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COB-2019-2276 AISI 4140 X H13 STEEL SLIDING WEAR BEHAVIOR

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Abstract. *This paper aims to present to the analysis about the resistance to wear by dry a steel x steel pair when normal force variation occurs. The method used to perform the sliding wear tests was the pin-on-disk test, keeping the pin and disk hardness constant (340 and 380 HV, respectively), with 05 tests for each pin-to-disk pair, as a function of 02 (two) normal load values (35 N and 70 N). To perform the tests were used ABNT 4140 steel pins with 5 mm diameter for 15 mm in length and ABNT H13 steel discs measuring 76 mm in diameter by 4 mm in thickness. The study showed that with the increase of normal force the analyzed factors also presented growth, the pins, mainly, with the applied load of 70 N suffered a very high increase reaching a difference of 120% in the level of hardening when compared with the material before the test.*

Keyword: *Coefficient of friction, Sliding wear, Normal load.*

1. INTRODUCTION

Modern research has established that there are four major forms of wear: abrasive, adhesive, corrosive and surface fatigue. Erosion and micro-oscillatory motion are also often declassified as forms of wear. (Rabinowicz E.,1995).

Sliding wear of steels occurs in a wide variety of applications in the industry. (VIÁFARA, 2010).

The consequences of friction and wear are diverse. Friction and wear cost money, in the form of loss of energy and loss of material, in any system and mechanical devices (SANTOS, 2013).

Mechanical failures of components and especially tribological faults, such as wear and friction failures, are one of the main causes for stopping and unavailability of production systems (Holmberg and Folkesson, 1991; Kimura, 1997).

It is common to relate the wear resistance as a function dependent only on the hardness of the materials involved, however, there are other characteristics that also influence the wear, such as: the type of crystalline structure, the existence of precipitates in the metal matrix and its homogeneity, as well. like, the nature of them. (SCHÖPF, 2011)

The sliding wear process occurs under sliding conditions between contacting bodies. It can be lubricated or dried. However, there are cases where an abrasion occurs in the slip wear process. Every wear process results in changes in the body when considered in its initial state, either by mass changes or by changes in its surface characteristics (e.g

topography, surface free energy). A difference between the wear processes is the mechanisms responsible for these changes. For slip use, the mechanisms are: adhesion (plastic deformation and rupture of body parts), such as tribochemical revisions, surface fatigue and even abrasion (LEITE, 2010).

H13 steel is developed for hot metal injection and extrusion molds such as aluminum, zinc and copper, as well as for hot forming in presses and hammers. Due to its chemical composition, H13 steel has: Great temperability, great heat softening resistance, good wear resistance at elevated temperatures, excellent toughness, good machinability in the tool steel category, excellent resistance to thermal shock due to continuous heating and cooling, causing the emergence of thermal cracks to be reduced (NADCA, 1997).

AISI H13 steel is part of a class of medium carbon steels with additional alloying elements that help maintain hardness and wear resistance at high temperatures. All grades contain chrome; grades H20 to H39 contain tungsten and H42 contains 5wt% Mo. All hot work steels are deeply hardenable. Typical applications involve use at high temperatures, such as forging and extrusion tools, dummy blocks, etc. (ASM, 1992).

SAE 4140 steel has characteristics such as high temperability, poor weldability and reasonable machinability; In addition, this steel has good torsion and fatigue strength and hardness in the temperate condition ranges from 54 to 59 HRC (677 to 579 HV). This steel is used in parts that require high hardness, strength and toughness, being of recurrent use in the manufacture of automobiles, airplanes, crankshafts, connecting rods, gears, guns, screws, oil equipment, among others (ROCHA, 2004).

The characteristics pointed by ASM (1992) and Rocha (2004) show that the interaction between AISI H13 and AISI H13 steel is of interest for better analysis of material wear, considering the situations in which they are used in the industry.

The further study of the tribological phenomena facilitates and clarifies the way in which the development of the industrial health of the mechanical systems should be treated, through the quantification of parameters and systematization of prevention methods for tribological failures through laboratory studies, both in the dynamics of systems as well as the responses of the metallic materials themselves. In that way, the research is important because the type of test used in this work, pin-on-disk, is relevant, the application of the same in the industry is commonly seen, especially in equipment where the contact is continuous as in machining materials and wire drawing processes.

2. MATERIALS AND METHODS

The working methodology of the experiments was divided into two phases, the first consisting of tests performed at the Polytechnic School of the University of São Paulo (USP), where all the stages of data collection for the analysis were performed.

The pins used in the tests, acquired in the temperate condition (with hardness around 440 HV), were standardized to obtain the average hardness of 340 HV, with 5 mm diameter by 15 mm long proposed by ABNT 4140 high grade steel screws. resistance. for the tests. The discs used in the tests were obtained from an ABNT H13 round steel bar (tool steel), measuring 76 mm in diameter by 4 mm in thickness, which were heat treated to obtain hardness (380 HV). Figure 1 shows a pin and a disc after the test.



Figure 1. Pin and disc used for the test. Source: GPEMAT GROUP.

The specimens after the tempering heat treatment, with austenitization at 1050 ° C for 1-hour, varying temperatures and tempering times to obtain hardness (380 HV) were machined by measuring the hardness of the bodies. The hardest body being (softer): ABNT 4140 steel pins and the hardest body: ABNT H13 steel discs. Before the pin-on-disk test, the equipment was calibrated after ten (10) test steps, with 05 tests for each pin-on-disk pair, as a function of 02 (two) normal load values (35 N and 70 N).). Thus, the values of friction force and coefficient of friction as a function of time

for each test were calculated using a specific program and the mass loss for each specimen was measured. ASTM G-99 (G-99-90, 1992).

Figure 2 shows a schematic illustration of the pin on disk assay. The equipment works by a shaft coupled to a geared motor that provides an induced rotary motion in a disk that has. The machine, developed by the group, has a lever arm for fixing the pin, which can be placed in contact with the rotating disc, which rotates at a constant rotation of 40 rpm and a constant tangential speed of 0.1 m / s. It also has the functionality of applying the normal load on the pin by means of the lever arm, either by circular plates or deadweight. Finally, the equipment features load cells to measure normal load

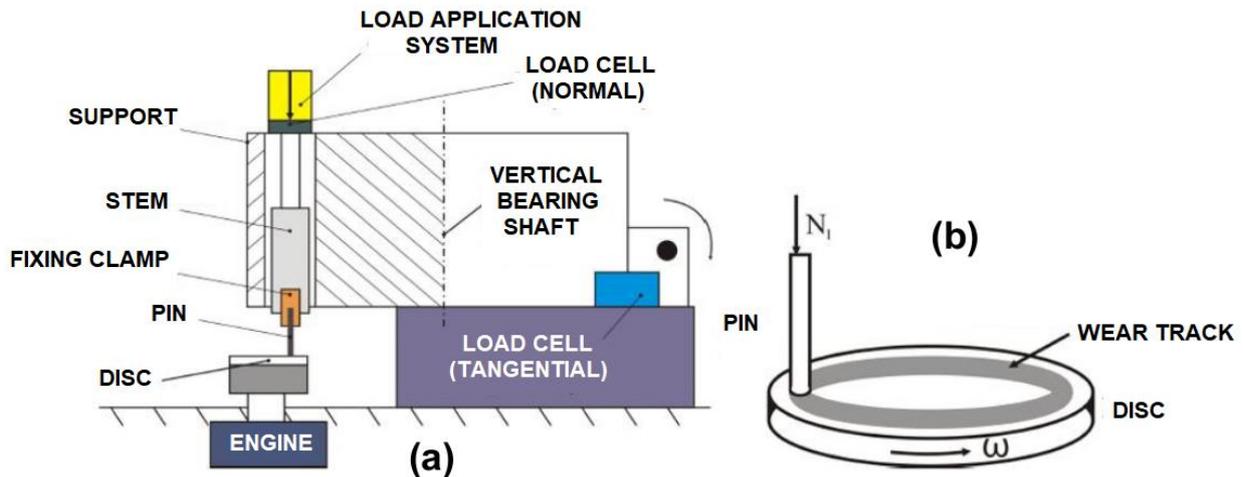


Figure 2. a) Illustrated equipment and contact diagram and b) Disc pin test. Source: VIÁFARA, 2010.

The basis of the activities in the second phase was the Federal University of Pará and the Emílio Goeldi Museum (CNPq), where the collected data and the analysis of the obtained results were treated.

The wear rate of the samples was calculated, so that the effect of wear on the bodies subjected to the slip tests was measured by mass loss measurements of the worn pins and discs with the aid of a special scale with an accuracy of 0.00001 g. Microhardness measurements on worn and untested surfaces occurred on a 50 g load digital microhardness, manufactured by Microtest S.A being the model HV-1000B , meter to stipulate the hardening suffered by worn parts of the surface in the tests.



Figure 3. Equipment used in microhardness measurements. Source: GPEMAT GROUP.

Figure 4. shows a schematic of the four regions where microhardness measurements will be made on the pins and discs.

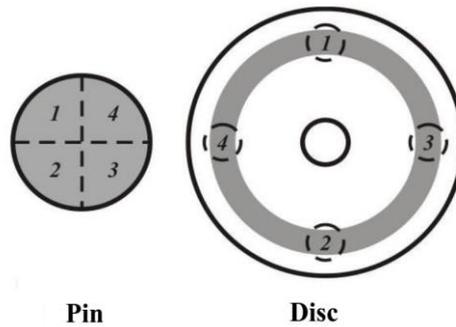


Figure 4. Illustrative scheme of microhardness measurement regions. Source: VIÁFARA, 2010.

Using the SEM (Scanning Electron Microscope) feature there was the characterization of the worn surfaces, in which it is possible to perceive the change in the wear behavior of the surfaces, with the normal force variation applied.

3. RESULTS AND DISCUSSIONS

The results of the tests were used to determine parameters for the research such as: friction coefficient curves as a function of time, mass loss curves, wear rate curve, micrographs of SEM surfaces, profiles and roughness parameters and microhardness (HV) measurements. From these data, the behavior of the specimens was analyzed by applying different loads.

The running-in periods are observed at the beginning of the interaction between two surfaces, and a permanent friction regime, in which the coefficient of friction tends to be constant. The figure 5 the graph shows all the friction coefficient curves as a function of slip time (3600 s) for the normal load of 35 N and disc and pin hardness of 380 HV and 340 HV, respectively.

It can also be observed that the running-in periods, which happens at the beginning of the interaction between two surfaces, which occurs in the first 400s in the graph and the permanent friction regime, characteristic of the slip wear tests. The running-in period was considered to mark the beginning of the stagnation of the increasing coefficient of friction behavior. The figure 5 also shows friction coefficient curves versus slip time (900 s) for the normal 70 N load.

The decrease in slip time for the 70 N load compared to the 35 N load was due to the high pin wear rate during the test, thus avoiding the total loss of the tested pin.

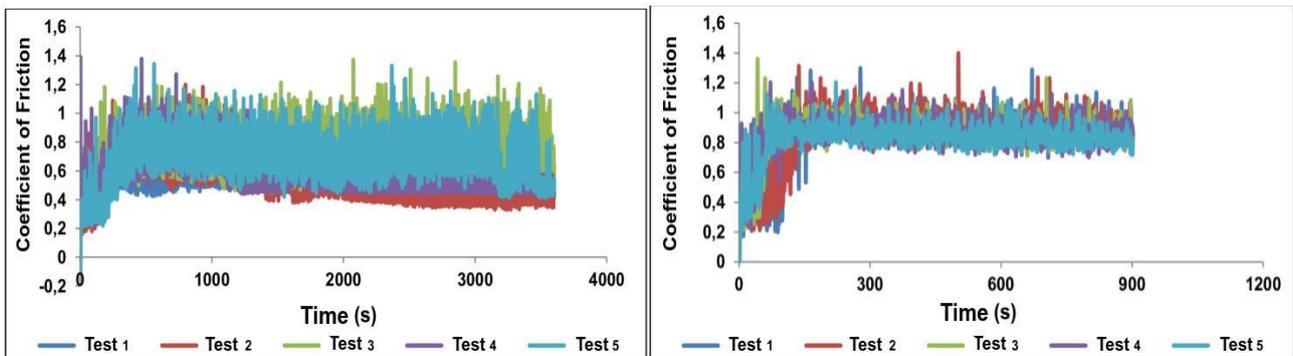


Figure 5. Friction coefficient curves as a function of slip time under a normal load of 35 and 70 N, respectively.
 Source: GPEMAT GROUP.

For a more detailed analysis only one test will be referenced for each load. Figure 6 shows that with the increase in applied load, from 35 N to 70 N, the softening period becomes shorter, the permanent friction regime presents higher values of coefficient and presents less variation. It is also observed that the amplitude of the friction coefficient becomes smaller with the increase of the applied load, as shown by a marked region, in the figure below.

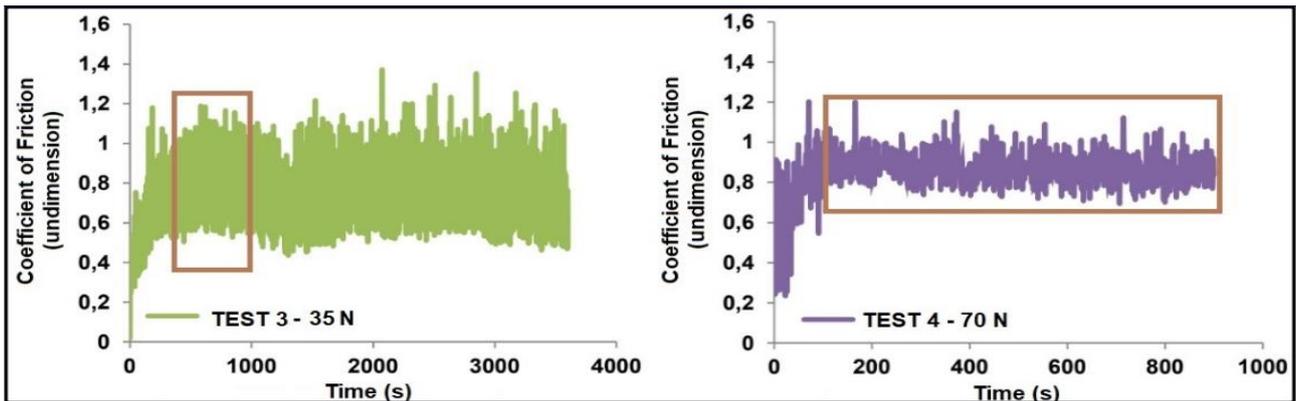


Figure 6. Friction coefficient values for the tests 3 and 4 as a function of the slip time under a normal load of 35 N and 70 N respectively. Source: GPEMAT GROUP.

Table 1 summarizes the calculated steady state friction coefficient values for each test, as well as the mean and standard deviation, then Fig. 7 presents a graph comparing these values.

Table 1. Average steady state friction coefficients for each trial studied.

PIN 340 HV X DISC 380 HV		
TEST	Coefficient of Friction	
	35 N	70 N
1	0,50	0,90
2	0,53	0,92
3	0,75	0,87
4	0,57	0,87
5	0,70	0,85
AVAREGE	0,61	0,88
STANDARD DEVIATION	0,11	0,03

Source: GPEMAT GROUP.

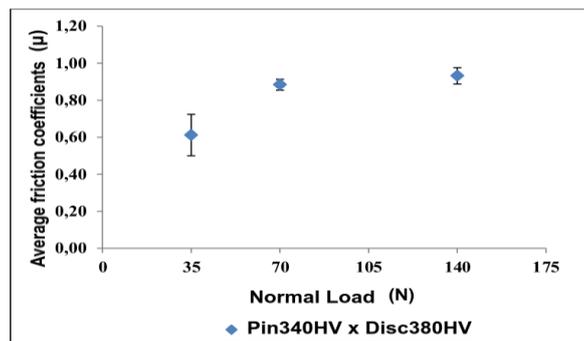


Figure 7. Comparison of the mean steady state friction coefficients for each essay studied. Source: GPEMAT GROUP.

3.1 Wear

The wear effect on the samples subjected to the sliding tests is represented by the mass loss measurements of worn pins and discs. For the normal load of 35 N the slip time was 3,600 s. The wear is very pronounced during test 4 for the 70N load, double that used in test 3, caused the slip time to be reduced to 900s. Because the normal load of 70 N, twice that used in test 3, was too high for the test, it was decided to reduce the slip time to 900 s for the other four tests.

The graphs in Fig. 8 show the results of average mass loss (in mg / m) for the pins and discs, after five repetitions of slip tests, for the two normal loads applied. It is observed that the graphs show similar behavior, the loss of mass for the pins is greater than in the discs. With the force of 70 N the loss of mass of the pin begins to get larger values with respect to the disk.

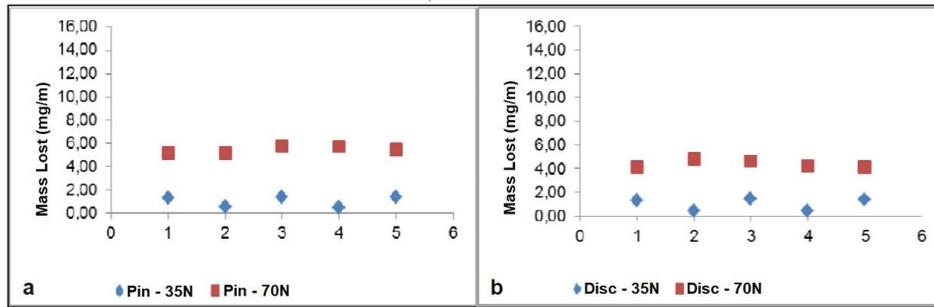


Figure 8. Results of loss of mass of the pins (a) and disks (b) after the five sliding wear tests, with a hardness of 380 HV. Source: GPEMAT GROUP.

The table 2 summarizes and shows the mass loss values for each test as well as the mean and standard deviation. In them one can see the variation in each condition, confirming the behavior presented in the previous graph.

Table 2. Mass loss results (in mg / m) from all pin 340 HV x tests380 HV disk for the three normal loads applied.

MASS LOST (mg/m) OF PIN (340 HV) AND DISC(380 HV)				
TEST	Load 35 N		Load 70 N	
	Pin	Disc	Pin	Disc
1	1,35	1,35	5,17	4,17
2	0,55	0,46	5,19	4,83
3	1,38	1,44	5,79	4,61
4	0,53	0,42	5,75	4,25
5	1,40	1,42	5,48	4,18
Average	1,04	1,02	5,48	4,41
Standard Deviation	0,46	0,53	0,29	0,30

Source: GPEMAT GROUP.

3.2 Analysis of worn surfaces

The study of the surfaces of the specimens was done by means of the Scanning Electron Microscope (SEM). A pin-to-disk pair was used for each test condition. In these images it is seen how the change in the wear behavior of the surfaces is affected with the increase of the normal force applied.

Figure 9 shows images of the SEM of a pin-to-disk pair, it can be seen in the images of the pins the plastic deformation marks that are better evidenced (a) in the image, in the increase of the load the image (b) shows besides the plastic deformation also formation of lateral edges (c) and (d) removed in the secondary electron mode (se) shows larger expansions of the wear region with the variation of the applied load.

The surface of the disk (e) shows the presence of particles removed from the (softer) pin together with plastic deformation marks, less evident than on the surface of the pin. With normal force growth the disk surface (f) shows much more pronounced adhesion and plastic deformation marks.

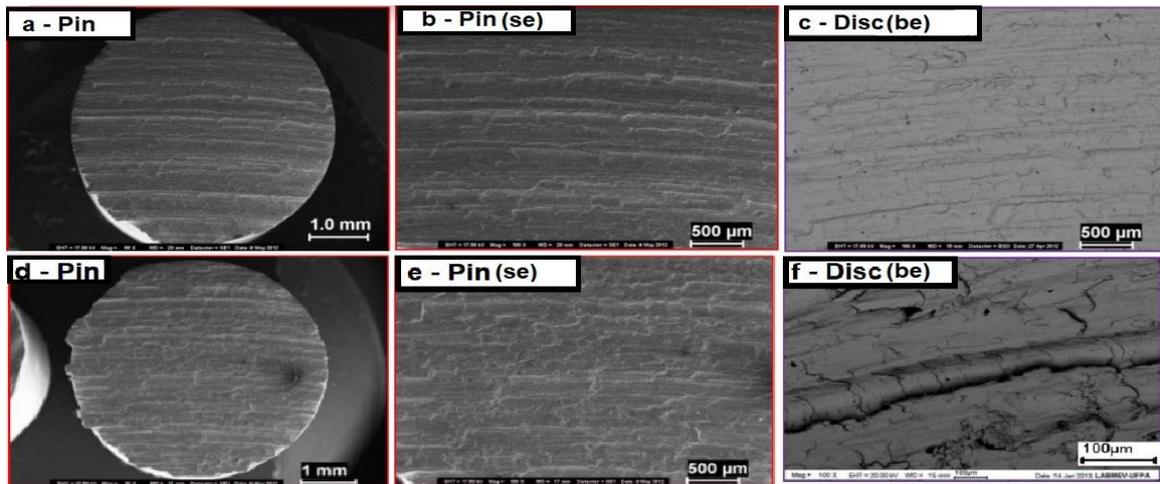


Figure 9. SEM images of the worn surfaces of a 340 pin x 380 HV disk pair, normal load of 35 N and 70 N, (a) and (b) pin surfaces at different loads. Images of the pin on secondary electrons in (c) and (d). Images of the disk in backscattered electrons (f) and (g). Source: GPEMAT GROUP.

For briefly show how wear affects slip on the tested surfaces, a comparative table was constructed in Fig. 10 SEM micrographs highlighting the main differences between the wear mechanisms acting on the pins and discs.

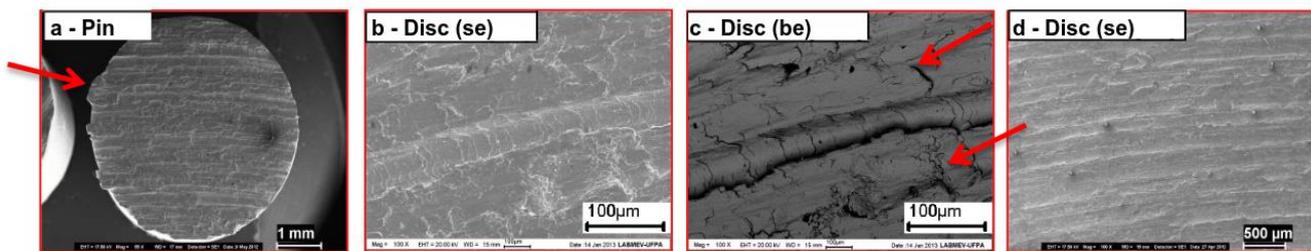


Figure 10. Comparison of SEM micrographs of worn surfaces. (a) 70 N load tested pin; (b) 70 N load-tested disc (secondary electron mode); (c) Test disc with a normal load of 70 N (backscattered electron mode); (g) 35 N load-tested disc (secondary electron mode). Source: GPEMAT GROUP.

Analyzing Fig. 10 Clearly observe it is the main differences in the micrographs. Micrographs “a” and “b” have a pin and a disc, respectively, from the same assay. There are strong marks of plastic deformation, typical of a severe wear mechanism, creating edges on the sides of the pin (red arrow) and marked wear marks on the disc. Other important features are shown in micrograph “c”. This is a backscattered electron mode disk image, in which it is possible to perceive cracks in the micrograph of deformation (red arrow), probably caused by the continuous metallic contact between the pin and the disk, at a high normal load (70 N). The micrograph “d” is from a standard 35 N load-tested disc where plastic deformation marks and small adhesion particles can be observed.

3.3 Microhardness Measurements

The worn surfaces were characterized by microhardness measurements on the wear tracks. Fig. 11 (a) shows a microhardness plot as a function of the applied normal load. The microhardness values for the normal load 0 N correspond to the values in the regions of the specimens that did not undergo the tests, so that if it were possible to compare how much the hardness was modified after the wear.

The graph of Fig. 11 (a) shows that the microhardness values of the pins are close to those of the disks and that they have increased with normal increasing load applied. This increase in hardness may be related to a cold plastic deformation.

In order to make a comparison of the magnitude of the hardening on the worn surfaces, it was stipulated the increment of the microhardness in percentage terms. The results showed that the disc had a microhardness higher than that of the pin in the two normal loads applied, although the pin had more hardening (average of 101%) than the disc (average of 45%) in all applied loads. In addition, it is observed that the pins have a greater hardness variation than the discs for the normal loads applied.

Figure 11 (b) shows the graphic of the pin and disk hardening plot for each normal load applied on the 380 HV hard disk, the results were calculated by measuring the hardness before and after the test, the hardness variation is the work hardening. It is believed that the pin presents a greater hardness variation when compared to the disc because it was excessively bent during its test cycles, being exposed beyond its design parameters.

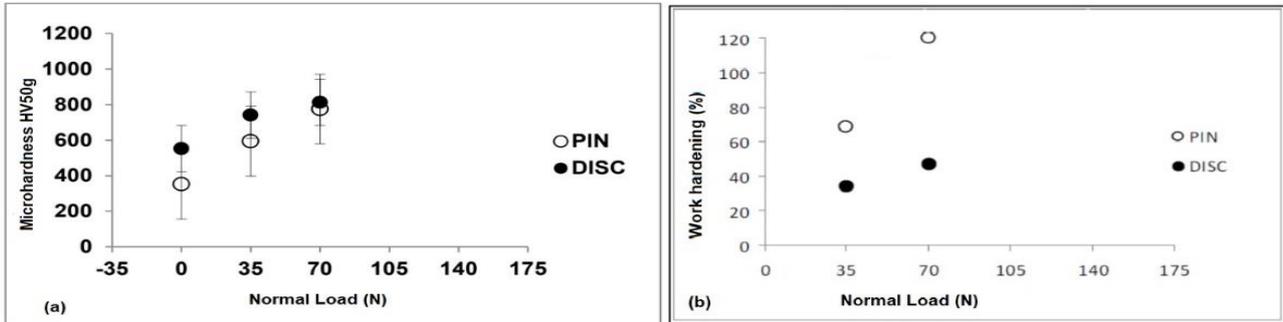


Figure 11. Microhardness graph of the surfaces of the pin 340 HV x 380 HV disk as a function of the normal load (a) and variation of the hull on the surfaces of the pin 340 HV x 380 HV disk as a function of the normal load (b). Source: GPEMAT GROUP.

The tables 3 and 4 summarize the average hardness and hardness results, respectively.

Table 3. Average microhardness results.

Microhardness of pins and discs		
Normal Load	PIN	DISC
0	352,15	552,12
35	594,67	741,53
70	775,97	812,78
140	755,61	842,78

Source: GPEMAT GROUP.

Table 4. Average work hardening results.

Work hardening of pin and disc (%)		
Normal Load	PIN	DISC
35	69	34
70	120	47
140	115	53
Avarage	101	45

Source: GPEMAT GROUP.

4. FINAL CONSIDERATIONS

The study evidences the common behavior among the parameters, with the increase of the normal load applied there is the growth of the values of coefficient of friction, loss of mass, microhardness and larger wear shown by MEV. There is a considerable difference between them in the decrease of the running-in, this is due to the fact of a strong adhesion of the surfaces, in which it causes a plastic deformation of the pins. The value of the friction coefficient in the steady state presents the same characteristics according to the increase of normal force, since the average friction coefficient is 0.61 and 0.81 for the 35 N and 70 N loads, respectively. . The increase occurs as a result of the shortening of the break-in time.

Note that as the load increases, the pin mass loss increases in relation to the disks of the same test, at the loads of 35, 70 N the disks averaged 1.02 and 4.41 mg / m, respectively, while the pins had a median of 1.04, 5.48 mg / m, respectively, it can be observed that the pins suffered a wear rate (mass loss), but accentuated than the discs, due to the fact that the pin has lower hardness than the disk.

The increase of the applied load, the micrograph shows remarkable marks of plastic deformation and adhesion, characteristic of a severe wear mechanism, so that the appearance of grooves and cracks caused by the strong continuous metallic contact were increasingly evident.

Microhardness results show little variation when applied load increases. For discs that showed increased hardening, as the untested pins with 70 N force had much higher hardening, or high increment (work hardening) on the pins, as the average percentage increase was 101%, very high in Compared to the disk that had an average increase of 45%, it is related to a greater interaction with roughness.

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6. RESPONSIBILITY NOTICE

Eric Elian Lima Espíndola, Mateus, José Araújo de Souza, Clóvis Iarlande Oliveira Santana, Emerson Rodrigues Prazeres, Beatriz Seabra Melo, Vinicius Silva dos Reis and José Maria do Vale Quaresma are the only responsible for the printed material included in this paper