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Role of the friction layer in the high-temperature pin-on-disc study of a brake material

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ABSTRACT

The tribological behavior of a commercial brake pad material, wear tested under dry sliding conditions against a cast iron counterface disc with a pin-on-disc apparatus, was investigated. Wear tests were conducted at the following disc temperatures: 25 °C, 170 °C, 200 °C, 250 °C, 300 °C and 350 °C. Above 170 °C a transition from mild to severe wear was observed. At 25 °C and 170 °C, the friction layer on the pin surface consists of primary and compacted secondary plateaus. At 200 °C and above, a progressive reduction of the pin surface coverage by the secondary plateaus, that are barely present after the 350 °C test, is observed. Wear tracks on the discs derive from wear fragments due to the tribo-oxidation of the disc itself and from the wearing out of the pin material. The observed tribological behavior is very much influenced by the thermal degradation of the phenolic binder of the friction material, confirmed by thermogravimetric analyses, conducted on purpose on the pin material. Raman spectroscopy indicated the presence of carbonaceous products on the high temperature worn out pin surface. Although referring to rather extreme and simplified sliding conditions, the results obtained in this study provide useful indications on the role of the thermal stability of the organic component.

1. Introduction

Brake materials transform the kinetic energy of the vehicle into thermal energy by friction between pad materials and metal, usually cast iron, disc [1]. Heat is then dissipated through exchange mainly with the environment and during braking, temperature may even rise tremendously in the contact regions. Wear behavior at the elevated temperatures resulting from the braking conditions, is highly dependent on the ingredients of the friction materials. These are to be selected in order to guarantee suitable braking conditions, high temperature stability and, consequently, reduced wear rates. However, at high temperatures, the degradation of friction material is a major issue, mostly associated with the thermal decomposition of phenolic resins, widely used as binders for friction materials [2–4]. They embed the ingredients effectively over most of the operational regimes, thanks to a good combination of mechanical properties, such as high hardness, compressive strength, creep resistance, and very good wetting capability. However, these resins are sensitive to heat and humidity, which cause serious threat to frictional, wear behavior at elevated temperatures, notwithstanding the common practice to add to the formulation suitable, carbon-based stabilizers, like graphite, coal, etc. [5,6]. Therefore, binder decomposition is blamed for various brake operational drawbacks, with specific studies displaying the importance of the heat resistance and mechanical strength of the binder in the wear behavior of brake materials.

Thermal decomposition of the phenolic resins involves several reactions, depending on the actual formulation and thermal history of the material. Temperatures falling in the 250–475 °C interval are reported for the onset of the main transformations involved with the resin decomposition [7,8]. Another important aspect affecting the tribological behavior of sliding wear systems is the trapping of wear debris in between the sliding surfaces [9–13], leading to the formation of the so-called friction layer, or friction film, that is paramount in determining the friction behavior of the mating surfaces in sliding contact [14–17]. Jacko et al. [18] concluded that “when stable friction films, commonly called friction layers, are readily formed for a given friction couple, a stable friction level and low wear rates can be maintained at various temperatures, as long as the friction film is not destroyed”. The wear processes, that occur at the pad and disc interface, display several steps, including the formation of the primary plateaus,

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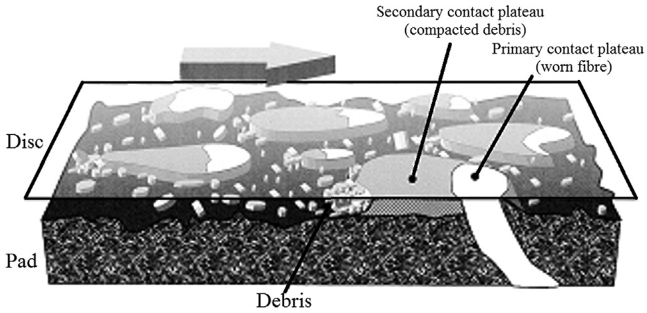

Fig. 1. Schematic of the contact situation between an organic friction material and a brake disc and formation of compacted plateaus [18].

formed by tough metallic fibers and coarse, hard particles (see Fig. 1); and secondary plateaus, that build up for the compaction of the wear debris blocked by the primary plateaus. The wear behavior of brake systems is thus influenced by the formation of the friction layer [3,14], its transformation related to its compactness and thickness, and, finally, by its possible detachment with consequent release of fragments and wear debris [8,15,17,19].

In this context, Verma et al. [20] reviewed the frictional behavior of a commercial low-steel pad material dry sliding against a cast iron disc at room temperature under mild wear conditions, using pin-on-disc wear tests. The formation of primary and secondary plateaus was observed. Two main kinds of secondary plateaus were identified: well compacted plateaus rich in copper, zirconium and iron oxide particles, forming quite large plate like fragments; less compacted plateaus, featuring a lower copper content, that tend to form comparatively smaller degradation fragments. As an extension of this former research work [20], an attempt is made herewith to investigate the friction and wear behavior of the above friction material at different disc temperatures. The degradation mechanisms observed in the friction material induced a transition from mild to severe wear during continuous dry sliding conditions. Through this study, it was possible to gain further information on the main wear mechanisms and in this way to identify critical parameters to develop better friction materials, in the context of performance, lifetimes and pollutant emissions.

Of course, this is just the first step forward. The indications obtained from the pin-on-disc lab tests require extension and validation through additional measurements carried out using experimental apparatuses, e.g., dynamometer rigs, better reproducing real brake conditions.

2. Experimental details

2.1. Friction material

The elemental composition of the friction material, as measured by X-ray fluorescence (XRF) spectroscopy is shown in Table 1a. Fig. 2 shows the microstructure of the starting friction material and the main identified phases in the pad materials are listed in Table 1b. Relevant phase concentrations were calculated from XRF data (Table 1a), with the help of stoichiometry. Further details concerning the characterization of the friction material, that is being investigated as a reference in the framework of a broad research project aiming at reducing particulate matter brake system emissions, can be found in [20]. The thermal degradation of the friction material was studied using a Netzsch JUPITER STA 449 F1 thermobalance. The tests were carried out at a constant heating rate of 10 °C min^{-1} from room temperature up to 1050 °C under a nitrogen (50 ml min^{-1}) and oxygen (20 ml min^{-1}) mixed flux, simulating an “*air atmosphere*”.

Table 1
Elemental composition of the friction material (no carbon and oxygen quantification) (a). Concentrations of the compounds present in friction material (b).

Elements	wt%
Mg	1.2
Al	2.5
Si	2.1
Zr	26.9
S	1.8
K	3.1
Sn	2.4
Ca	3.2
Ti	8.3
Fe	6.1
Cu	8.1
Zn	3.1

Component	wt%	Component	wt%
Zirconia (ZrO_2)	31	Calcite ($CaCO_3$)	2.5
Al & Mg oxides	9.5	Tin Sulfide (SnS)	2.5
Iron (Fe)	8	Zinc (Zn)	2
Copper (Cu)	7.5	Bismuth (Bi)	0.6
Vermiculite	6	Iron Sulfide(FeS)	0.5
Barite ($BaSO_4$)	5	Rest (phenolic resin, graphite, etc.)	
Potassium Titanate ($K_2O \cdot 6TiO_2$) titanite	5		
Alumina (Al_2O_3)	3		

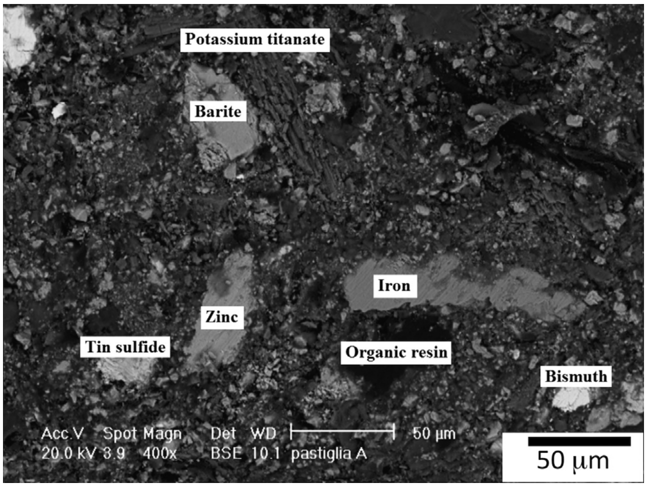

Fig. 2. Microstructure of starting friction material with the indication of the main component phases.

2.2. Test procedure and high temperature setup

In this study, dry sliding wear tests were carried out using a pin-on-disc rig. The disc was made of pearlitic-bainitic gray cast iron with a hardness of 350 ± 11 HV60. The cylindrical pins (Ø 5.5 mm × 7.7 ± 0.3 mm height) were extracted from the above commercial low-steel friction material. The dimensions of the pin, particularly its diameter, if compared with the microstructure of the friction material (Fig. 2), can be safely regarded as representative of the actual material properties. The pins were abraded on the bottom side, opposite to the test surface with a SiC 800 grit abrasive paper to render this surface planar for a better thermal contact with the pin-holder and a conformal contact with the disc. The wear of the pin was measured by checking its weight before and after each test, using an analytical balance with a precision of 10^{-4} g. Data were then converted into wear volumes using a