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CHARACTERIZATION OF FRICTION MATERIALS FOR BRAKE PADS USING A TRIBOMETER

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Abstract. *In order to evaluate the behavior of two different friction materials during the stick-slip phenomenon, tests were performed using a braking tribometer that in addition to original sensors (normal force, rotational speed and torque) had an accelerometer for evaluation of vibration generated during the stick-slip phenomenon. For each material, three different tests were performed varying the rotation speed of the disc and the normal force applied. The analysis of the results of the tests show significant difference in the static and kinetic coefficients of friction of the materials at the slip phase, in the angular displacement during sliding and in the sliding speed. The fact that the tribometer has an accelerometer installed near the testing sample make possible to observe the difference in tangential vibration response of the two materials, which show differences in the peak values of vibration, and that one material showed a rapid damping of vibration, while the other showed two vibration peaks, one at the beginning and another at the end of slip phase. The method used in these assays proved to be very efficient characterization of friction materials, allowing the researcher to measure certain material parameters and qualitatively determine other characteristics of the friction material.*

Keywords: brake, stick-slip, characterization, vibration.

1. INTRODUCTION

For the development of friction materials, several tests are performed to ensure and certify the quality of friction materials. Various types of machines have been developed over the past 60 years to perform tests on these materials, in order to evaluate samples in scale without the need for instrumenting a vehicle, facilitating research and product development related to brake systems of vehicles. The use of these machines allows the selection of materials with better performance in tests for after this being tested on vehicles in real situations, saving time and money in research (Neis, 2008).

Actually, there are several types of machines for testing friction materials, each one with specific characteristics and procedures, among which may be mentioned: inertial dynamometers, Chase machines, FAST machines (Friction Assessment and Screening Test), Krauss type machines, and tribometers.

It is known that the friction material for automotive brake systems are composed of several ingredients, metallic and non-metallic, each ingredient having its specific contribution to confer or improve any property in friction material, such as wear resistance, thermal stability or strength (Solomon, 2007). However, the exact compositions of friction materials are industrial secrets, and developing a standard test of friction is difficult because there is no known combination of materials which always produce the same performance independently of the manner in which the measurements are performed, considering that the friction materials are developed, still today, from the application of empirical rules by manufacturers, as claimed by some researchers (Desplanques, *et al.*, 2007).

According to Crolla and Lang (1991), as the problems of noise and vibration in brake systems are not characterized as critical issues of performance or safety, they had to wait for the demands of improvements and low-noise receive significant attention. Due to great technological improvement of vehicles today, which makes them even quieter, noise and vibration may be the only problems noticeable by the owners in brake systems, and according to Yoon, *et al.*, 2012, currently the noise in automotive brake systems has been seen as a growing challenge to be overcome by the manufacturers of automotive brake pads, because it is the target of many complaints from customers, generating high expenditures warranty. Thus, eliminating or reducing the noise and vibration of the vehicle structure and its systems has become a competitive advantage in the automotive market. Thus, besides the need to provide security, the friction material is also required to submit comfort features as noise.

In the current paper, two different friction materials were characterized by means of a tribometer developed by Neis (2008). The characterization was performed mainly focusing on the behavior of the materials during the occurrence of the stick-slip phenomenon, because this phenomenon is the main cause of self-excited vibrations produced by friction in brake systems, generating unwanted noise, such as creep-groan.

2. THE PHENOMENON OF STICK-SLIP IN FRICTION MATERIALS

The stick-slip phenomenon is characterized by alternating episodes of adhesion and sliding during the friction process between two materials and as a result the coefficient of friction continuously varies between a static (stick phase) and dynamic (phase slip) values, as show in Fig. 1. The excitation mechanism is based on the principle that there is a certain amount of periodic discharge of stored energy associated with damping, which is released in a cycle of vibration (Neis *et al*, 2011). The stick-slip events may occur repeatedly or randomly.

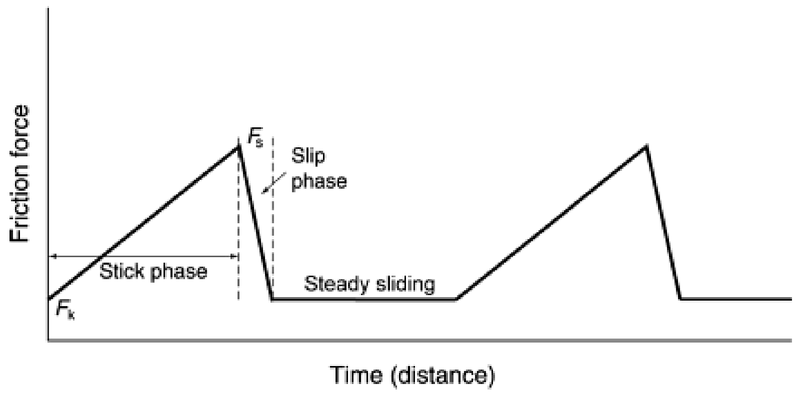

Figure 1. Friction force versus time showing the typical behavior of the stick-slip phenomenon.

In automotive brake systems, according Fuadi, *et al.*, 2009, the stick-slip occurs when the brake pressure is relieved and the vehicle starts to get moving slowly. At this time, the brake system pressure is still high to allow the disc to rotate freely, creating the conditions for the occurrence of stick-slip.

The phenomenon of stick-slip is the main cause of the creep-groan noise, which is a classic example of self-excitation of a damped vibrating system, causing a very characteristic noise during braking at low speeds (Kim, et al., 2011). In another words, the creep-groan is a low-frequency vibration, excited by stick-slip, which occurs at low speeds during the transition between stationary vehicle and starting the movement, and is influenced in part by the vehicle's suspension and hard enough for the materials in contact (Canali, 2002).

According Fuadi, *et al.*, 2009, creep-groan vibration is the only stick-slip motion that still is not fully understood and a possible way to eliminate creep-groan in brake systems is to find more information about the interaction of various parameters and sensitive their respective contribution in the event. According Neis (2008), stick-slip effect is compounded with: a low system damping rate, low values of fundamental frequency components of the brake; high variation between the magnitudes of the static and dynamic coefficient of friction.

3. EXPERIMENTAL APPARATUS

All tests were performed at the Laboratory of Tribology (Latrib) of Federal University of Rio Grande do Sul (UFRGS), where the tribometer shown in Fig. 2, developed by Neis (2008), was used for testing the behavior the friction materials.

The tribometer used in the tests is instrumented with sensors of force, rotation, temperature and torque, which are connected to a control unit responsible for managing the main parameters of the testing machine, which allows it to be used in different modes of operation.

In addition to the sensors already installed in tribometer, it was used a piezoelectric accelerometer for evaluation of vibration responses of each test. The accelerometer was fixed on top of the base that fixing the brake pad under test (specimen) so as to capture the tangential vibrations of the system, as shown in Fig. 3.

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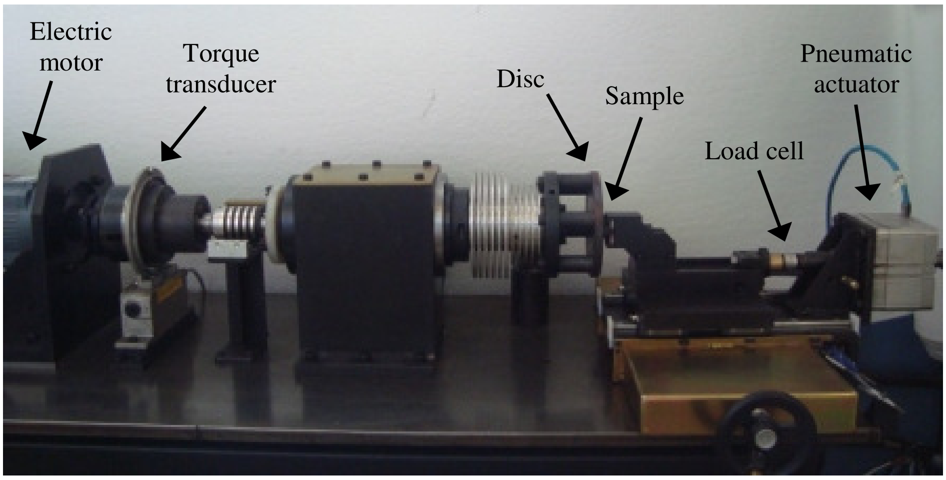

Figure 2. Tribometer used in tests of friction materials.

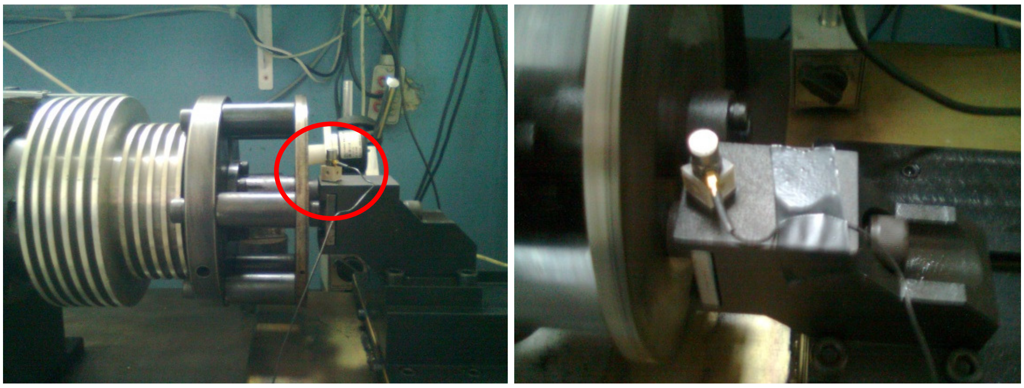

Figure 3. Installation position of the accelerometer in the tribometer.

4. TESTS PERFORMANCE

In the experiments, the following parameters were measured: normal force (contact pressure), friction force (braking torque), angular displacement of the disc, relative rotational speed between the disc and the specimen and the response of vibration tangential acceleration measured by the accelerometer.

We used two different types of friction materials, which, for reasons of industrial secrecy in this work were referenced by the codes 466 and 539.

4.1 Operating parameters

For each material, three experiments were performed where the rotational speed of the disc and the normal force applied to the tests were varied as parameters shown in Tab. 1.

Table 1. Parameters used in tests.

Test	Material	Rotational speed (rpm)	Normal force (N)
1	466	0,5	1250
2	466	0,5	2500
3	466	3,0	2500
4	539	0,5	1250
5	539	0,5	2500
6	539	3,0	2500

Before performing each test, a pre-test was done for at least 15 minutes for fixing friction material on the brake disc, thereby reducing potential sources of uncertainty.

5. RESULTS

In the results presented in the tests it is possible to observe that there is a clear difference between the two materials during the occurrence of stick-slip phenomenon.

Figure 4 shows the variation of the coefficient of friction of the materials for the stick-slip phenomenon subjected to a normal force of 1250 N and 2500 N at a disc rotation of 0.5 rpm. It can be seen that the material 466 has a higher average coefficient of friction than the material 539, and the average values of the friction coefficient are not influenced by the variation of the load, ie, the friction coefficient is independent of the applied normal force on the specimen.

On the other hand, an increase in normal force implies a reduction of the frequency of occurrence of stick-slip.

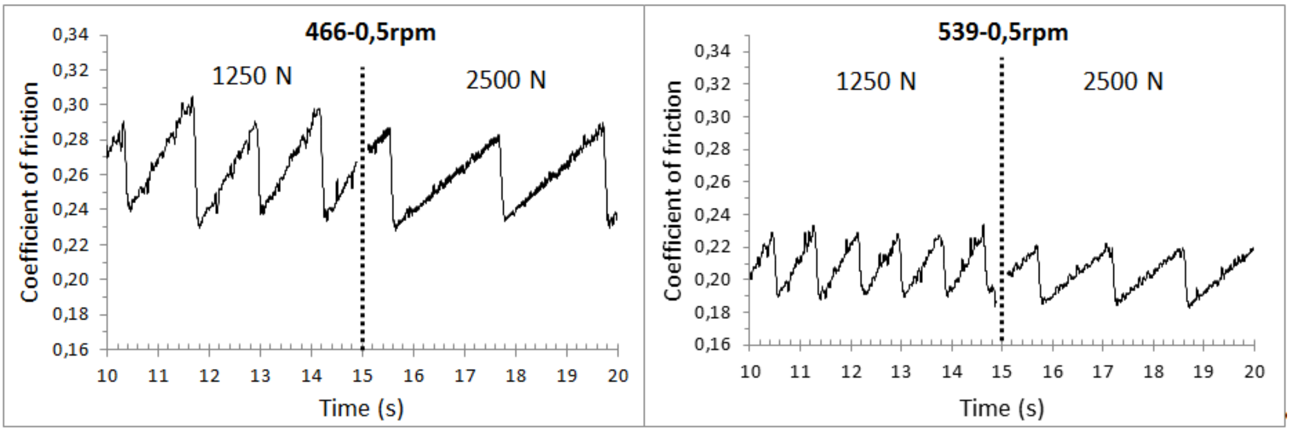

Figure 4. Coefficient of friction versus time for the material 466 (left) and the material 539 (right), both tests conducted at 0.5 rpm to normal forces of 1250 N and 2500 N.

When the normal force is held constant, and the disc rotational speed is varied (0.5 rpm and 3.0 rpm) as shown in Fig. 5, it can be seen that the mean values of coefficient of friction are not influenced by variation in the disc speed, contrary to what happened with the increase of load, when increasing the rotational speed of the disc, there is an increase in the frequency of occurrence of stick-slip.

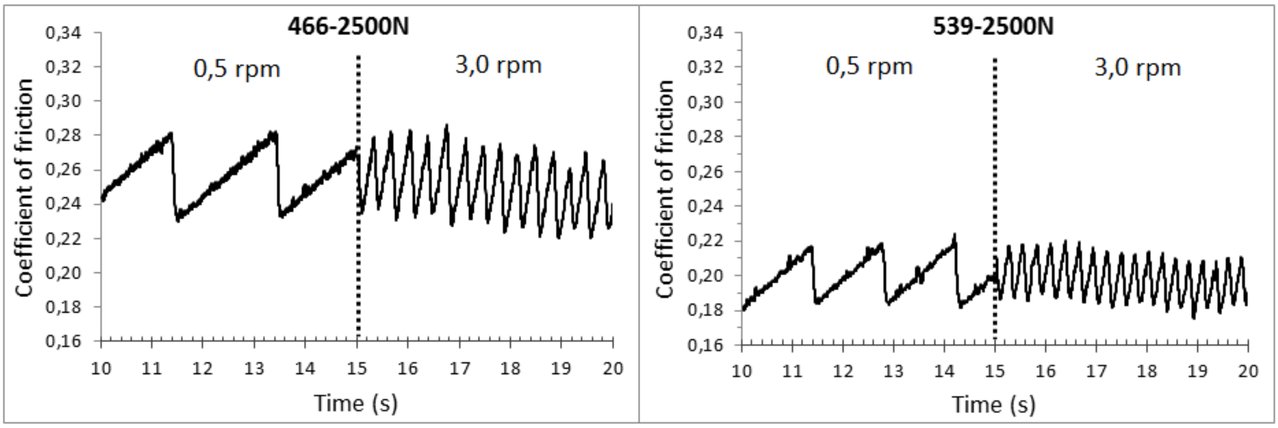

Figure 5. Coefficient of friction versus time for the material 466 (left) and the material 539 (right), both at 2500 N normal force, and disc rotational speed of 0.5 rpm and 3.0 rpm.

Them the frictional forces were determined, which are shown in Fig. 6. The frictional force depends directly on the applied normal force on the contact surface and the coefficient of friction.

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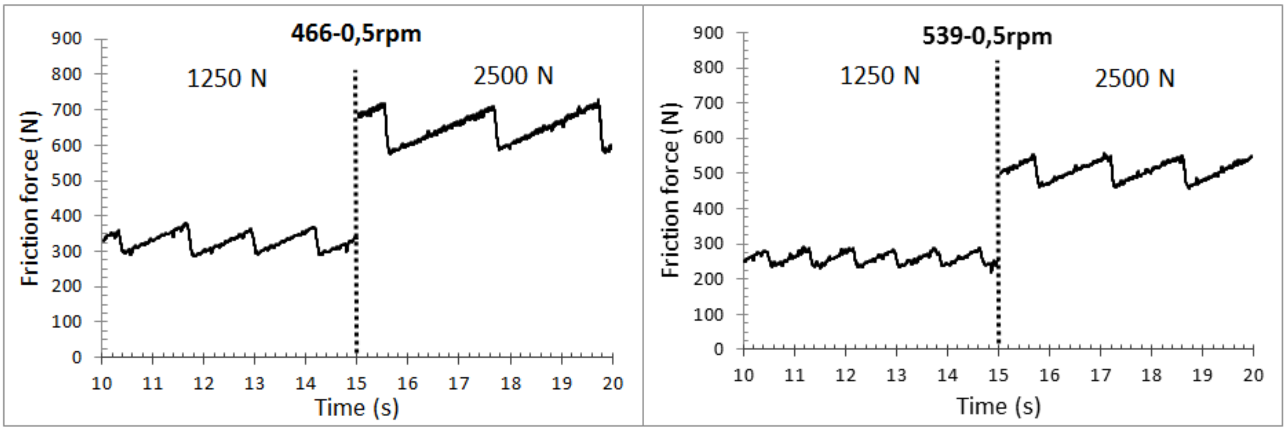

Figure 6. Friction force versus time for the material 466 (left) and the material 539 (right), both at disc rotation of 0.5 rpm and normal forces of 1250 N and 2500 N.

Figure 7 shows the variation of the position of the disc as a function of time. It can be observed that for the same parameters, the test material 466 has a major advance during the slip phase and the frequency of slips occur in the material 466 are larger compared to the material 539.

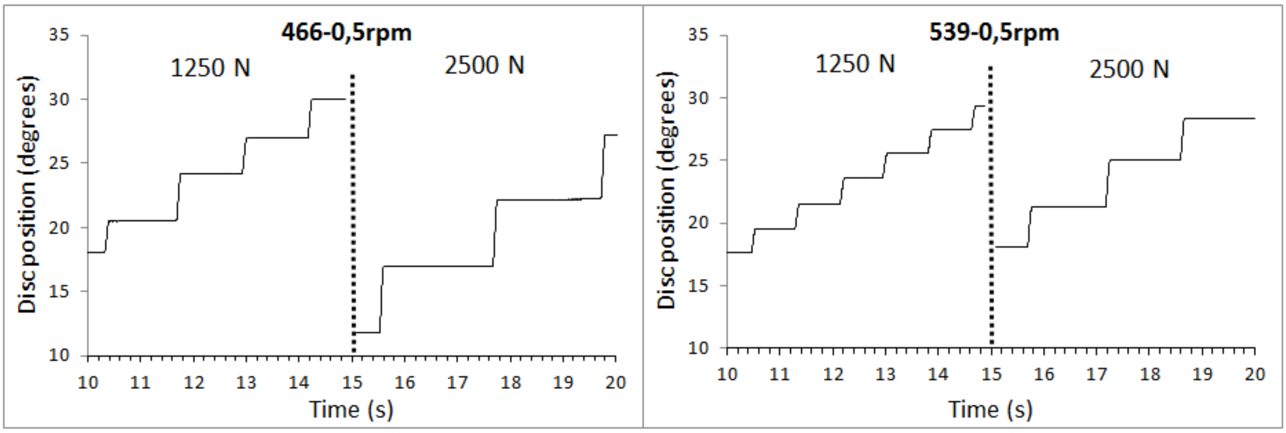

Figure 7. Variation of the disc position versus time for the material 466 (left) and the material 539 (right), both a disc rotational speed of 0.5 rpm for normal forces 1250 N and 2500 N.

It is also possible to observe that the angular displacement during the sliding and the frequency that the sliding occurs are influenced by the normal force, because with increasing normal force, the angular displacement in each slip increases, but on the other hand the frequency that slips occurring decreases, keeping the average advance of the disc similar in both cases.

Figure 8 shows that the material 466 has peaks of rotational speed of sliding about 45% greater than the peak of rotational speed of sliding of the material 539. The test results show that the increase in normal force causes an increases in the sliding speed, showing that there is a direct dependency between these two parameters.

In the analysis of the tangential vibration generated during the stick-slip phenomenon is possible to observe a different behavior for the two materials, which can be considered one of the most significant factors seen until now, as shown in Fig. 9.

The material 539 has a vibration peak at the instant when the brake pad starts slipping, and this vibration is rapidly damped by the system until the slip stops and the system reenter in the stick phase.

In the material 466, in addition of a vibration peak at the instant when the brake pad begins to slip, this material presents another vibration peak (lower than the initial one) at the instant that the disc stop to slip and beginning the stick phase. It probably denote that the first peak represents an acceleration (start of movement) and the second peak represents a deceleration (hard braking).

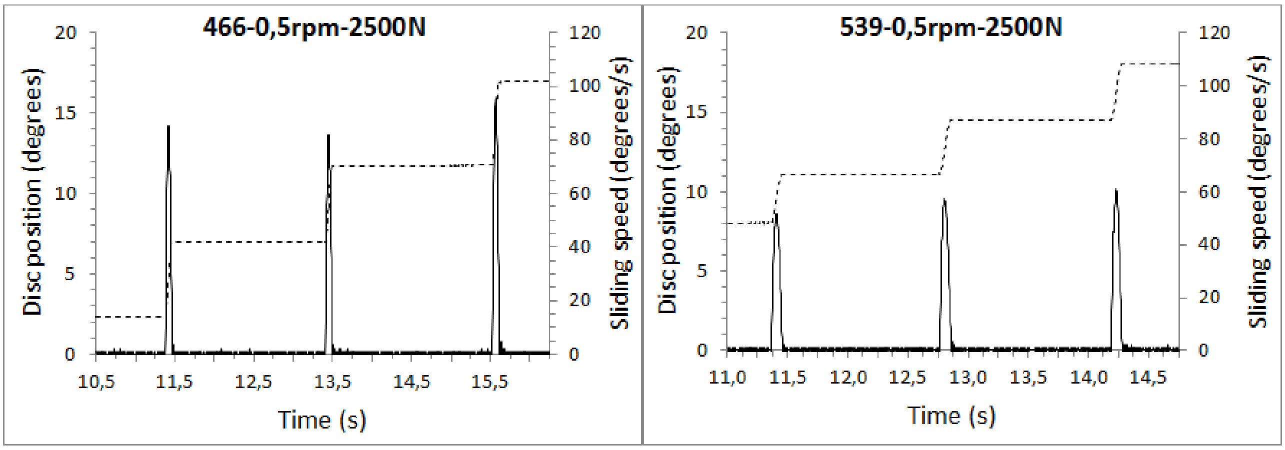

Figure 8. Variation of disc position (dotted line) and the sliding speed of the disc (solid line) versus time for the material 466 (left) and the material 539 (right), both with a normal force of 2500 N and nominal disc rotational speed of 0.5 rpm.

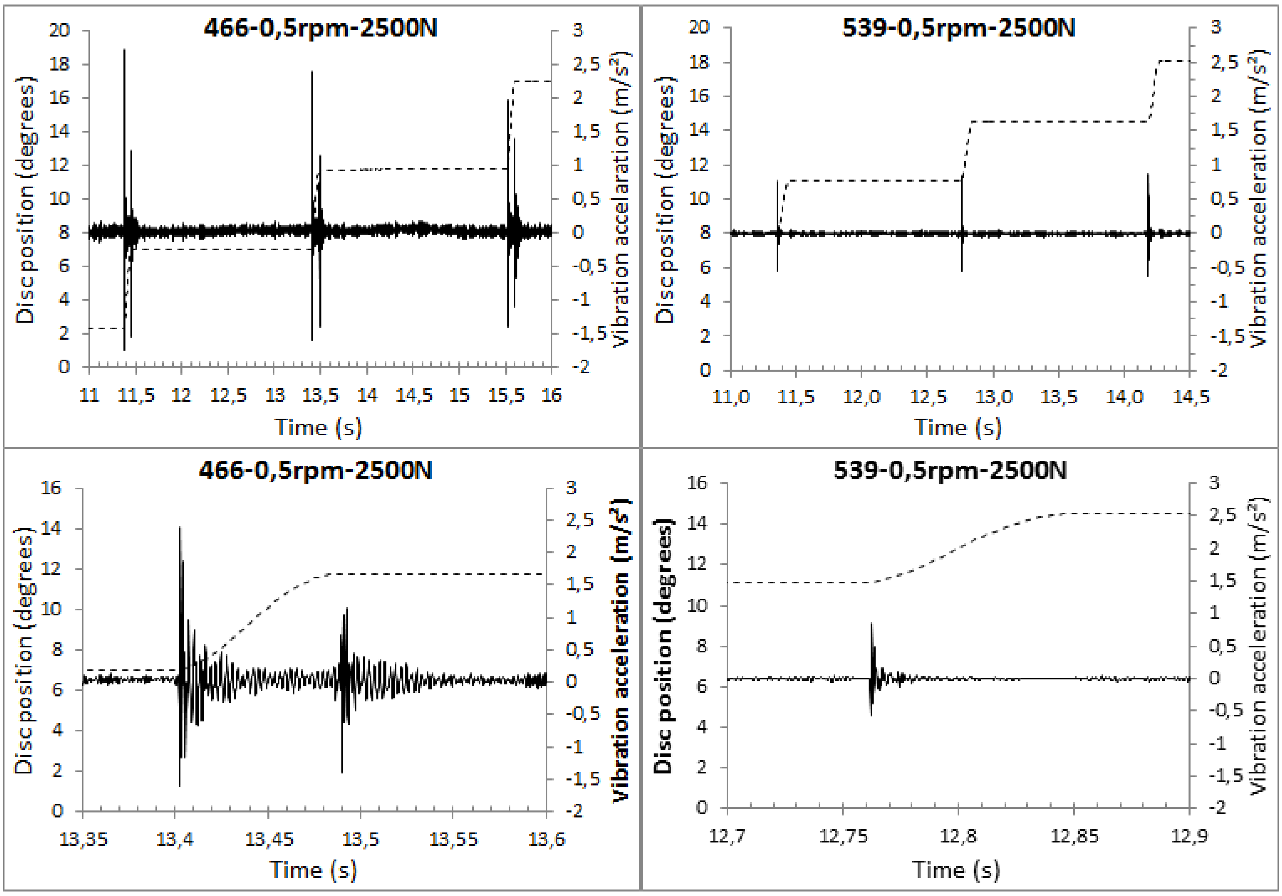

Figure 9. Variation of disc position (dotted line) and the vibration acceleration (solid line) versus time for the material 466 (left) and the material 539 (right), both with a normal force of 2500 N and speed disc 0.5 rpm.

This vibration behavior of the material 466 shown in Fig. 9 was obtained in all tests of this material, allowing the conclusion that this behavior of one peak in the beginning and another in the end of slip phase is a vibrational characteristic of this material.

Table 2 shows the results from tests of the two materials.

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Table 2. Overview of test results obtained for the two materials.

Average values	Material 466			Material 539		
Normal force	1250 N	2500 N	2500 N	1250 N	2500 N	2500 N
Disc rotation speed	0,5 rpm	0,5 rpm	3,0 rpm	0,5 rpm	0,5 rpm	3,0 rpm
Static coefficient of friction (μ_s)	0,30	0,29	0,29	0,23	0,22	0,22
Kinetic coefficient of friction (μ_k)	0,23	0,23	0,23	0,19	0,18	0,19
Friction variation ($\mu_s - \mu_k$)	0,07	0,06	0,06	0,04	0,04	0,03
Angular displacement (degrees)	2,9	5,0	5,9	2,0	3,3	5,1
Slip time (s)	0,09	0,09	0,1	0,09	0,09	0,12
Sliding speed (degrees/s)	51,0	89,5	93,6	34,3	58	70,4
Average vibration peak (m/s²)	1,9	2,3	1,7	2,3	0,8	2,0
Number of slidings per second	0,8	0,5	3,0	1,2	0,7	3,8

6. CONCLUSIONS

The tribometer used in the tests proved to be suitable to characterize the performance of friction materials used in brakes, because it allows to control some parameters while keeping other variables constant.

By analyzing the test results, which are summarized in Tab. 2, it can be seen that some parameters (angular displacement during slip, slip time, sliding speed, average value of vibration peak and the number of slip per second) are directly dependent of applied normal force and rotational speed of the disc, while static and dynamic coefficients of friction remains practically unchanged.

With the increase of the normal force: the angular displacement increases, the sliding speed increases, and the number of slips per second decreases.

With increasing rotational speed of the disc: the rotational displacement of slip increases, the sliding speed increases, the number of slips per second increases, and increases the slip time.

About the vibration, it was not possible to establish a precise relationship between the parameters controlled in the tests (normal force and rotational speed of the disc) and the vibratory responses of each material, because there were different performance in each test. But through this work became evident that the vibration characteristics of the friction material must be taken into account in the characterization of materials and deserve to be studied in more detail.

However, with the results obtained for the two materials, we can conclude that the material 466 has a greater propensity to be noisier than the material 539, due the higher variation between the static and kinetic coefficients of friction, its vibration characteristics and his higher rotational displacement and slip speed during the slip phase.

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