RELATION BETWEEN THE TEMPERATURE OF THE DISC MEASURED WITH THERMOCOUPLE AND BY THERMOGRAPHY USING A REDUCED SCALE DYNAMOMETER

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Abstract. *The objective of this work is to present the comparison between the disc temperature measured with thermocouple and by thermography and establish the relations between these measures. To execute this study, a reduced-scale dynamometer instrumented with a thermocouple embedded at 1mm from the disc surface and a thermographic camera to evaluate the thermal gradients generated on contact was used. Two different kinds of pads were used as specimens in this work, called material A and B. The disc brake is made of the same material that is used in commercial discs, ie gray cast iron. The tests were performed under 3 different conditions of velocity and torque and repeated 3 times for each condition, totaling 27 tests for each material. The machine used for testing was adjusted for the torque control condition to maintain constant the heating rate that is delivered to the system during the braking, independent of the friction coefficient. The comparison between the thermographic images on the disc surface and the curves of temperature measured via thermocouple during each braking showed that there is a coupling between the region where localized heating areas occur and heating rates recorded by thermocouple. The presence of localized heating areas on the disc surface, which can be seen through the thermographic images, suggests a significantly irregular contact on the friction pair. The test results show that specimen A presents better uniformity in the distribution of temperature (and hence in contact) than material B. Furthermore, using the methodology applied in this paper, the analysis the temperature dispersion of the curves recorded by thermocouple can be an alternative way to measure the mechanical contact uniformity on the friction pair.*

Keywords: *braking, thermography, friction*

1. INTRODUCTION

The development of new friction materials for use in automobile brakes is a constant challenge due to the increase in engine power and due to increasing market demands. A very common machine used in the stage of development of brake pads and lining is the inertial dynamometer, a machine capable of generating results very similar to real vehicles. However, dynamometers have as disadvantage high cost and time consumption when it performing tests. So, the design of new products of friction can take several days, hindering the development of brake systems. To minimize these difficulties, a scale dynamometer was developed, which operates with a scale factor to reproduce the different brake systems. The major limitation of this type of equipment is that it test a single brakes system at a time, with a corresponding scale factor for each system. So, the Universidade Federal do Rio Grande do Sul (UFRGS), in partnership with the Fras-le S/A company, have developed a dynamometer with a fixed scale factor. So, results of each material can be extrapolated to a number of different brake systems from a single test. This equipment was called Fras-le Scale Dynamometer (FSD) and its development had the support of the Fonte Financiadora de Estudos e Projetos (FINEP).

Once the machine was designed tests on brake systems were performed. During this stage, it was observed that the evolution of temperature with time, measured by thermocouple in the disc, had significant differences at each braking performed under the same condition operation. Such evidence led to further investigation.

To investigate the issues reported above, a thermographic camera was used to measure the thermal gradients generated in the contact between the surfaces of the friction pair. The results obtained using thermography were associated with the heating rate measured on a point on the disc by a thermocouple embedded at 1mm from disc surface.

2. METHODOLOGY

2.1 The experimental set up

The tests were performed with a FSD (Fig. 2.2 – b), which is a dynamometer that reproduces in scale from a single material the results of a number of different brake systems.

The specimens used in this work have 2 different compositions and were called material A and material B. The brake disc is made of gray cast iron. A K-type thermocouple was embedded at 1 mm from the friction track surface of the disc. The thickness of the disc brakes used in this study is of 10 mm. Figure 2.1 shows the pad and disc used during the tests in this work.

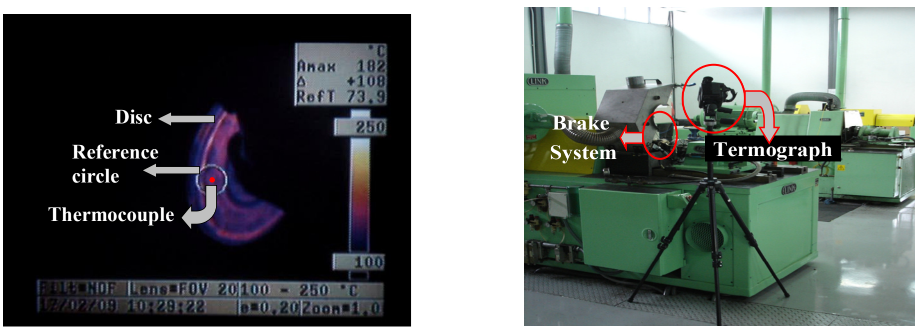
Figure 2.1 – Friction pair tested.

The tests were performed under 3 different speed and torque conditions, as shown in Table 2.1. The tests were repeated 3 times for each condition, totaling 27 tests for each material. The FSD machine was adjusted for the torque control condition in order to maintain constant the heating rate generated during the brakings, independent of the friction coefficient. The initial temperature (trigger) of the tests was 100 °C for all brakings.

Table 2.1 – Operation condition used in the tests.

	Operation Condition		
Group	Slipping velocity [m/s]	Torque [Nm]	Emissivity
1	V = 7.4 - 3.7	47	0.2
		126	
		211	
2	V = 11.1 - 7.4	47	0.5
		126	
		211	
3	V = 16.6 - 13.8	47	0.98
		126	
		211	

During the brakings, the disc temperature was recorded by thermocouple at the same time that the thermal gradient of the disc surface was recorded by a thermographic camera. The emissivity of the thermograph was adjusted for each group of tests (as shown in Tab. 2.1) to avoid temperature saturation, since the range of operation permitted by the equipment is relatively small (100 to 250°C). Thus, no experimental calibration procedure was performed for the emissivity, and the results of temperature measured by thermography during this work should be evaluated on a qualitative and not absolute way. The thermocouple is installed in the center of the disc wear track, as shown by thermographic image in Fig. 2.2 - a. The experimental apparatus used in this work is presented in Fig. 2.2 - b, where the thermograph, the brake system and the FSD machine can be seen. A reference circle was drawn on the disc to mark the disc wear track.



(a) Thermographic image example. (b) Equipment used during the tests.

Figure 2.2 – Schematic of the tests.

In order to quantify the dispersion among the curves of temperature measured by thermocouple during the three brakings performed on each group under equal operating conditions, the mathematical expression shown below was produced:

$$A_r = \frac{A_{m123}}{T_m}100 \tag{1}$$

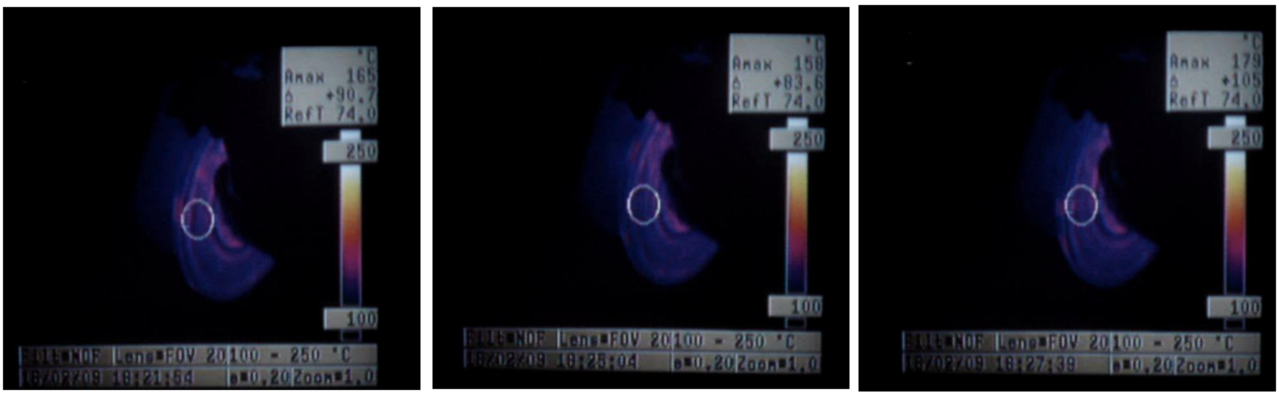
where A_r is a measure of the maximum amplitude among the 3 temperature curves of the thermocouple [%], A_{m123} is the absolute maximum amplitude determined by the largest difference in temperature between the 3 temperature curves measured by thermocouple [°C] along the time and T_m is the temperature averaged over all points of the 3 curves in [°C] along the time.

These data weren't handled as statistical data because the temperature rapidly varied along the time (transient condition). The data acquisition rate used was 1000 data per second.

3. RESULTS

Due to a space issue, only was selected a few important brakings selected to illustrate the relationship between the temperature measured via thermography and by thermocouple.

Figure 3.1 presents the thermographic images of the 3 brakings generated during tests performed on condition of slip velocity from 7.4 to 3.7 m /s and constant torque of 47 Nm for material B. These images were produced at 0.25 seconds of braking application.



(a) Braking 1 (b) Braking 2 (c) Braking 3

Figure 3.1-Thermographic images produced at velocity of 7.4 to 3.7 m/s and torque of 47 Nm (material B).

Figure 3.1 shows that the thermal gradient is relatively uniform under the condition evaluated, since no regions of localized heating occur on the disc surface. This could also be demonstrated by the measurements taken with the thermocouple, where the curves of heating produced during each braking show similar behavior (Fig. 3.2). The measure of relative dispersion among the 3 curves, estimated using Eq. 1, is 2.51%.

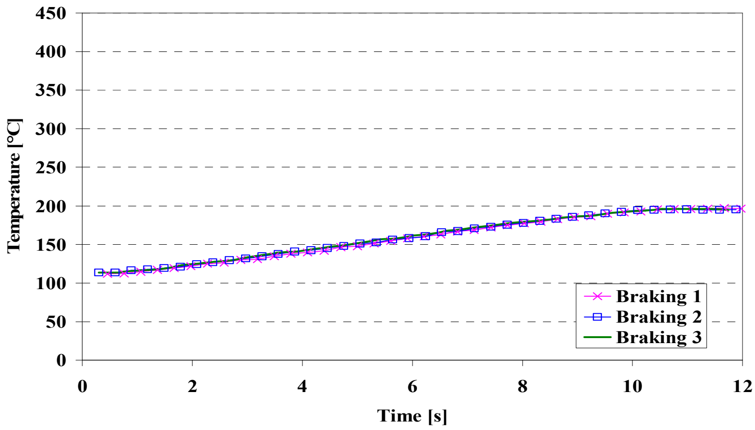
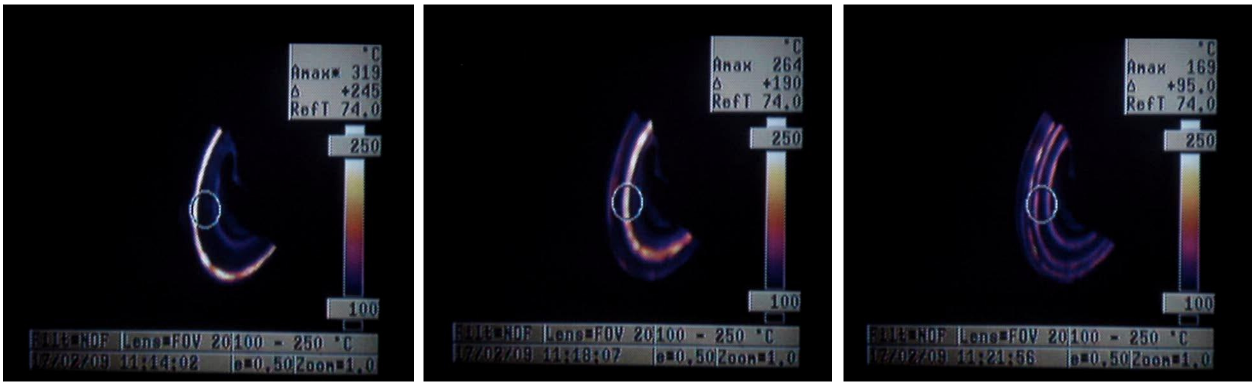


Figure 3.2 – Temperature curves measured by thermocouple (slipping velocity of 7.4 to 3.7 m/s, torque of 47 Nm and material B).

Figures 3.1 and 3.2 just serve to exemplify the dependence of thermal gradient uniformity and the operation parameters of the tests, since the other tests, performed under more severe conditions, will show a non-uniform thermal gradient for material B.

Figure 3.3 presents the thermographic images of the 3 curves generated during tests performed under condition of slipping velocity from 11.1 to 7.4 m /s and constant torque of 126 Nm for material B. These images were produced at 0.3 seconds of braking application.



a) Braking 1 (b) Braking 2 (c) Braking 3

Figure 3.3-Thermografic images produced at velocity from 11.1 to 7.4 m/s and torque of 126 Nm (material B).

Figure 3.3 shows that the thermal gradient is relatively non-uniform under the condition evaluated for material B. This can be viewed through localized heating in the shape of a ring on the disc, especially in brakings 1 and 2. The non-uniformity of thermal distribution is also indicated by the relatively high measure of dispersion among the 3 curves of temperature recorded by thermocouple (Fig. 3.4), whose value given by Eq. 1 is 48.15%. Figure 3.4 shows that braking 2 presents the greatest heating rate measured by thermocouple of the 3 brakings. This is explained by the proximity of the localized heating band in the shape of a ring to the radius where the thermocouple is installed. On the other hand, the braking 1 shows the lowest heating rate measured by thermocouple of the 3 brakings due to the distance of the localized heating ring (outside region of disc) to the radius where the thermocouple is installed.

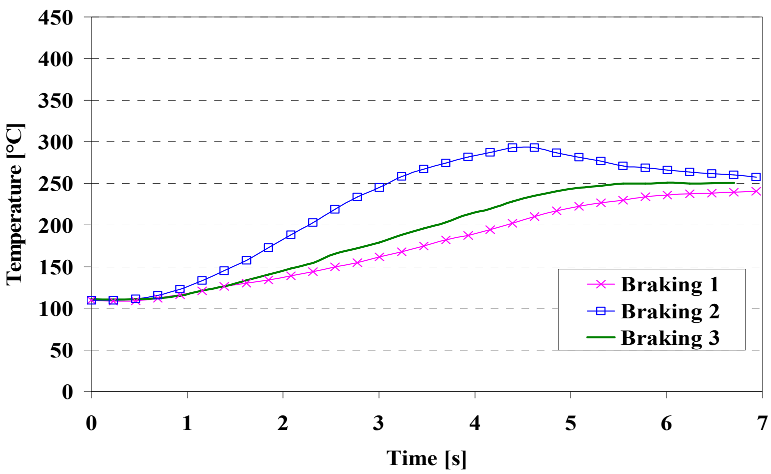
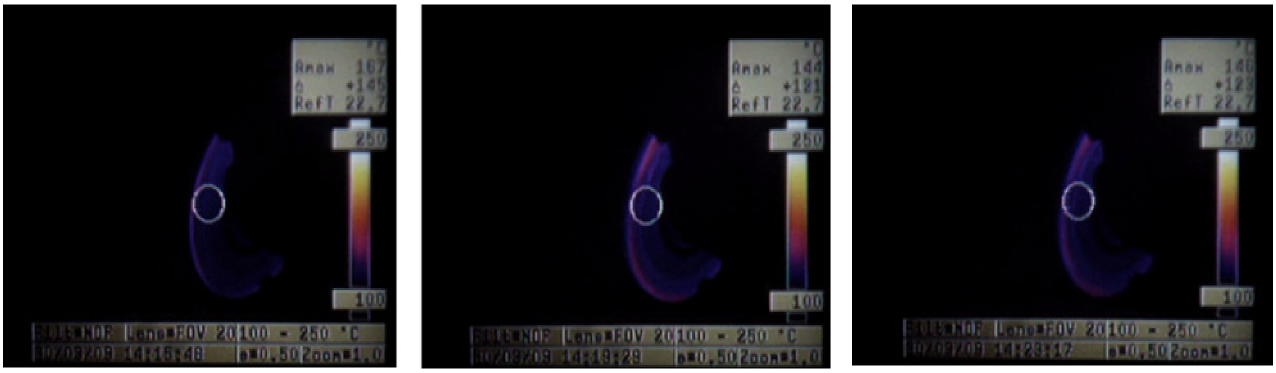


Figure 3.4-Temperature curves measured by thermocouple (slipping velocity from 11.1 to 7.4 m/s, torque of 126 Nm and material B).

Figure 3.5 presents the thermographic images of the 3 curves generated during tests performed under condition of slipping velocity from 11.1 to 7.4 m /s and constant torque of 126 Nm for material A. These images were produced at 0.3 seconds of braking application.



(a) Braking 1 (b) Braking 2 (c) Braking 3

Figure 3.5 – Thermografic images produced at velocity of 11.1 to 7.4 m/s and torque of 126 Nm (material A).

Figure 3.5 shows that the thermal gradient is relatively uniform under evaluated condition for material A. There were no areas of localized heating, contrary to what has been observed with material B under the same operation conditions. The uniformity of thermal distribution is also indicated by the relatively small measure of dispersion among the 3 temperature curves recorded by thermocouple (Fig. 3.6) in this case, whose value given by equation 1 is 1.92%. Figure 3.6 shows that the 3 curves recorded by thermocouple have relatively good repeatability.

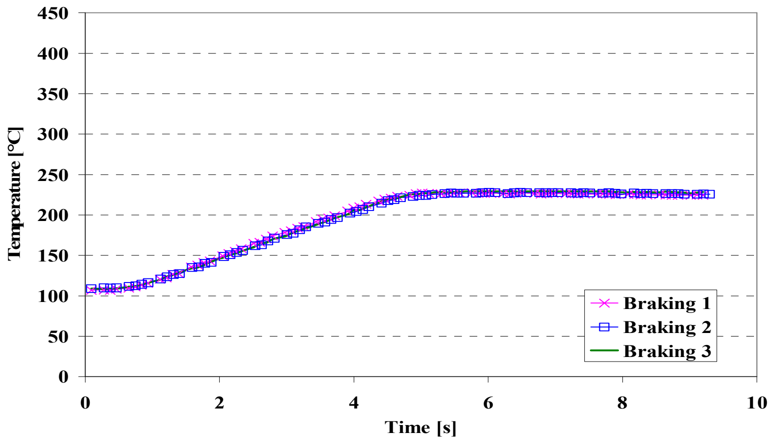


Figure 3.6 -Temperature curves measured by thermocouple (slipping velocity from 11.1 to 7.4 m/s, torque of 126 Nm and material A).

Figure 3.7 presents the thermographic images of the 3 curves generated during tests performed under condition of slipping velocity from 16.6 to 13.8 m /s and constant torque of 47 Nm for material B. These images were produced at 0.5 seconds of braking application.

(a) Braking 1 (b) Braking 2 (c) Braking 3

Figure 3.7 – Thermografic images produced at velocity of 16.6 to 13.8 m/s and torque of 47 Nm (material B).

Figure 3.7 shows that the thermal gradient is relatively non-uniform during the braking under this condition for material B. This can be seen through the appearance of one or more bands of localized heating in the shape of rings on the disc surface in the 3 brakings. The non-uniformity of the thermal distribution is also indicated by the relatively high measure of dispersion among the 3 temperature curves recorded by thermocouple (Fig 3.8), whose value given by Eq. 1 is 52.45%.

Figure 3.8 shows that braking 2 presents the greatest heating rate measured by thermocouple of the 3 brakings. This is explained by the proximity of the localized heating band in the shape of a ring in the center of disc to the radius where the thermocouple is installed. Brakings 1 and 3 present a relatively similar thermal distribution, which is also reflected by relative similarity between these temperature curves measured by thermocouple.

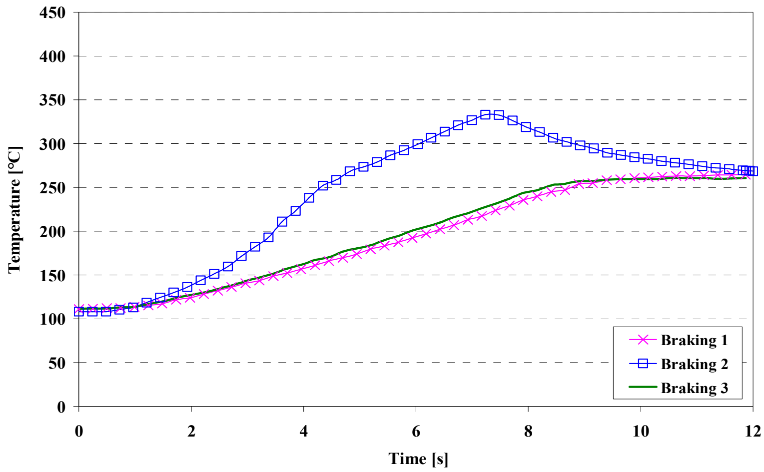
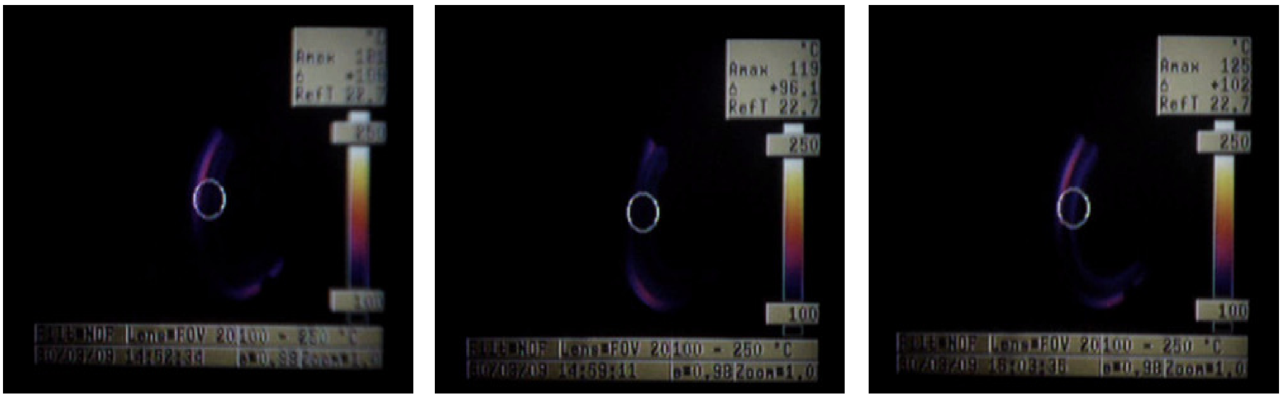


Figure 3.8 – Temperature curves measured by thermocouple (slipping velocity of 16.6 to 13.8 m/s, torque of 47 Nm and material B).

Figure 3.9 presents the thermographic images of the 3 curves generated during tests performed under condition of slipping velocity from 16.6 to 13.8 m /s and constant torque of 47 Nm for material A. These images were produced at 0.5 seconds of braking application.



(a) Braking 1 (b) Braking 2 (c) Braking 3

Figure 3.9 – Thermografic images produced at velocity of 16.6 to 13.8 m/s and torque of 47 Nm (material A).

Figure 3.9 shows that the thermal gradient is relatively uniform for material A. There were no areas of localized heating as previously shown for material B under the same operation condition. The uniformity of the thermal distribution is also indicated by the relatively small measure of dispersion among the 3 temperature curves recorded by thermocouple (Fig. 3.10) in this case, whose value given by equation 1 is 3.25%. Figure 3.10 shows that the 3 curves recorded by thermocouple have relativity good repeatability for material A.

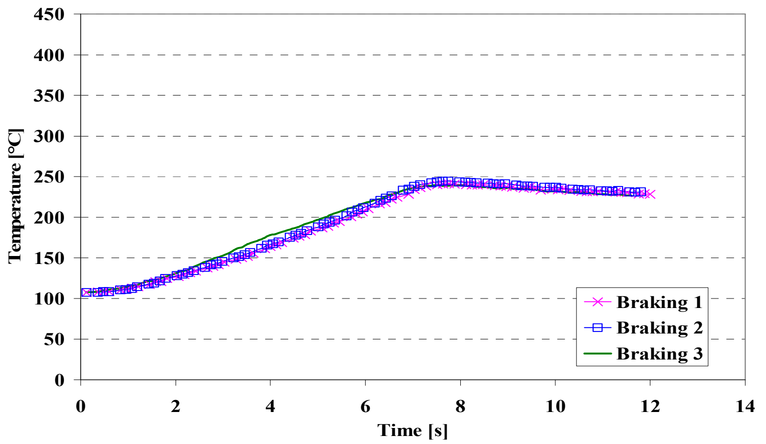


Figure 3.10 – Temperature curves measured by thermocouple (slipping velocity of 16.6 to 13.8 m/s, torque of 47 Nm and material A).

3.1 Maximum amplitude among the temperature curves

In order to couple the results of relative dispersion between the temperature curves measured by thermocouple for each material, Tab. 3.1 was created, which presents the maximum amplitude results for all tested condition, according to Eq. 1.

Table 3.1 - Results of maximum amplitude among the temperature curves measured by thermocouple.

	Operation Condition		Maximum Amplitude [%]	
Group	Slipping velocity [m/s]	Torque [Nm]	Material A	Material B
1	V = 7.4 - 3.7	47	1.35	2.51
		126	1.46	7.26
		211	1.45	7.34
2	V = 11.1 - 7.4	47	1.88	17.17
		126	1.92	48.15
		211	1.87	18.3
3	V = 16.6 - 13.8	47	3.25	52.45
		126	7.53	72.76
		211	3.98	54.4

The results presented in Tab. 3.1 show that the dispersion between the temperature curves measured by thermocouple is lower for material A, which means that this material has more uniform thermal distribution over the disc surface than material B. These results are consistent with the results found by thermography. So, the analysis the temperature dispersion of the curves recorded by thermocouple can be an alternative way to measure the mechanical contact uniformity on the friction pair.

The dispersion is actually a combination of speed and torque effects and it is difficult to disassociate one from the other factor. However, an analysis based on the presented results indicates that there is a tendency for the dispersion between the curves to increase with speed increase, independent of the type of material used.

Now the ratio between dispersion and torque seems to be more complex, since the data show a trend of increase followed by decrease in dispersion with the increase in torque. We need further testing to provide more solid support for this last finding.

A more detailed examination shows that the temperature distribution on the disc surface is related to the friction pair contact form. Thus, a more uniformly distributed temperature on the disc surface indicates a more homogeneous contact, while the appearance of localized heating areas indicates a less homogeneous contact. From this point of view, material A has the more homogeneous contact, because it does not present localized heating areas, which is demonstrated by the relatively low measure of dispersion of the temperature curves recorded by thermocouple.

It should also be taken into consideration that the final temperature of braking measured by thermocouple, which is an important test result, may differ significantly during each braking application due to dispersion among the curves recorded by this instrument, a consequence of the non uniformity of contact for some friction materials. Precaution should be taken especially with high speed brakings.

Thus, it is suggested that the measurement of final temperature braking should be taken after reaching a uniform temperature distribution on the disc, which occurs a few seconds after the process of braking. It there should be an ideal time to obtain the final temperature after the braking ends. However, to determining the ideal time would require more testing, which is not the purpose of this study.

4. CONCLUSIONS

The comparison between the thermographic images on the disc surface with temperature curves measured via thermocouple showed that there is a coupling between the region where localized heating occur and heating rates recorded by the thermocouple. Moreover, the presence of localized heating areas on the disc surface, which can be seen through the thermographic images, suggests a significantly irregular contact on the friction pair. Thus, an alternative way to measure the mechanical contact uniformity on the friction pair is by analyzing the temperature dispersion of the curves recorded by thermocouple for each brakings performed under similar operation conditions.

The test results show that specimen A presents better uniformity in the distribution of temperature (and hence in contact) than material B.

The dispersion among the temperature curves measured via thermocouple is actually a combination of speed and torque effects and it is difficult to disassociate one from the other factor. However, an analysis based on the presented results indicates that there is a tendency for the dispersion between the curves to increase with speed increase. Now the ratio between dispersion and torque applied seems to be more complex, demanding a greater amount of testing.

For some kinds of materials (such as material B used in this work), some precaution must be taken o determine the final temperature of braking measured by thermocouple, since the presence of localized heating areas on the disc surface may distort this result.

5. REFERENCES

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7. RESPONSIBILITY NOTICE

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