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THE ROLE OF FRICTION COEFFICIENT OF GRAY CAST IRON MEASURED IN DRY AND LUBRICATED CONTACTS

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Abstract. Surface texturing is the formation of micro-cavities on the surfaces according certain shapes and patterns. In lubricated systems, those micro-cavities promote hydrodynamic effects that potentially reduce friction and wear. For example, different texturing techniques are applied in cylinders of internal combustion engines and in sliding bearings. In the present, chevron patterns were produced by maskless electrochemical texturing (MECT) on gray cast iron. A microtribometer was used to evaluate the reciprocating wear test. This equipment was specially developed to perform a high sensitive reciprocating sliding wear test. The counter body was a 5 mm sphere of AISI 52100 steel. The input parameters for experiment was frequency, normal load and test time. The efficiency of the presence of texture, tests will be conducted in smooth and textured surfaces, in dry and lubricated conditions.

Keywords: Microtribometer, reciprocating sliding wear, triboscopy.

1. INTRODUCTION

The superficial texture present several characteristic appreciable from the tribological point of view (Pettersson, U., Jacobson, S, 2004 e2003). The regular microcavities decrease the contact area and consequently the wear between the superficies. The microcavities can retain abrasive particles (Varenberg; Halperin; Etsion, 2002) generated during the relative motion of dry or lubricated contact superficies, besides serving how lubricant reservoir (Saeidi Et Al., 2016), being responsible for assist training of lubricant film. In this context, the texture can be employed to decrease the wear in various systems, such as: sliding bearings, internal combustion engines, etc.

To analysis the behavior a tribological pair aiming at the predominant wear mechanisms in the system, a microtribometer is used. Such equipment is characterized by presenting a proper load for measuring the friction and wear properties of both dry and lubricated materials under specific loading conditions, as velocity, temperature and time (Satchowiak ;Batchelor, 2005).

The aim of this work is to investigate the influence of texture produced by the maskless electrochemical texturing method (MECT) in lubricated contacts. The texture was made in gray cast iron samples. The sliding wear tests were carried out in a microtribometer using an AISI 52100 steel ball with 5 mm in diameter as counterbody.

2. EXPERIMENTAL METHODS AND MATERIALS

The counterbody used in this work were 5 mm diameter beads of AISI 52100 (Figure 1), with hardness 7.57 GPa. The nominal chemical composition is found on the Table 1.



Figure 1 Image of the counterbody and counterbody holder

Table 1 Chemical composition of steel AISI 52100 (percentage by weight).

Element	C	Si	Mn	P	S	Cr
Percentage (%)	0.994	0.27	0.32	0.013	0.005	1.49

The specimens used in this work were gray cast iron blocks with molybdenum (Mo) and graphite refining, with 100% perlite matrix, and the hardness is on the Table 2 . The format of the samples are blocks in the follow size 35x15x8 mm for the texturized and width = 35 mm; length = 25 mm; height = 8 mm for the smooth surface. All the samples were ground with sandpaper mesh 600. For the lubricated tests, the lubricant was a commercial hydraulic oil kinematic viscosity (ν) varied from 185.03 mm².s⁻¹ at 20 °C to 9.86 mm².s⁻¹ at 100 °C.

Table 2 Hardness and mechanical strength of gray cast

Hardness [HB]	LR [Mpa]
217	283

The textures were developed by the same process of Parreira et al., (2012) apply, in Figure 2 the scheme of the apparatus used for the MECT is shown.

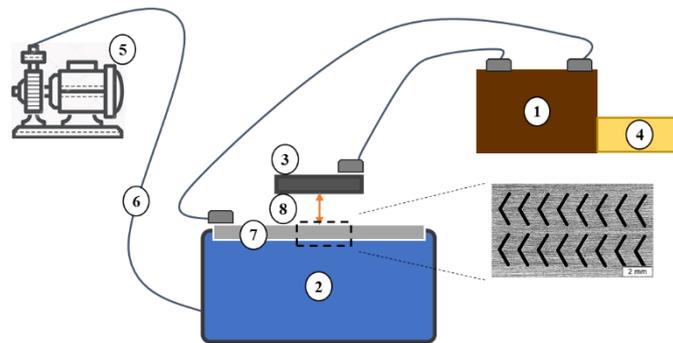


Figure 2 Experimental apparatus used in MECT.

The total texturing time was 60 s, with maximum voltage value of 7.5 V. This parameterization was extensively studied in previous studies (Silva, 2016) and the test parameters were chosen considering the best performance for gray cast iron. The deterministic texture pattern was chevron, as the Figure 3.

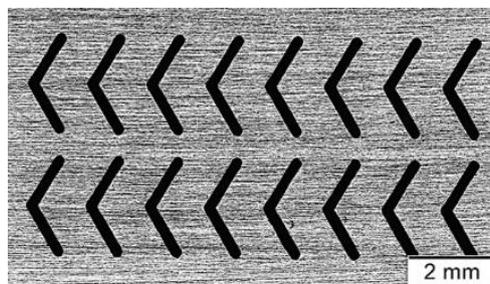


Figure 3 Mask used for non-conventional machining of texture (RODRIGUES,2018).

The reciprocating sliding wear tests were performed using a specially developed test rig called Microtribometer (Figure 4(a), Dutra, 2017). The equipment has a system of coordinate table, an engine connected by a mechanical

system that enables the reciprocating movement. The contact force is imposed by a piezoelectric actuator and measured by a load cell with sensibility of 0,020 N. Figure 4(b) shows how the lubricated test was realized.

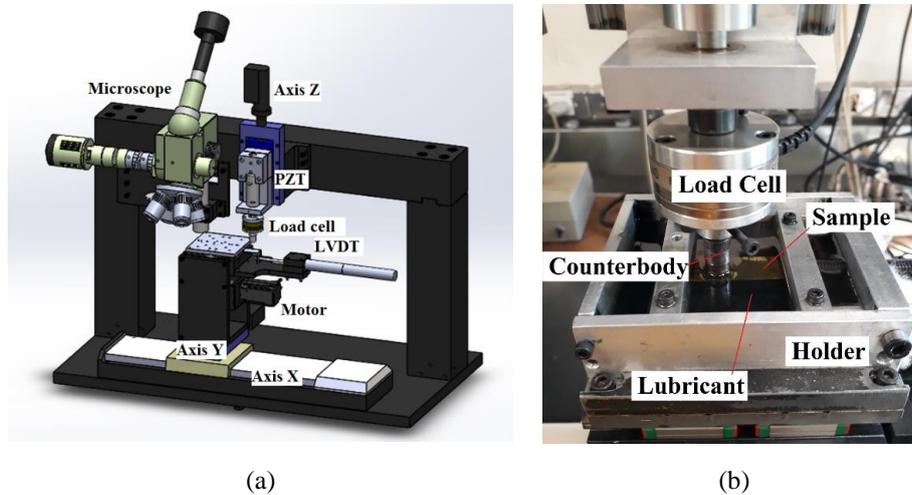


Figure 4 (a) Microtribometer (b) lubricated test.

A program was developed in LabView[®] to control the microtribometer, where the main parameters of the test are selected, such as strength, time and frequency (Barbosa, 2018). The type of sliding choose was reciprocating sliding, as exemplified on Figure 5.

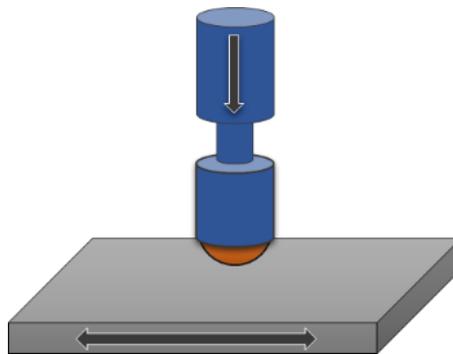


Figure 5 Reciprocating sliding.

The parameters to perform the test was 5 N of normal force, 0.5 Hz of frequency, 10 mm of amplitude of sliding and the duration of the test was 60 min. Were performed four types of tests with three replicates each test, the first smooth surface without lubricant, second textured surface without lubricant, third smooth surface with lubricant and the fourth textured surface with lubricant.

For a quantitative analysis as the triboscopic map and the medium friction coefficient during the test was used a program with assistance of Matlab[®] software, adapted by DUTRA (2018). Already for the qualitative analysis was used an optic microscope. And the chemical study of the surface was by electron microscope (SEM) and energy dispersive spectroscopy (EDS).

3. RESULTS AND DISCUSSION

3.1 Sample with smooth surface

Figure 6 has the micrography of the test without lubricant and is possible to see that the wear track is well defined and constant, the same is observed on the counterbody where was formed a circle.

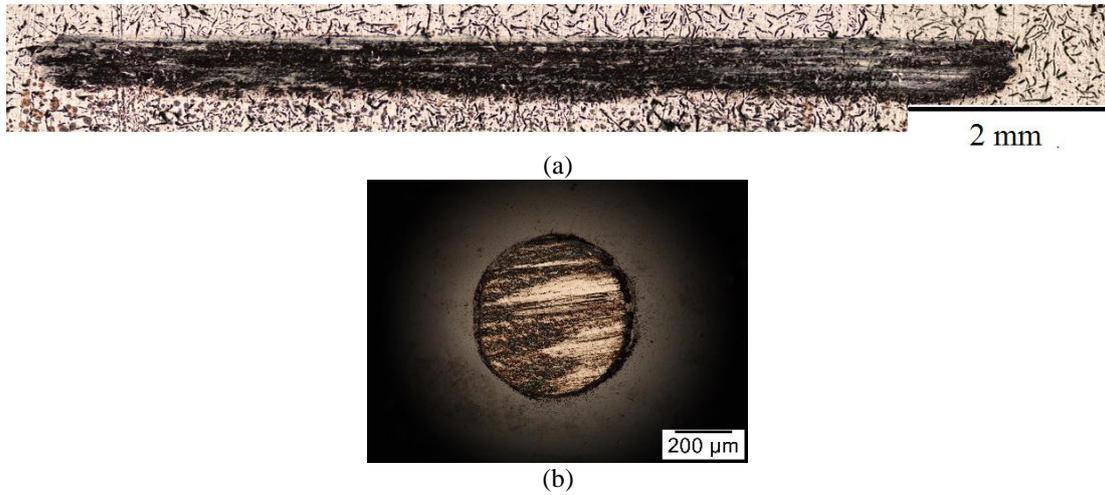


Figure 6 Optic micrography of the (a) sample and the (b) counterbody of dry test.

The SEM images show that the wear track is not total uniform (Fig. 7(a)), and on the counterbody (Fig. 7 (b)), it is focused on the border. The EDS images shows details of the composition of possible tribo layer, in the specimen (Fig. 7(c)) as much as the counterbody (Fig. 7(d)) have the same composition, iron oxide, showing that had adhesion of material.

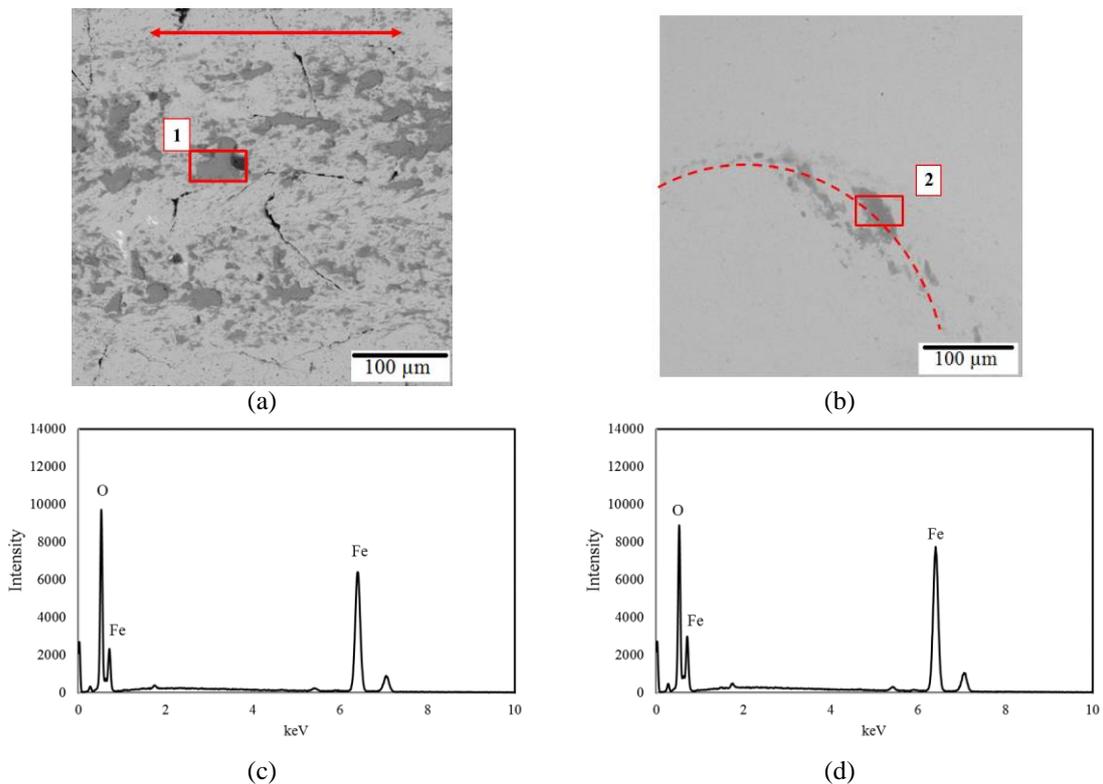


Figure 7 SEM of the (a)sample and the (b)counterbody. And t the EDS analysis of (c) sample [1] and (d) counterbody [2]. The arrow shows the direction of sliding.

The lubricated test has a drastic reduction of the dimension of the wear track (Fig. 8(a)), a decreasing of 66.7 % when compared with the dry test. Do not have the tribo layer formation, how is possible to see on the SEM analysis (Fig. 8(c)(d)). On the counterbody (Fig. 8(b)) have a lower plastic deformation while on the wear track the direction of sliding is almost imperceptible, showing that the wear was the least possible.

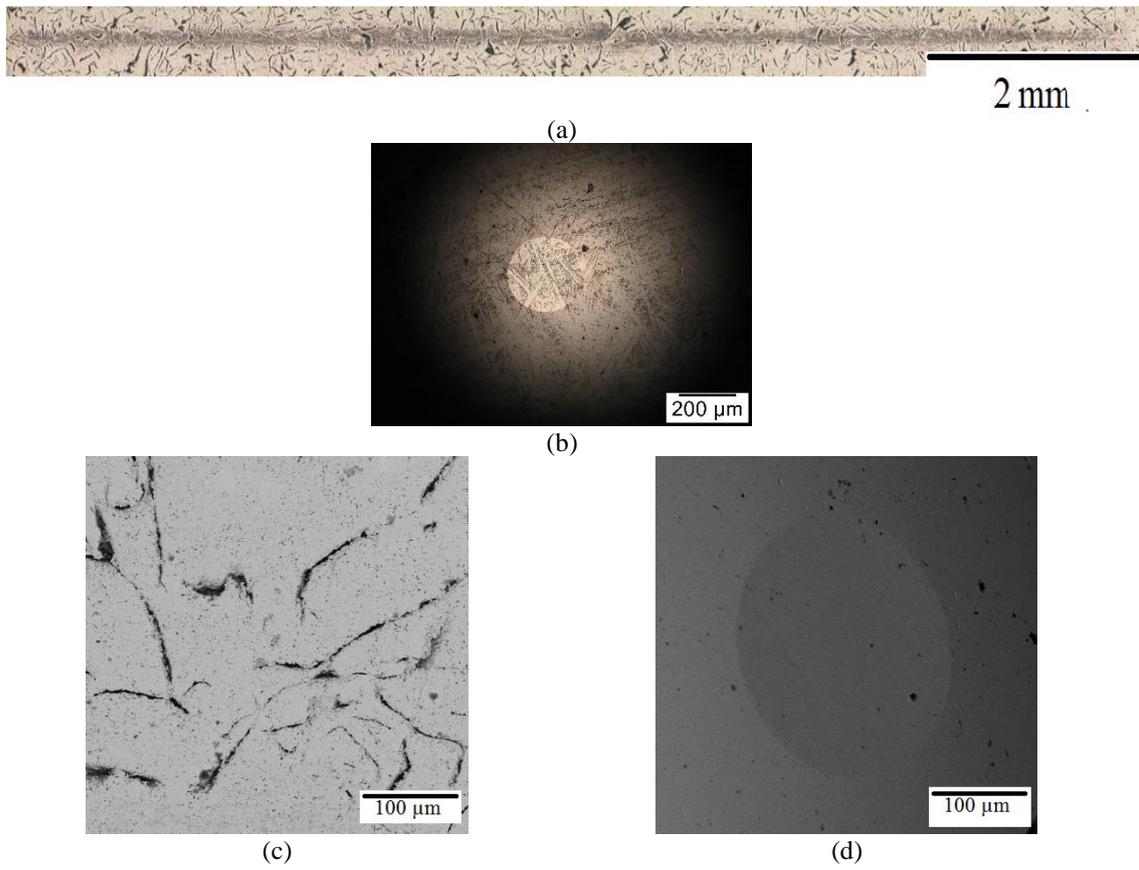


Figure 8 Optic micrograph of the (a)sample and (b)counterbody, SEM analysis of (c) sample and (d)counterbody in the lubricated test.

Observing the wear track and the mark on the counterbody, for the lubricated test, the lubrication regime was mixed lubricant, because had some mechanical interactions between opposing surface, the load was supported part by the lubricant film and the other by the asperities (Hutchings; Shipway, 2017). In the triboscopic map of the dry test, (Fig. 9(a)) it is possible to see that the friction coefficient had a gradual increase and was constant throughout the length of the track, already in the test with lubricant (Fig. 9(b)) had lower friction coefficient and were constant throughout the length of the track and in the time.

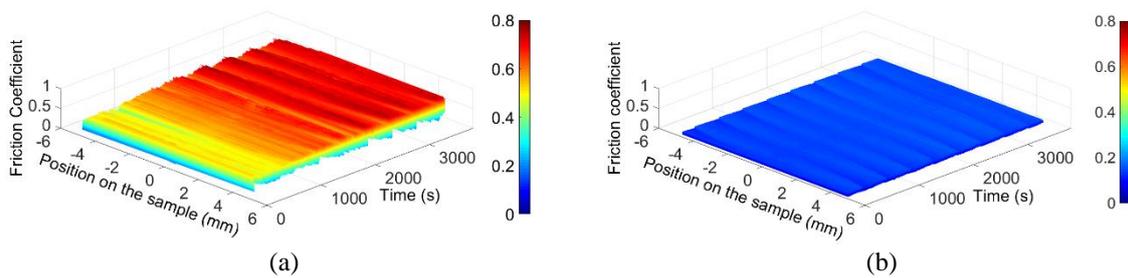


Figure 9 Triboscopic map of smooth surface of the test (a) without lubricant and (b) with lubricant.

3.2 Sample with textured surface

It is observed that the wear track showed in the Figure 10(a) is not uniform, on the valley of texture do not had the effective contact between sample and counterbody, just had contact among Chevrons. The wear track on the counterbody (Figure 10(a)) was not a circle and is possible to see the accumulation of material in the extremity, especially in the direction of sliding.

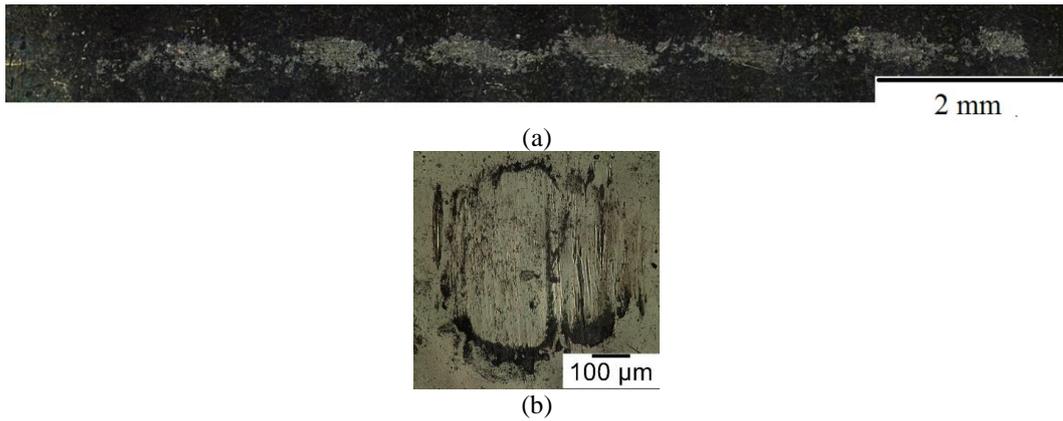


Figure 10 Optic micrography of the dry test, (a) sample and (b) counterbody.

By the SEM is possible see that the MECT make the graphite flakes to be exposed (Figure 11(a)) and with the EDS analysis (Figure 11(c)) this effect can be observed by the presence of carbon (C). In the wear track, it is possible to see the presence of oxygen and iron giving evidence of oxide formation (Figure 11(d)). The transfer of sample material to the counterbody (Figure 11(b)) is tried with the ESD analysis by the presence of carbon (Figure 11(e)).

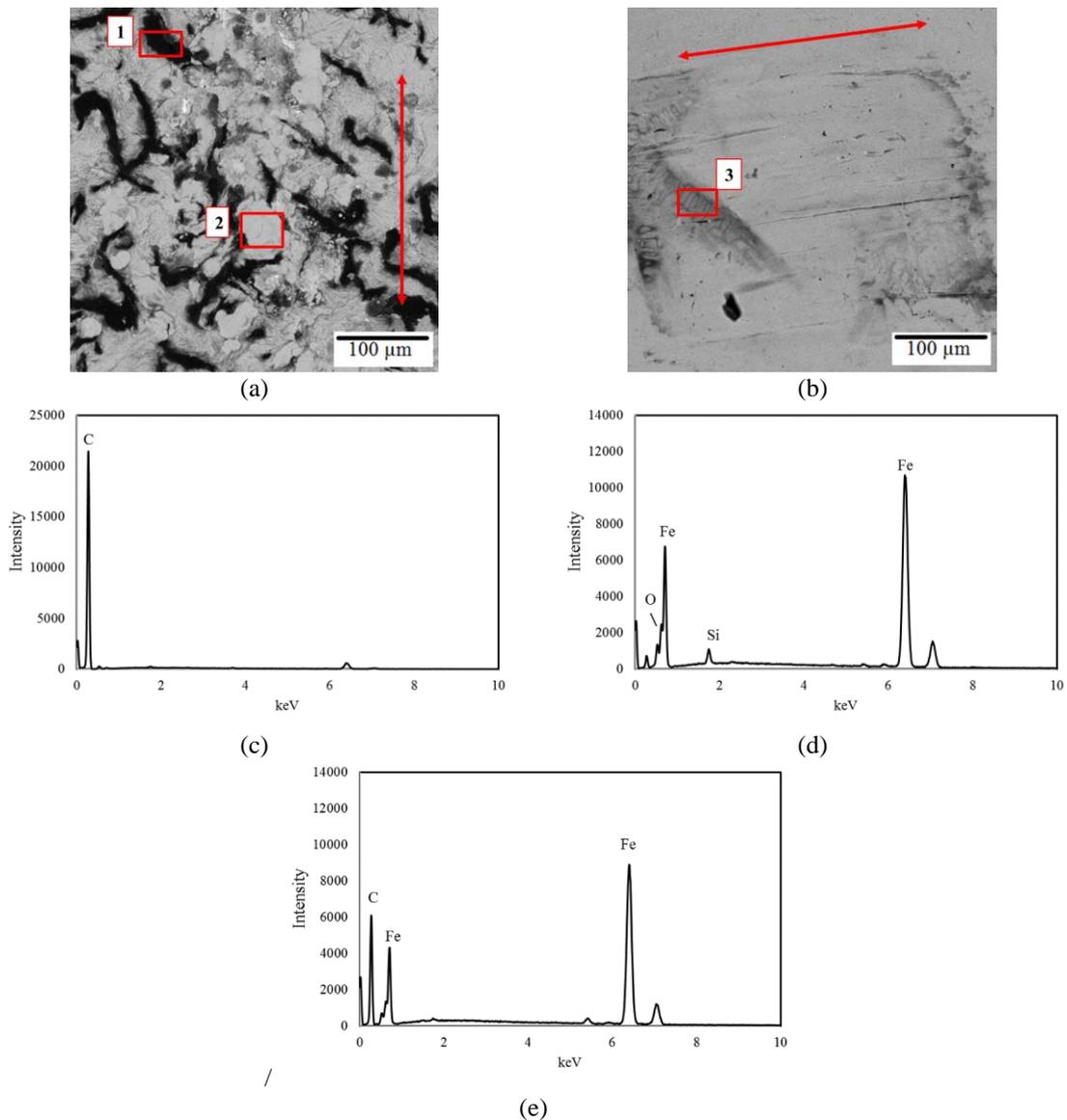


Figure 11 SEM of the (a) sample and (b) counterbody, and the EDS analysis of point (c) 1 and (d) 2 on the sample and (e) 3 on the counterbody. The arrow shows the direction of sliding.

The wear track was very similar to the dry test, only having the formation of wear track among the Chevrons and in the counterbody the wear was not circular having risks in the direction of sliding.

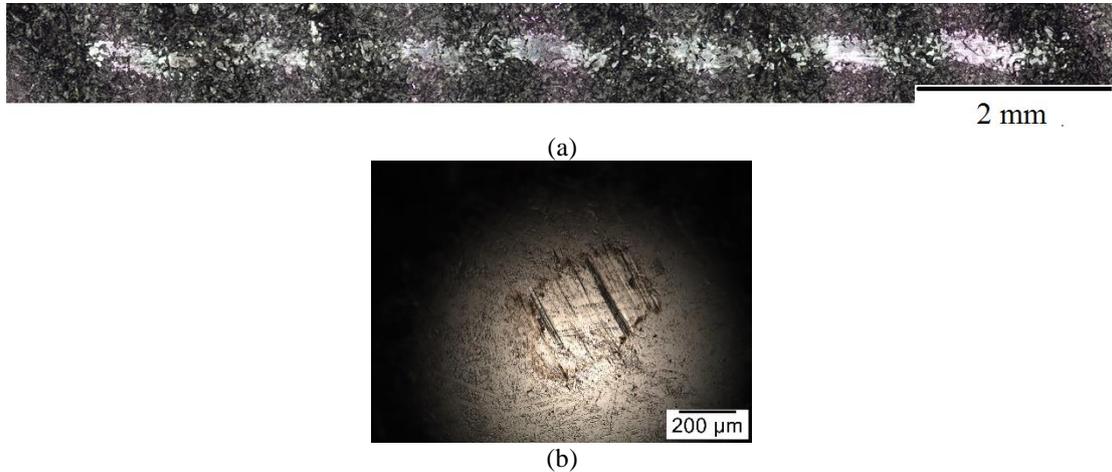


Figure 12 Optic micrography of lubricated test, (a) sample and (b) counterbody.

As in the dry test the lubricated test had the presence of oxygen and iron indicating a possible oxide formation. Along the wear track is noticeable the presence of carbon by the analysis of EDS. The appearance and the distribution of wear track is more uniform when compared with the dry test. On the counterbody is not possible identify the presence of any element of the sample, by the analysis of EDS, showing that do not had transfer.

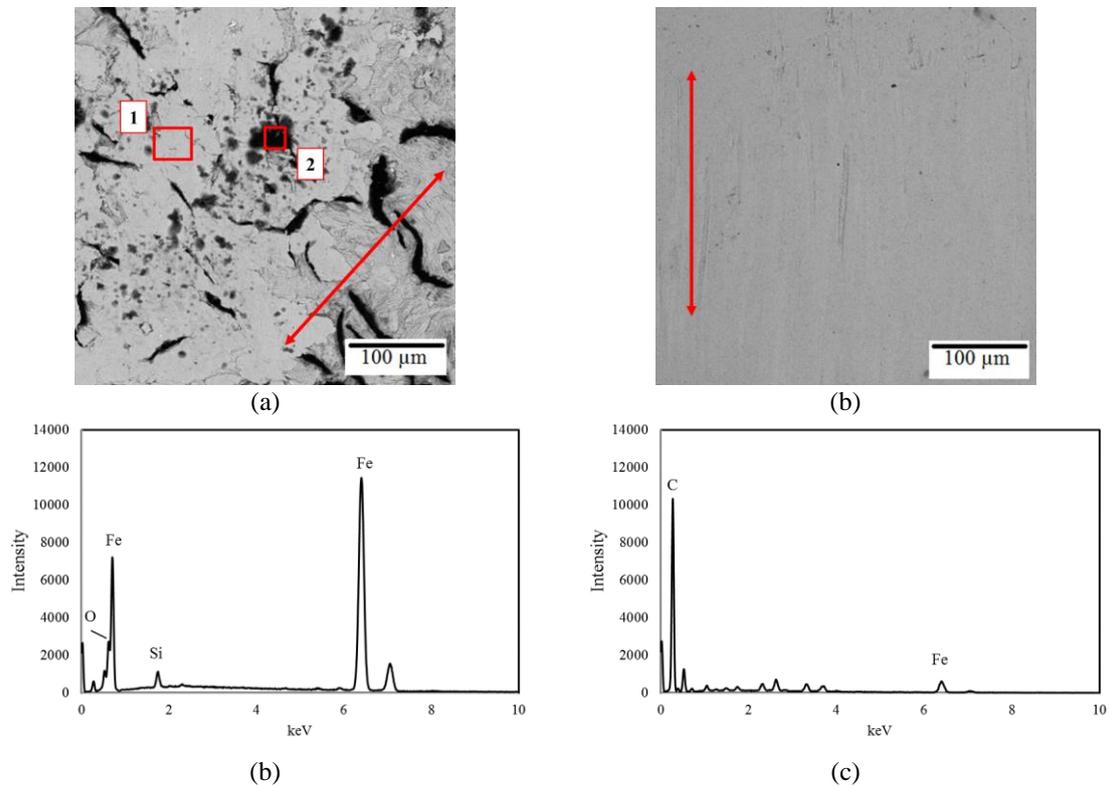


Figure 13 SEM of the (a) sample and (b) counterbody, and the EDS analysis of point (c) 1 and (d) 2 on the sample. The arrow shows the direction of sliding.

The presence of texture is evidenced by the triboscopic map (Fig. 14), where the friction coefficient decayed in the valleys of the texture. The local friction coefficient is higher in the lubricated test (Fig. 14(b)).

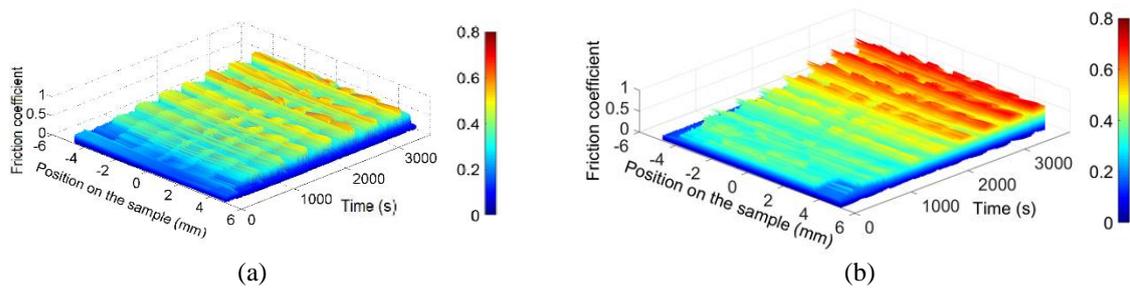


Figure 14 Triboscopic map of textured surface of the test (a) without lubricant and (b) with lubricant.

3.3 Friction coefficient

Figure 15 (a) shows the medium friction coefficient of all tests. The smooth surface in dry condition (blue) stands out to be the higher friction coefficient, when compare this test with the others has the decrease at least of 50 % of the friction coefficient. Both, textured and smooth surfaces, without lubricant (blue and orange, respectively) showed the benefits of the surface texturing, with a reduction of 70 % in the friction coefficient. Already in the lubricated tests (yellow and gray), the texture application (yellow) does not become advantageous, being more expensive.

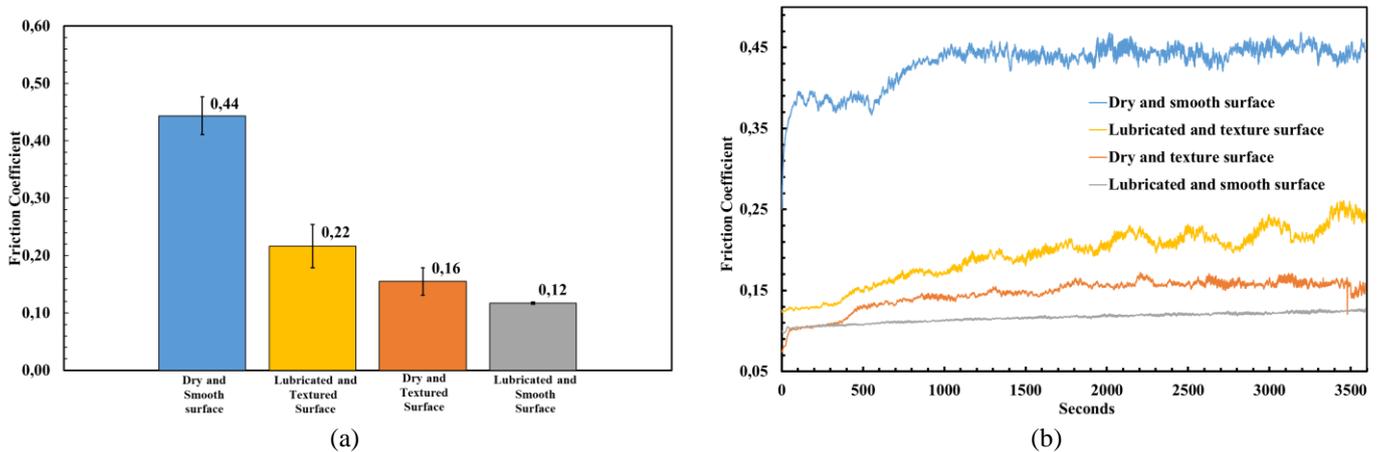


Figure 15 (a) Medium friction coefficient of all tests and (b) Coefficient of friction during the test.

The Fig. 15(b) shows how, the behavior of the coefficient of friction during the test. For the smooth surface in dry condition, we can observe that after 1100 s, the test achieve the steady state. For lubricated and smooth surface, this occurs in the first 200 s. For the textured surface, coefficient of friction is more unstable because has more variables, when the test has lubricant this unstable became expressive.

4. CONCLUSION

The purposed methodology evidenced the differences in friction coefficient and wear behavior of gray cast iron samples measured in dry and lubricated contacts.

In a cast iron sample, when the friction coefficient is analyzed, the presence of texture or lubricant make decrease at least 60 % of this coefficient. But when the two was combined it does not become advantageous. Textured samples presented the best performance of cast iron samples was in dry tests. This fact was related to a stable tribolayer formation due to the presence of graphite. Lubricated regime presented a higher friction coefficient with evidences of a partial tribolayer formation.

For the application of texture in systems with inputs similar to those simulated in this work, as the load, velocity and material, the advisable will be a dry regime, because when used lubricant does not bring great benefits when compared wit dry one.

The higher friction coefficient of dry smooth surfaces was related to the formation of particles in the contact.

5. REFERENCES

- Barbosa, L. M., “Ortomicrotribômetro”, 2018. Uberlândia. Tese de Mestrado – Universidade Federal de Uberlândia.
- Dutra, R. M. A.. “*Controle e validação de um microtribômetro instrumentado para observar a evolução da marca de desgaste via microscopia óptica.*” 2017. 85f. Dissertação de Mestrado. Universidade Federal de Uberlândia. Uberlândia.
- Hutchings, I.; Shipway, P. *Tribology: Friction and Wear of Engineering Materials*. [s.l.] Elsevier, 2017.
- Parreira, J. G.; Gallo, C. A.; Costa, H. L. “*New advances on maskless electrochemical texturing (MECT) for tribologica purposes. Surface and Coatings Technology*”, v. 212, n. 0, p. 1-13, 11// 2012. ISSN 0257-8972
- Silva, L. R. R., “*Texturização superficial de cilindros automotivos*”,2016. Uberlândia. Tese de Mestrado –Universidade Federal de Uberlândia.
- SATCHOWIAK, G. W.; BATCHELOR, A. W. “*Engineering tribology*”. 3. Elsevier Butterworth Heinemann, 2005. p. ISBN 0-7506-7836-4.
- SAEIDI, F. et al. “*Effect of surface texturing on cast iron reciprocating against steel under starved lubrication conditions*”: A parametric study. *Wear*, v. 348–349, p. 17–26, fev. 2016. <https://doi.org/10.1016/j.wear.2015.10.020>
- VARENBERG, M.; HALPERIN, G.; ETSION, I. “*Different aspects of the role of wear debris in fretting wear. Wear*”, v. 252, n. 11–12, p. 902–910, jul. 2002. [https://doi.org/10.1016/S0043-1648\(02\)00044-3](https://doi.org/10.1016/S0043-1648(02)00044-3)

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