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Tribological study of Fe–Cu–Cr–graphite alloy and cast iron railway brake shoes by pin-on-disc technique

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ABSTRACT

A new class of materials is being installed in railway brake blocks to substitute classic cast iron in order to reduce the rolling noise produced by the roughness of the tread-wheel surface. The tribological properties of cast iron and Fe–Cu–Cr–graphite sintered alloy brake shoes were analyzed. Kinetic friction coefficient (μ) and wear were monitored by means of a pin-on-disc technique. The sintered alloy brake showed an increase in μ at higher braking velocities while the cast iron brake exhibited a decrease in μ. Wear was greater on the sintered alloy, explained by its low shear strength which decreased due to its low thermal conductivity. The roughness produced by the sintered brake shoes in wheel-tread surface was 10 times lower than that produced by cast iron.

1. Introduction

Noise elimination is an issue that is gaining importance on railways. At present, an estimate of one million people in Europe has to be protected from railway noise, by noise barriers and by noise-insulated buildings [1,2]. One of the main sources of railway noise is rolling noise arising from the contact between the wheels and the tracks. Rolling noise is the dominant source of noise at speeds between 60 km/h and 200–250 km/h [3,4]. Rough wheels and rough tracks increase the noise emission. Thus, the rougher the wheel surface, the greater the noise produced. Other sources of noise such as aerodynamic friction are only important when high velocities are reached (more than 300 km/h).

The simplest way to reduce the velocity of a railway in motion is through the friction produced between a brake shoe and the wagons' wheel tread. Cast iron (usually as a gray cast iron) has been the most used material in brake shoes [5]. Cast iron brake shoes have the disadvantage of making the wheel-tread surface rougher during braking [6]. Thus, a reduction in noise should be achievable through the substitution of cast iron brake shoes by other material leading to lower wheel surface roughness.

In fact, over the last years, cast iron shoes have been replaced by composite synthetic brake shoes. It has been demonstrated that cast iron brake shoes make the wheel surface much rougher than a similar product made with a composite material. Replacing the cast iron shoes with a synthetic product can therefore substantially reduce the wagon noise emissions, for example, by about 10 dB for a 100 km/h freight train [6]. Nevertheless, previous experiences using a polymeric composite brake demonstrated that the organic material can be burned, coating the wheel-tread with an organic film. This film diminishes the friction between the wheel tread and rail or brake shoe [7,8]. Other sintered alloys have been used as an Fe–Cu–Cr–Sn–graphite alloy [9]. These brake shoes exhibited a better braking behavior with less wear on the tread wheel. However, premature wear has been observed in this material, being less cost-effective.

The aim of this work is to study and compare the tribological properties of a gray cast iron brake and a composite sintered alloy brake (Fe–Cu–Cr–Sn–graphite). A pin-on-disc technique is proposed to analyze comparatively the friction coefficient of both materials. Other mechanical analysis and photothermal techniques were performed to discuss the wear phenomena.

2. Experimental set-up

The samples used in this work were extracted directly from the commercial brake shoes of a locomotive train. Microstructure and chemical composition were analyzed by standard metallographic and energy dispersive X-ray analysis (EDX) on a SEM respectively. The sintered alloy sample showed a composition of 38% Cu, 34%

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Fe, 3% Cr, 15% C, 4% Sn, 4% O and 2% Al. Graphite, bronze and α-alumina were detected. The cast iron brake shoe showed a gray cast iron structure with graphite sheets in a perlite matrix. Standard compression testing showed a stress limit at 350 MPa, which corresponds to EN-GJL-300 standard. The Brinell hardness value measured for this material was 223 HB. On the other hand, a Brinell hardness value of 39 HB and compressive strength of 45 MPa was obtained for the sintered alloy. All measures were carried out at room temperature.

2.1. *Friction testing*

Although pin-on-disc technique does not describe the contact geometry, applied normal pressure and asperity distribution of wheel-tread, this technique is useful in the comparative tribological study of both materials. In fact, this technique allows the measurement of the kinetic friction and wear when a plate (the disc) of one material rolls in contact with a sample (the pin) of another material which can provide valuable information on the tribological behavior of both systems. Therefore, the aim of this study is the comparative study of two materials rather than replication of a real braking condition.

The test apparatus and testing technique is described as follows. MicroTest® pin-on-disc equipment was used to measure the wear and friction coefficient between the brake sample (cast iron or sintered alloy pin) and the steel plate (as the train wheel). A load of between 10 N and 500 N and angular velocities ranging from 10 rpm to 500 rpm can be programmed by a computer. The friction is then calculated and recorded in the computer by means of several sensors installed on the rotary's axis plate.

Fig. 1 shows the Microtest® pin-on-disc used. The following can be distinguished in the photograph: the plate (1), which moved the wheel sample (2) against the pin (3). Weights (4), which apply the contact force and a magnetic sensor (5) to measure the vertical movement of the arm, thus obtaining the wear of the pin.

The wheel sample was composed of the same material as the steel wheel railway with a composition of: 0.56% C, 0.4% Si, 0.8% Mn, 0.035% P, 0.035% S, 0.3% Cr, 0.3% Cu, 0.08% Mo, 0.3% Ni, 0.05% V and 0.4% Ti. The plate was polished until an average roughness value of R_a = 0.015 μm was achieved on both sides. One side of the plate was used for the cast iron pin test and the other side was used to perform the sintered alloy pin test.

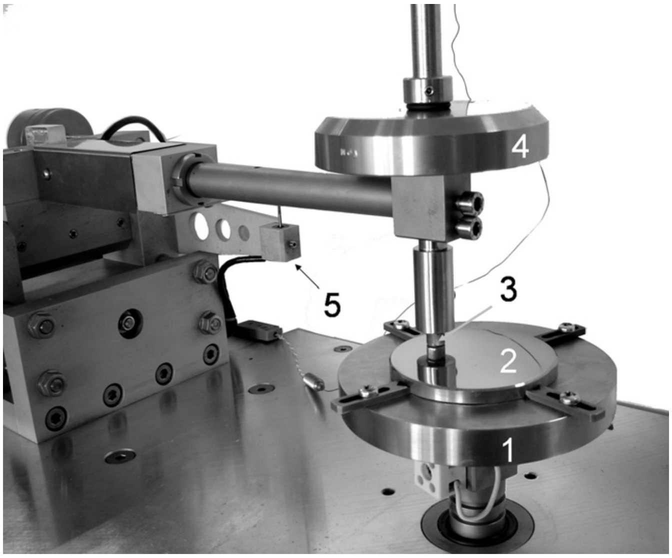

Fig. 1. Photography of Microtest® pin-on-disc technique used. (1) Disc which rolled at programmed velocity. (2) Steel disc sample extracted from locomotive wheel. (3) Sintered alloy or cast iron pin extracted from locomotive brake shoes. (4) Weights used to apply the braking contact force and (5) magnetic sensor to measure the wear.

The parameters selected for our experiments were loads of 10 N (0.2 MPa) and 20 N (0.4 MPa) and velocities of 0.31 ms^{-1} and 1.05 ms^{-1}.

2.2. *Thermal analysis*

The thermal study of the brake materials is interesting from the point of view of the power dissipation capacity of each material. Thermal studies for both materials were performed using a Flir Systems ThermaCAM™ S65 infrared camera. Again, samples were extracted from a commercial brake shoe. Pieces 11 mm × 11 mm × 40 mm in size were then installed on a cylinder with large mass made of steel at 25 °C. With the large mass of the cylinder, we assumed the break's holder to have good thermal dissipation. A cylindrical steel piece preheated to 500 °C as a means to simulate the heat released during breaking was placed on top of the sample at the same moment that the images began to be recorded every 5 s. The initial temperature conditions were the same for all of the samples and experiments.

3. Results

3.1. *Tribological results*

The friction coefficient μ were recorded for both brake materials sliding above the steel plate. Fig. 2A shows the μ for cast iron and Fig. 2B shows the μ for sintered alloy. Cast iron curves showed that μ increased during the experiments regardless of the load conditions and velocities studied, unlike sintered alloy, which exhibited a more stable coefficient.

Braking pressures of 0.2 MPa and 0.4 MPa and velocities of 0.31 ms^{-1} and 1.03 ms^{-1} were tested. The average friction coefficients for these conditions are summarized in Fig. 3 for clearer presentation.

The cast iron results showed that when the braking pressure was increased from 0.2 MPa to 0.4 MPa, the friction coefficients decreased from 0.55 to 0.25 at 1.03 ms^{-1} and from 0.7 to 0.4 at 0.3 ms^{-1}. Moreover, when the velocity was increased from 0.3 ms^{-1} to 1.03 ms^{-1}, the friction coefficient decreased from 0.7 to 0.55 under pressures of 0.2 MPa and from 0.4 to 0.25 under pressures of 0.4 MPa. Thus, the cast iron brake shoe sample presented two specific characteristics: (i) the higher the speed, the lower the friction coefficient and (ii) the higher the contact force of the brake shoe on the wheel, the lower the friction coefficient. These results agree with previously published reports [10,11]. In fact, both of these characteristics led to specific brake system designs for vehicles braked with cast iron shoes. This included reducing the brake cylinder pressure at low speeds to prevent the wheels from locking, and equipping vehicles with twin or even triple brake blocks to prevent the specific application force from becoming too great and, as a result, the friction coefficient from becoming too low.

Kinetic friction results for sintered alloy showed a very stable μ coefficient along the 500 m distance tested. Average μ was 80% higher than that of the cast iron results. The μ behavior under the pressures tested was similar to that of the cast iron: when the pressure was increased from 0.2 MPa to 0.4 MPa, μ decreased from 0.9 to 0.7 at 0.3 ms^{-1} and from 1.3 to 1.1 at 1 ms^{-1}. Nevertheless, at higher velocities μ was higher: from 0.3 ms^{-1} to 1.03 ms^{-1}, μ increased from 0.9 to 1.3 under 0.2 MPa and from 0.7 to 1.1 under 0.4 MPa. These results must be taken into account when designing the brake system in railway transport because, in this way, equivalent speeds