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METHOD FOR LUBRICATED SLIDING WEAR PARTICLE CHARACTERIZATION.

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Abstract. *The present work aimed to develop a methodology to classify and identify abrasive particles, based on the mechanisms and types of wear correlating their test conditions. The abrasive particles (debris) were obtained from samples obtained by block on ring lubricated sliding wear tests with ABNT 1045 steel textured specimens. The debris were extracted from the lubricating fluid by a vacuum filtration process. In order to characterize these particulates, ImageJ® software was used, which provides geometric characteristics such as area, perimeter, centroid, aspect ratio and Feret diameter, which are fundamental for their characterization. Understanding these parameters can help clarify the mechanisms of wear of sliding bearings, since the morphological characterization of the particles is of paramount importance for the understanding of the abrasive wear phenomenon.*
Keywords: *Debris characterization, Abrasive wear, Lubrication, Tribology.*

1. INTRODUCTION

The use of topography control techniques with the objective of improving the tribological performance of surfaces is a well-studied in engineering, allowing to improve the efficiency of mechanical systems, their useful life and reducing maintenance costs.

One type of superficial modification, that has been emphasizing in recent years, is the micro surface texturization, which consists in the alteration of the topography of a surface by means of the generation of regular microtextures, with aesthetic or tribological purposes.

Recent studies allow us to infer that the use of textured surfaces can reduce friction and also the rate of wear. This behavior can be understood due to four main mechanisms: lubricant reservoir; mechanism of hydrodynamic micro bearings; mechanism of retention of abrasive particles and due to the suction effect at the entrance (ETSION; BURSTEIN, 1996).

Although most mechanical components are designed to operate in the elastic regime and under lubricated conditions, surfaces that are in contact with relative motion tend to deteriorate because of hard particles that penetrate the surface interface known as debris. These particles have external origin or can be derived from the wear of the pair in contact (WILLIAMS, 2005).

The study of the characteristics of abrasive particles is of paramount importance for the diagnosis of equipment wear. (STACHOWIAK; STACHOWIAK; PODSIADLO, 2008). As the abrasive wear rate is influenced according to the shape, hardness and size of the particles present in the interface (COSEGLIO, 2009; HAMILTON; WALOWIT; ALLEN, 1966b), understanding these parameters can lead to the improvement of mechanical systems such as sliding bearings, since the characterization of the particle morphology is an important basis for the understanding of the abrasion phenomenon (PONCIANO; DA SILVEIRA, 2018).

The most common wear types found in the industry can be classified into three groups: abrasive, adhesive and fatigue. However, each of these is related to different cases and found in different components, such as gears and bearings, or even in different industry sectors, such as ore processing and mining abrasion (STACHOWIAK; STACHOWIAK; PODSIADLO, 2008).

If there are surfaces in periodic contact subject to high frequencies of vibration, such as in bearings and gears, fatigue wear can occur. These contacts are subjected to varying loads in small time intervals, and fatigue can be located on the surface of the material, leading to wear with the formation of irregular particles. In this case, the wear rate is not high, but the vibration is aggravated when the corrosion is formed (SAKA; TIAN; SUH, 1989; HONG et al., 2018).

The second case (adhesive wear) occurs when the roughness of two surfaces in contact overlaps, generating a high coefficient of friction on the surface, raising the temperature rapidly, so that wear conditions such as property of the material and lubrication deteriorate further. A four-ball test indicated that metal transfer occurs in adhesive wear, where it was observed that pieces of metal are removed from the friction surface during wear, and the debris is generally flat (HONG et al., 2018).

Abrasive wear usually occurs between a soft surface and hard asperities. In this case, the harder and more fragile asperities fragment from their substrate, move at the contact interface, causing soft surface scratches and elongated cutting debris, generating elongated debris increasing wear (HONG et al., 2018).

The present work aimed to develop a methodology to classify and identify abrasive particles, based on wear mechanisms, wear type and operating conditions. The debris were obtained from samples taken from ABNT 1045 steel textured samples, following the work of Rodrigues (2018). The abrasive particles were filtered through a vacuum filtration system and analyzed morphologically using optical microscopy techniques with the aid of ImageJ® software.

2. METHODOLOGY

The methodology used in this work can be divided into three stages. At first, the debris originating from wear tests were carried out by sliding block on ring, after which the particles were subjected to a drying and filtering process. Finally, captures were made in an optical microscope followed by a treatment of the image and its analysis via software.

2.1 Acquisition of wear particles

The particulates used in this work came from tribological tests of block-on-ring type for a non-conforming contact geometry, with tests performed for two lubrication regimes, mixed ($1 \leq \lambda \leq 3$) and borderline ($\lambda < 1$) as shown in the work of Rodrigues (2018), where λ is the ratio between the specific lubricating film thickness (h_{min}) and the combined value of the standard deviation of the roughness heights of the two surfaces in contact (σ *). In these tribological assays, the Falex® Block on Ring test machine Model 6100B tribometer was used, with a non-conforming test body, the schematic assembly of which is represented by Figure 1.

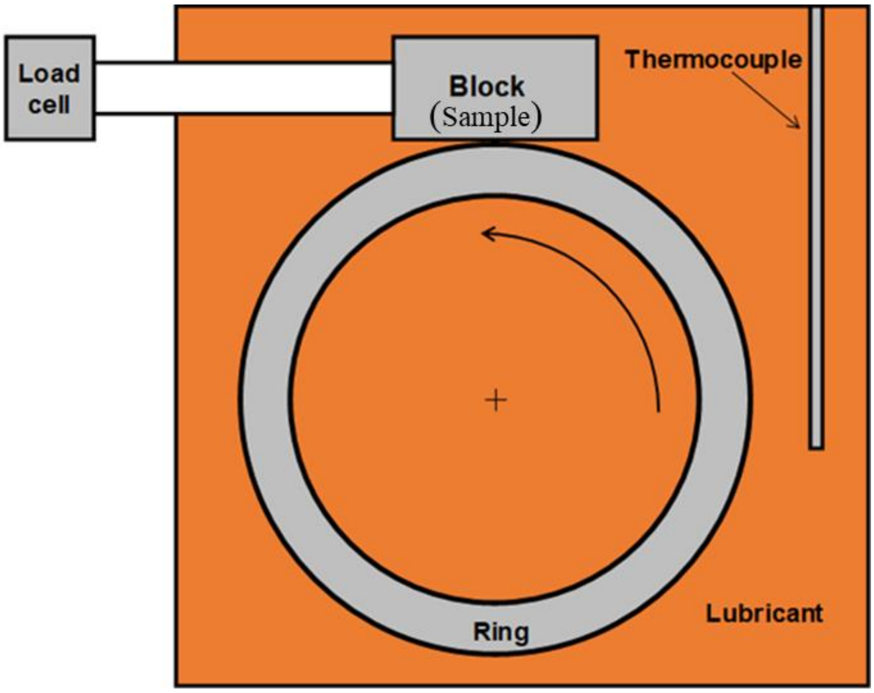


Figure 1. Representation of the Block on Ring Test. (Rodrigues 2018)

Rodrigues (2018) tested different topographic conditions, such as: surface without surface changes (Pattern); fully textured surface with textures oriented in the same direction of movement of the counter body (FTSD); fully textured surface with patterns oriented in the opposite direction of counter-body movement (FTOD); partially textured surface with textures positioned in the inlet region oriented in the same direction of movement of the counter body (PTSDI); partially textured surface with textures positioned in the outlet region oriented in the same direction of movement of the counter body (PTSDO); partially textured surface with patterns positioned in the inlet region oriented in the opposite direction of movement as the counter body (PTODI) and partially textured surface with textures positioned in the outlet region oriented in the opposite direction of movement direction (PTODO). To perform the tests, a fixed rotation speed of 1500 rpm, load of 315 N and duration of 3600 seconds was used.

After the tests were carried out, abrasive particles resulting from the test were removed and mixed with the lubricating oil (for storage) were stored appropriately in plastic containers.

2.2 Vacuum Filtration

The samples were dried and cleaned through a vacuum filter (Figure 2) in order to clean their surface impurities and allow their analysis.

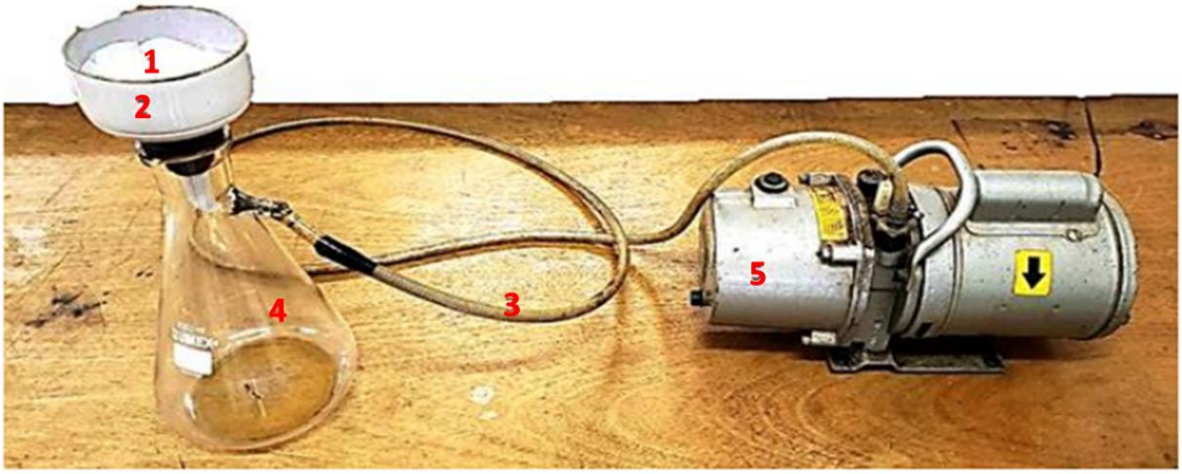


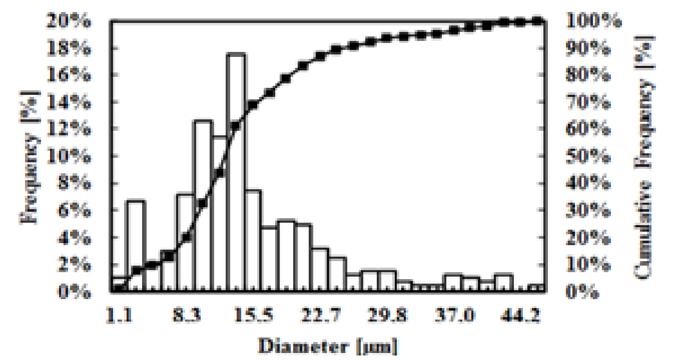
Figure 2. Schematic of the vacuum filter apparatus.

As shown in Fig. 2, the apparatus is composed of a vacuum pump (5), which aims to remove all the air that is in the Erlenmeyer (4), through a hose (3), causing the oil with (2) passes through a round cotton filter (1) with a gray content of 0.0006 kg / m², the filtered oil will be trapped in the Erlenmever (4), while the particulate will remain in the filter. After this process, the retained particulate was analyzed by optical microscopy with the aid of an imaging software called ImageJ®.

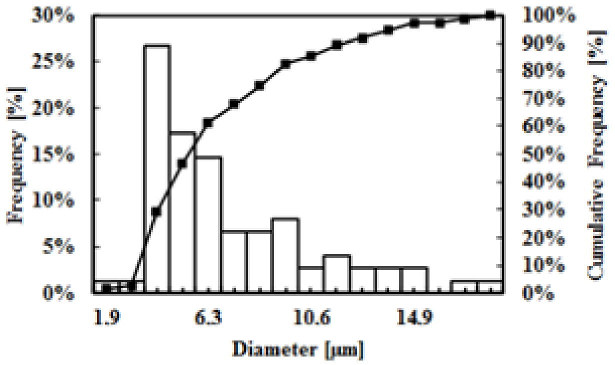
3. RESULTS AND DISCUSSION

After vacuum filtration, captures and particle image analysis were performed using ImageJ® software for image editing and processing. Samples were selected for each condition tested and, with the software, particle data were acquired as illustrated in the histograms below (Figure 3).

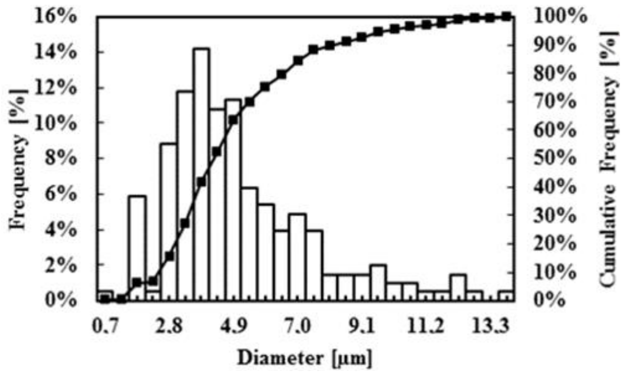
In all conditions analyzed, larger particles were found than those observed in the histograms, but they were not statistically significant, because they could be the result of agglomeration of smaller particles, beyond its low frequency of occurrence.



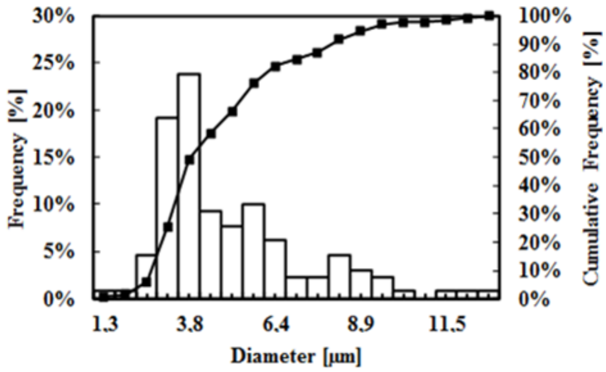
(a)



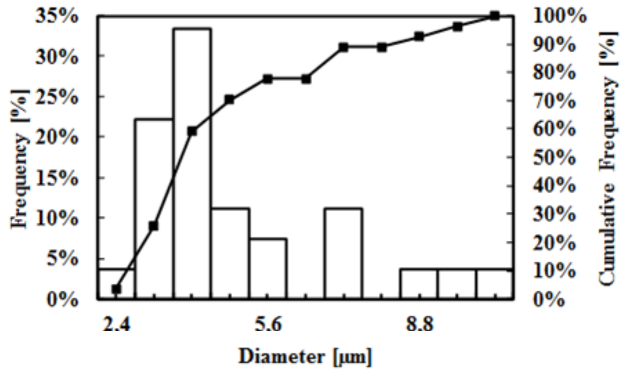
(b)



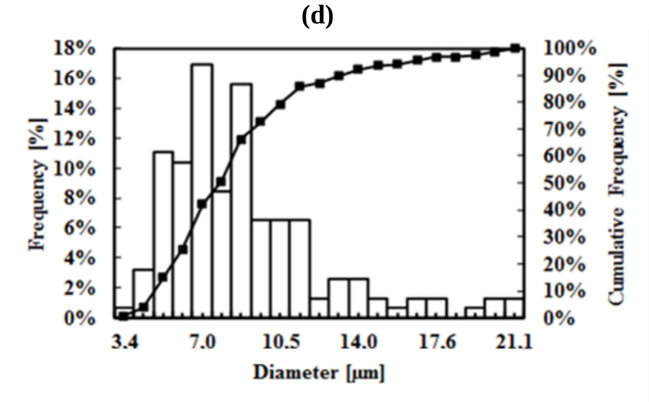
(c)



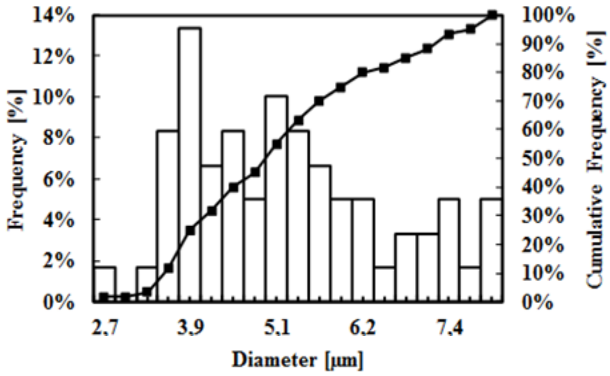
(d)



(e)



(f)



(g)

Figure 3. Wear particle histogram with diameter values as a function of individual and cumulative frequency of tested cases: a-Smooth; b- Fully Textured with textures in Same Direction of counter body slip; c- Fully Textured with textures in Opposite Direction of counter body slip; d- Partially Textured (Outlet position) with textures in Same Direction of counter body slip; e- Partially Textured (Inlet position) with textures in Same Direction of counter body slip; f- Partially Textured (Outlet position) with textures in Opposite Direction of counter body slip; g- Partially Textured (Outlet position) with textures in Opposite Direction of counter body slip

A correlation was made between the above values, more specifically the modal value of the particles for each case, and the wear values found in the Rodrigues (2018) research, whose results are listed in Table 1

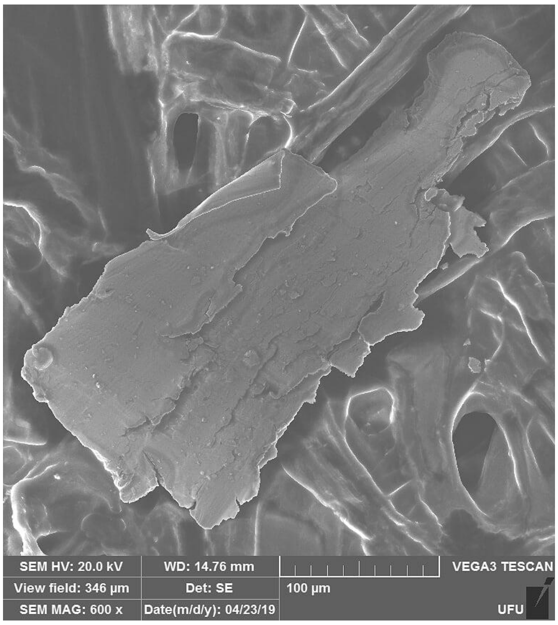
Table 1. Experimental results for wear rate for each condition tested with the modal diameter of its particles.

Sample	**Wear Rate** $(mm^3 \cdot N \cdot m^{-1}) \cdot 10^{-7}$	**Modal Diameter (μm)**
Smooth	3.871 ± 0.607	14.485
FTSD	1.138 ± 0.265	4.371
FTOD	1.856 ± 0.161	3.867
PTSDO	1.378 ± 0.343	3.816
PTSDI	1.389 ± 0.495	4.016
PTODO	1.452 ± 0.590	6.964
PTODI	2.153 ± 0.159	4.059

By relating the above histograms and comparing them with the table, it can be inferred that surface texturing helped to reduce the wear rate and also the diameter of the abrasive particles when compared to the non-textured surface. This was probably due to the presence of textures that reduced abrasion severity in lubricated contact, probably due to the mechanisms mentioned by Etsion and Burstein (1996). As a consequence, there was less material removal due to the reduction of the material severity, demonstrated by the reduction in the coefficient of friction and consequent reduction in the plastic deformation involved in the process, reducing the formation of abrasive particles and their consequent size when comparing the particles. of almost 15 μm found in the tests.

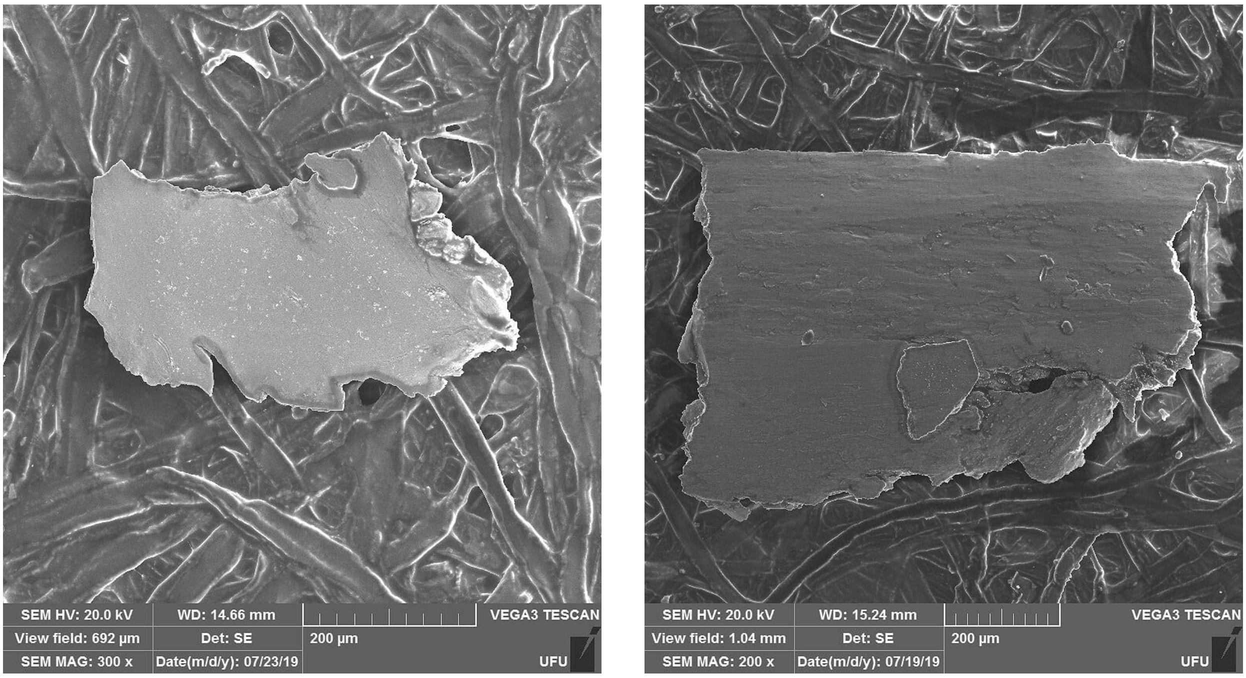
When analyzing the textured samples, it is possible to observe that the parameters vary as the topography varies (fully or partially textured), the direction of movement of the body, and the position of the textures (inlet or outlet region). For these, it is noticeable that the influence of the orientation of the partial textures in relation to the movement of the body is very relevant, because in the case of PTSDO there is a reduction of debris diameters of approximately 45.20% in relation to PTODO, which resulted in a lower wear rate

For the tests with partial textures, whose patterns are in the inlet position, there was a 1.07% reduction in the diameters compared to the PTODI case. To better analyze and understand the significant difference in the wear rate, the abrasive particles were subjected to scanning electron microscopy (SEM) analysis, the images of which can be observed below.



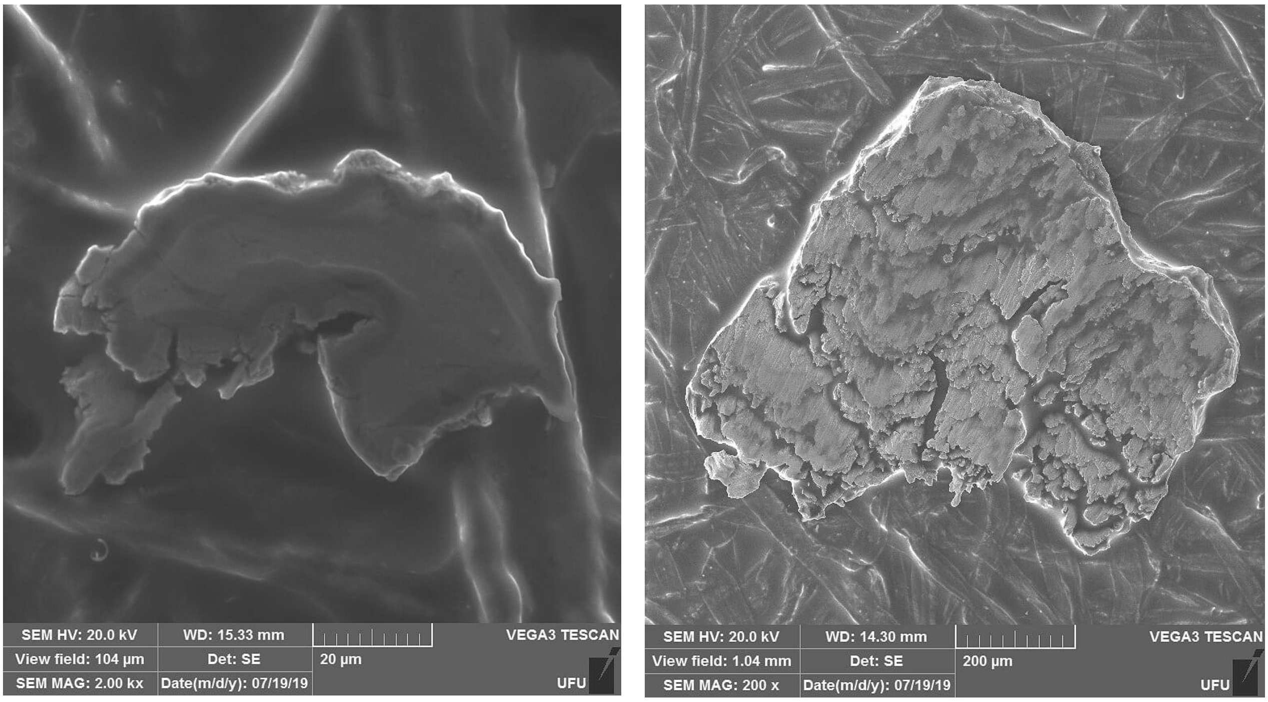
(a)

Figure 4. SEM of a debri particle from the test as a non-textured specimen (Smooth)



(a) (b)

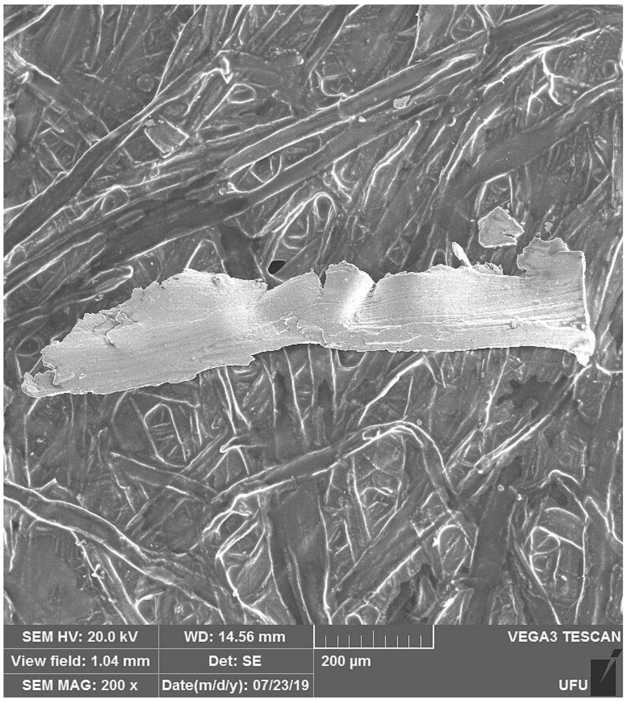
Figure 5. SEM of a debri particle from the fully textured specimen test: a - same direction of counter body(FTSD); b- opposite direction of counter body (FTOD)



(a) (b)

Figure 6. SEM of a debri particle from the partially textured specimen test (same direction of counter body): a - Outlet position (PTSDO); b- Inlet position (PTSDI);

(a)



(b)

Figure 7. SEM of a debri particle from the partially textured specimen test (opposite direction of counter body): (a) - Outlet position (PTODO); b- Inlet position (PTODI);

When analyzing Figure 7-b, is noticeable a particle with a different morphology in relation to the others, possibly indicating higher abrasive severity on contact, with predominance of mechanisms such as microcutting, resulting in a higher wear rate for the tribosystems of the imposed conditions in PTODI.

For fully textured surfaces with chevrons oriented in the same direction of movement as the body, it was not possible to relate the diameter of the debris to the wear rate. This is because when comparing with the fully textured surfaces with opposite-direction oriented textures, the sample size was not large enough to describe the population to be analyzed.

4. CONCLUSIONS

The analysis of images from optical microscopy with the aid of the ImageJ software enabled the qualitative and quantitative characterization of the abrasive particles from lubricated block-on-ring tests.

According to the analysis of the results, it was possible to compare and relate the wear rate of the samples with the diameters of the abrasive particles. It was observed that the non-textured surface generated particulates with higher diameters when compared to the samples with some type of topographic alteration, which consequently presented high rates of wear. It was also possible to observe that for the textured samples, the orientations of the partial textures in relation to the movement direction of the against body influenced the wear rates. It is noteworthy that for the condition PTODI, which presented the second highest wear rates, presented differentiated morphology in relation to the other debris, which may mean a greater abrasive severity in the contact between the body and counter body, possibly a microcutting mechanism predominating.

Analyzing the SEM images, it was possible to correlate the influence of contact severity, based on the higher wear rates presented in the tested condition and in the case of samples without topographic alterations, we found particles in the form of long microchips, confirming the increase in severity of the acting wear mechanism.

5. ACKNOWLEDGEMENTS

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