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Study of the interaction between microstructure, mechanical and tribo-performance of a commercial brake lining material

Amira Sellami [a], Mohamed Kchaou [a], Riadh Elleuch [a,*], Anne-Lise Cristol [b,c,d], Yannick Desplanques [b,c,d]

[a] Université de Sfax, Ecole Nationale d'Ingénieurs de Sfax, LASEM, 3038 Sfax, Tunisia
[b] Univ Lille Nord de France, F-59000 Lille, France
[c] ECLille, LML, F-59650 Villeneuve d'Ascq, France
[d] 5CNRS, UMR 8107, F-59650 Villeneuve d'Ascq, France

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ABSTRACT

The interaction between microstructure, mechanical, and frictional properties of a commercial brake lining material (BLM) was investigated in order to correlate them to braking performance. For this purpose, a Scanning Electron Microscope (SEM) with energy dispersive X-ray (EDX) mapping and spectrum were used to identify and analyze different constituents. The mechanical properties were determined using compression test. Relevant physical properties (density and porosity) were determined using standard test methods. The friction coefficient and wear behavior of the friction material on contact with the grey cast iron disc were established using a pad-on disc tribometer. The results have shown that the brake lining material contains phenol resin such as the matrix and other various ingredients, including silica, rock and mineral filler reinforcement, barium sulfate and carbon-rich particles as filler and brass particles as friction modifier. It had a varied amount and size up to 1 mm for brass particles. The density and porosity were 1.8 g cm^{-3} and 7%, respectively. The investigated material exhibited excellent mechanical properties in the normal solicitation direction. The average friction coefficient was about 0.65, whereas the friction coefficient was stable. The different actions of various ingredients in terms of their effects on the friction and wear behavior of the BLM could be related to their different bonding strengths with the resin matrix and their different abilities to form friction films (third-body layer) on the surfaces of the material and transfer films on the counterpart cast iron surface in relation to the surface temperature evolution and mechanical properties.

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1. Introduction

Automobile brake system consists of a metallic brake disc and two brake pads of friction material. Brake pads help in transferring into heat the kinetic energy produced by friction during the application of brake to stop or slow down a moving automobile. This material is usually manufactured from a phenolic resin binder with the addition of more than 10 ingredients. They should maintain a relatively high, stable and reliable friction coefficient at a wide range of braking conditions, temperature, humidity, presence of dirt and water spraying from the road. The lining materials should also present a good combination of mechanical properties such as high hardness, compressive strength and good resistance to severe temperatures. During braking, the pad material is submitted to severe solicitation which is affected strongly by the microstructure of the material according to nature of involved ingredient [1,2]. So, the changes on the tribological and mechanical behaviors widely depend on the nature and size of ingredients [3] which are very complex and diverse [4–6]. In fact, the friction materials for automotive brake systems typically contain a binder that holds the other components together and forms a thermally-stable matrix. Thermosetting phenolic resins are commonly used, often with the addition of rubber for increased damping properties. Furthermore, fillers such as ($BaSO_4$, $CaCO_3$, Al_2O_3), are used not only to reduce cost but also to improve manufacturability. It is worthwhile to note that barium sulfate is commonly-used filler. In order to ensure stable frictional properties and control the wear rates of both pad and disc, frictional additives are added. Although solid lubricants such as graphite and different metal sulfides (MoS_3, Sb_2S_3, as well as sulfides of Cu, Sn, Sb) are added in relatively small amounts. They strongly affect various brake performance such as

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* Corresponding author. Tel.: +216 74216655; fax: +216 74655192.
E-mail address: riadh.elleuch@gnet.tn (R. Elleuch).

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wear resistance, stopping distance, friction stability, torque variation, and noise propensity [7,8]. Abrasive particles, typically alumina and silica (Al_2O_3, SiO_2), increase both friction coefficient and disc wear whose purpose is to give a better defined rubbing surface [9]. Various, metals such as copper, steel and brass have been used in order to affect the friction and wear of friction materials by their type, morphology, and hardness [10,11]. These variablities induced strong heterogeneity in the composite materials and influenced the microstructure characteristics and their tribo-mechanical performance in different scale and interaction.

According to some researchers [12,13], the topography is the central aspect for the description of the friction processes. This is a very helpful item because the brake system consists of many complex interdependencies, such as the couplings of temperature, load, wear, friction and the topography. In this context the expression "topography" contains the hill and valley surface and the distribution of areas having hard material (patches) on top or not.

To the best of our knowledge, there have been a few attempts to understand the relationship between ingredients variability and materials properties and their effect to the tribo-performance of the friction materials.

In the present study, a multi scale characterization, such as physical, mechanical and tribological properties of a commercial brake lining material (BLM), was developed in order to correlate such properties to the material ability for better brake performance. We organize this paper as follows. In the following section, we describe the BLM and the different test procedure. In Section 3, we present the results of such characterization. Finally, a correlation between the triplets (material structure–friction–material properties) was established.

2. Materials and test procedure

The studied material is a commercial brake lining material (BLM) for automotive applications. It will be subjected to different analysis and tests such as mechanical (compressibility, Young's modulus), physical (density, porosity) and tribological (coefficient of friction (COF), weight loss) characterizations in accordance with various relevant international standards.

2.1. Morphological characterization

The microstructure of the BLM was examined in an optical microscope to analyze the surface distribution of the particulates and fillers. Scanning Electron Microscopy (SEM) equipped with energy dispersive X-ray (EDX) microanalysis was used to identify the morphology and the composition of the pad material and to determine the size of each element. X-ray cartography of the material allows the study of the distribution of its different components.

2.2. Mechanical and physical properties

Compression tests were carried out on a universal testing machine (Instron 1196) to find out the stress vs. strain relationship, employing ASTM: D3039/D3039M-08 standard test method. Tests were performed with a pre-load of 0.5 N and speed of 0.1 mm/min. Cylindrical specimens were cut from the lining material in normal and transversal directions (14 mm diameter and 16 mm thickness) to quantify its anisotropy sensibility. Each result was an average of four experimental data.

The density of the BLM was determined using Archimedes' principle, according to ISO standard [14]. The samples were first weighed in air and then in water using a Mettler Toledo electronic balance with 0.5 g accuracy. The void fraction of the BLM is measured using Archimedes' principle. The porosity, which is the percentage of pore volume with the bulk total volume of the specimens', is deduced from the density value.

2.3. Tribological characterization

A continuous friction test was carried out for the study of the friction coefficient evolution, wear loss and wear mechanism. With this type of friction test, temperature can achieve important level, using a pad-on-disc tribometer, with specimen dimensions of 14 mm for the diameter and 25 mm for the length. A gray cast iron material was used as the disc in our study (diameter, thickness, roughness and hardness were 80 mm, 22 mm, 350 μm and 258 Hv, respectively). The radial distance from the center of the pad specimen to the center of the turning disc was 32 mm. The continuous friction test was conducted with the monitoring of the disc temperature (T_d) with a thermocouple put from 2 mm of the friction. The test is stopped at 500 °C which corresponds to the phenolic resin degradation. Regarding the test procedure, it is as follows:

- The test began with a running-in of at least 15–20 min duration at a load of 50 N, and a sliding speed of 6 m/s. T_d temperature lower than 80 °C on the tribometer until an a apparent contact area between the pad and the disc materials exceeded 95%.
- Then, the effective test is running with the same controlled parameters.

Before the test, the disc was cleaned with ethanol-soaked cotton. Weight loss of the pad was measured using a high precision electronic balance (with an accuracy of 0.001 mg). SEM was used to analyze the rubbed surface after friction test and to examine the wear tracks.

3. Results and discussion

3.1. Morphological characterization

SEM observations related to some regions of the pad surface mainly reveal the bulk microstructure of the pad and show the presence of ingredients having different shapes and sizes distributed in the phenolic binder (Fig. 1). A dark and clear contrast is noticed. Dark ingredient, with different sizes and shapes, are observed. These particles cover the majority of the pad surface and that is why in first impression the surface tends to be homogeneous. The dominant form is spherical, which can achieve 1 mm in diameter. Rough and smooth ones are distinguished; there are probably different natures of ingredients. Some gray constituents are observed (indicated by arrows), having millimetric scale sizes. Fiber packages are also detected (circled with interrupted line) in different regions of the pad surface. The width and the length of this package can reach 0.5 and 2 mm respectively (Fig. 1d). These fibers are privileged oriented lengthwise, this orientation is caused probably by the striking of the press during the cold performing and the hot molding of the plate. Such material also presents certain other elements with micrometric size, well distributed in the surface. It is noted that the gray shades from the lightest to the darkest correspond to the heaviest to the lightest elements, respectively.

To further identify pad ingredients, EDX maps of the main elements found on the surface of the pad are established (Fig. 2). Particles which are clear are those heavy, with the concordance of the EDX results; it is certainly brass fibers composed of Copper (Cu) and Zinc (Zn). Dark particles are light referring to the Backscattered Electron and rich in carbon referring to the EDX map; it can be only C element or C and S elements. The surface is dominated by Al, Si,

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