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Topographical Study of Textured Cutting Tools by Jetting and Laser Blasting Techniques

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Abstract:

In the last two decades, micro-topography surface modification has received great attention, as a result of its evenly distributed asperities and depressions. The process, known as surface texturization, has been successfully used in many applications with the aim to increasing surface performance in various aspects. The purpose of this work is to compare laser texturization in ISO K-class hardness metal inserts that were coated with TiAlN-Futura®, AlCrN-Alcrona® and AlCrN-Hélica®, as well as to validate its efficiency on the mechanical coating of substrates in comparison to the commercially available by the jetting technique. Therefore, the topographies of the textured tools were studied by jetting and laser blasting techniques and later assessed with a 3D profilometer, resulting in greater isotropy for textured substrates with the jetting technology as opposed to laser machining.

Keywords: Topography, texturization, jetting, 3D profilometry, coating

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1. INTRODUCTION

Surface phenomena mechanisms such as wear, oxidation, corrosion and cavitation depend essentially on the evolution of the surface texture [1]. The investigation of 3D surface topographies by using statistical parameters is a contemporary and very powerful instrument for the analysis of surface changes in mechanical tools throughout their life span [2]. According to Francis [3], the consistency and robustness

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in the use of a 3D surface topography technique are based on two new possibilities: firstly, it concerns measurement precision (nanometric resolution profilometry) and, secondly, it refers to spatial visualization enhanced capacities. Finally, the two-dimensional analysis coupled with conventional roughness measurement has thus so far provided an incomplete and abridged description of the real surface topography.

Texture is the assembly of typical deviations of a real surface, which includes roughness and undulations [4]. Controlled laser machining can substantially improve texture as well as benefit the functionality and reliability of engineering components, favor lubrication of slipping or rolling mechanical parts, remove wear residues, recede friction, reduce jamming and gripping over contact surfaces, recover adhesion, increase mechanical strength and sealing capacity, regulate surface wetting and hydrodynamic effects, improve aesthetics and increase heat transfer, to name a few [5].

Surface texturization with precision machining has been primarily applied to improve the adhesivity of hard coatings on cutting tools. Various methods can be used to produce texture change in tool's substrates. Among them are rectification, polishing, hard particle shot blasting, grit blasting, suspended high-pressure water spray, electroerosion, electrochemical attack, acid chemical attack (hydrochloric, sulfuric and nitric acids) and a myriad of other processes that have some control [6; 7; 8; 9; 10].

The science of texture modification in order to improve coating adhesivity on cutting tools is relatively new. A great deal of research is still being conducted worldwide and demonstrates the potential to deliver promising alternatives to as-usual techniques. The aim of this study is to compare the topographies of textured tools by engaging jetting and laser blasting techniques on assorted samples, assessed with 3D profilometry, as well as to the gathering of refined data that will provide technical means for the spread of this new technology, thus contributing to optimizing the best conditions for tooling.

2. EXPERIMENTAL PROCEDURE

Textured cutting tools of hard metal inserts, manufactured by Sandvik, are specified as follows: SEMN 1204 AZ H13A (without coating) and ISO-K15-K25-K-30 class (with tungsten carbide) - Figure 1. Insertions of flat surfaces with no chippings were chosen as a geometry delimiter, which facilitates the carrying out of tests for coating characterization.

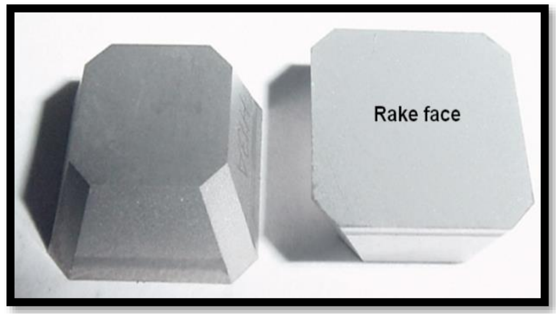

Figure 1. Hard metal inserts used for texturization.

Prior to the coating deposition, the test specimens were surface modified on the outlet (12x12 mm2) and the slack (12x2 mm2): jetting and laser blasting. Jetting was carried out by Sandvik with the intent to remove excess cobalt from the surface of the insert, thus improving coating adhesivity, deposited afterwards. Jetting creates an uncontrolled texture on the surface of the insert that could help to anchor the coating. Other hard metal inserts had been superficially modified using a copper vapor laser beam (CuHBr), developed by the photonics division of the Institute of Advanced Studies of the General Aerospace Technology Command (IEAv-CTA).

The laser energy output was 1 mJ, with high pulsing rates ranging from 10 to 20 kHz, short-pulse emission from 20 to 50 ns, visible wavelength from green to yellow (510 nm and 578 nm) with a focal diameter of 50 µm. The CuHBr laser beam could be used in the ablation of practically any material that absorbed energy in this region of the spectrum. Due to its high frequency, it was possible to obtain important material evaporation levels, allowing for a vast array of applications that included fine deposition films, cutting, boring, welding and sintering [11].

Figure 2 depicts an illustrative diagram of the assembly used in the laser texturization of hard metal tools. The laser beam experimental configuration was set to perform pulse frequency rates at 13.8 kHz, operating with wavelengths of 510 nm, pulse emissions of 30 ns and having a focal diameter of approximately 30 µm. According to [11], the laser beam displacement over the tool was controlled by a programmable Scan Head Unit with an adjustable laser beam triggered according to variations in the diaphragmatic iris opening.

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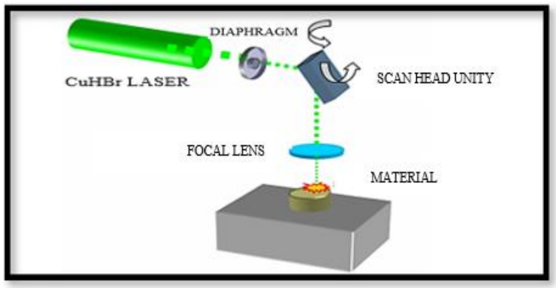

Figure 2. Laser texturization experimental assembly scheme [11]

Figures 3 and 4 show the laser texturization technique of a hard metal substrate followed by coating deposition. The substrate received a high pulsed and localized energy, generating a textured surface due to the ablation of the substrate material. The formation of microcraters is also shown.

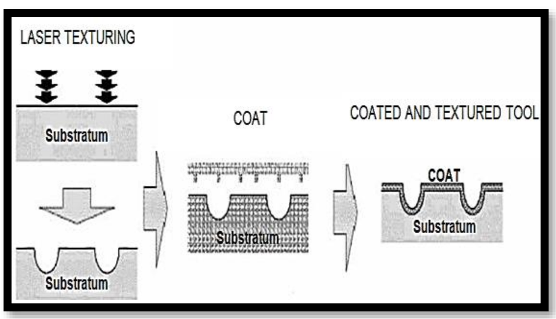

Figure 3. Laser texturization steps for a hard metal substrate [12]

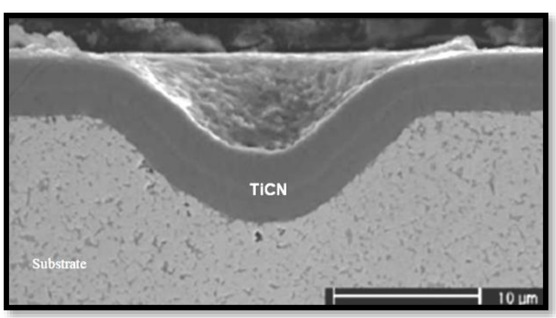

Figure 4. Crater formed in a hard metal tool when textured by laser and subsequently coated with TICN [12]

After the tooling surface texturization with jetting and laser blasting, the inserts were coated with TiAlN-Futura®, AlCrN-Alcrona® and AlCrN-Hélica® by using a cathodic-arc evaporation process (PVD). The topographies of the textured tools were then analyzed by means of an Electronic Microscopy Scanner and a 3D profilometer. The analysis of the topographies allowed for a discussion on the intrinsic characteristics of the experimented tool substrates, including their influence on the deposition and adhesivity of the coatings used.

With the use of 3D profilometry, it was possible to obtain the width roughness of the surface-textured tools (Sq, Sa, Sz and St), the statistical distribution (Ssk and Sku) and two additional parameters that describe the surface spatial properties (Sds and Str). By means of an inductive method with a palpator, two areas of the insert outlet surfaces were swept away. Such parameters and surface image generation that reached a 40 nm resolution were performed using dedicated software, a Mountains Map® version 3.1.9. The studied topographical parameters are based on the works of [13], described as follows:

Sq - mean square of surface deviation (RMS);
Sa - arithmetic average of surface deviation;
Sz - height average of ten largest peak-valley distances;
St - total surface height;
Ssk - distribution skewness of surface topography amplitudes (asymmetry of surface amplitudes);
Sku - Curthose distribution of surface topography amplitudes;
Sds - number of peaks per unit area, using the peak definition criterion of the largest height of the neighboring peaks;
Str - superficial texture reason, which indicates texture orientation.

The surface analysis was carried out using a high-resolution 3D profilometer: a Taylor Hobson Precision Model Talysurf CLI 1000 from the Materials Surface Characterization Laboratory of the Federal University of Espirito Santo (LCSM-UFES) - figure 5.

For the visualization of the tooling topography, there was employed a Zeiss DSM 960 scanning electron microscope, from the Materials and Metallurgy Science Department (DCMM) of PUC-Rio.

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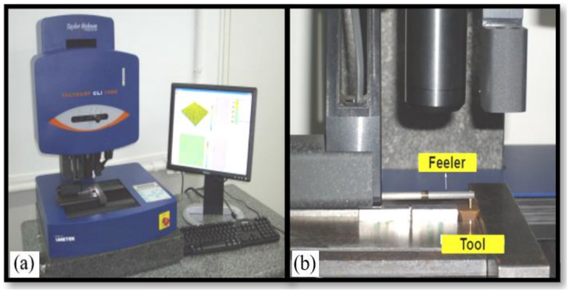

Figure 5. (a) 3D profilometer; (b) tool and feeder output surface in detail

3. RESULTS and DISCUSSION

Figure 6(a) shows the topography of the output surfaces with a jetting texture without coating, whereas Figure 6(b) derives from a mechanical action and is characterized by a fuzzy topography accompanied by a series of depressions and protrusions, probably caused by jetting hard particle impacts on the insert substrate. Figure 7 reveals the topography of the hard metal substrate using the laser beam technique at incidence angles of 0°, 30° and 60°. Figure 7(a) shows that the laser beam creates on the substrate surface a semi-orderly topography of peaks and valleys, attributed to the different melting temperatures and/or evaporation of the constituent elements of the substrate. Comparing both figures 6 and 7, it is also noted that the laser beam modified substrate has a rougher appearance than jetting modified substrate. According to [14], the laser beam forms evenly spaced rough lines that are, however, very close to each other on the surface of the substrate.

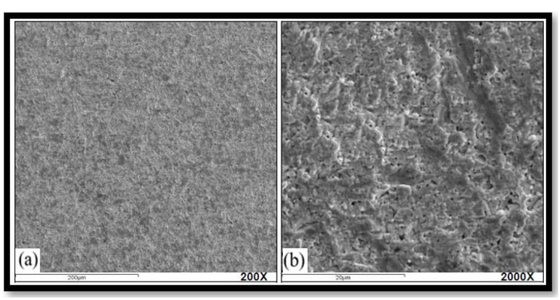

Figure 6. (a) SEM of hard metal substrate with jetting and without coating deposition. 200x; (b) 2000x

According to [15], the substrate material is removed from the surface in a non-uniform manner, resulting in the formation of a microstructure with periodic or semi-periodic morphology, probably due to preferential absorptions of the laser beam. The surface produced with this experimentation comprises of microstructures in the form of cones, columns, peaks, grooves and valleys.

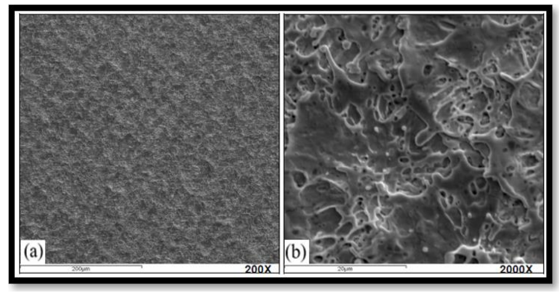

Figure 7. (a) SEM of hard metal substrate with laser and without coating deposition. (a) 200x; (b) 2000x

The peaks and valleys observed in Figure 7(a) are possibly shaped by the refusion of the materials constituting the insert, respectively WC and Cobalt, as a consequence of the micrometric layer vaporization during the ablation of the material, followed by the high level of power density or irradiance of the laser, around 683 MW/cm2, even at short exposures (30 ns). The ablation promotes a rapid transition from overheated liquid to a mixture of steam and surface substrate droplets, also verified by [9]. However, the ablation does not influence the mechanical properties of the modified substrate, but can significantly improve the surface properties as described by [12].

In figure 7(b) we can observe the droplet aspect on the surface of the hard metal substrate of the solidified material treated with laser beam. Phase transitions of Co and WC also depend on the amount of laser pulses used in surface processing. It was observed [8; 16] that the Co melted with a minimum irradiance of 32 MW/cm^2, against 80 MW/cm^2 for the WC. At 200 MW/cm^2 the WC evaporates. Cobalt reaches melting and evaporation points at respectively 1495ºC and 2927ºC. On the other hand, WC melts at approximately 2870ºC and evaporates at around 6000ºC. Figures 8 to 11 show the results of the substrates' topographical amplitude parameters obtained with 3D profilometry. The 3D roughness was measured by scanning the areas A1 and A2 (2x2 mm^2), located each on two different output surfaces of the inserts.

In Figures 8 to 11, the Sa, Sq, Sz, and St range parameters show that the uncoated jetting-modified substrate (SR-Jateada) has a lower roughness than the laser-treated non-coating substrate (SR-laser).

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Considering all selected amplitude parameters, the Sq is the most statistically representative, once it indicates that the roughness dispersion is greater for the laser-beam modified substrate. This increase may be related to process severity, to intense formation and overlapping of droplets in the solidified material, as figure 7(b) indicates, possibly resulting in a preferential absorption of the laser beam when interacting with the constituent materials of the substrate.

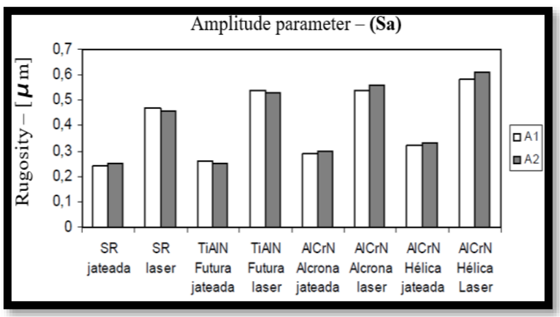

Figure 8. Jetting and laser blasting scanned areas (A1, A2) and the arithmetic average surface deviation (Sa) of the textured tools

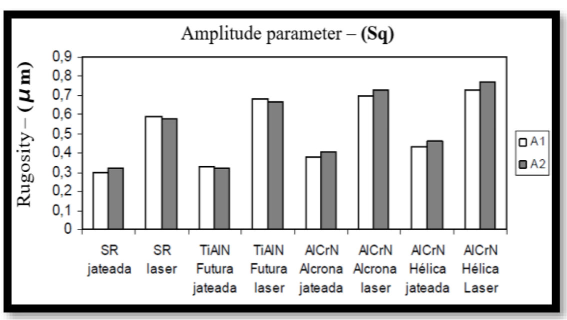

Figure 9. Jetting and laser blasting scanned areas (A1, A2) and the mean square surface deviation (Sq) of the textured tools

Another important characteristic observed in figures 8 to 11 is that the roughness of the SR-Jateada and SR-laser substrates increases when depositing the TiAlN, AlCrN-Alcrone and AlCrN-Hélica coatings. This is likely due to the formation of macro particles or granules on the surface of the substrate after coating has been deposited. The formation of these macro particles is the main disadvantage of the PVD deposition by evaporation arc cathode, a process used in this work. These macro particles are the result of droplets formed during the evaporation of the arc in materials with low melting points, which is the case of aluminum, our major coating constituent. It is also believed very rapid evaporation produces an excess of atoms that are not completely ionized before reaching the surface of the substrate. An excess of neutral atoms can coalesce to form macro particles even before they reach the substrate [17]. Figures 12 and 13 show the values obtained for the distribution parameters.

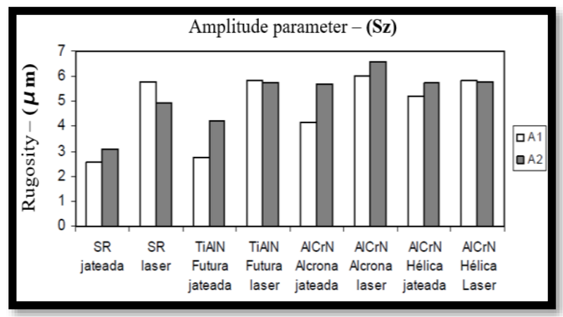

Figure 10. Jetting and laser blasting scanned areas (A1, A2) with the height average of ten largest peak-valley distances (Sz) of the textured tools

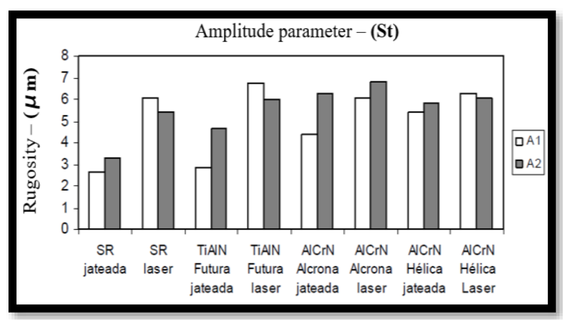

Figure 11. Jetting and laser blasting scanned areas (A1, A2) with the total surface height (St) of the textured

Ssk represents the degree of asymmetry of the width of the surface roughness over the median plane. More specifically, it indicates that a surface, consisting predominantly of valleys, will present a Ssk value of less than zero, while that of peaks, will tend to a positive Ssk value [18]. As shown in figure 12, the Ssk of the non-coated SR-Jateada substrate indicates a surface with valley preponderance. However, the non-coating SR-laser substrate demonstrates a preponderance of peaks. After coating deposition, only TiAlN retained a negative

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Ssk value for the SR-Jateada sample. On the contrary, AlCrN-Alcrona and AlCrN-Hélica coatings were positive. As for the SR-laser substrate, the TiAlN deposition yielded a Ssk negative, whereas AlCrN-Alcrona and AlCrN-Hélica presented the same Ssk as for the SR-Laser substrate – figure 12.

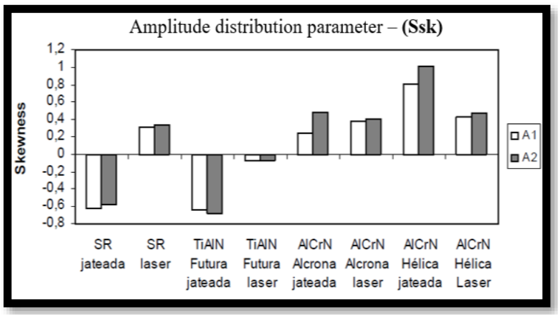

Figure 12. Jetting and laser blasting scanned areas (A1, A2) with skewness (Ssk) of the textured tools

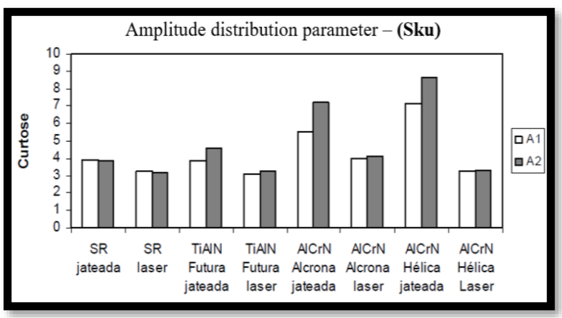

Figure 13. Jetting and laser blasting scanned areas (A1, A2) with Curthose (Sku) of the textured tools

Sku is related to the amplitude distribution curve of the surface roughness. If the surface amplitude follows a Gaussian distribution, then the Sku equals 3 and the Ssk equals zero. If the curve is sharper, the Sku is larger and its value tends to be greater than 3. If the curve is flattened, the Sku tends to be less than 3 [13]. For [18], the Sku greater than 3 indicates the excessive presence of high peaks/deep valleys on the analyzed A1, A2 surfaces. In absence of either peaks or valleys, the Sku tends to be lower than 3. It is noticeable in figure 13 that all tested substrates, whether coated or not, have a Sku greater than 3, indicating that the substrate amplitude distribution is not Gaussian. It is also perceived that the laser treated substrates are closer to a Gaussian distribution, as confirmed by a Sku value near 3.

As for the A1 surface, the textured TiAlN laser treated substrate has a Ssk near zero (~ -0.07) and a Sku near 3 (~ 3.12), representative of a normal distribution. However, as for the A2 surface of the textured substrate studied with jetting technique and covered with AlCrN-Hélica coating, a sharper amplitude distribution curve becomes apparent, reaching the largest Sku value of 8.67 and is characterized by disordered spikes on the surface, having a greater Ssk value of nearly 1 (~ 1.01).

The distribution parameters Ssk and Sku tend to suffer from poor repeatability, as very high or very low surface amplitude points may affect their calculation. For this reason, sufficient surface measurements should be made in order to provide statistically significant values [18]. As only A1 and A2 areas were considered in the study, this may result in less accurate Ssk and Sku distribution values. Taking into consideration the coated substrates, the variability of results may also be attributed to specific characteristics of the coating deposition process, which mainly affects the morphology of the film. A greater dispersion in roughness of the coated substrate can be also put down to the increasing complexity of the coating nucleation and growth mechanisms, as an impending amount of coating constituent elements enhances the possibility of defects, such as pores.

Considering that the topography of a surface is three-dimensional by nature, two parameters for describing the spatial properties of the surfaces were also acquired and analyzed using Mountains Map software in order to better evaluate the morphology of the studied substrates, such as the peak density (Sds) and the superficial texture ratio (Str). The former is characterized by the number of peaks per unit area, using the peak definition criterion, as being the highest of the eight neighboring peaks around the mid-plane measured area of the inserts. The latter indicates the texture orientation or the preferred direction of the surface texture. Figures 14 and 15 represent histograms with peak estimates of textured substrates without coatings.

According to figure 14, as for the SR-Jateada substrate, the highest densities of surface peaks range from 2900 to 3300 pks/mm² and their concentration is around 2.4 to 2.6 µm. On the other hand, figure 15 reveals that the SR-Laser substrates with the highest surface peak densities range from 1900 to 2000 pks/mm² and their concentration is between 3 to 3.4 µm.

The data obtained from Figures 14 and 15 identify peak concentrations for SR-Jateada and SR-laser

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substrates at different heights, making it hard to directly analyze the influence of these peaks basing on the coatings adhesivity. Moreover, it is difficult to differentiate the peak effects on surfaces, considering the chemical bonds between the substrate and the coating. Figures 14 to 18 show that laser modified substrates relative to jetting have a peak dispersion that approaches a normal distribution, justifying (Sku) values close to 3 for the SR-laser substrate, as also implied in figure 13.

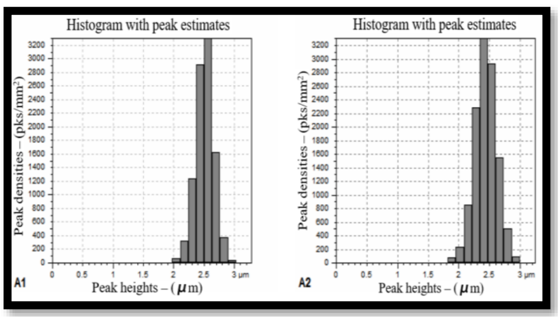

Figure 14. Jetting scanned areas (A1, A2) with the estimate peak density of textured substrates without coating deposition

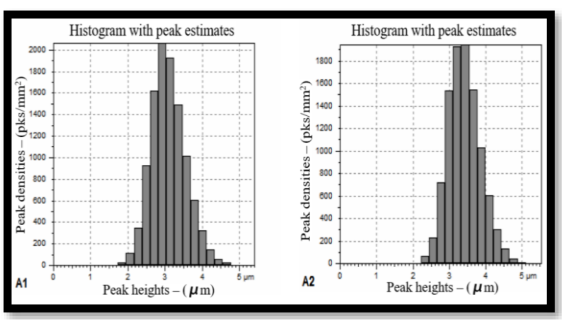

Figure 15. Laser blasting scanned areas (A1, A2) with the estimate peak density of textured substrate without coating

Figures 16 to 18 show peak densities for both SR-Jateada and SR-laser substrates after TiAlN, AlCrN-Alcrona and AlCrN-Hélica coating depositions. These layers increased the peak density and, on average, had also contributed to heighten the peak range on surfaces.

Peak density and height are two factors that may control the chemical bonds between the substrate targeted surface and the atoms of the constituent coatings during the deposition process [19]. In addition, the angular distribution of the coating atoms also directly influences these substrate chemical bindings. The density and height of the surface peaks of SR-Jateada and SR-Laser substrates are indicative of the coating adhesion level, as poor adhesions can be accredited to low degrees of chemical linkage between coating atoms and substrate [19]. Complementary, higher peak density would also undermine the transit of atoms from the coating towards the lower roughness profile substrate, forming a defective-populated-void interface.

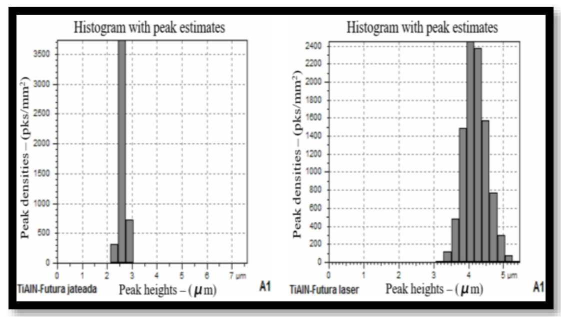

Figure 16. Jetting and laser blasting substrate scanned area (A1) and peak density estimate for TiAlN-Futura coatings

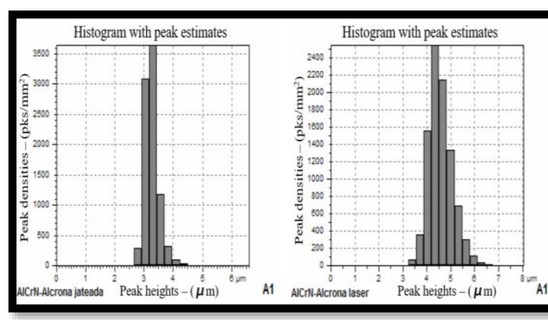

Figure 17. Jetting and laser blasting substrate scanned area (A1) and peak density estimate for AlCrN-Alcrona coating

The average spacing between successive peaks of the surface roughness profile may influence the mechanical locking of the coating on the substrate [20]. Thus, an increase in peak density would reduce the spacing between the roughness profile peaks and that could effectively increase the mechanical coating lock.

Another peculiar aspect that differentiates the textured substrates is the apparent periodic ordering of the texture, particularly the peaks, of the SR-laser substrate in relation to the SR-jateada substrate, as can be

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verified in the 3D profilometry images of the roughness of the substrates – figures 19 and 20.

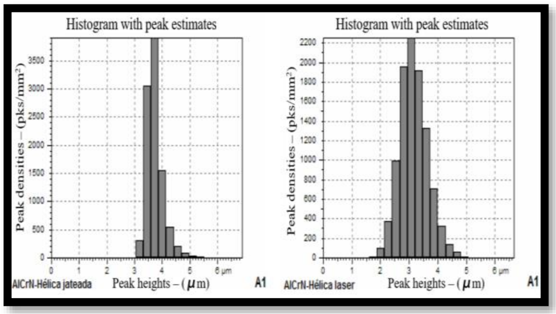

Figure 18. Jetting and laser blasting substrate scanned area (A1) and peak density estimate for AlCrN-Hélica coating

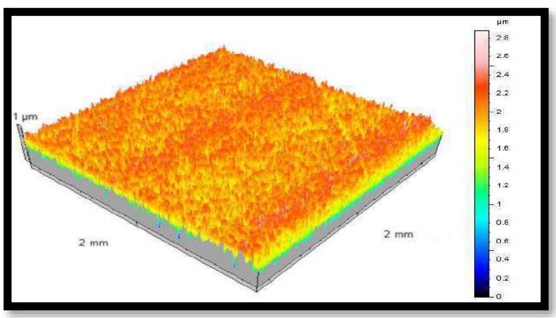

Figure 19. Jetting modified 3D roughness profilometry of the substrate without coating

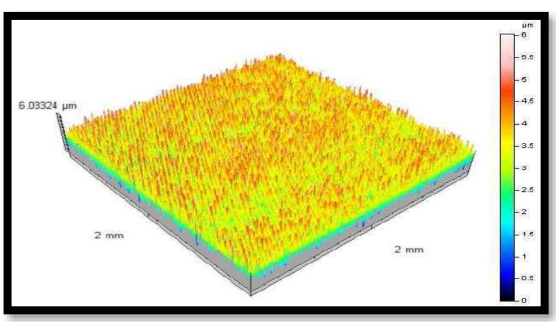

Figure 20. Laser blasting 3D roughness profilometry of the substrate without coating

The 3D profilometry images from figures 19 and 20 reveal that jetting generates a more disordered superficial texture or somewhat less isotropic than the directional texture brought about by the laser blasting technique. Figure 21 shows that the laser beam actually creates a directional texture on the hard metal substrate. Figura 22, obtained by 3D profilometry is a real image of the texture of the substrates, which was characterized using the Mountains Map software, shows that the texture orientation of the laser-modified substrate is maintained, even after the coating deposition process. The degree of isotropy and directionality of jetting and laser blasting textures can be compared by means of polar graphs, as illustrated in figures 23 and 24. The surface texture is considered to be isotropic when it has identical characteristics, independent of the direction of measurement [21]. This is not the case of surfaces with a random texture, such as the jetting generated surfaces or those submitted to chemical treatment, which does not show any distinctive texture variation.

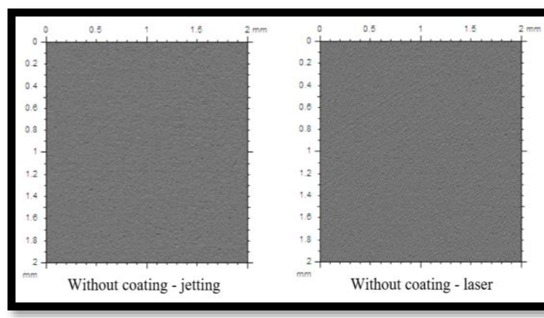

Figure 21. Jetting and laser blasting 3D profilometry of surface texture for substrates without coating

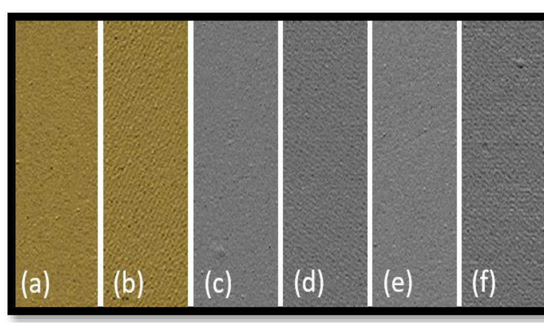

Figure 22. 3D profilometry of the surface texture of coated substrates. Jetting: (a) AlCrN-Hélica jateada, (c) AlCrN-Alcrona, (e) TiAlN-Futura; – Laser: (b) AlCrN-Hélica, (d) AlCrN-Alcrona, (f) TiAlN-Futura

The superficial texture with a periodic orientation is referred to as anisotropic. One way of determining and

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quantifying the surface isotropy is by applying the Fourier transform (FT), which in turn, would allow the creation of a spatial reference that could represent the isotropy of a surface. This parameter is known as texture aspect ratio or surface texture ratio (Str). The (Str) comprises of a dimensionless value that ranges between 0 and 1. It can also be respectively expressed as a percentage of values between 0 and 100 %. An isotropic surface has (Str) close to 1 or 100 %, whereas a strong anisotropic surface has (Str) close to 0 or 0%.

Figure 23 illustrates the surface of the hard metal substrate after jetting, reaching an isotropy level of 75.4 %, in contrast to figure 24, as for the laser blasting technique, showing much less prominent isotropy of 38.7%. Furthermore, with polar graphics it is possible to determine the preferred texture directions by means of a more intense spectrum.

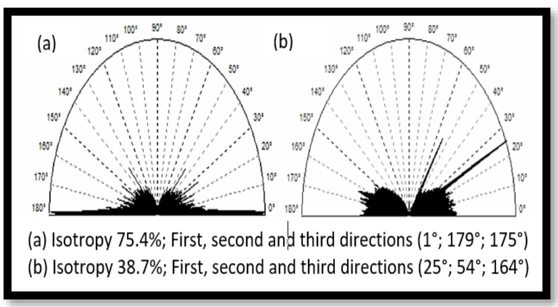

Figure 23. Polar graph texture indicator for (a) SR-Jetting and (b) SR-Laser substrates

In the case of jetting, figure 23 (a), the core directions are 1° and 179°, showing a surface with random directionality. As for laser texture, the core directions are 25° and 54.5°, indicating a preferential texture directionality, closer to the laser beam interaction substrate angles at 30° and 60°. The obtained and discussed results exposed the texture differences between hard metal substrates, modified by jetting and laser blasting techniques in which the coating topography of each substrate was characterized by a randomized flattened appearance (jetting) in contrast to a semi-denatured distribution of high peaks and valleys (laser beam). The aspects of the two textures play an important role in terms of qualifying the adhesivity of deposited coatings. In a direct relation to the topographical statistical parameters, it can be said that the roughness increase in textured laser tools is an indication of their prominent coating adhesivity and, subsequently, their stability performance contribution is higher than that of the jetting technique.

4. CONCLUSION

The insert analysis showed that jetting surfaces were topographically randomized and that of the laser beam characterized by a semi-denatured distribution of peaks and valleys. The topographical statistical parameters analyzed with 3D profilometry (Sq, Sa, Sz and St) showed that the uncoated substrate (SR-Jetting) had a lower roughness in comparison to the laser-treated non-coating substrate (SR-Laser). As for the PVD deposition process, the AlCrN-Hélica, AlCrN-Alcrone and TiAlN-Futura coatings increased the amplitude of substrates, either with jetting or laser blasting techniques. Finally, the images in 3D profilometry showed that the jetting texture is more isotropic (75.4%) than that of laser beam (38.7%).

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