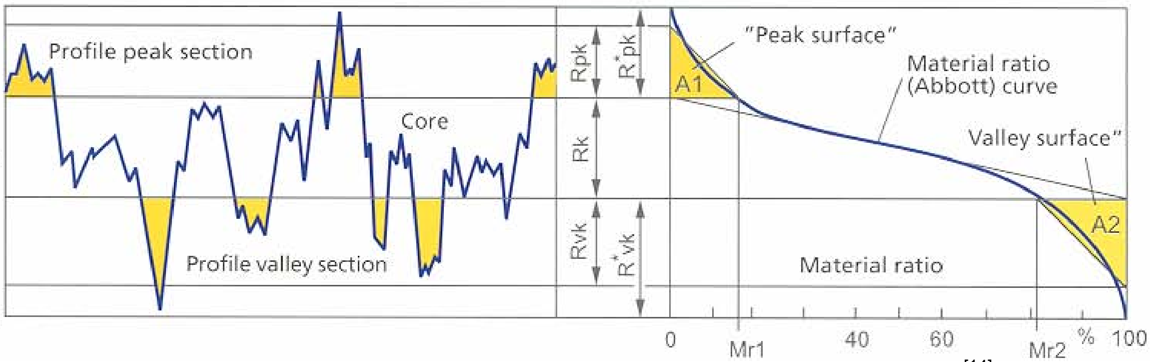


Figure 3. Functional parameters: R_k family functional parameters.[14]

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.

For this purpose was considered Rk families parameters (2D), that have been an important relation with: retention and maintenance lubrificant films. This work is focused on the influence of nanostrutured coatings of Ti1-x Alx N and Crx Al1-x N on surface finish of AISI 1047 steel. For this purpose were realized the following steps: processing of ternary coatings on low (x ≤ 0.3) and high Al content (x ≥ 0.7), characterized by: EDS analysis, machining tests (real cutting conditions) and surface analysis by amplitude and functional parameters in accordance with JIS 2001 and DIN 4776 respectively.

2 MATERIALS AND METHODS

2.1 Coating Process and Characterization Techniques

ISO grade K 10 cemented carbide (6% Co) inserts with geometry ISO SNMA 120408 (without chip breaker) was used as substrates. Prior to the deposition of the hard film, a thin layer (100 – 300nm) of Ti was applied to the substrate in order to ensure satisfactory adhesion. Levels of aluminum present were predetermined low and high aluminum: $x \leq 0.3$ and $x \geq 0.7$, respectively for $Ti_{1-x}\,Al_x\,N$ e $Cr_x\,Al_{1-x}\,N$ coatings. The range of thickness established was 2,0 to 3,0 μm.

Cr and Ti based coatings were grown using electron beam evaporation plasma-assisted PVD (EBPAPVD), both coatings were produced by TECVAK Ltda. (UK). The aluminum content was defined taking into account the results of recent research presented earlier in literature. For the tracks of predetermined content of Al were considered: pure Al, time of evaporation, temperature of deposition among other parameters of the deposition chamber. The chemical composition of the Ti_{1-x} Al_x N e Cr_x Al_{1-x} N thin films was analyzed by SEM photomicrographs on metallographic cross-sections.

2.2 Machining Tests and Surface Finish Analysis

Bars of AISI 1047 steel with 76,2mm diameter and 200mm long were used as work materials. The machining trials were carried out in a CNC lathe (4000rpm and 7,5kW) in real finish conditions (Table 1) shows the cutting conditions chosen after preliminary machining tests and (Figure 4) some details of machining test. For statistical analysis were considered three regions (Figure 5). Each machining test was conducted with a fresh cutting edge for fixed workpiece.

Table 1. Optimized cutting conditions for machining tests

Tribological systems	cutting speed (m/min)	feed rate (mm/rev)	depth of cut (mm)
WC-Co (substrate)	500	0,05	0,5
Ti_{1-x} Al_x N (high Al) - ha			
Ti_{1-x} Al_x N (low Al) - la			
Cr_x Al_{1-x} N (high Al) - ha			
Cr_x Al_{1-x} N(low Al) - la			

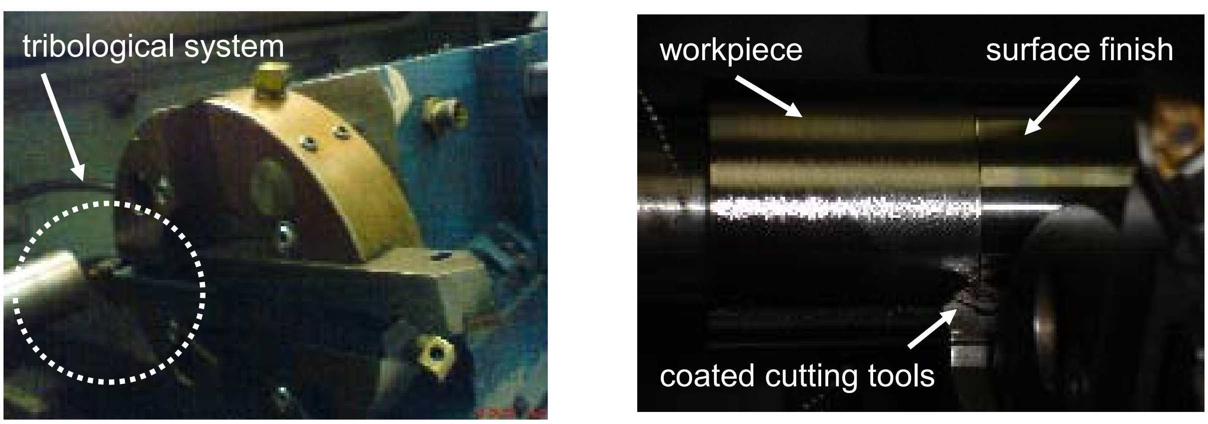


Figure 4. Tribological system and details: workpiece, coated cutting tools and surface.

After the trials the bars were cleaned in an isopropyl alcohol (pure) in order to remove residual of the surface. Surface roughness (amplitude and functional parameters) of the machined surface were obtaned after each pass using a Surftest Mitutoyo portable stylus type instrument with sampling length of 0.8mm for all conditions investigated. Measurements were carried out in three different regions (R1, R2 and R3) (Figure 5).

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Three measurements were realized on each region and the average of three readings represents the surface roughness value of the machined surface for each region showed on the Figure 5. Quantitative bidimensional parameters were conducted on a rugosimetro Surftest SL-301. For this step was chosen profile R, length of 4,0mm, λ_c (cut-off) of 0,8mm, scanning speed of 0,50mm/s. Amplitude and functional parameters were obtained in according with standard JIS 2001 and DIN 4776, respectively.

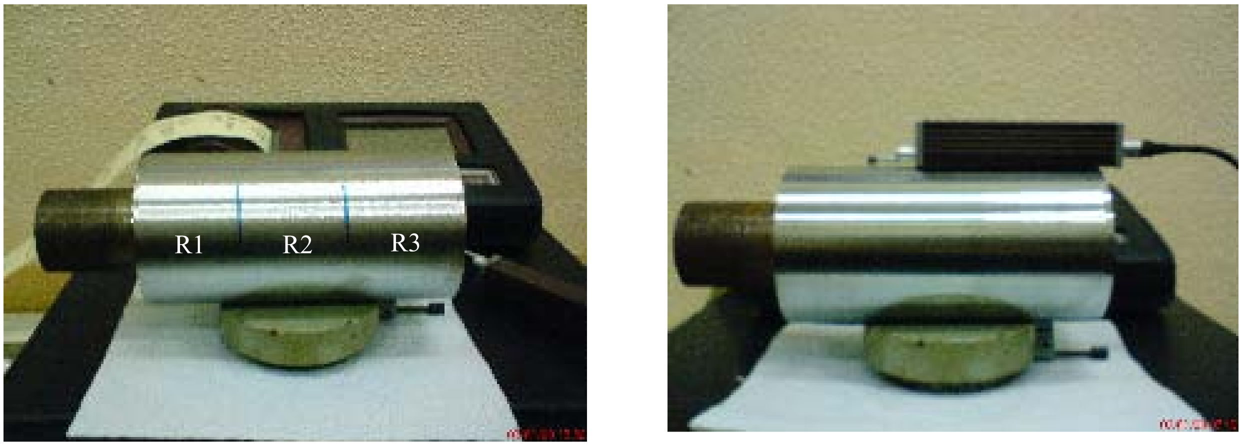
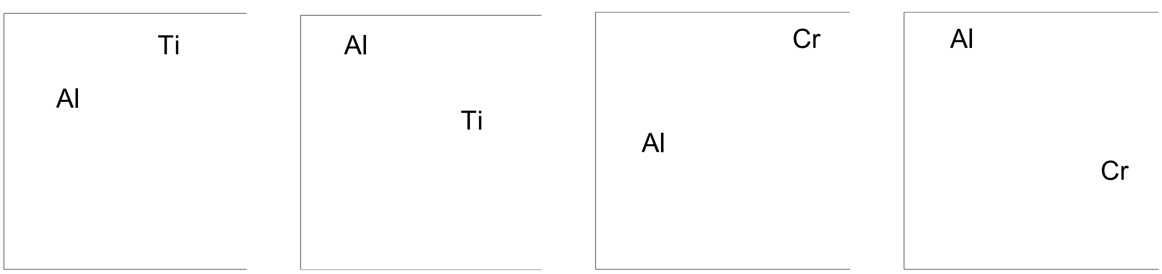


Figure 5. Regions (R1, R2 and R3) considered for monitoring of surface roughness and procedure for the analysis of amplitude and functional parameters.

3 RESULTS AND DISCUSSION

3.1 Chemical Compositions

Figure 6 shows the qualitative results obtained by EDS (*Spectroscopy Energy Dispersive*) analysis were obtained by areas for each nanostructured ternary coatings. Values calculated are showed on Table 2.



(a) (b) (c) (d)

Figure 6. EDS analysis: (a) Ti-Al-N (low Aluminum - la), (b) Ti-Al-N (high Aluminum - ha), (c) Cr-Al-N (low Aluminum - la) e (d) Cr-Al-N (high Aluminum - ha).

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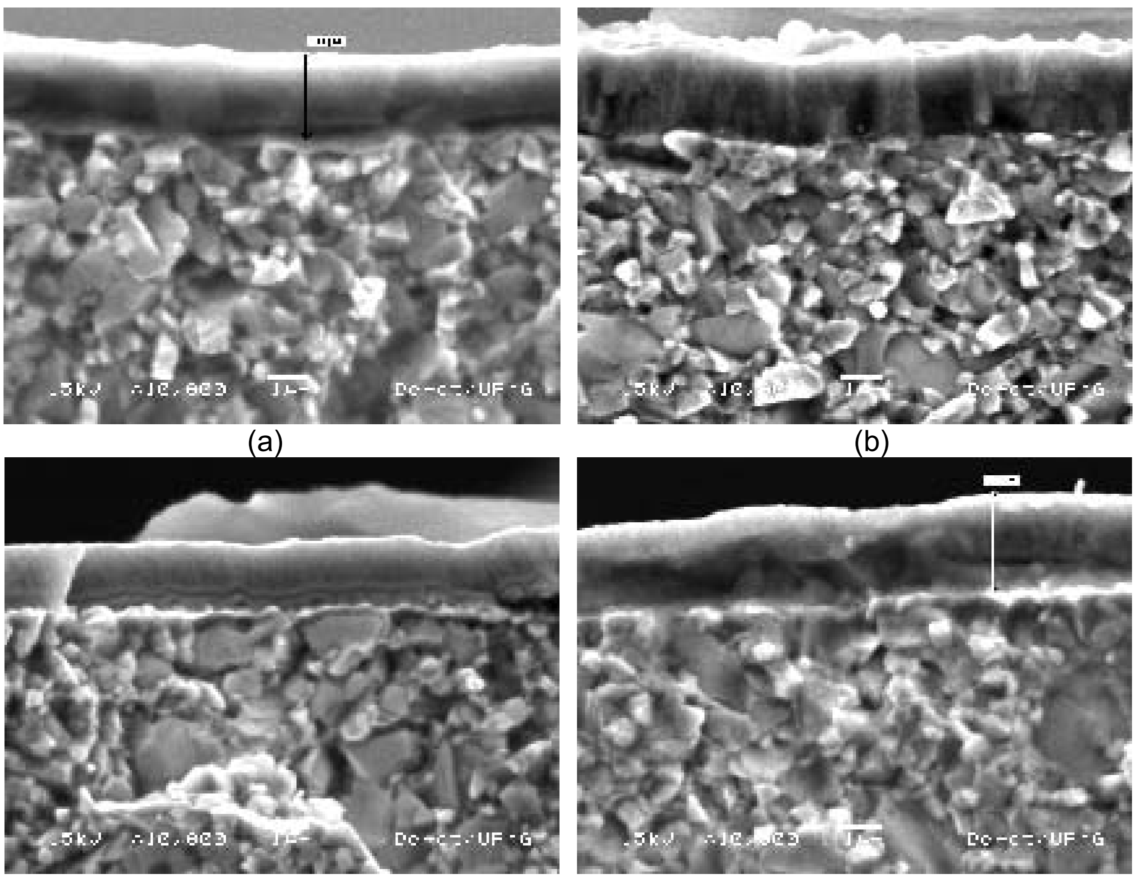
Table 2. Average of Aluminum contents on nanostructured ternary coatings

$Ti_{1-x} Al_x N$	% (at.)	$Cr_x Al_{1-x} N$	% (at.)
Low Al content	~24,3	Low Al content	~21,7
High Al conten	~62,3	High Al conten	~70,6

Aluminum contents and thickness in both coatings were within the limits established for the production to order: low and high aluminum: x ≤ 0.3 and x ≥ 0.7, respectively.

3.2 Fracture Cross-section

SEM photomicrographs on metallographic cross-sections are shown (Figure 7).



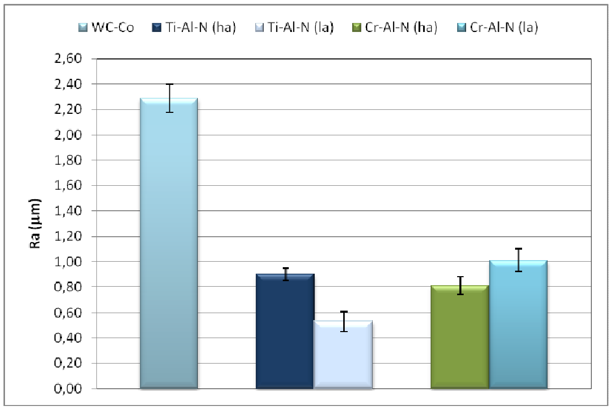
(a) (b) (c) (d)

Figure 7. SEM micrographs: (a) Ti-Al-N (high aluminum), (b) Ti-Al-N (low aluminum), (c) Cr-Al-N (high aluminum) and (d) Cr-Al-N (low aluminum).

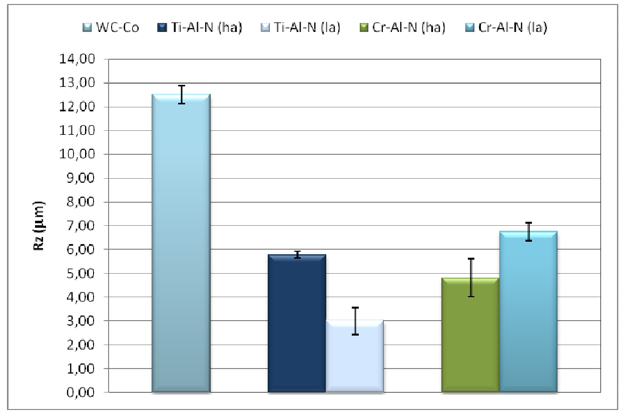
All films are very dense and ostensibly not columnar similar qualitative results were show by Reiter et al.[5] Thickness obtained were range of 2,0 to 3,0 μm. This value is very important when considered probabilities of increase of internal residual stress and delaminations occurrence.

3.3 Surface Finish Analysis

Figures 8 shows the results for amplitude parameters (R_a and R_z) JIS 2001.



(a)



(b)

Figure 8. (a) R_a obtained for WC-Co (substrate), Ti-Al-N (ha), Ti-Al-N (la), Cr-Al-N (ha) and Cr-Al-N (la) after continuous cutting and (b) total roughness height (ten point height) obtained for WC-Co (substrate), Ti-Al-N (ha), Ti-Al-N (la), Cr-Al-N (ha) and Cr-Al-N (la) after continuous cutting.

In general although these preliminaries results suggest that is possible to obtain different surface finish when used coatings ternary with low and high Aluminum content. The lowest values of amplitude parameters were obtained when used both coatings if compared with substrate (WC-Co). Considering the Al content (%at) the lowest results were observed for Ti-Al-N (low Aluminum) and the highest values obtained for Cr-Al-N (low Aluminum).

Ding, et al.[9] studied a series of CrAlN coatings with Al/Cr, in your reports show the friction coefficient of the CrAlN coatings increased slightly with the increase of Al/Cr atomic ratio, which could be partially related to the slightly increased coatings roughness. Residual stress and hardness drop down for the high Aluminum containing films. The stress reduction can be ascribed to the smaller amount of dissolved Chromium and the hardness decrease to the lower of hcp-AlN observed.

Schramm et al.,[11] studied tribological properties and dry machining characteristics of PVD - coated carbide inserts in particular analysis of cutting forces show increasing flank wear, the cutting forces also increase. The best coating in the short test in this respect is the reference TiAlN coating, since the cutting force Fc remains on a relative level. The surface quality differs from the results above. Usually increasing flank wear and cutting forces com along with rougher surfaces. The results show that both R_a and R_{max} are significantly lower for CrAlN compared to the TiAlN-coated tool. In according the authors, the low machining properties can be derived from their layer structure.

In this context, Reiter et al, 2005 show the performance of Al_{1-x} Cr $_x$N of different Al contents a drilling test (non continuous cutting) on HSS substrate. The highest tool life was obtained by the Al_{1-x} Cr $_x$ N with 0,71- Aluminum. Authors attributed these results with the highest abrasive wear resistance and maximum oxidation resistance of the entire composition range. Phase change into hcp-lattice resulted in a decrease in tool life of ~50% when compared (1-x = 0,71) which underscores the importance of the

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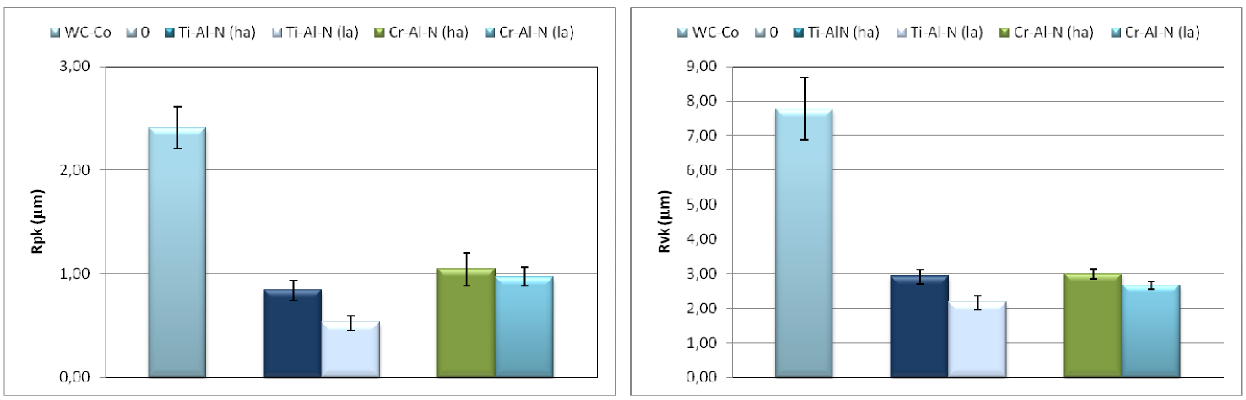
formation of the cubic phase during deposition on cutting performance. Experimental reports indicate that Cr1-xAlxN crystallizes in the cubic NaCl modification (B1 structure) up to to AlN mole fractions (x). Elemental analysis by EDX reveals that Cr_{1-x} Al_x N films are soichiometric with N/metal ratios.

Analysis of XRD patterns reveal that as deposited Cr_{1-x} Al_x N coatings on steel and cemented carbide substrates contain a single phase crystalline cubic structure for AlN mole fractions x ≤ 0,71, a mixed cubic + hexagonal structure for x = 0,75 and a single phase hexagonal structure for x ≥ 0,83 (Figure 1).[4-5] For Ti1-xAlxN, studies show that a single cubic phase structure form for x ≤ 0,50, a mixture phase for x between 0,6 to 0,7 and a single phase hexagonal structure for x ≥ 0,8.[6,1]

Figure 9 show results obtained for functional parameter (R_{pk} and R_{vk}) in according with DIN 4776.



(a) (b)

Figure 9. (a) Reduced peak height (R_{pk}) obtained for WC-Co (substrate), Ti-Al-N (ha), Ti-Al-N (la), Cr-Al-N (ha) and Cr-Al-N (la) after continuous cutting and (b) reduced valley depth (R_{vk}) obtained for WC-Co (substrate), Ti-Al-N (ha), Ti-Al-N (la), Cr-Al-N (ha) and Cr-Al-N (la) after continuous cutting.

First analysis indicated that the functional parameters (R_{pk} and R_{vk}) give different results when used, in the same cutting conditions; nanostructured coated cemented carbide cutting tools (high and low Aluminum) content.

In general, reduced peak height (R_{pk}) was less than reduced valley depth (R_{vk}) for all conditions (approximately 3x): uncoated and coatings Ti-Al-N and Cr-Al-N (high and low) Aluminum content. This fact suggests the best performance for fluid retention if compared with bearing properties. Comparing coated cutting tools, not significant difference with high and low Al, content, except for the Cr-Al-N (low Aluminum).

Although preliminary study, these facts suggests that the selection of the coating has got an influence about the surface finish for different and strategic applications in engineering, for example the oil retention that 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.[15]

Best mechanical properties, such as higher hardness and lowest coefficient of friction of these protective layers.[1,2,3,16,17,18] 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. Results, of this study, constitute a first investigation. Others parameters and the methodology have been improved in future steps for the same tribological analysis.

4 CONCLUSIONS

Main conclusions for this first study were:

- There is influence of the Al content (high and low) in ceramic ternary coatings (Ti-Al-N and Cr-Al-N) on the surface finish (amplitude and functional parameters);
- The lowest values of amplitude parameters were obtained when used both coatings if compared with substrate (WC-Co - substrate).
- Considering the Al content (%at) the lowest results were observed for Ti-Al-N (low Aluminum) and the highest values obtained for Cr-Al-N (low Aluminum).
- The selection of the coating and Al content has got high influence about the surface finish for different and strategic applications in engineering, for example fluid retention and bearing properties,
- Reduced peak height (R_{pk}) was less than reduced valley depth (R_{vk}) for all conditions (approximately 3x): uncoated and coatings Ti-Al-N and Cr-Al-N (high and low) Aluminum content.
- Comparing coated cutting tools, not significant difference with high and low Al, content, except for the Cr-Al-N (low Aluminum).

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