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Morphological analysis of pad–disc system during braking operations

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ABSTRACT

A method has been developed for quantifying the percentage of friction layer coverage on a brake disc surface. The method is used to examine the relationship of layer coverage to the coefficient of friction and the morphology of the contact plateaus existing on the brake pad surface. Two kinds of brake pads, a non asbestos organic (NAO) and a semi-metallic (SM), were subjected to sliding against a gray cast iron disc in a laboratory-scaled tribometer. In order to observe the effect caused by the contact pressure on the measured parameters, tests were carried out with two normal forces (600 N and 1200 N). Micrographs of brake discs and pads were obtained as the tests progressed. MatLab (Mathworks®) scripts were developed to process the images of the brake disc and pad. Using these, the number and the area fraction of contact plateaus were investigated. Both the NAO and the SM materials formed a heterogeneous friction layer on the disc surface, but SM material produced a more uniform distribution of the friction layer. An increase in the normal force led to an increase in the friction layer deposited on the brake disc surface for the NAO; however, the opposite was observed for the SM material, that is, an increase in the normal force tended to remove the friction layer on the brake disc surface. Correlations among friction, friction layer coverage, temperature variation and morphology parameters are discussed.

1. Introduction

The operation of automotive brake systems comes from the contact between a fixed (brake pad or lining) and a rotating element (brake disc or drum). This last component is attached to the wheel of the vehicle [1]. Friction contact between pad and disc produces the force necessary to reduce the speed of the vehicle, converting the kinetic energy into heat [1] and also vibration and noise [2]. Since the surfaces are subjected to sliding motion, they may suffer wear. Thus, a periodical replacement of brake pads is necessary.

This paper addresses a particular aspect relating to the tribocontact of the pad–disc system: the friction layer, also defined as third body by Godet, in 1970s. The friction layer consists of a thin layer, which is deposited on both brake pad and disc surfaces as a result of the wear process [3]. According to the literature [4], friction layer determines friction characteristics during a braking process. It is well known from literature [5,6] that the particles released in braking processes are either being emitted into the air as airborne particulate matter, or may be deposited on the brake hardware (including the disc) or fall onto the road surface and into roadside environments deposited matter. Some authors [7,8] measured the thickness of the friction layer which is deposited on the brake disc surface. According to these authors, it can measure from some micrometers up to 10 μm. Österle and Urban [7] stated that the composition of the friction layer is mainly determined by the solid lubricant, which is part of the brake pad formulation.

Although the friction layer exert direct influence on braking performance [2,9], studies about this subject are largely undocumented in the literature. It is especially true when it comes to the evolution of the friction layer during braking operations. Literature has reported [9] that the friction layer contributes to preserve the integrity of the brake disc because it prevents direct contact between the friction material (brake pad or lining) and the rotor (brake disc or drum). Stability of the coefficient of friction [2], as well as noise and vibration reduction [7], are also important features associated with the third body.

As shown in the above paragraph, most of the studies relating to the third body focus on its effects on brake performance (friction and wear), as well as on noise and vibration. Relatively few researches have discussed techniques for friction layer quantification. Examples of these studies can be found in [7,8], which

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measured the thickness of the friction layer. However, it was not found in the technical literature any publication addressing the percentage of friction layer covered on the brake disc surface during braking operations. Besides, the relationship between the parameters studied (friction layer, morphology of the contact plateaus, and coefficient of friction) was not reported in the literature. Thus, the current paper aims to present a method for quantifying the percentage of friction layer covered on the brake disc surface, as well as to discuss the relationship between the parameters studied. So, results of this research paper can offer a better understanding of the interaction between the brake pad and disc during braking operations. It can also contribute to increase the wear life time of brake friction materials (brake pad and disc), which represents an important cost factor for car owners.

2. Methodology

2.1. The laboratory-scale tribometer

The laboratory-scaled tribometer used in these experiments has been designed to match the range of contact pressure and sliding speed as those in automotive brake systems (Fig. 1). This test rig has been especially developed in order to characterize friction materials used as brake pads [10]. Details about the mechanical design and functions of the tribometer are found in Neis, 2012.

2.2. Samples preparation

Two different brake pad compositions were used as samples in the braking tests. According to the brake material classification described in the literature [11,12], one pad can be classified as "Non-Asbestos Organic – NAO" and the other as "Semimetallic – SM". Both brake pads are available in the Brazilian market. Table 1 shows the material composition of each brake pad tested in the experiments.

Each brake pad was machined into a cylindrical shape (or pin) with diameter of 18 mm in order to be used as samples in the laboratory-scale tribometer. The rotor used in the tests consists of a commercial brake disc, made of gray cast iron with a diameter of 159 mm and thickness of 12 mm. Before to the tests, the surface of the disc was sanded with sandpapers of different grits (280, 360, 400, 500, 600, and 1500) aiming to achieve a roughness Ra lower than 0.20 mm, measured in the radial direction of the disc surface. A photograph of the brake disc and pin is shown in Fig. 2.

2.3. Setup of the experiments

Table 2 presents the operating parameters used in the experiments. The range of the initial and final sliding velocity (7.7 to 0.0 m/s) represents a vehicle moving from 80 km/h to the standstill (0 km/h). Two different normal forces (600 N and 1200 N) were employed in the tribotests in order to investigate the influence of the contact pressure on the morphology of the brake pad and also its effect on the percentage of friction layer coverage on the brake disc surface.

Micrographs of the brake disc and pad were taken as the tests progressed, for the braking numbers 5, 10, 20, 30 and 40, respectively. It allows observing the evolution of the friction layer coverage on the disc surface as well as differences in the morphology of the brake pad. Two scripts were specially developed in Matlab (Mathworks®) to process the micrographs of the brake pad and disc, respectively.

2.4. Micrography

The micrographs were obtained by a stereo-microscope (CARL ZEISS®, model Axio Lab A1, designed in Germany). It is equipped with a digital CCD camera with a resolution of 3.0 Mega Pixel,

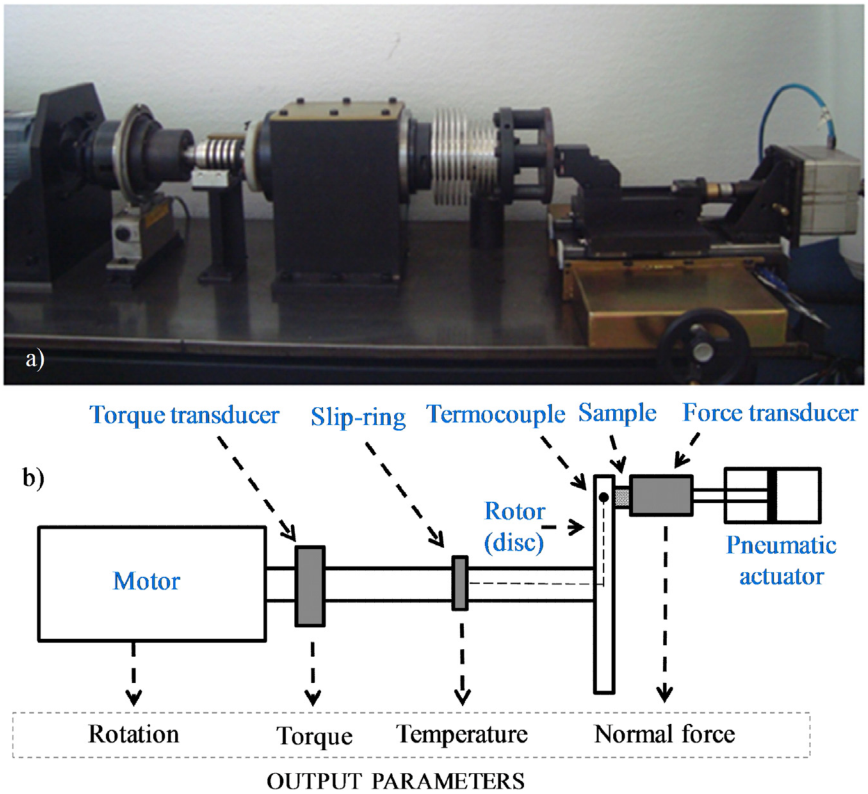

Fig. 1. Laboratory-scale tribometer: a) digital photograph and b) schematic.