IOP Conference Series: Materials Science and Engineering

PAPER • **OPEN ACCESS**

Tribological properties of the disc brake friction couple materials in the range of small and very small speeds

To cite this article: N A Stoica *et al* 2017 *IOP Conf. Ser.: Mater. Sci. Eng.* **174** 012019

IOP Conf. Series: Materials Science and Engineering **174** (2017) 012019 doi:10.1088/1757-899X/174/1/012019

Tribological properties of the disc brake friction couple materials in the range of small and very small speeds

N A Stoica[1], A M Petrescu, A Tudor and A Predescu

Department of Machine Elements and Tribology, University Politehnica of Bucharest, 313 Splaiul Independentei, Bucharest, Romania

E-mail: nicolae.stoica@upb.ro

Abstract. The tribological properties of the friction couple materials have a major influence on the brake system operation and its failure. One of the main phenomena associated as a symptom of failure in the brake system are the noises and vibrations produced during braking. The stick-slip phenomenon is attributed as the cause of these noises and vibrations. The stick-slip phenomenon usually appears at low and very low sliding speeds and is described as intermittences in the friction process caused by the differences between the values of the kinetic and the static friction coefficients. The present paper addresses an investigation about the influence of the static and kinetic friction on the occurrence of above mentioned noises and vibrations in the disc brake system. For this, extensive experimental work was performed on a laboratory tribometer in the form of pin-on-disc tests, where the pin was manufactured out of an automotive brake pad and the disc was manufactured out of an automotive grey cast iron brake disc. The results highlight the effects of the sliding speed and contact pressure on the friction coefficient and its influence on the brake noises and vibrations caused by the stick-slip phenomenon.

1. Introduction

The tribological properties of the friction couple materials have a major influence on the brake system operation and its failure. One of the main phenomena associated as a symptom of failure in the brake system are the noises and vibrations produced during braking. The noises and vibration produced during braking have led the owners of vehicles to present complaints against the automobile manufacturer, which lead to a large amount of money being spent on the warranty and repair costs [1-4]. A wide array of brake noise and vibration phenomena are described by an even wider array of terminology. Squeal, groan, chatter, judder, moan, hum, and squeak are just a few of the names found in the literature [2]. Researchers attribute the stick-slip phenomenon as one of the causes of these noises and vibrations [1-7].

Typically, for the stick-slip phenomenon to occur, the static friction coefficient (μ_s) between the two contact surfaces of the friction materials must be greater than the kinetic friction coefficient (μ_k) [7, 8]. The stick-slip phenomenon usually appears at low and very low sliding speeds and is described as intermittences in the friction process caused by the differences between the values of the kinetic and the static friction coefficients. It appears in friction couples with dry or limited friction regime, when the sliding speed is in the range of 0.01 – 3 mm/s or when the angular speed is somewhere in the 1 –

25 rad/s [9, 10]. If these speeds have higher values, then the movement takes the form of self-induced vibrations sustained by the friction force itself [11].

The present paper addresses an investigation about the influence of the static and kinetic friction on the occurrence of above mentioned noises and vibrations in the disc brake system. For this, extensive experimental work was performed on a UMT laboratory tribometer in the form of pin-on-disc tests, where the pin was manufactured out of an automotive brake pad and the disc was manufactured out of an automotive grey cast iron brake disc.

2. Testing procedure

The experimental research presented in this paper was conducted on a Bruker (former CETR) UMT-2 Tribometer, which can be used effectively for the tribological testing of ferrous and non-ferrous metals, plastics, ceramics, paper, composites, thin and thick coatings, as well as of solid lubricants, lubricating fluids, oils and greases.

For the current tests conducted on the UMT a pin-on-disc system setup was used. This test method involves a pin shaped upper specimen that slides against a rotating disk as a lower specimen under a prescribed set of conditions. The UMT allows for monitoring during the test the actual dynamic normal load, friction force and friction coefficient, depth of wear and contact acoustic emission. In figure 1 we have an overview of the UMT tester and the two specimens used for the experiments. The upper specimen is a pin manufactured out of a semi-metallic automotive brake pad and the lower specimen is a disc manufactured out of an automotive grey cast iron. The pin has a diameter of 12 mm and the disc has a 55 mm diameter. Thus the contact between the pin and the disc is a flat circular surfaces with an area of 113.1 mm^2.

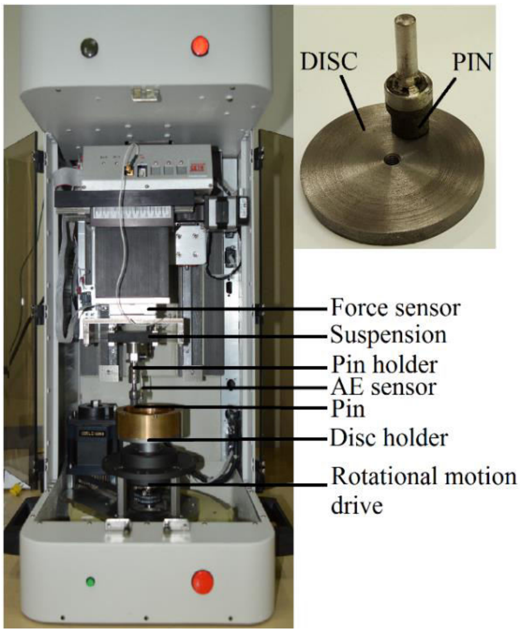

Figure 1. Overview of the UMT tester and the two specimens.

The UMT tester was equipped with a model DFH-20 two dimensional force sensor used to measure the sliding and breakaway friction force between the upper and lower test specimens as well as measuring and controlling the loading force. The model DFH-20 dual friction/load sensor has a range from 2 to 200 N and a resolution of 10 mN. In order to maintain a constant load it is sometimes necessary to have a suspension between the force sensor assembly and the upper specimen holder. The suspensions equipped on the UMT tester is a spring device used to compensate for variations in the distance between the force sensors and the surface of the lower specimen when the lower specimen is in motion. The upper specimen holder connects the pin to the suspension, while the lower specimen holder connects the disc to the model S25LE lower rotational motion drive used for the tests. The contact acoustic emission (AE) sensor is mounted on the pin and gives a voltage output.

The tests were performed at a normal load of 50 N, 75 N and 100 N and at three different speeds: 20 rpm, 40 rpm and 60 rpm. The values of the coefficient of friction (COF) and acoustic emission (AE) were monitored during the tests. The testing time for all the nine test was 300 s. Before these tests, a series of running in tests at 100 N and 60 rpm with a total time of one hour were undertaken to ensure that the real contact area is as close as possible to the nominal contact are so that the measured parameters do not vary from one test to another done at the same load and speed.

3. Results and discussions

The results were analyzed graphically and they highlight in comparison the evolution of the friction coefficient and acoustic emission during the tests.

From the diameter of the pin we can determine the nominal contact surface between the pin and the disc, which is 113.1 mm^2 and with the normal load we can determine the contact pressure between the pin and the disc. So, for 50 N the contact pressure is 0.44 MPa, for 75 N we have a contact pressure of 0.66 MPa and for 100 N the contact pressure is 0.88 MPa. Also, corresponding to the 20 rpm, 40 rpm and 60 rpm rotational speeds and the distance between the center of the pin and that of the disc (21.5 mm) the sliding speed is 0.045 m/s, 0.09 m/s and 0.13 m/s.

All three test conducted at 50 N present almost no acoustic emission as shown in figure 2.

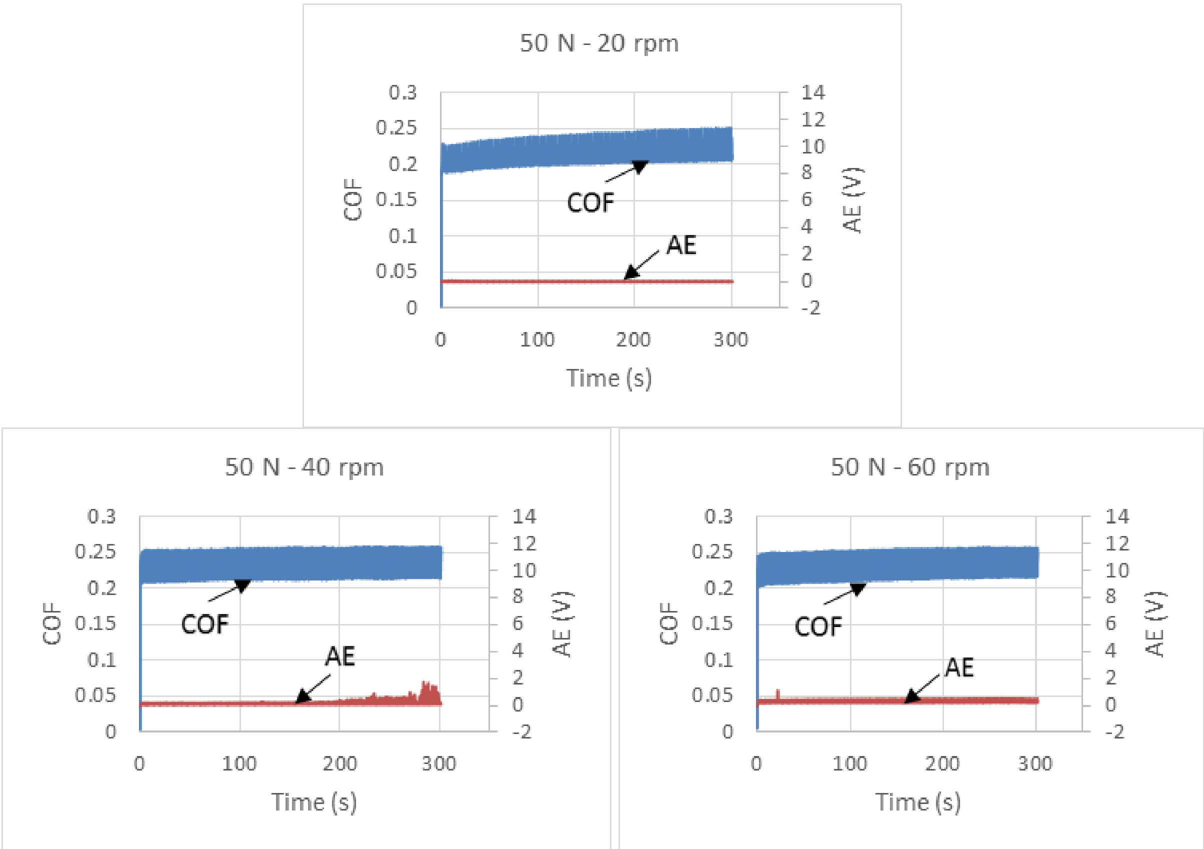

Figure 2. The evolution of the friction coefficient and acoustic emission for the three 50 N tests conducted at 20, 40 and 60 rpm.

As seen from in the graphs, only the test conducted at 50 N and 40 rpm the acoustic emission has a slight increase, but that is in the end of the 300 s duration of the test and no noise was audible as in the other two cases of the 50 N tests. The cyclical variation of the friction coefficient observed in the graphs is given by the loading force. This is explained by the fact that the misalignment of the surface of the disc determines a cyclical variation of the loading force and the tester is not able to keep the load constant throughout a rotation of the disc. This phenomenon is present in all the pin-on-disc tests.

Figure 3 presents the evolution of the friction coefficient and acoustic emission for the three 75 N tests conducted at 20, 40 and 60 rpm. In this case, when the load is increased to 75 N we can observe an increase of the acoustic emission. Comparing the three graphs we can see that by increasing the speed the acoustic emission will have a higher amplitude.

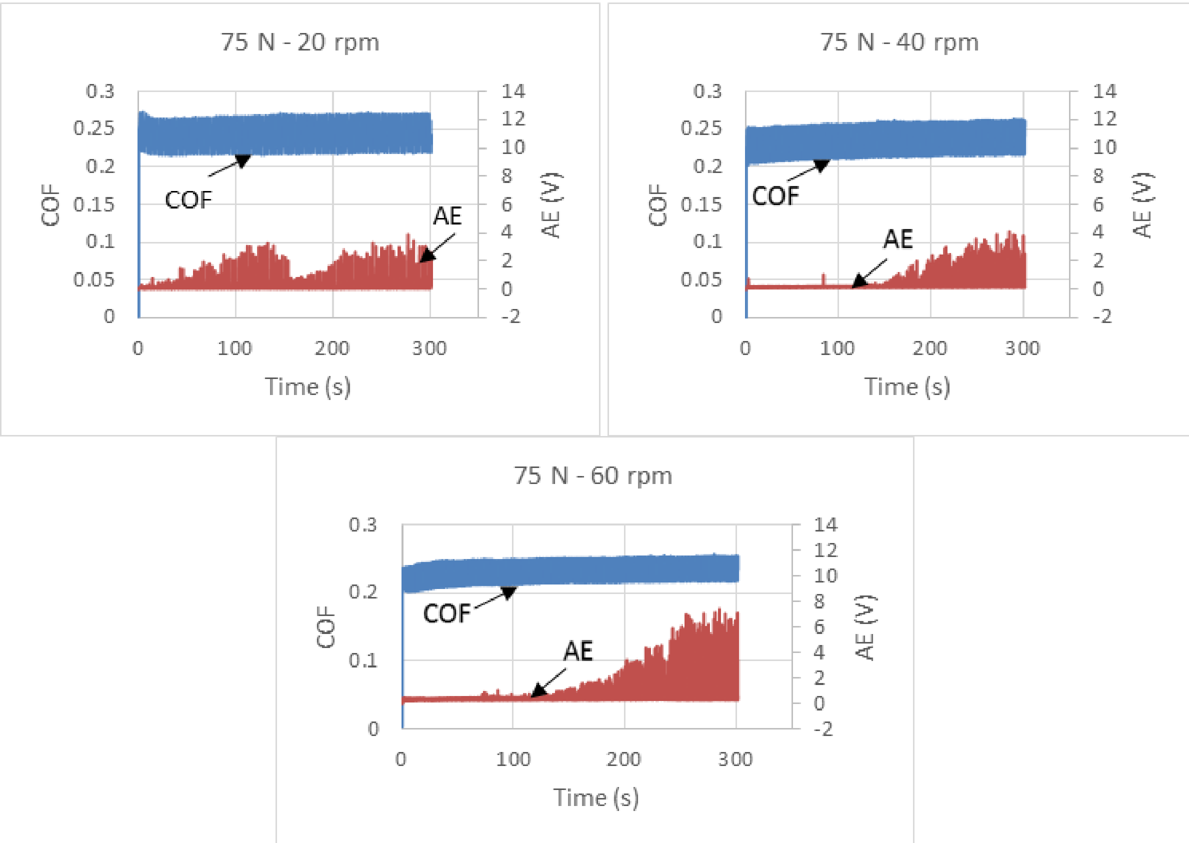

Figure 3. The evolution of the friction coefficient and acoustic emission for the three 75 N tests conducted at 20, 40 and 60 rpm.

During the three 75 N tests a short duration and low intensity noise coming from the two samples in contact can be heard. This noise could be heard in the last part of the tests and was cyclical, repeating every second, with just a few intermittences. In the last part of the 75 N and 60 rpm the noise grew louder with time and was louder than in the other two 75 N tests.

For a better understanding of what is happening, we have chosen a 10 seconds period of the experiment to highlight the phenomenon. This period can be observed in figure 4, in which we can see the evolution of the friction coefficient and acoustic emission between second 200 and second 210 of the 300 seconds test conducted at 75 N and 60 rpm. Here, the disc makes a complete rotation every second and the friction coefficient has the almost the same evolution from a cycle to another, but compared with the tests where we don't have acoustic emission there is a sudden drop and rise in the values of the friction coefficient that repeats every cycle with different amplitudes. This can be considered a stick-slip period.

The last tests were performed at a normal load of 100 N. Figure 5 presents the evolution of the friction coefficient and acoustic emission for the three tests conducted at a normal force of 100 N and 20, 40 and 60 rpm speed.

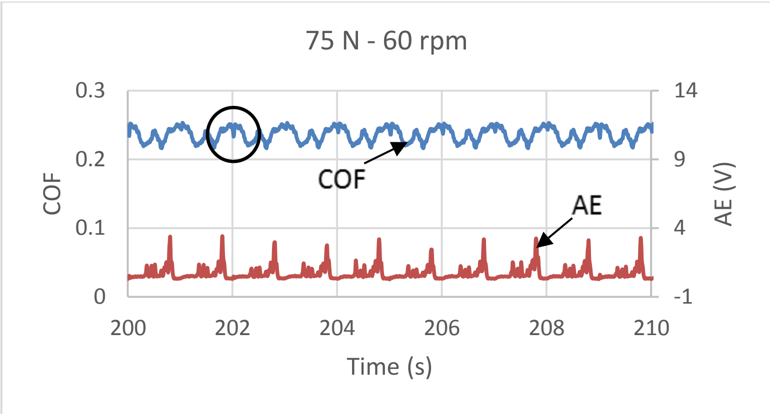

Figure 4. The evolution of the friction coefficient and acoustic emission for a 10 seconds period for the 75 N test conducted at 60 rpm.

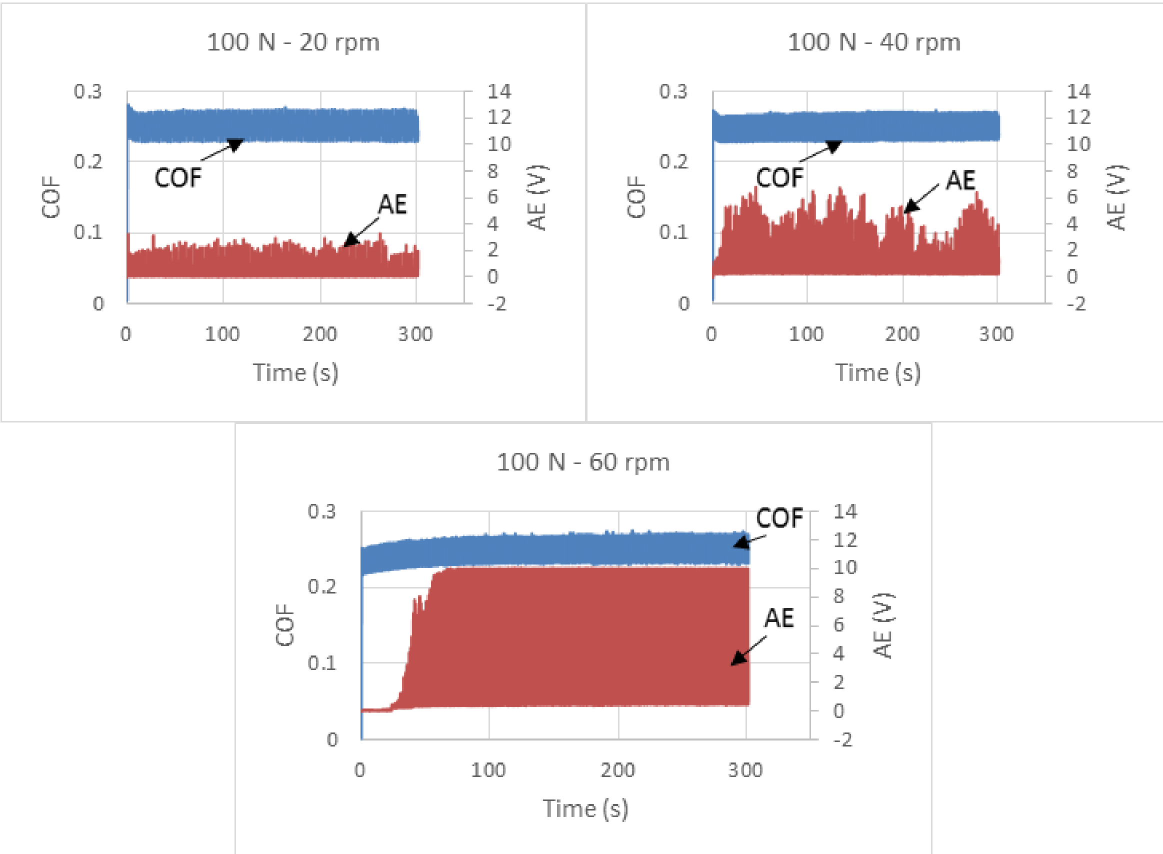

Figure 5. The evolution of the friction coefficient and acoustic emission for the three 100 N tests conducted at 20, 40 and 60 rpm.

From the graphs in figure 5 we can see that for all the three tests conducted for the 100 N normal force we have acoustic emission which increases with the rotational speed of the disc. The noise present in the 75 N tests was also present in the 100 N test, but much louder, and it grew in intensity as the speed increased. For the 100 N tests the amplitude of the stick-slip phenomenon described above increases with the increase of the relative speed between the pin and the disc. This can be observed in figure 6 where there is a sudden drop and rise in the values of the friction coefficient that repeats every cycle.

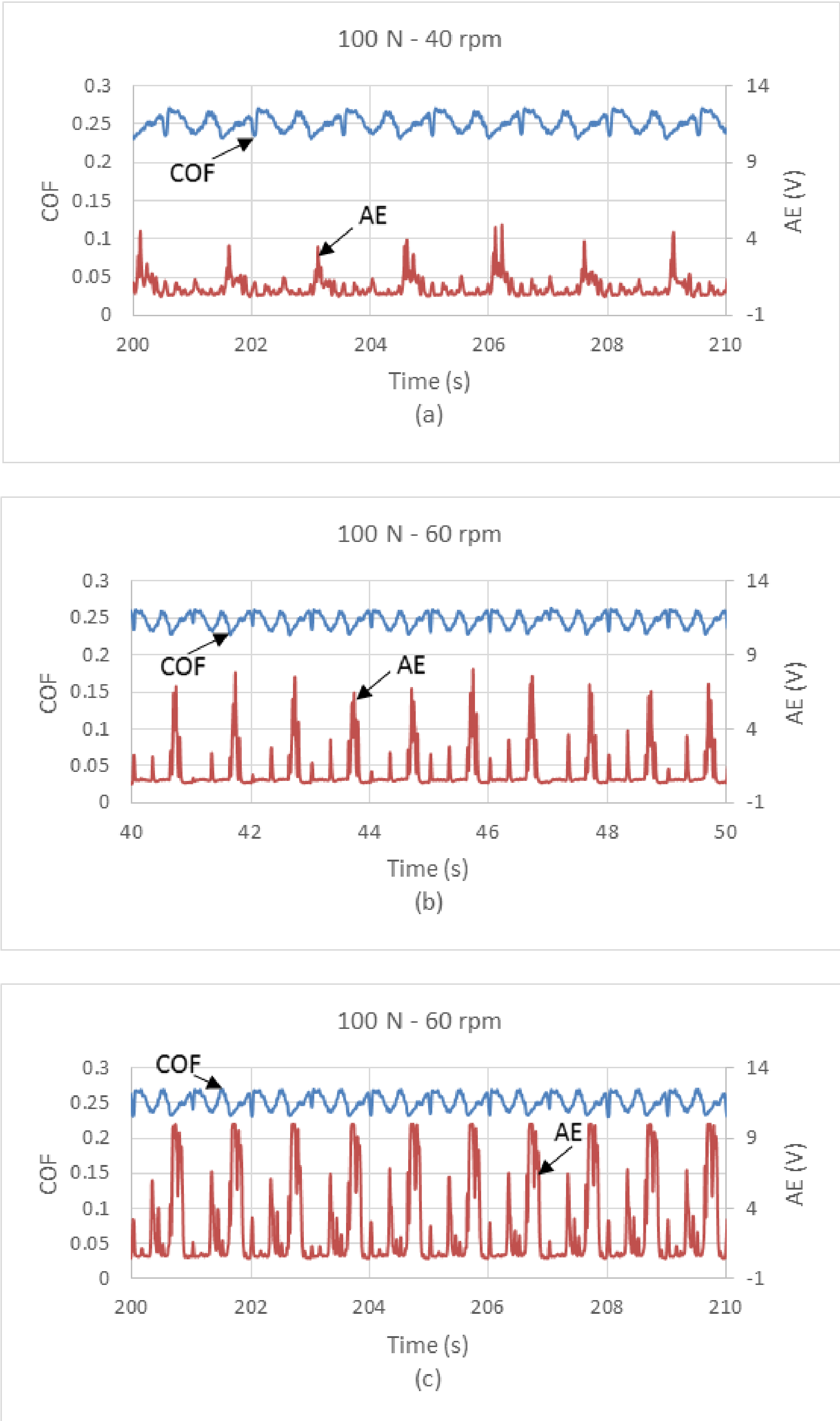

Figure 6. The evolution of the friction coefficient and acoustic emission for a 10 seconds period for the 100 N test conducted at: a) 40 rpm; b) 60 rpm (beginning of the test); c) 60 rpm (end of the test).

To better observe the correlation between the stick-slip phenomenon and the acoustic emission a two seconds period was chosen. This period can be seen in figure 7 for the 100 N and 40 rpm test (figure 7 a), the beginning of the 100 N and 60 rpm test (figure 7 b) and the end of the 100 N and 60 rpm test (figure 7 c).

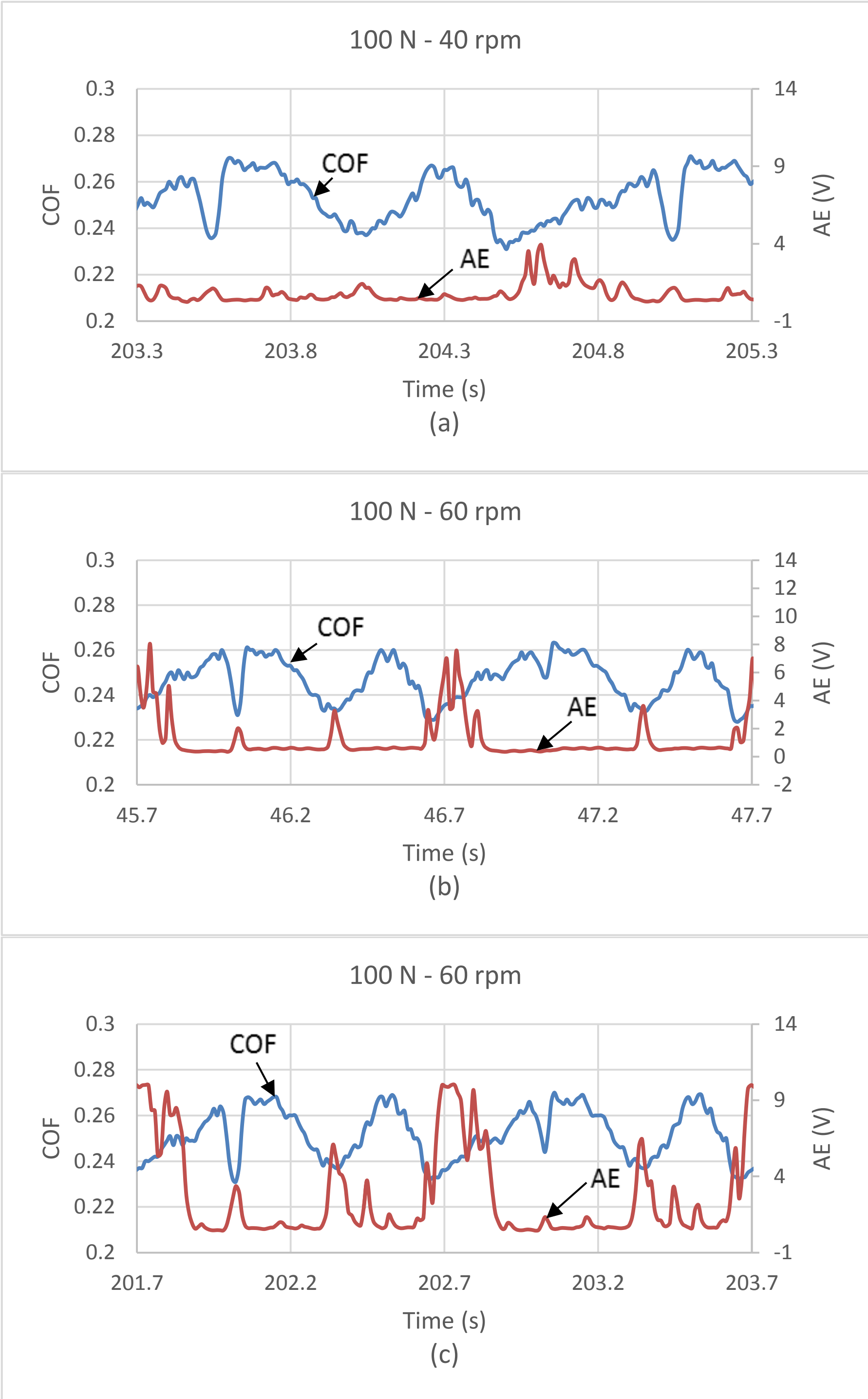

Figure 7. The evolution of the friction coefficient and acoustic emission for a 2 seconds period for the 100 N test conducted at: a) 40 rpm; b) 60 rpm (beginning of the test); c) 60 rpm (end of the test).

IOP Conf. Series: Materials Science and Engineering **174** (2017) 012019 doi:10.1088/1757-899X/174/1/012019

The results presented in figure 6 and figure 7 highlight the correlation between the acoustic emission and the sudden drop and rise of the values of the friction coefficient. Thus, we can see that amplitude of the friction coefficient influences the amplitude of the acoustic emission. Regarding the noise produced during the 100 N tests, it was more intense than the 50 N and 75 N tests and it grew in intensity as the rotational speed of the disc sample was increased.

The average value of the acoustic emission was calculated for each test in order to see how the contact pressure and sliding speed influences the level of the acoustic emission. These values have been inserted in the two graphs in figure 8.

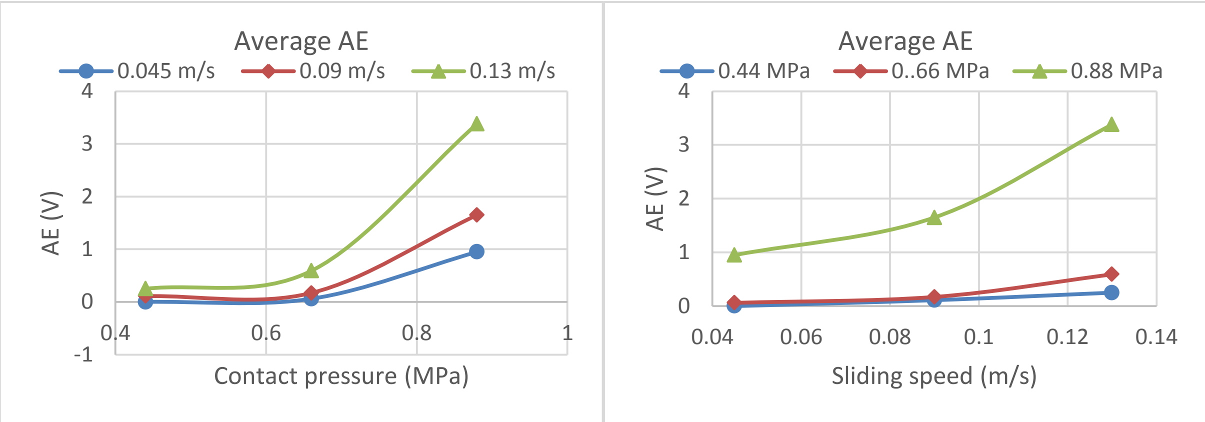

Figure 8. The evolution of the average AE versus contact pressure and sliding speed

As clearly seen form the two graphs from figure 8, by increasing either the contact pressure or the sliding speed the level of the acoustic emission increases significantly. For the current tests, when the sliding speed was tripled the average level of the acoustic emission increased from 0 V to 0.25 V for the 50 N test, from 0.06 V to 0.59 V for the 75 N test and from 0.95 V to 3.38 V for the 100 N test. Also, by doubling the contact pressure between the pin and the disc the average level of the acoustic emission increases from 0 V to 0.95 V for the 20 rpm test, from 0.11 V to 1.65 V for the 40 rpm test and from 0.25 V to 3.38 V for the 60 rpm test.

Friction generates heat and a significant temperature rise at the contact between the two sliding surfaces can influence the tribological properties of the brake friction couple materials. Consequently the maximum temperature rise has been estimated for the following conditions:

- maximum sliding speed: 0.13 m/s;
- maximum contact pressure: 0.88 MPa;
- average friction coefficient: 0.25;
- total sliding time: 300 s;
- disc mass: 0.167 g;
- specific heat for grey cast iron: 560 J/(kg·grd).

It is considered that 80% of the heat generated by friction is dissipated through conduction in the grey cast iron disc. In these conditions, the estimated temperature rise at the local contact is 6.8°C. This temperature rise does not significantly alter the mechanical properties or the tribological properties of the materials.

4. Conclusions

The results highlight the effects of the sliding speed and contact pressure on the friction coefficient and its influence on the brake noises and vibrations caused by the stick-slip phenomenon.

The results of the pin-on disc tests indicate that in the case of the 50 N (0.44 MPa) tests, where the friction coefficient has no major variations caused other than the misalignment of the surface of the disc, there is no acoustic emission and audible noise.

On the other hand, in the cases of the 75 N (0.66 MPa) and 100 N (0.88 MPa) tests, where the stick-slip phenomenon can be observed a notable amount acoustic emission is also present, accompanied by an audible noise.

The results reveal that by increasing the contact pressure and the sliding speed between the two samples the amplitude of the stick-slip increases, which can be correlated with the increase of the acoustic emission level and the intensity of the audible noise.

References

[1] Yoon S W, Shin M W, Lee W G and Jang H 2012 Effect of surface contact conditions on the stick–slip behavior of brake friction material *Wear* **294-295** 305-12
[2] Kinkaid N M, O'Reilly O M and Papadopoulos P 2003 Automotive discbrake squeal *J. Sound. Vib.* **267** 105-66
[3] Kruse S, Stingl B, Hieke J, Papangelo A, Tiedemann M, Hoffmann N and Ciavarella M 2014 The influence of loading conditions on the static coefficient of friction – a study on brake creep groan *Topics in Modal Analysis I* **7** 149-60
[4] Neis P D, Ferreira N F, Matos L T, Masotti D and Poletto J C 2015 Definition of a suitable parameter for characterizing creep-groan propensity in brake pads *SAE Tech. Pap.* 2015-36-0004
[5] Akay A, Giannini O, Massi F and Sestieri A 2009 Disc brake squeal characterization through simplified test rigs *Mech. Syst. Signal Pr.* **23** 2590-2607
[6] Polt G, Sebestyén T, A Pauschitz and Franek F 2005 Investigations of stick-slip effects in wet friction drive elements *Mater. Sci. Forum* **473-474** 249-54
[7] Stoica N A and Tudor A 2015 Some aspects concerning the behaviour of friction materials at low and very low sliding speeds *Tribology in Industry* **37** 374-79
[8] Gao C, Kuhlmann-Wilsdorf D and Makel D D 1994 The dynamic analysis of stick-slip motion *Wear* **173** 1-12
[9] Pavelescu D, Mușat M and A. Tudor 1977 *Tribologie (Tribology)* (Bucharest: Ed. Did. Ped.)
[10] Antoniu S S and Cameron A 1976 The friction-speed relation for stick data *Wear* **36** 235-54
[11] Tudor A and Bo L C 1981 Aspecte teoretice privind influenta vitezei de antrenare si a amortizarii asupra mişcării sacadate *Studii și Cercetări de Mecanică Aplicată (Applied Mechanics Research and Studies)* **40** 741-51