MECHANICAL AND TRIBOLOGICAL CHARACTERIZATION OF FOUR COMMERCIAL BRAKING FORMULATION MATERIALS

P. V. Antunes[1](*), A. Ramalho[1], L.M. Vilhena[1]
[1] CEMUC, Mechanical Engineering Department, University of Coimbra, Portugal

ABSTRACT
Organic friction materials for brake linings, namely brake pads are polymer matrix composites usually containing numerous macroscopic as well as microscopic constituents such as filamentary reinforcements, solid lubricants, abrasives and fillers. Their main objective of the these composite system are that a constant and stable coefficient of friction (COF) is provided irrespective of environmental conditions such as pressure, sliding velocity, temperature, humidity etc. Brake pads performance should be maintained over a wide range of stress conditions. Although the wear of the brake pad is inevitable, it should be minimized as far as possible. While cast iron has been the dominant material for brake discs, brake pad materials are constantly evolving into more complex composites.
The main objectives of the present work is to characterize the physical and the tribological behavior of four commercial braking pads material formulations. For all compositions the studied factors are normal pressure and sliding speed, considering one braking-test protocol designed with temperature and friction load data acquisition. A double pad-on-disc tribological test configuration was used to determine tribological properties of brake pad for heavy vehicles commercial. Three wear tests via increased severity of rubbing conditions for a constant braking distance.

KEYWORDS: Brake Pads, Tribological Test, Specific Wear, Elastic Modulus.

1.- INTRODUCTION

Nowadays, a wide range of friction lining materials are available, the behaviour of those material is highly dependent on their composition and service conditions. Through a series of tests on small-scale samples, they found the friction performances and wear resistance of the same material to be changing with load, sliding speed, and temperature.
Besides the operating brake conditions friction material wear rate is determined largely by the properties of the rubbing surfaces. A characteristic brake lining pad is a multicomponent composite typically formulated of more than 10 constituents and polymer matrix. More than 2000 different materials and their variants are now used in commercial brake components [1].
Industrial pads/shoes usually contain a large number of different constituents like ceramic particles and fibres, minerals, metallic chips, solid lubricants and elastomers in a matrix material such as phenolic resin. Up to now, the development of new friction materials has been done empirically, starting from well-known base compositions which have been successively optimized by adding friction modifiers [2]. Hence when brake materials are developed, it is still necessary to perform experimental tests to characterize the lining material.

Friction characterization test systems have dual-purpose function, they could be used as equipment for qualifying the manufacturing process through quality inspection, or for material development. For the purpose of objective quality inspection, exist several machines/equipment are utilized to evaluate acceptable product tolerances and consistency within part production from material batch-to-batch variation and development. With respect to tribological characterization, several machines can be utilized to evaluate frictional properties and effect of individual raw material ingredients. This means that extrapolations of results of small scale tests on friction material cannot always be used to make reliable predictions on the behaviour of the full-scale brake.

2.- MATERIALS AND EXPERIMENTAL PROCEDURES

MATERIALS

The friction lining materials used in this study have physical and mechanical properties in later designated points that differ according to each formulation.

As mentioned above, the wear materials used in this study were provided by *Auto Brake Viseu Lda*. These materials are brake pads used in heavy vehicles: ACERCHINA (China), ATV 55 (Portugal), FRASLE FLE1749 (Brazil) and JURID FF29 (Germany).

Regarding the antagonist material a commercial automotive disc was used and typically it is a gray cast iron with Type A graphite (flakes having a uniform distribution and random orientation) with a pearlitic matrix of low ferrite and carbide content.

EXPERIMENTAL SET-UP AND TEST CONDITIONS

TRIBOLOGICAL TESTS

In terms of configuration, the experimental apparatus used is a tribological system similar to the one in the automotive vehicles. With a rotating disc and two pads actuating at the same time. The applied pressure, unlike the hydraulic drive used in actual application, was replaced by mechanical actuation, by means of two parallel springs. This apparatus's main shaft was driven by a lathe in "between centers", and the required speed were controlled by the lathe ratio gear train.

Each pad had a contact surface with an approximated dimensions of 15x15 [mm×mm], which were mounted in the main supports. All friction lining pads were tested at 4m/s and 6m/s, and for each speed, 3 normal load conditions, ranging from 0.3 to 0.7 MPa were used.

In order to record the pads temperature in each test performed, a thermistor, positioned at 1.5 mm from the rubbing surfaces, was introduced in one of the pads.

Besides the amount of wear, measured using a precision scale, the specific wear, W_{SPE}, was also determined for each test condition and each material. The W_{SPE} corresponds to the ratio between amount of both pad's removed material, in mg, and the total work done by friction force along each test, i.e. determined by the numerical integration of the graph Friction Force [N] *vs.* sliding distance [m].

For each test the friction force and temperature were acquired and plotted against sliding distance. For all tests average COF and specific wear values were determined, disregarding the run-in period.

MECHANICAL TESTS

Brinell hardness test. In this test for each braking material a parallelepiped specimen was used. Tests were done in a Shimadzu AG-X Universal Testing Machines, the Brinnel hardness was determined using a 10 millimeters diameter steel ball as indenter. A load of 490 Newton (N) was applied for a period of 60 seconds, five indentations were made on the surface of each specimen. The resulting impression was measured across two perpendicular directions and these result averaged in order to determine the material's hardness.

Dynamic tests. The elastic modulus was measured by the impulse excitation technique as described by Braem *et al.* [4] and according to the standard ASTM C1259-96 [5]. Each specimen was set in free flexural vibration by a light mechanical impulse. A metal wire was used to suspend the specimens in the furnace. The specimen should be initially suspended at distances of approximately 0.1 L from each end, in order to maximize the vibrational deflection and resulting signal.
A piezoelectric transducer was used to capture the flexural vibration signal. The fundamental frequency of the first flexural vibration mode was determined analysing the vibration response by Fast Fourier Transform.
Ten tests were performed for each sample at each temperature; ambient (≈25ºC), 50ºC, 100ºC, 150ºC and 200ºC. Knowing the specimen's dimensions, mass and first flexural vibration mode, the elastic modulus was determined using equation (1)

$$E = 0.9465\left(\frac{mf_t^2}{d}\right)\left(\frac{l^3}{t^3}\right)T_1 \qquad (1)$$

Where *l* and *d* are the length and width of the bar, m their mass and *ft* is the fundamental frequency. According to ASTM standard, T_1 is a correction factor to take into account the finite dimensions of the bar. For the calculation of T_1 a constant Poisson ratio of 0.3 was used.

3.- RESULTS AND CONCLUSIONS

TRIBOLOGICAL TESTS

Regarding tribological tests the result representation selected was friction force, in N, and COF versus sliding distance, Figure1. The measured temperature was also plotted against sliding distance, Figure 2. The effect of normal pressure was also analysed, plotting friction force along the tests for each speed and the three normal pressures tested, Figure 3.

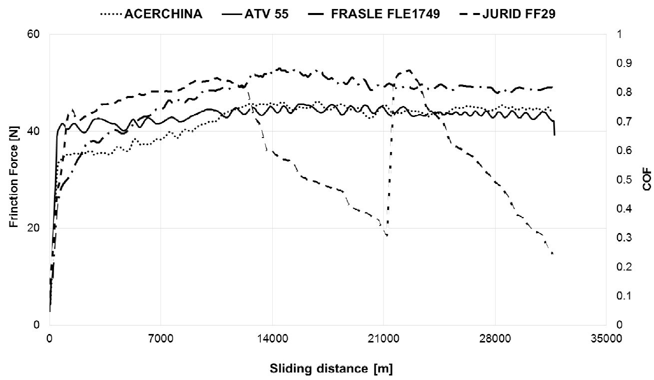

Figura 1. Friction force and COF versus sliding distance for all tested materials for tests condition of 4 m/s and normal pressure of 0.3 MPa.

.

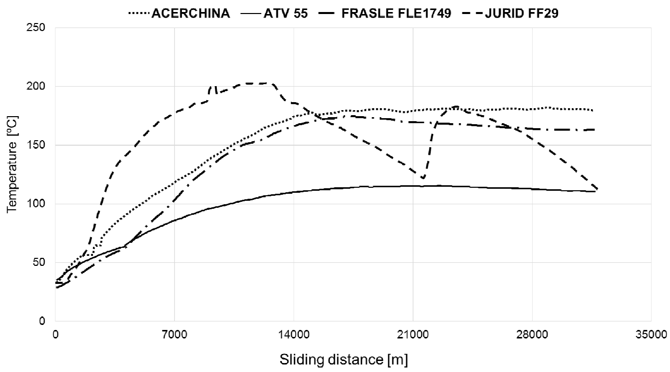

Figure 2. Plot of temperature versus sliding distance values for all tested materials at 4 m/s and normal pressure of 0.3 MPa tests condition.

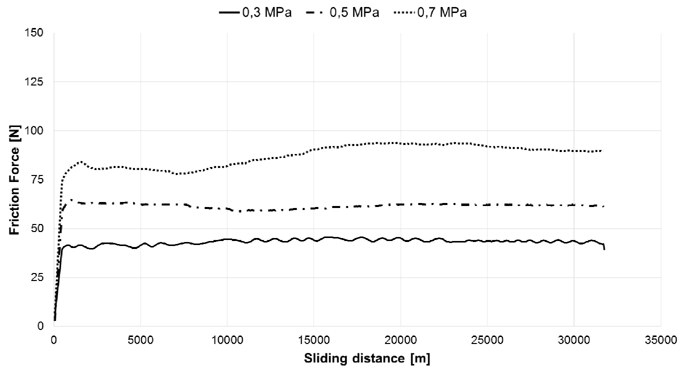

Figure 3. Friction force versus sliding distance for of 4 m/s and normal pressure of 0.3, 0.5 and 0.7 MPa for ATV lining material.

Regarding the quantification of wear amount Table 2, presents the specific wear [mg/MJ] and COF for all materials tested for sliding speeds of 4m/s and 6m/s and normal pressure ranging from 0.3 MPa to 0.7 MPa.

Table 2. Overall results for lining materials, for each speed (m/s) and normal pressure [MPa] test condition are presented the specific wear [mg/MJ] (cell on the left) and average COF of each material in each test (cell on the right).

Speed [m/s]	**4**						**6**					
N. Pressure [MPa]	**0.3**		**0.5**		**0.7**		**0.3**		**0.5**		**0.7**	
Material	[mg/MJ]	COF	[mg/MJ]	COF	[mg/MJ]	COF	[mg/MJ]	COF	[mg/MJ]	COF	[mg/MJ]	COF
ACERCHINA	126.6	0.35	142.1	0.38	170.3	0.34	134.4	0.38	173.3	0.34	*	*
ATV 55	96.1	0.36	84.8	0.27	106.8	0.28	105.1	0.34	106.9	0.28	257.9	0.32
FRASLE	57.6	0.40	63.7	0.33	81.7	0.34	68.2	0.41	71.1	0.10	84.4	0.10
JURID	77.2	0.32	129.9	0.34	128.2	0.37	73.5	0.42	136.1	0.35	108.3	0.33

* Test could not be performed.

MECHANICAL TESTS

Regarding mechanical test results Figure 4, presents the average Brinnel hardness results for the friction lining materials tested. Acer presents the highest hardness values, while JURID presents the lowest, a 36% decrease relatively to ACER.

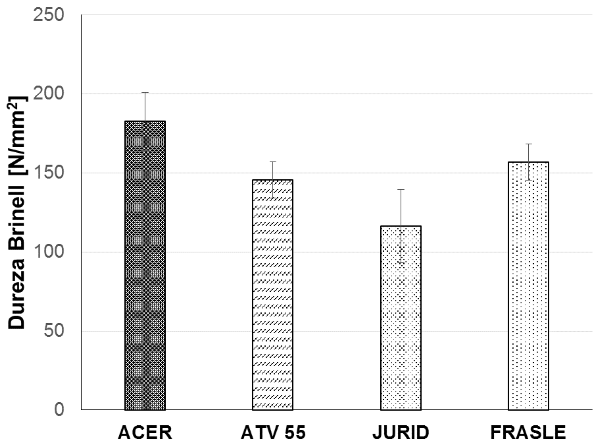

Figure 4. Brinnel hardness average measured values for materials in study.

Figure 5, presents the average Elastic modulus results all friction lining materials tested at controlled temperature at Tambient, 50ºC, 100ºC and 150ºC using the impulse excitation technique. It is possible to observe a clear tendency of decrease in elastic modulus for increasing temperatures for all friction materials.

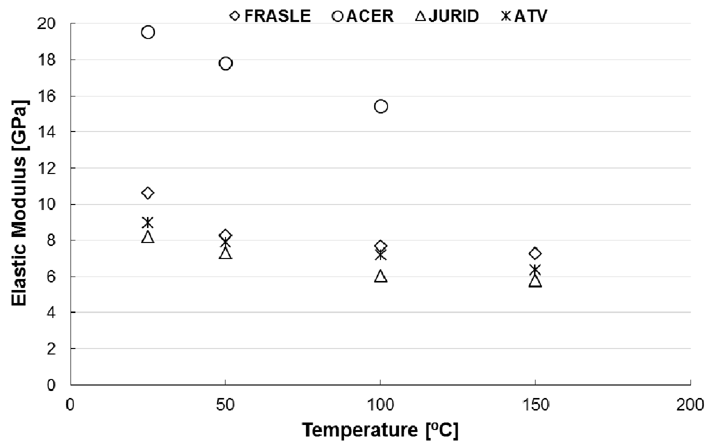

Figure 5. Elastic modulus average measured values attained for friction material for temperatures ranging from Tambient to 150ºC.

In the present study it was only possible to test tribologically and mechanically four commercial friction lining materials pads for heavy duty vehicles. This materials presented distinct behaviour for the same service conditions. Concerning the tribological several sliding speeds and normal pressure were used, friction force and temperature were measured. Hardness tests and Elastic modulus were done to understand the materials behaviour. It was possible to conclude that:

- Generally with the increase in sliding speed and normal pressure there is an increase in friction coefficient, and therefore dissipated energy;
- Temperature follow the same general tendency as friction force during tribological tests;
- In some cases, during the tribological test, the pads produced an acute continuous noise, this phenomenon happening mainly with the loading conditions and higher speeds. ACER due to its high content of glassy elements, harder and therefore more likely to cause this phenomenon;
- JURID pads were the ones recording a higher COF in most of the tests;

- The friction material that better dissipate the heat are the ATV 55, even if the COF is generally lower than the rest, the pads that worst dissipate heat are ACERCHINA and JURID;
- Regarding wear, ACER China are the ones with the highest wear values in most of the tests, while FRASLE are the ones with less material losses during tests;
- Ideal specific wear values, should range between 40 and 100 mg/MJ [2], in the present study, only FRASLE maintained this parameter in between the interval for all test conditions;
- Hardness values have wide range of values, JURID presented 36% reduction in hardness relatively to ACER;
- With increasing temperature friction lining materials present decreasing elastic modulus.

ACKNOWLEDGEMENTS
The authors acknowledge *Auto Travões Viseu-recondicionamento de Travões e embraiagens Lda* the support through the provision of the frictrion linning materials presented in the study.

REFERENCES
[1] Blau, Peter J. “Compositions, Functions, and Testing of Friction Brake Materials and Their Additives”, Energy, vol. 27. (2001) pp. 1-23.
[2] I. Mutlu, Investigation of Tribological Properties of Brake Pads by using Rice Straw and rice husk dust, J. Applied Sciences 9(2): (2009), pp: 377-381.
[3] A. E. Anderson, “ASM Handbook, Friction, Lubrication and Wear Technology”, Technology, vol. 18, (1992), pp. 1169-1186.
[4] M. Braem, P. Lambrechts, V.Van Doren and G. Vanherle: The impact of composite structure on its elastic response, J. Dent. Res. Vol, 65 (1986), pp: 648-53.
[5] ASTM: Standard test method for Dynamic Young´s modulus, shear modulus, and Poisson´s ratio for advanced ceramics by impulse excitation of vibration C1259 (1996), pp. 374-82.