ANALYSIS OF THE INFLUENCE OF TEMPERATURE ON THE FRICTION COEFFICIENT OF FRICTION MATERIALS

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Abstract: The objective of this work is to verify the behavior of the friction coefficient when the friction material is submitted to high temperature brakings (stage also known as Fade). For this study, a tribometer projected and located at GPFAI of Federal University of Rio Grande do Sul (UFRGS) was used.The specimens used were machined from commercial formats of braking pads of light vehicles. Four samples are classified as semi-metallic and they are of materials for commercial replacement parts. The other specimens are classified as NAO (Non Asbestos Organic) and they are an experimental friction material. The experiments were performed in three distinct stages: bedding-in, characterization and fade. The bedding-in stage was the first to be performed, with the aim of increasing the friction pair contact. Then, three sets of twelve brakings were performed for friction characterization, where each braking was interspersed with a stage of fade (severe temperature conditions). The fade stages degrade the phenolic resins of the materials and affect the performance of the friction material. The test results of this paper show that brake pads with different formulations have a variation on the performance of friction coefficient with brakings at high temperatures (fade), which is in accordance with specialized literature.

1. INTRODUCTION

The highly competitive automotive industry has required large investments in research and development of various vehicle components in order to obtain high performance combined with cost reduction in the manufacturing process and safety. All brake systems observe this market requirement: they are meant for high performance sports cars or popular cars.

A very important variable in the braking phenomena is temperature. Under severe temperature conditions (also known as fade), there is a degradation of the phenolic resins in the organic matrix of the friction material. In this context, friction experiments using a tribometer under high temperature help to understand and evaluate the friction behavior against chemical composition changes during the braking (Desplanques et al., 2006 and Cristol-Bulthé et al., 2008).

The first part of this work presents the conditions employed during the tests (methodology) as well as aspects related to the machine used (a braking tribometer), which was designed by the authors of this paper. The second part presents the results of the experiments, with the friction coefficient behavior against the stages of the braking test at high temperatures. A brief discussion of the results obtained is also included in this section.

2. METHODOLOGY

2.1. The braking tribometer

All tests were performed in a specially designed braking tribometer (Figure 1) capable of employing braking conditions similar to those that occur in vehicles (Neis, 2008). Basically, the designed machine consists of a vertical rotor (disc) on which the specimen (friction material) is pressed. To measure the temperature, there is a K-type thermocouple placed at 4 mm from the disc surface, in a radius of 40 mm. The general performance characteristics of the described machine are presented in Table 1.

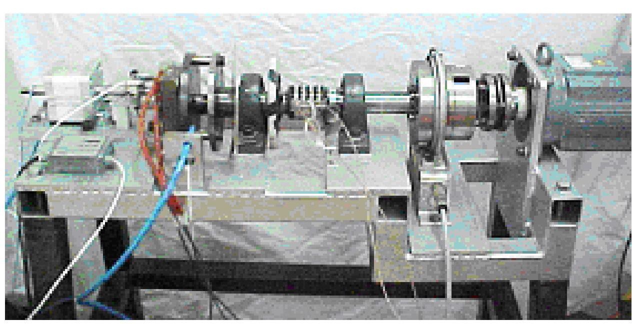


Figure 1 - Braking tribometer designed at UFRGS.

Table 1 - General characteristics of the designed tribometer.

Normal load	0 to 1800 N
Motor power	11 kW
Mean radius of disc rubbing surface	27 to 54 mm
Rotational speed	0 to 4500 rpm
Disc diameter	159 mm
Dimensions (LxWxH)	784 mm x 350 mm x 865 mm

2.2. The specimens

The friction materials (pads) used in the samples during the tests were provided by a national company in this segment. Two of the samples were manufactured from a basic formulation for research (samples A1 and A2) and they are classified as NAO (Non Asbestos Organic), while the other four pads were manufactured from commercial materials used in the automotive industry and classified as semi-metallic (samples B1, B2, C1 and C2). Samples B1 and B2 have a different formulation from samples C1 and C2. All the pads were shaped into a cylindrical-shaped piece with 18 mm diameter (Figure 2).

Figure 2 - Specimen geometry.

2.3. The test

The tests were performed to check the influence of the materials on the friction coefficient when subjected to high temperatures. The experiments were performed in three distinct stages (Table 2): bedding-in, characterization and fade. The bedding-in stage was the first to be performed, with the aim of increasing the friction pair contact. Then, three sets of twelve brakings were performed for friction characterization, where each group of characterization was interspersed with a stage of fade (severe temperature conditions) (Table 3). The characterization brakings were executed to verify the repeatability of the experiment and also the behavior of the friction coefficient. In these stages of fade, to guarantee that all samples have the same heat rate and reach the temperature of 520ºC with the same energy given to the system, the torque was maintained constant at a value of 13 N.m. The effective radius was 39,05 mm for all samples and each specimen was subjected to the conditions shown on Table 3 just once.

Table 2 – Stages of the experiment.

Stage	Disc Initial Temperature (°C)	Disc Final Temperature (ºC)	Force (N)	Sliding Speed (m/s)	Time (min)	Torque (N.m)
Bedding-in	Environment	-	500	2,19	5	-
Caracterization	100	-	400	3,29	3	-
Fade	150	520	-	4,39	-	13

Table 3 – Stages of the experiment.

Order	Stage	Number of Brakings
1	Bedding-in	1
2	Caracterization	12
3	Fade	1
4	Caracterization	12
5	Fade	1
6	Caracterization	12

3. RESULTS

The results for the average friction coefficient for all the samples tested are shown in Figure 3, Figure 6 and Figure 9. Figure 4, Figure 7 and Figure 10 show the final temperature measured by the thermocouple in the disc. Figure 5 (a) and (b), Figure 8 (a) and (b) and Figure 11 (a) and (b) show the results for temperature and friction coefficient during stages of Fade 1 (Friction 1 and Temp 1) and Fade 2 (Friction 2 and Temp 2).

For samples A1 and A2 (Figure 3), the value of the average friction coefficient for the same fade brakings from same stages are very close, where those from Fade 1 are 10% lower than those from Fade 2. The friction coefficient calculated for the characterization stages gets lower with high temperature steps. The decrease in the average friction coefficient before the first fade and after the second one is of 30% for specimen A1 and 40% for specimen A2. Please note that after the stage of Fade 2, both samples show similar curves. Figure 4 shows that the temperature curves have a similar behavior to its correspondent friction curve. Figure 5 (a) and (b) show that the behavior of friction coefficient for each fade stage braking is similar. In both specimens, Fade 1 starts at a high value (0,8 for sample A1 and 0,7 for A2), decreases, and when it reaches a temperature around 350º, the curves start a period of positive rate. For Fade 2, the period of positive rate starts, for samples A1 and A2, at a temperature around 230ºC.

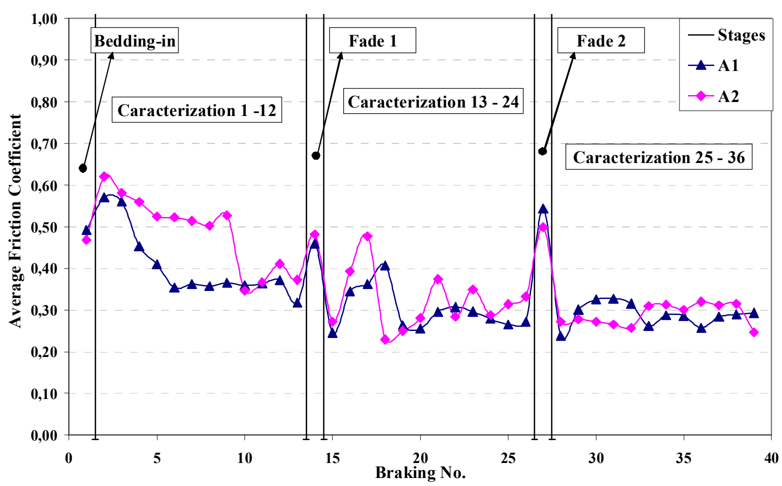


Figure 3 – Average Fiction coefficient for samples A1 and A2.

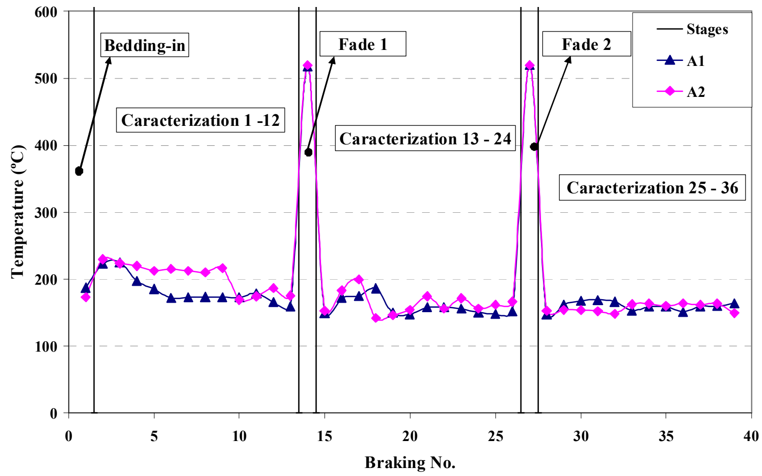
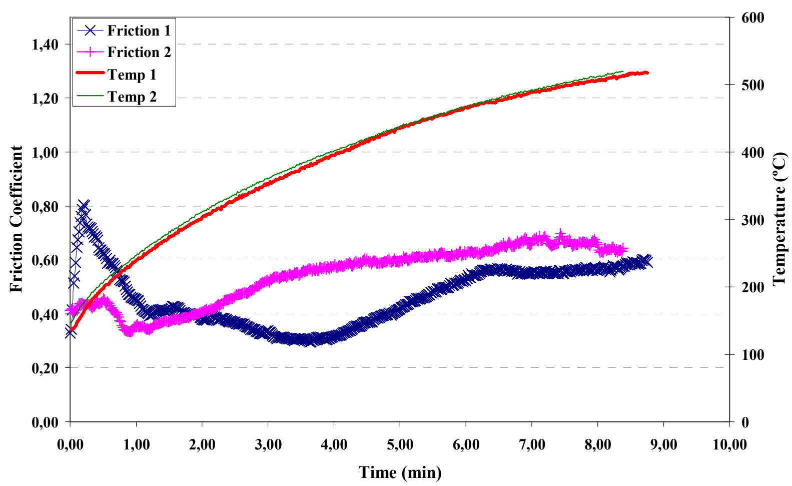
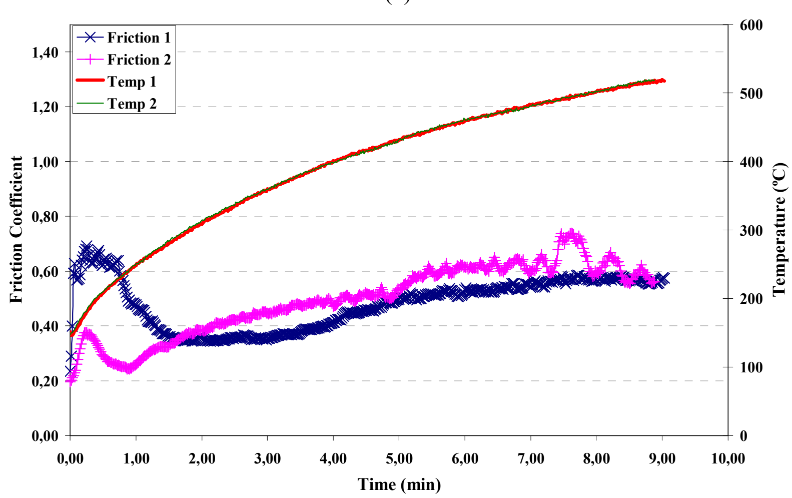


Figure 4 – Disc final temperature curves for samples A1 and A2.



(a)



(b)

Figure 5 – Friction and temperature curves during fade stages for (a) sample A1 and (b) sample A2.

For specimens B1 and B2 (Figure 6), as also seen in Figure 3, the average friction coefficient of brakings from the same stages is similar. The calculated values for Fade 1 braking are approximately 75% lower than those calculated for Fade 2. Comparing the characterization stages before Fade 1 and after Fade 2, sample B1 shows a loss of 40% and sample B2 shows a gain of 2%. Specimen B2 also shows a significant 10% gain in the average friction coefficient between the brakings of Characterization 1 -12 and Characterization 13 – 24. Figure 7 shows that each temperature curve has a correspondence with its friction curve. Figure 8 (a) and (b) shows that the behavior of the friction coefficient for each fade stage braking is similar, even though sample B2 took 2 more minutes than sample B1 to reach 520ºC. This was caused by the low friction during the test which the tribometer couldn't compensate with force. In both specimens, Fade 1 starts at a certain value (0,8 for B1 and 0,4 for B2), decreases and when it reaches a temperature near 350º, the curves start a constant period. Then, when for both samples the temperature measured in the disc reaches 440ºC, the positive rate starts. For Fade 2, for both samples, the curves start with positive rate (reaching values above 1,00) and the negative rate period begins around the temperature of 440ºC.

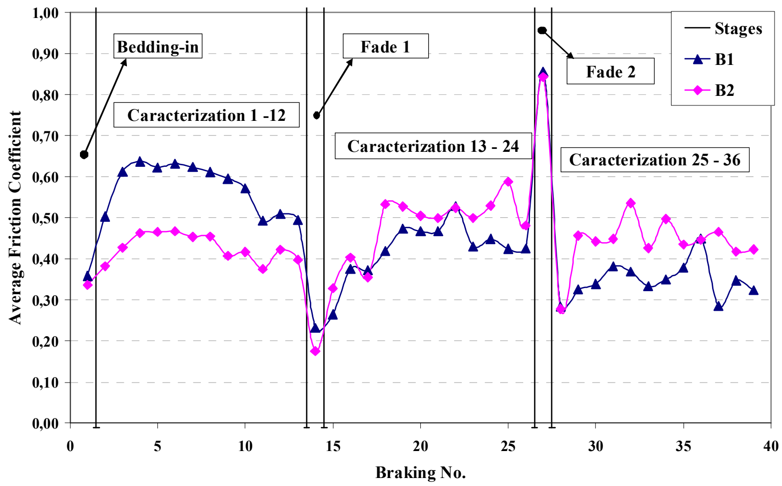


Figure 6 – Average Fiction coefficient for samples B1 and B2.

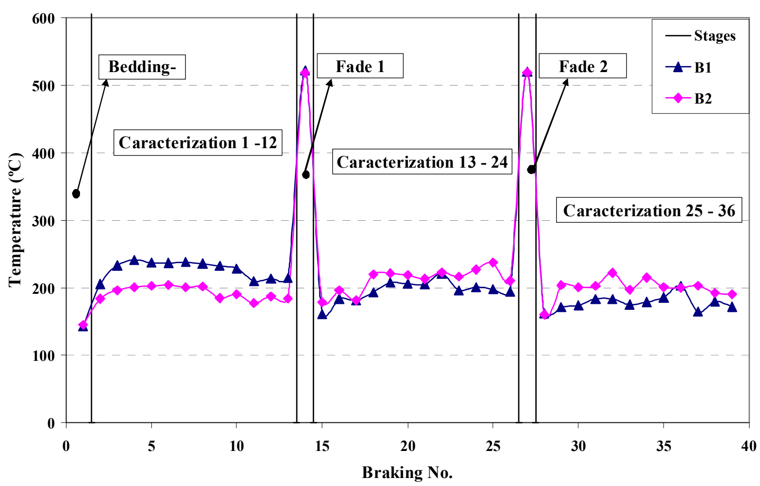
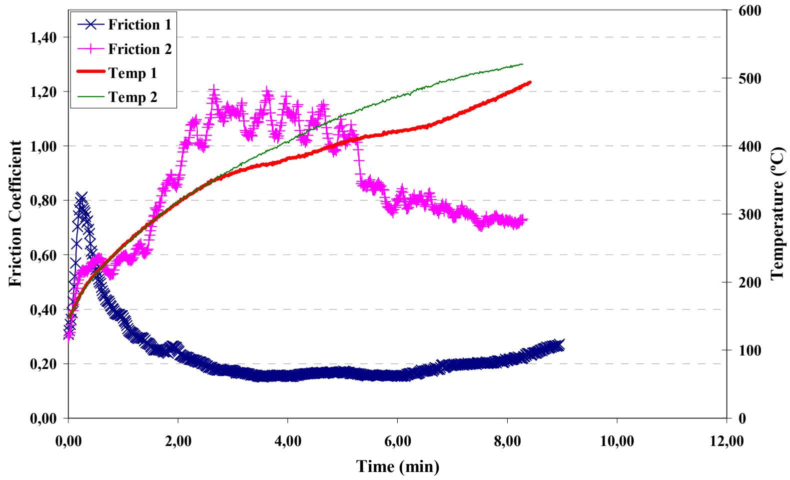
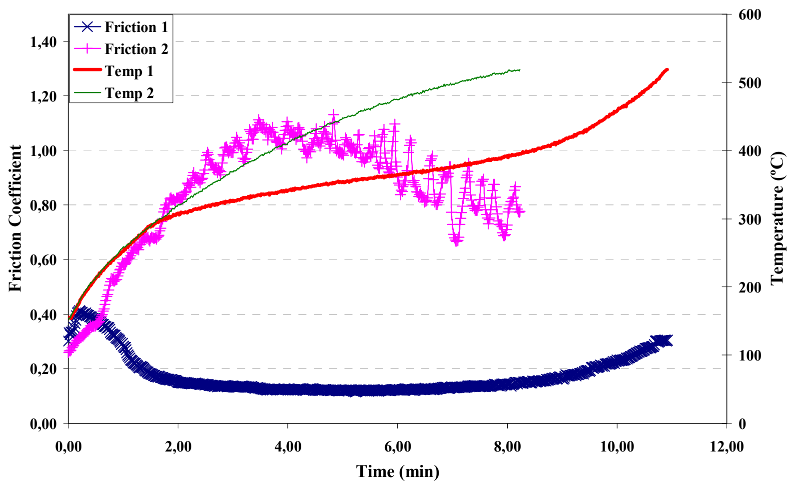


Figure 7 – Disc final temperature curves for samples B1 and B2.



(a)



(b)

Figure 8 – Friction and temperature curves during fade stages for (a) sample B1 and (b) sample B2.

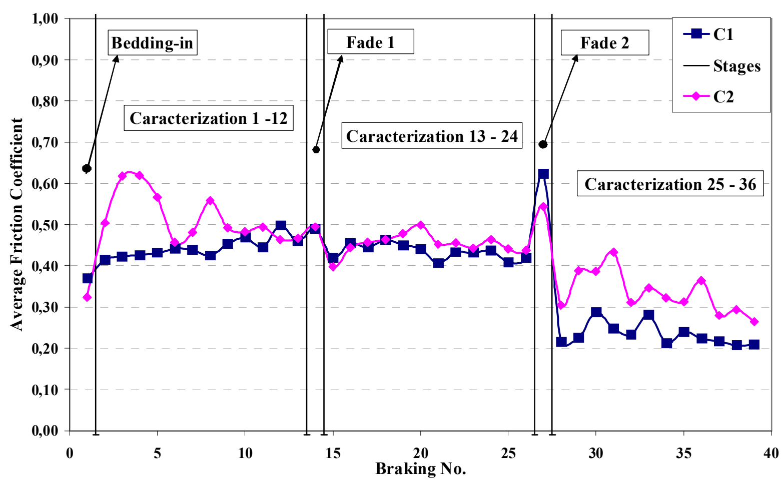


Figure 9 – Average Friction coefficient for samples C1 and C2.

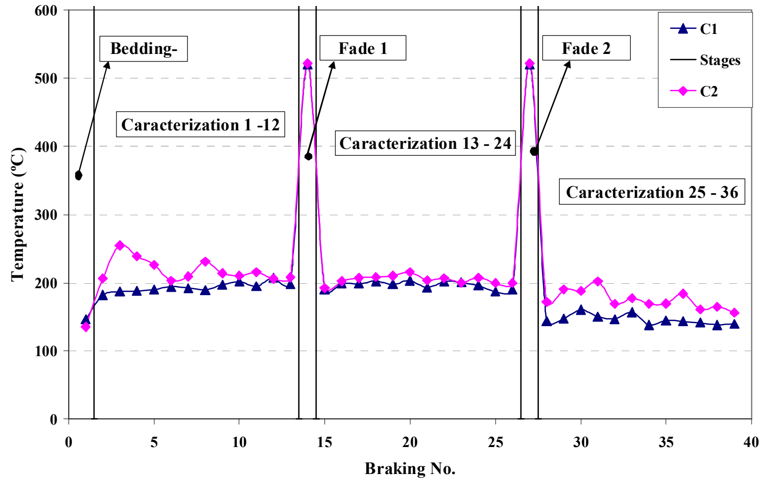
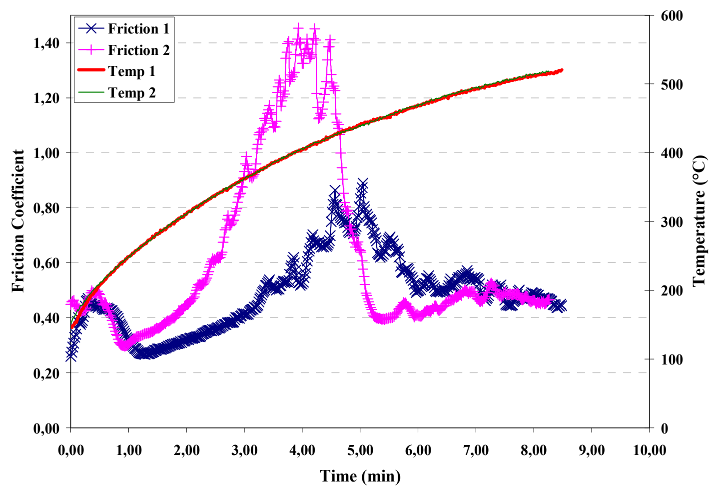
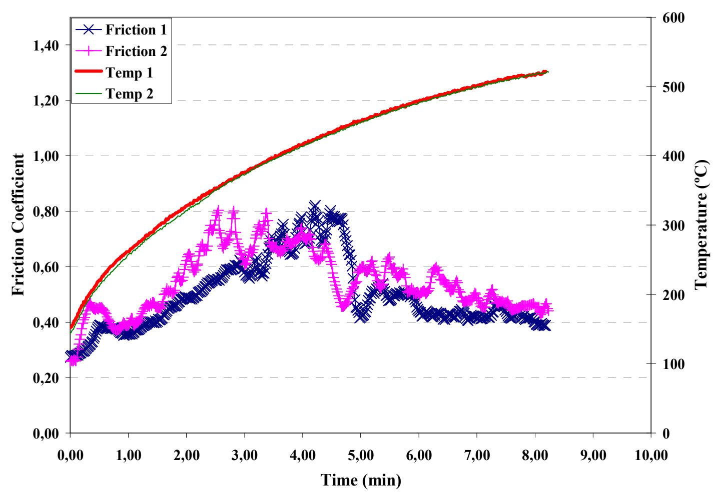


Figure 10 – Disc final temperature curves for samples C1 and C2.



(a)



(b)

Figure 11 – Friction and temperature curves during fade stages for (a) sample C1 and (b) sample C2

Figure 9 shows the results for average friction coefficient for samples C1 and C2. Again, the calculated values for the friction coefficient for brakings from the same fade stages are very close. The values for Fade 1 are lower than Fade

2 by 16%. The friction decay between the characterization stages before the first fade and after the second one reaches 50% and 25% for samples C1 and C2 respectively. Figure 10 shows that the temperature curves for samples C1 and C2 have the same behavior as the friction curves. Figure 11 (a) and (b) shows that the behavior of friction coefficient for each fade stage braking is similar, even though Fade 2 braking for sample C1 reaches values higher than Fade 2 for sample C2. In both specimens, Fade 1 friction curves have positive rate after the temperature of 250°C and the negative rate period starts with temperatures around 440ºC. For Fade 2, after a little period of negative rate, the curves start with positive rate at the temperature of 240º (in this period, specimen C1 reaches friction coefficient above 1,00). Then for both curves, a negative period of rate starts on 440ºC until the end of braking.

The friction coefficient for each sample group during similar fade stages has similar behavior. For samples of group A (A1 and A2), the friction coefficient curves of Fade 1 start with negative rate and become positive after reaching 350ºC. For Fade 2, this positive rate starts at 230ºC. For specimens of group B, the friction coefficient curves of Fade 1 start with negative rate, become constant at 350ºC and start the positive rate period at 440ºC. For Fade 2, the curves have positive rate until 440ºC when they reach values over 1,00, then the negative rate period starts. For the specimens of group C, the friction curves of Fade 1 start the positive rate period at the temperature of 250ºC and become negative at 440ºC. For Fade 2, the friction curves start with negative rate, become positive after 240ºC (when friction reaches values over 1,00 for sample C1) until the temperature of 440º, when another period of negative rate starts and is maintained for the rest of the braking.

3. CONCLUSIONS

According to the results for the experiment to verify the influence of temperature on the performance of friction material, all the values for fade brakings with its correspondent stage (ex: Fade 1 for sample A1 with Fade 1 for sample A2) were similar between the specimens. On the other hand, the difference between the brakings of Fade 1 and Fade 2 is significant. In all cases, the average value calculated for friction coefficient from Fade 1 is lower than Fade 2 by 10% to samples A1 and A2, 75% for samples B1 and B2 and 16% for samples C1 and C2.

When comparing the characterization stages before the first fade and after the second one, the specimens also showed variation in behavior of average friction coefficient. With exception of sample B2 – that had a gain of 2% – all samples showed a significant decrease in the value of average friction coefficient, with losses of 30% for sample A1, 40% for samples A2 and B1, 50% for sample C1 and 25% for sample C2. Other important evidence is that the specimens from group A and group C showed a behavior more stable than that of specimens from group B. All of these results can be explained by the degradation of phenolic resins of the friction material tested (Cristol-Bulthé, 2008).

The final disc temperature curves showed that, for all samples tested, there is a correlation with their respective average friction coefficient curves. Disregarding the stages of Fade 1 and Fade 2, where the disc final temperature was controlled, all other brakings showed that high average friction coefficient implies high final temperature measured in the friction disc.

The test results of this paper show that materials with different formulations have a variation in behavior of friction coefficient with high temperature brakings (fade), which is in accordance with specialized literature.

4. REFERENCES

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