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TOPOGRAPHIC CHARACTERIZATION AND TRIBOLOGICAL ANALYSIS OF PARTIAL AND TOTAL TEXTURED SURFACES

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Abstract. *The Surface texturing is the alteration of the surface topography by standardized micro-cavities. These can create hydrodynamic pressures, retaining debris and storing lubricant, increasing the load capacity on contact. The main objective of this method is to find the situation that provides the best tribological behavior, that is, it presents a good performance in reducing the coefficient of friction at a low cost. The methodology consists in the use of unmasked surface texturing of Chevron profiles ("V" format) to obtain totally and partially of ABNT 1045 steel in lubricated sliding tests. The tests performed with the aid of a microtribometer with textured and non-textured samples. The set of modifications resulting from the surface texturing makes the textured samples less energy efficient and had greater wear, when compared to the smooth ones. This was understood by the reduction of real contact area of the textured samples and the presence of a more stable tribofilm in the smooth samples.*
Keywords: *Lubricated sliding wear; Surface texturization; Partial texturing; Surface engineer, Tribology.*

1. INTRODUCTION

In the 1960s numerous cases of factory and machine failure caused by wear have been reported, resulting in large financial and low productivity. This scenario interested specialists in the areas of friction, wear and lubrication. Thus, in 1966 a report by H. Peter Jost was published for the committee of the British Department of Education and Science, introducing a new term, called tribology. Word originated from the Greek *Τριβο* (Tribo - rub) and *Λογοσ* (Logos - study). In this report, the term was defined as the "science and technology of interactive surfaces in relative movement and related subjects and practices" (JOST, 1990).

In order to improve the tribological performance of mechanical systems, the surface texturization method is used. Being this, it consists in the formation of standardized micro surface cavities that, according to Hamilton; Walowit and Allen (1966), were able to create hydrodynamic pressures and, consequently, increase the load on rotating mechanical seals.

The ways to create micro or nanometric textures with controlled geometries are varied, which can basically be by adding material, moving material by plastic deformation or removing material (GACHOT, 2016). This last approach is the most used, highlighting the use of Laser Texturization that has in recent work great potential for bearings with COF reduction of up to 10–15% (ROSENKRANZ 2019). An alternative to the laser method, which has low texturization speeds and creates highly deformed zones in the pattern region, recently studied by PARREIRA (2012) and RODRIGUES 2018 is based on a cheaper, simpler and faster electrochemical corrosion process than the thermal cited approach.

The unmasked method, developed by Costa and Hutchings (2009), requires a standard protection, that is, that can be used for all the pieces. Although this methodology requires conductive materials to consolidate, its process is faster and simpler, since in the method with masking, it is necessary to make masks for each sample, making the process less viable.

This present work was to compare the efficiency of full, partial texturing, realized in ABNT 1045 steel shapes using the maskless electrochemical texturing (MECT) technique, and evaluate the influence of the coefficient of friction and wear rate.

2. METHODOLOGY

2.1 Surface texturization tests

For the experimental part of this work, ABNT 1045 steel samples were used, it is possible to observe its microstructure in Figure 1. In order to obtain samples with similar metallurgical structures, all of them are submitted to the annealing process. Then, for the purpose of surface leveling, sandpaper of the following granulation was used: 120, 220, 320, 400, 600 and 1200 mesh, succeed by polishing with alumina (3 µm particle size). For wear tests, 5 mm diameter AISI 52100 steel balls were used as counter bodies.

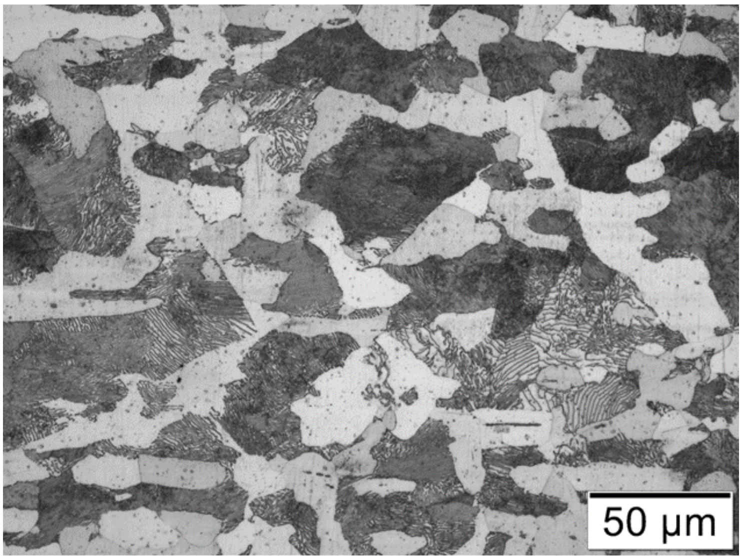


Figure 1. ABNT 1045 steel micrography of one of the tested samples.

Three topographic conditions were evaluated: non-textured surface (Smooth); Partly textured and fully textured. For each condition tested, at least three repetitions were performed to ensure reproducibility. For each condition tested, at least three repetitions were performed to ensure reproducible. The texture pattern consisted of V-shaped pockets (chevron) by the texturing process (MECT). The apparatus to be used was similar to Parreira's; Gallo and Costa (2012), indicated below (Figure 2)

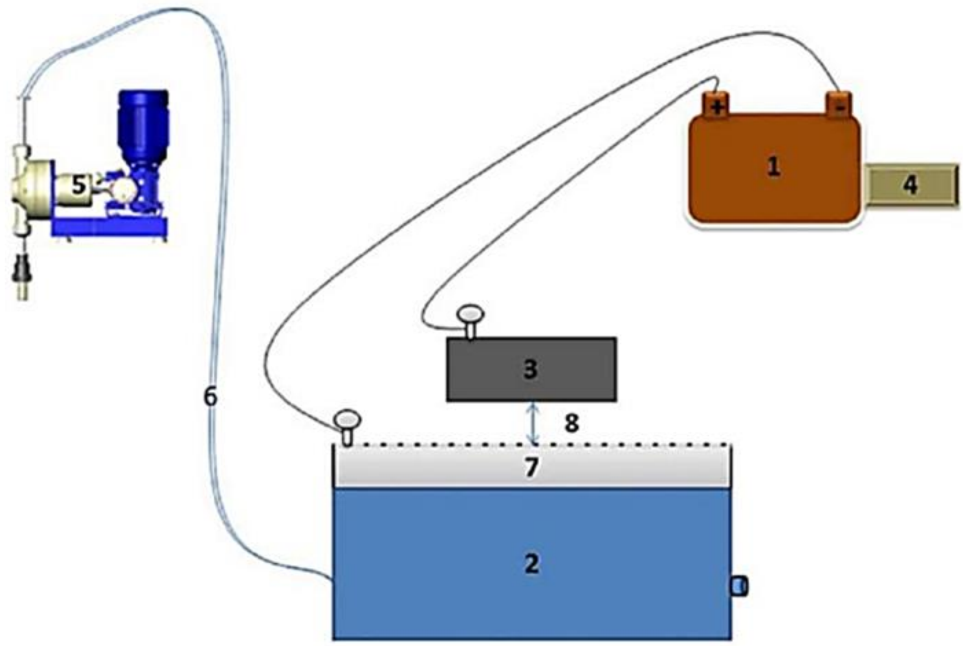


Figure 2. Experimental apparatus used in MECT (PARREIRA; GALLO; COSTA, 2012).

The experimental apparatus presented is constituted by a source of continuous electric voltage (1), which supplies current to enable anodic polarization, in order that the sample (3), which the texturing will be performed, will be connected to the positive pole and the negative pole will be connected to the tool (7). From a peristaltic pump (5), the electrolyte (2) is pumped through a pipe (6) so that the electrolyte contacts the sample (3) through holes in the tool (7), which flow, later, thanks to the distance between the tool and the Specimen (8). From an electronic circuit, the current is pulsed (4), enabling the cleaning of products from anodic dissolution in non-electrically pulsed periods.

The tools used to texturize the specimens were the same as those used by Silva (2016), made of austenitic AISI 304 stainless steel, 10 mm wide, 10 mm high and 0.3 mm thick. These were submitted to an electrostatic painting process on one of their faces, responsible for creating a non-reactive protective layer on the tool (RODRIGUES, 2018). From the presented method, it is possible to texturize several deterministic texture formats, according to the pattern printed on the machining tool.

In order to achieve proper lubrication conditions, a tool-to-workpiece distance of 100 μm and a voltage of 30 V (PARREIRA, 2011) and a depth-to-width ratio (DWR) between 0.10 and 0.18 (RONEN; ETSION; KLIGERMAN, 2001). Rodrigues (2018) proved that the times of 20 and 30 seconds are within this indicated range. It was decided to choose the time of 30 seconds since it presented less deviation from the mean (relative error) for both DWR and roughness, in agreement with the results presented by Parreira (2011) (RODRIGUES, 2018).

2.2 Microtibrometer tests

After texturing, the samples were again subjected to a polishing process in order to reduce the increase in roughness resulting from the texturing process used (Rodrigues - 2018). Then, to evaluate the tribological performance of the samples, tests were performed on the microtribometer represented in Figure 3, which is composed of a motor connected to a mechanical system and it operates on a coordinate table system. It is possible to perform alternating slip tests lubricated with liquid, solid, mixed lubricant, as well as dry tests. In addition to enabling the differentiation of data collected in textured and non-textured areas

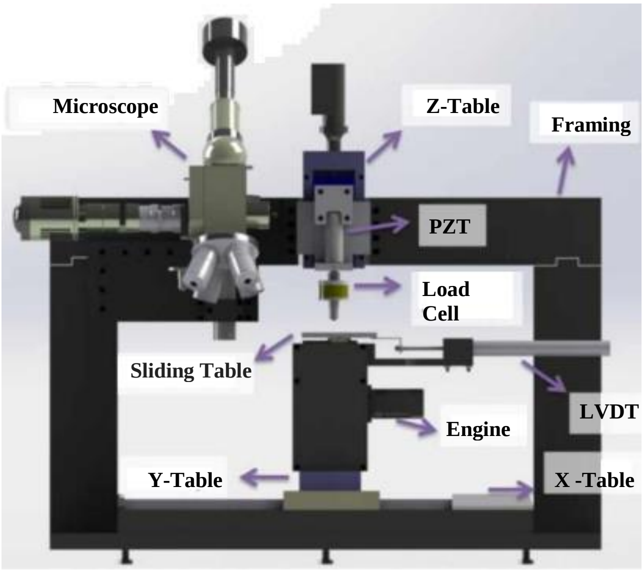


Figure 3. Microtribometer used in tests.

In this work, lubricated tribological tests were performed using BP 68 hydraulic oil, with viscosity of 185.03 cSt at 20 °C to 9.86 cSt at 100 °C. Results were analyzed using LabVIEW™ and Microsoft Excel® which generated graphs representing the coefficient of friction behavior as a function of time.

In order to establish the design of the experiments, it was necessary to define some constant and fundamental test parameters, such as: normal force, test time and movement frequency. In this case, the normal force used was 5 N and the frequency 0.5 Hz. The tests lasted 30 minutes to ensure the stabilization of the tested conditions. Finally, the topographies of the textured surfaces were characterized by the optical microscope and the scanning electron microscope (SEM).

3. RESULTS AND DISCUSSION

3.1 Coefficient of fricction

Figure 4 shows the average performance coefficients as a function of time for the three topographic conditions studied. As can be observed, the smooth surface presented the lowest coefficients of friction (0.1223 ± 0.0078) when compared to the partial case (0.2331 ± 0.0095) or fully textured (0.1550 ± 0.0051).

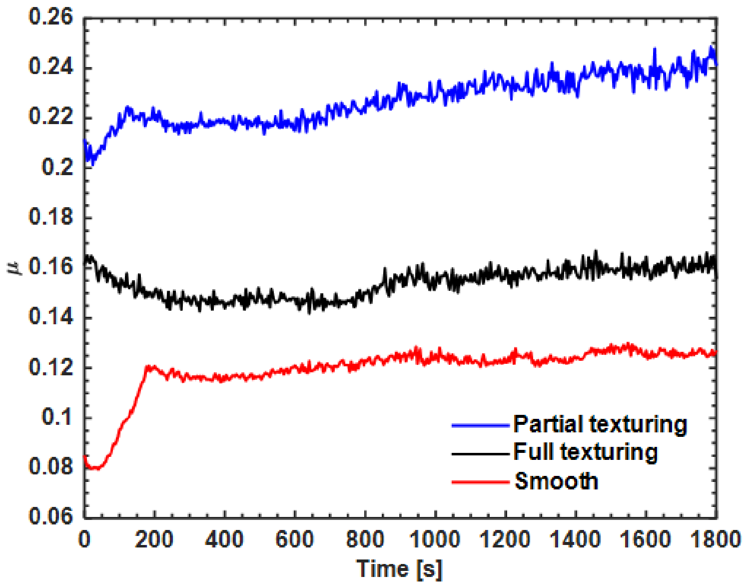


Figure 4. Coefficient of Friction of the three cases studied.

The increased coefficient of friction on textured surfaces, may have been since the actual contact area is smaller than the textured area, not generating enough disturbance in the pressure field to generate lift, leading to a likely occurrence of contact between the asperities. As a result, there is an increase in the coefficient of friction and, consequently, greater mechanical deformation, which generated values of up to 40 % higher for the case full and up to 112 % for the partially textured compared to smooth surface.

Still analyzing the partial and total textured conditions (Figure 4), it is observed that the average coefficient of friction of the partial texture is higher than the full texture (up to 62 % higher). This is probably due to topographic changes between contact surfaces that have very distinct characteristics throughout the slip test. Thus, it can be said that the abrupt change of topographic conditions causes the increase of the coefficient of friction.

3.2 Wear

Three methods were used to estimate material loss due to wear test: mass loss, optical interferometry and analysis of wear scars areas from photos taken from the optical microscope. Among the mentioned methods, only the last one was efficient and obtained more coherent data, since the mass loss was very small, in the order of scale uncertainty. For optical interferometry, the wear scars, caused by the sphere-plane contact, was shallow, being outside the measuring range of the equipment.

Figure 5 shows the average wear trail areas for each of the topographic conditions studied in this paper. For the smooth surface, the area was $2.56 \pm 0.0627 \cdot 10^{-6}$ m², while for the partially textured it was $3.84 \pm 0.3800 \cdot 10^{-6}$ m² and for the full it was $3.16 \pm 0.6300 \cdot 10^{-6}$ m².

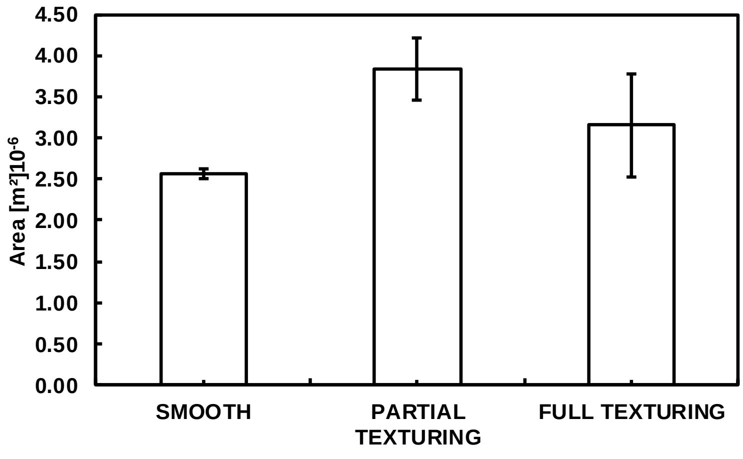
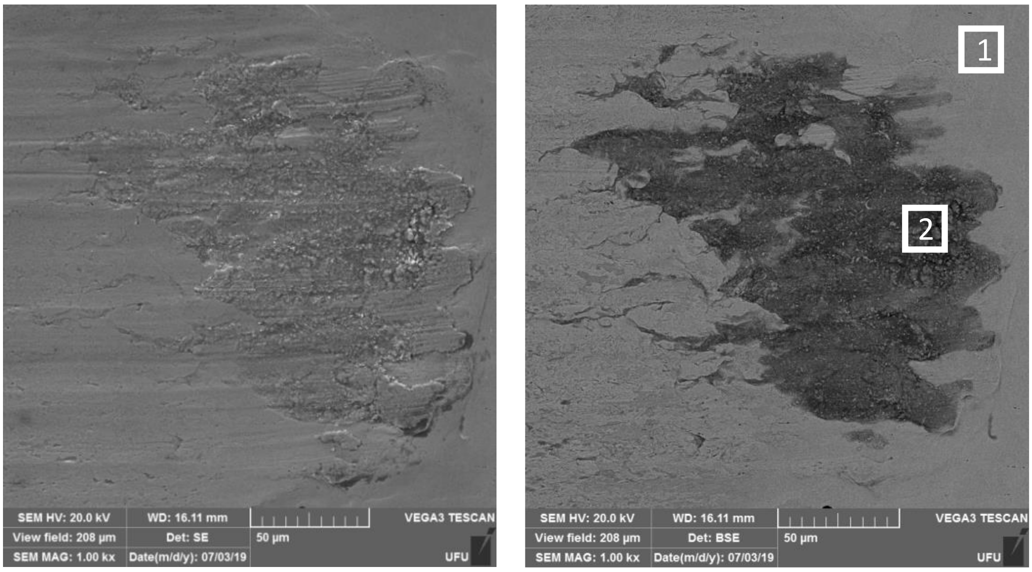


Figure 5. Average wear trail areas for each of conditions.

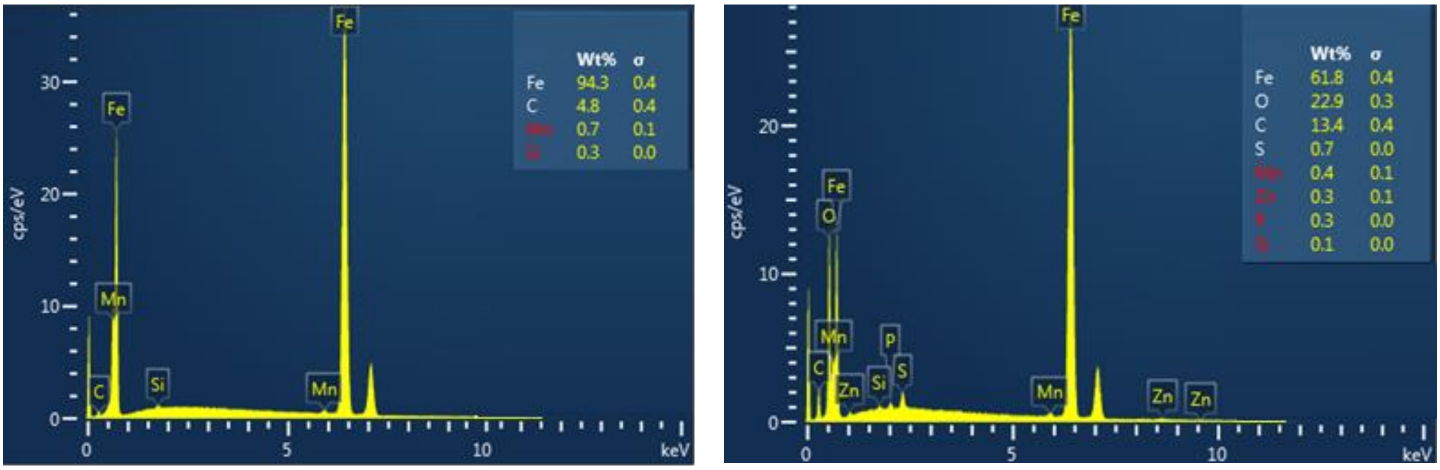
Analyzing the figure above, it can be observed that the smooth sample has the smallest wear path, while the partially textured sample has the largest (up to 69 % higher than Smooth case and 52 % higher than average wear of Full Textured Surfaces). This result agrees to the data presented and discussed in the mean coefficients of friction. Thus, it can be stated that, in the cases studied, the higher the coefficient of friction, the greater the wear and, consequently, the wider the wear scars.

For a better understanding of the studied tribossystem, SEM captures were made of the wear trails of each of the samples tested under the three conditions. Data were also acquired for qualitative analysis using the Energy Dispersive Spectroscopy (EDS) method, the images of which are below.



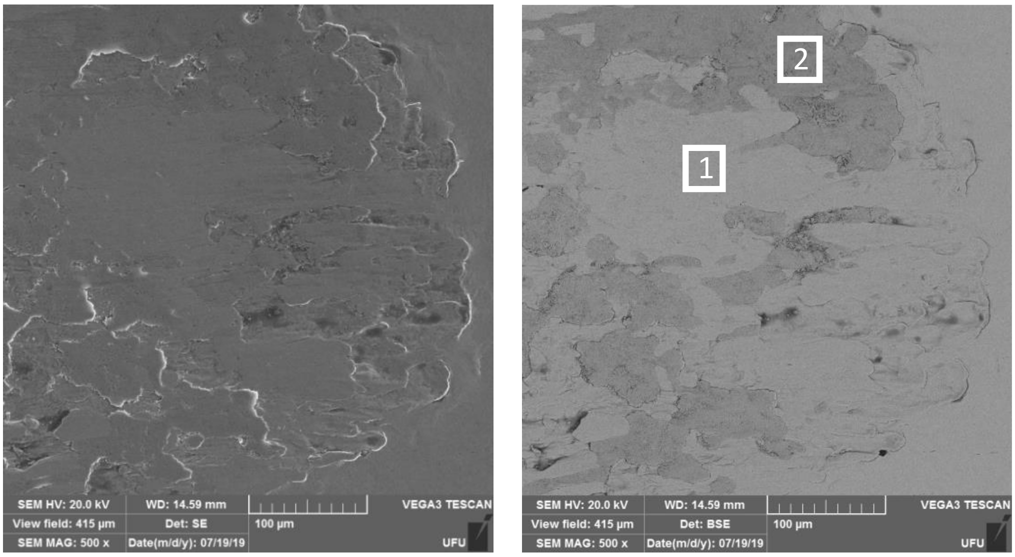
(a) (b)

Figure 6. Wear region obtained by SEM for Smooth case:
(a) Secundary electrons (SE) image; (b) Backscattered-Electron (BSE) image;



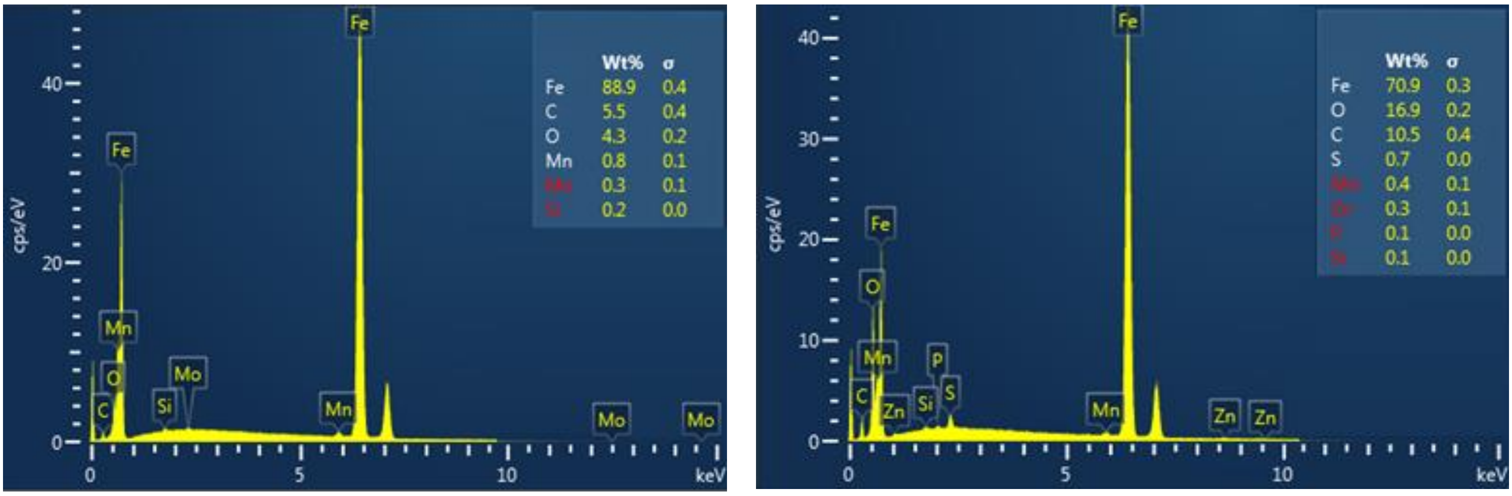
(a) (b)

Figure 7. Energy Dispersive Spectroscopy (EDS) of wear regions for Smooth case (Fig. 6):
(a) Qualitative analysis of region 1; (b) Qualitative analysis of region 2;



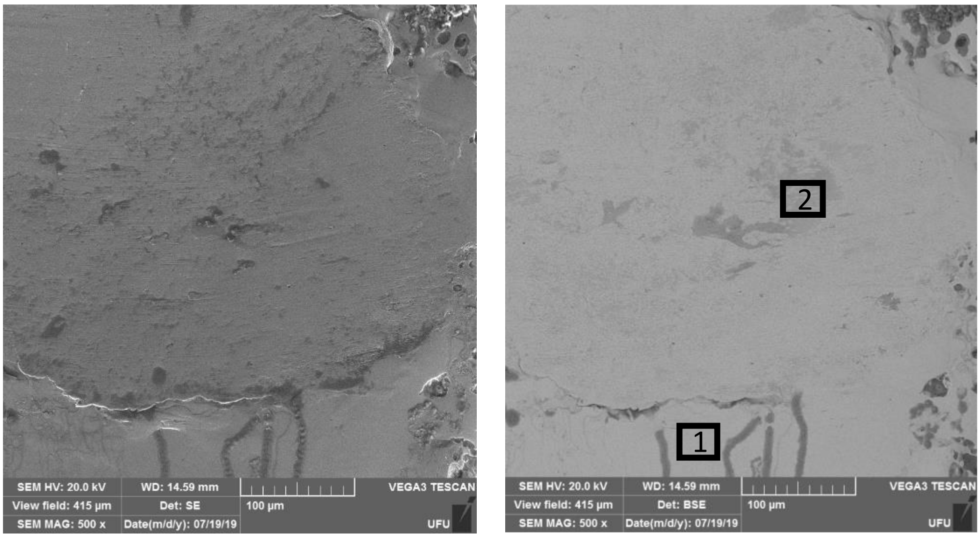
(a) (b)

Figure 8. Wear region obtained by SEM for Partially Textured case:
(a) SE image; (b) BSE image;



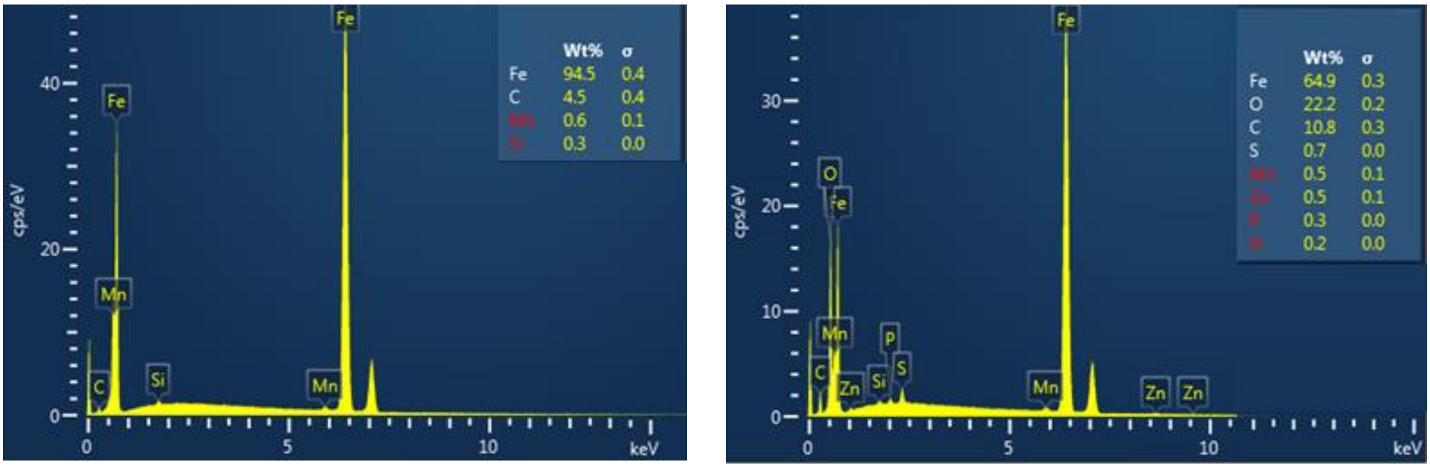
(a) (b)

Figure 9. EDS of wear regions for Partially Textured case (Fig. 8):
(a) Qualitative analysis of region 1; (b) Qualitative analysis of region 2;



(a) (b)

Figure 10. Wear region obtained by SEM for Total Textured case:
(a) SE image; (b) BSE image;



(a) (b)

Figure 11. EDS of wear regions for Total Textured case (Fig. 10):
(a) Qualitative analysis of region 1; (b) Qualitative analysis of region 2.

The above figures were specifically analyzed in the regions of the wear trail borders. Thus, it was chosen due to the conditions to which they were submitted, with low sliding speed, which possibly increased the tensions involved and the wear, being then a region of interest for the study.

In general, all topographic conditions have a large mechanical deformation at the start and end edges of the wear trails. This is more evident in the non-textured condition, since in the others, the tests ended in the texture valley, where there is no contact between the surfaces.

Looking at Figure 7, a darker region was observed, which may indicate the presence of oxide tribolayer (corroborated by the EDS of Fig. 7-b). This confirms the better performance found for the smooth sample, in this way, the presence of a larger and more stable oxide layer than the others, gave a sliding contact a lower frictional dissipation, harder, with greater resistance to plastic flow and, consequently, to abrasive wear.

4. CONCLUSIONS

Through this work, the sphere-plane alternating slip tests have been addressed the influence of topography modifications on the efficiency of lubricated concentrated contacts. In the tests, the positioning of standardized cavities in chevron shapes (texture) and their area on the study surface consisting of ABNT 1045 steel were varied. Non-textured samples were also tested and subjected to similar conditions to evaluate their performance in relation to the others.

The main results obtained through this work are listed below:

- The use of microtribometer for tribological tests was satisfactory and allowed a better understanding of textured samples in lubricated contacts;
- The tests with fully and partially textured samples, under the conditions proposed in the work, did not present satisfactory results when compared to the non-textured condition, resulting in coefficients of friction 112 % and 40 % higher, respectively, than smooth samples under similar conditions;
- Textured surfaces showed higher wear trails, which indicated greater severity of the tested conditions, which possibly generated 69 % higher wear trails (partial texture) and 52% higher than average wear value (Full Textured Surfaces) compared to non-textured samples under similar conditions;
- The formation and stability of oxide tribofilm at the ends of the wear marks proved to be very relevant, giving contact, especially that formed from the non-textured surface to the AISI 52100 (5 mm diameter) spherical steel backbone, a low friction tribosystem. and greater wear resistance.

The authors of this paper recommend for future studies:

- Conducting similar tribological tests to evaluate the performance of textured samples in the starving lubrication and dry conditions;
- To evaluate the performance of textured samples by conducting similar tests in the three lubrication regimes: hydrodynamic, mixed and boundary;
- The use of textured samples with smaller patterns and evaluate their performance under similar conditions;
- The evaluation of the influence of the dimensions and shape of counter body;

5. ACKNOWLEDGEMENTS

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