METHODOLOGY FOR CHARACTERIZING BRAKE FRICTION MATERIAL ON HIGH TEMPERATURES

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Abstract: The current work aims to describe a methodology to test brake friction materials through a braking tribometer, which is integrated by an electromagnetic induction heater. This technology allows to characterize the isolated effect of load and temperature on friction. Characteristics of the main machines and procedures for testing friction materials are evaluated, paying particular attention with regard to the effect of load and temperature on friction. Experimental methodology consisted of performing brakings under 3 levels of load and 4 levels of temperature. Results from the experiments show that coefficient of friction decreases considerably when temperature is higher than 300°C. It was also observed that the effect of load on friction varies according to the friction material evaluated. About the number of braking applications at each temperature level, it has been verified that at temperatures of 200°C, 300°C and 350°C, three braking are able to characterize the friction behavior. However, when temperature is 100°C, at least 10 brakings are required in order to obtain satisfactory results. The reason for that is due to the bedding-in and also recovery effect of friction, which occurs immediately after to the brake friction material to be subjected to high temperatures (300°C or higher).

Keywords: fade; braking test; friction; high temperature.

1 INTRODUCTION

As mentioned by Tsang et al. [1], Rusnak et al. [2] and Rhee and Schwartz [3], until the middle of the 50's, tests involving brake systems were only performed on vehicles, in a type of test called "on road". However, such methodology has high costs due to the time involved in set up and execution. In addition, different drivers, changes in environmental conditions and traffic can make the analysis of these tests a hard task. Currently, most tests involving friction materials from brakes has been performed in laboratories and simulations [4]. According to Müller [5], on road tests remain important, but they are restricted to ergonomic, comfort and noise evaluations of brake system as well as for confirmation of results obtained in brake dynamometer.

According to Rusnak et al. [2], braking evaluations performed on laboratory equipments have a number of advantages such as ease of instrumentation, a more precise control of the variables involved in the process as well as time and cost reduction.

There are several types of machines for the purpose of testing friction materials from car brakes. As mentioned by some publications (Rusnak et al.[2]; Zimmer and Teves [6]) due to constructive features and technologies involved on those machines, each one is especially suitable for a specific type of evaluation, such as quality control or research and development, for instance.

In order to evaluate the effect of the temperature on braking performance, some laboratory equipments, such as Chase testing machine and high temperature tribometer can be indicated. Electrical resistance are used on these machines aiming to provide an additional amount of heat to the friction process while the sample slides at a constant speed on the disc surface. However, according to SAE J2784 [7], a constant sliding speed does not represent an actual vehicle braking procedure, where deceleration of the disc usually occurs.

In tests performed on brake dynamometers, temperature is just measured and it is not possible to control this parameter. The section that is generally used to evaluate the effect of the temperature on friction by using a brake dynamometer is known as fade. As described by some standard procedures for testing brakes, such as SAE J2784 [7], AK-Master [8] and ISO 26867 [9], in a fade section, temperature is increased by successive braking applications. The long time involved to run these procedures, typically higher than 24 hours, can be considered one of the main disadvantages with respect to the use of such methodologies.

In the current paper, it is presented a new testing procedure (methodology) which allows to characterize the isolated effect of temperature and load on friction during braking cycles performed on a tribometer.

2 EXPERIMENTAL APPARATUS

The testing machine used to perform the tests is a laboratory-scale tribometer (Figure 1), especially developed to characterize friction materials used in brake pads. The mechanical design of the tribometer is comprised of 3 different units: a) loading unit, b) rotation unit and c) machine structure.

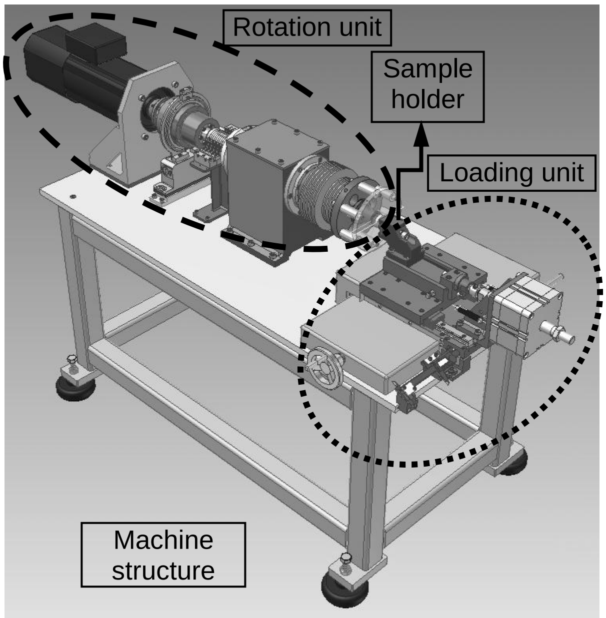


Figure 1. Tridimensional drawing of the tribometer

The loading unit is responsible for carrying out the normal load exerted by the sample on the disc. This system can operate in two different modes:

1) Constant force mode: the normal force is kept constant over time during the experiments, while the braking torque remains free to vary as friction is changed.

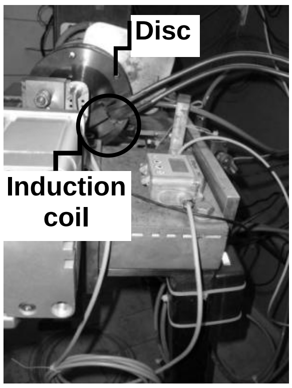
2) Constant torque mode: the braking torque is kept constant regardless of the friction force.

The rotation unit is responsible for controlling the disc rotation. It can operate in two different modes:

1) Constant drag mode: rotation speed of the disc is kept constant over time during the tests.

2) Disc deceleration mode: the rotation speed of the disc decreases at a pre-set rate as the braking proceeds.

In order to provide the brake disc an additional amount of heat during brakings, the testing machine is integrated to an induction heater (Figure 2). By means of that technology, the isolated effect of temperature on friction can be evaluated.



(a) (b)

Figure 2. Induction heater integrated to the tribometer: (a) induction heater equipment and (b) detail of the induction coil installed 1 mm close of the disc surface

Figure 3 shows typical thermal curves obtained by using the induction heater integrated to the tribometer. The same type of curves has been produced during the experiments described by the current paper.

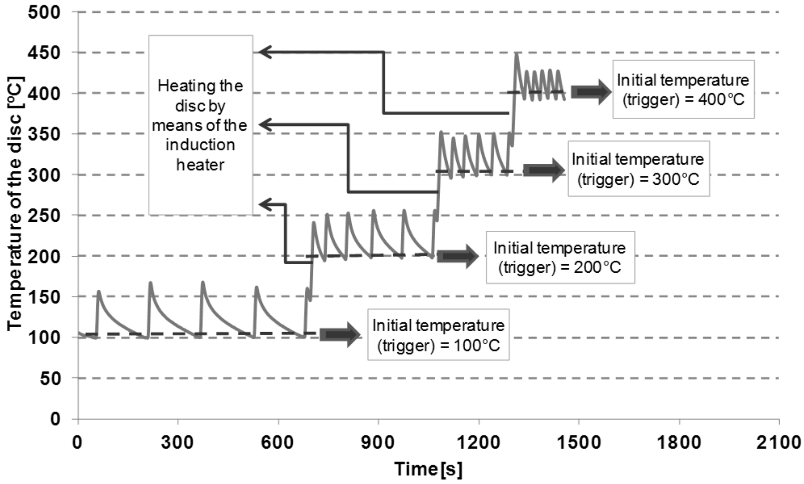


Figure 3. Typical temperature curves from the experiments

In the designed tribometer, the coefficient of friction is determined by an indirect measurement method, which considers the relationship given by the Eq. (1).

$$\mu = \frac{T}{RF_N} \qquad (1)$$

According to a previous study (Neis, [10]), repeatability (precision) of the friction measurements performed by the testing machine is ±0,013.

3 RESULTS AND DISCUTION

During the development of a methodology for characterizing friction materials on high temperatures, two different experiments were performed on the tribometer. Brake discs used in both experiments are made from grey cast iron. A thermocouple has been embedded in the discs in order to measure the temperature. Samples are made from commercially available brake pads in Brazil. Codes were used to distinguish the friction materials employed in each experiment. Aiming to eliminate transient effects, such as running-in, a pre-run sliding with velocity of 1,67 m/s and normal constant load of 400 N has been performed on the tribometer during 300 s prior to the tests.

3.1 Testing procedure 1

Table 1 summarizes the operating parameters used in the first experiment for characterizing friction materials on high temperatures.

Table 1. Operating parameters used in the first experiment

Material	Samples	Normal force [N]	Number of cycles	Levels of initial temperature in each cycle [°C]	Number of brakings in each level of temperature	Initial-final sliding velocity [m/s]	Braking time [s]
HB	1 and 2	2400	3	100/200/300/400	5	9,6 - 0	6,9
		1900	1				
		1400	1				

Friction results from both sample 1 and sample 2 are shown in the Figure 4. At the caption of that figure, the number that follows the character “F” represents the normal force used in the test and the number that follows the character “n” corresponds to the number of the cycle. Three different effects can be observed: i) loss in friction at high temperatures (usually, higher than 300°C): this effect is known as fade and it is usually attributed to the degradation of the phenolic resin from organic matrix composite (Bulthé et al [10]);

ii) effect of the number of the cycle: it is observed that the coefficient of friction obtained in the first cycle (F2400 n1) is considerably lower than in the second (F2400 n2) and third (F2400 n3) cycles; iii) differences between sample 1 and 2: although the friction material is the same, differences higher than 0,06 have been encountered between coefficient of friction obtained from both samples. These differences in magnitude are approximately 5 times higher than the machine precision (0,013), which suggests they are significant. One reason for this effect can be attributed to no good quality control in the manufacturing process of these brake pads.

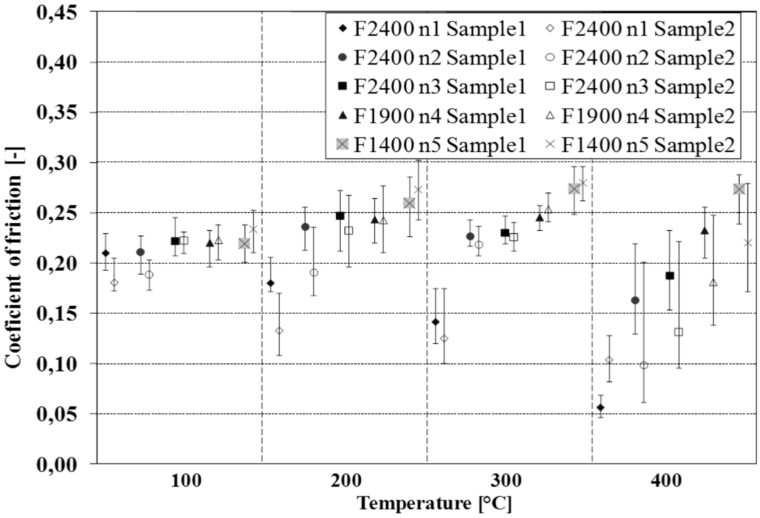


Figure 4. Comparison between friction results from samples 1 and 2, which were obtained in the first experiment

The effect of the load and temperature on friction can be better observed in the multi-analysis graph (Figure 5), whose data represent the average between the results obtained from both samples 1 and 2. Due to transient effects that may occur in the first two high temperature cycles (n1, n2), they are not considered in that graph.

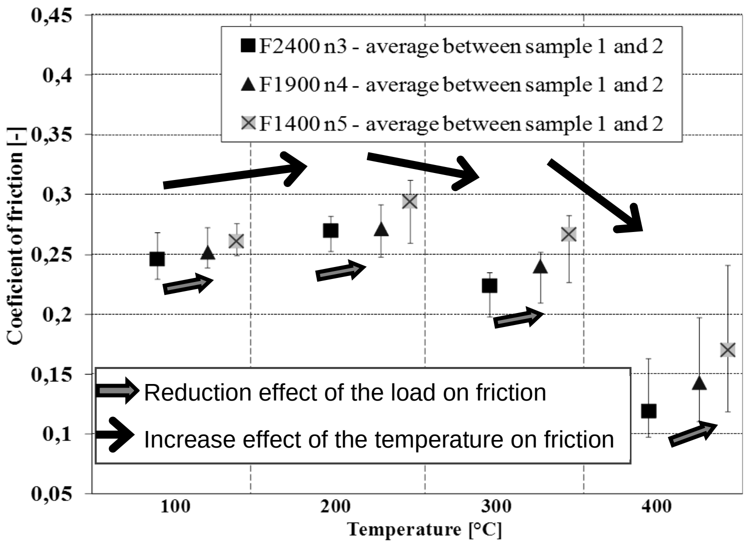


Figure 5. Effects of temperature and load on friction, considering data from cycles 3, 4 and 5

From Figure 5, it can be observed that the reduction in load leads to increase the coefficient of friction, especially towards higher temperatures. It can be also verified a slight increase in the coefficient of friction at 200°C compared to 100°C. Finally, at temperatures of 300°C and 400°C, the friction material shows a fade effect, where the coefficient of friction is considerably reduced.

3.2 Testing procedure 2

Although the testing procedure evaluated according to the experiment 1 has been able to show the effects of temperature and load on the friction, it was not able to characterize the recovery and bedding-in effects. The recovery is the transient period which occurs immediately after the friction material to be subjected to high temperatures. According to Bulthé et al. [11], the reasons for the recovery include additional curing material (most materials are 100% cured by the manufacturer), chemical changes (reversible and irreversible) and vaporization of volatile components. The bedding-in is a transient period where the coefficient of friction tends to stabilize. As mentioned by Kumar and Bijwe [12], bedding-in is an effect caused by the increase in the contact area of the sample.

Aiming to overcome the limitations related to the first methodology (experiment 1), a second testing procedure was evaluated by means the experiment 2. The main difference is the number of braking applications at 100°C. Now, a total of 10 brakings are performed at 100°C, instead of 3 as in the first testing procedure. Another difference relates to the initial velocity. In the experiment 2, this parameter was reduced to 7,8 m/s in order to operate as indicated by the section "characterization", which is part of most standard testing procedures for brakes. As a consequence of the velocity reduction in the second experiment, it was also reduced the maximum temperature. A preliminary test showed that at the initial velocity of 7,8 m/s, it was not possible to carry out the brakings at 400°C due to the lower energy released by the process in that case. Table 2 summarizes the operating parameters used in the experiment 2.

Table 2. Operating parameters used in the second experiment

Material	Normal force [N]	Number of cycles	Levels of initial temperature in each cycle [°C]	Number of brakings in each level of temperature	Initial-final sliding velocity [m/s]	Braking time [s]
587	1200	4	100/200/300/350	10 brakings at 100°C 3 brakings at 200/300/350°C	7,8 - 0	10

Figure 6 shows the results from experiment 2. Data from the first seven brakings performed at 100°C are shown point by point in order to clarify the transient behavior of friction in this condition (effects of the bedding-in and recovery). The average data calculated for the braking number 8, 9 and 10 is considered to represent the friction result at 100°C. In the other temperatures (200°C, 300°C and 350°C), the data used in the graph correspond to the average of the three consecutive braking operations which have been performed on the respective temperatures.

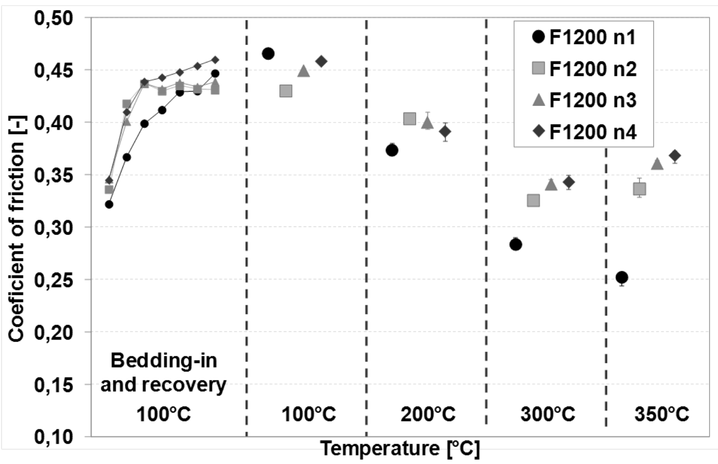


Figure 6. Friction results obtained in the experiment 2

As in the testing procedure 1, the second testing procedure (Figure 6) was also able to represent the loss in friction at high temperatures (fade) as well as the effect of the number of the cycle. The main advantage of the second method in comparison with the first one is the ability to represent the bedding-in and recovery effects, putting them apart.

So, the second testing procedure is considered suitable to characterize the effect of temperature on the friction by using the tribometer integrated with the induction heater. The estimated time to perform on the tribometer a procedure as that described by the Table 2 (including the setup time) is approximately 1h. This estimation is valid for each normal force, ie a time of 2h is required to run a test with 2 different forces.

4 CONCLUSIONS

The use of the experimental apparatus (tribometer + induction heater) together with the proposed methodology, which is described by the testing procedure 2 in the current paper, proved to be a suitable tool for characterizing the isolated effect of temperature on friction during braking tests. Effects of bedding-in and recovery can also be evaluated in the tribometer by means of the proposed methodology.

The time for running a full braking cycle (2 normal forces and 4 levels of temperature) in the tribometer is approximately 2h. It can be considered one of the major advantages in using the proposed methodology, since the time involved to run testing procedures for brakes in commercial machines can be higher than 24 hours.

The technique of post-processing the data by means of a multi-analysis graph proved to be a clear way to assess the simultaneous effects of load and temperature on friction. For both material tested, it was observed friction reduction at high temperatures (> 300°C). About the effect of load, a reduction in the normal force led to an increase in the coefficient of friction for the evaluated material (code HB).

5 NOMENCLATURE

T	braking torque	Nm
μ	coefficient of friction	-
R	sliding radius	m
F_N	normal force	N

6 ACKNOWLEDGEMENTS

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