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Wear behavior of a low metallic friction material dry sliding against a cast iron disc: Role of the heat-treatment of the disc

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ABSTRACT

In commercial automotive braking systems, consisting of a friction pad dry sliding against a pearlitic cast iron disc, the wear of the disc contributes significantly to the overall wear. In the present work, pin-on-disc sliding tests were carried out for determining the role of conventional heat-treatment conducted on cast iron discs on the friction and wear behavior of the above coupling. Wear rates of both disc and friction materials were reduced by almost one order of magnitude when the disc is preliminarily heat-treated and then ground to remove the surface decarburized layer that forms during the thermal cycle. Heat-treatment and heat-treatment plus grinding resulted also in the decrease of the friction coefficient, which was comparatively lower for the ground samples. The friction and wear behavior along with the contact temperature evolutions were rationalized according to the actual materials characteristics, as resulting from the different treatments.

1. Introduction

The optimal performances of the pad-disc braking system depend on the properties of the friction material and of the counterface disc [1]. During braking, the kinetic energy of the moving vehicle is converted into thermal energy. The disc provides an appropriate friction coefficient during sliding against the friction pad. Moreover, it ensures an important contribution to the cooling of the system, since the largest fraction of the frictional heat abandons the system through the disc [2]. The discs in automotive braking systems are typically made of pearlitic grey cast iron. This material has several advantages and interesting features. It shows good dry sliding behavior against different counterface materials due to its relatively high hardness and for the presence of graphite lamellae, protruding from the disc surface during sliding, providing a self-lubricating effect [3,4]. The lamellar morphology of graphite also improves the thermal conductivity of the material, and, consequently, its resistance to thermal stresses associated with the braking action [5]. Finally, cast iron discs are relatively cheap, another important element for mass production components. On the other hand, the pearlitic cast iron disc greatly contributes to the overall wear of a braking system [1,6]. Recent investigations have demonstrated that wear debris from the discs are an important fraction of particulate matter (PM) emissions in the environment [7], mostly concerning particles with an average size below 20 μm [7,8].

So far, most experimental investigations on the reduction of the wear in braking systems have been especially focused on the optimization of the friction materials, by selecting suitable ingredients and relevant concentrations [9–11]. The present research is focused instead on the cast iron disc. According to literature reports, several alternative approaches can be followed. Thornton et al. [12] have recently shown that a deep cryogenic treatment may increase the wear resistance of pearlitic cast iron when sliding against a bearing steel counterface. Also conventional heat-treatments increase wear resistance of cast iron dry sliding against a steel counterface [13]. These treatments include the usual quenching plus tempering and austempering, recommended to obtain a comparatively more ductile cast iron material [14,15]. The laboratory experimental results are definitely promising and provide solid indications that excellent wear performances can be achieved by adopting a suitable treatment that may induce the formation of a hard phase in the alloy matrix, which creates the conditions for a mild tribo-oxidative wear and shifts to highest loads the occurrence of a severe adhesive wear [3].

In the present work, the role of a conventional heat-treatment on the dry sliding behavior of a cast iron material, for brake discs,

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is investigated. The wear tests were carried out in a pin-on-disc configuration, and the pins were machined from a commercial low metallic friction material [7]. The exploratory research is aimed at obtaining starting information on the feasibility of the process, and relevant modifications on the acting wear mechanisms. The tests were carried out at constant pressure (2 MPa) and constant sliding speed (1.31 m/s). The wear tests were not meant to reproduce real braking conditions, for which specific equipment, like dyno-tests and bench test apparatuses, are available and are going to be considered at a subsequent step. The experimental pv-value (given by the product of the contact pressure and the sliding velocity) was 2.62 MPa m/s, corresponding to mild sliding wear conditions, attained when the average contact temperature is below 250 °C approximately [1–3]. In this regime, the wear behavior of the materials under study is just slightly dependent on the contact pressure and the sliding speed [1–4]. Future work will be devoted to the optimization of the heat-treatment parameters and on the execution of specific tests aimed at reproducing the real braking conditions, including high-contact temperature conditions pertaining to intense braking action that would typically involve a transition to severe wear conditions [1–3].

2. Experimental procedures

2.1. Materials

A commercial low metallic friction material has been used. Fig. 1 shows its microstructure.

EDXS analyses from image fields representative of the actual microstructure of the friction material were acquired to evaluate its average elemental composition (Table 1). From these data and with simple stoichiometric assumptions, the phase composition of the pad material was obtained (Table 2). Incidentally, the concentrations of iron and copper would confirm the low metallic classification of the investigated friction material (%Fe+%Cu < 10–50%) [7]. In Table 2 the specific role of each phase of the friction material is also indicated, whereas additional information on the friction material can be found in [16].

The disc counterface was made of a grey cast iron with a pearlitic microstructure (*untreated condition*), as shown by the optical micrographs in Fig. 2. Other discs were heat-treated in an industrial plant, according to the following cycle: austenitization at 850 °C in a controlled atmosphere for 2 h, oil quenching followed by tempering at 180 °C for 1 h to exploit its elevated hardness. This is a standard heat treatment cycle adopted for cast iron parts, which was assumed as reference treatment for our discs. The resulting microstructure is shown in Fig. 3. A uniform martensitic matrix was obtained in the inner part of the alloy (Fig. 3a). At the surface, some decarburization occurred (Fig. 3b), induced by the treatment cycle. Surface oxidation was also observed: this is quite a common aspect in industrial treatments of cast irons, Fig. 4a shows the surface of the heat-treated disc and the EDXS analysis shown in Fig. 4b confirms the presence of oxygen that was not detected on the untreated disc surface.

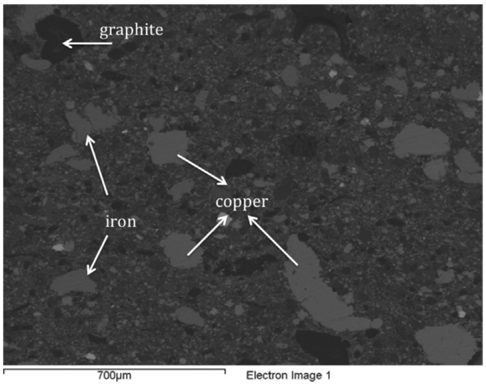

Fig. 1. Microstructure of the virgin brake pad material. Some of the components are indicated.

Some heat-treated discs were mechanically ground to remove the decarburized surface layer. In the as-delivered conditions, a surface roughness approximately equal to $R_a = 2$ µm was measured both on the untreated and heat-treated discs. After grinding, the discs had a lower surface roughness ($R_a = 0.58$ µm) thanks to the grinding operation. Microhardness tests were carried out on the metallographically polished sections with Vickers indenter loaded at 50 g. The results are listed in Table 3.

2.2. Pin on disc tests

Dry sliding pin-on-disc tests were performed with a horizontal rotating disc and a dead-weight loaded pin. Cylindrical pins with a diameter of 6.2 mm and a height of 7 mm were machined from an original brake pad. From original brake discs, 63 mm diameter counterface discs for pin-on-disc tests were machined [16]. Testing conditions are listed in Table 4. Three tests were carried out for each experimental point. Before starting wear data acquisition, at the beginning of each test, a 10 min running-in period was allowed to obtain stable and reproducible contact conditions during the subsequent test.

Pin temperature was continuously recorded by two chromel-alumel thermocouples, positioned inside the pin at a distance of 4 and 6 mm from the initial contact surface with the disc. The average contact temperature was thus estimated by assuming a linear decreasing trend, moving from the contact surface towards the interior of the pin [17]. Although this is an underestimation of the real contact temperature, in this work it is used mostly for a comparison among the different tribological conditions, i.e., the

Table 1
EDXS results: elemental composition of the friction material.

Element	% wt	Element	% wt
Mg	1.8	Cu	10.5
Al	3.7	Zn	3
Si	3.8	Zr	24.7
S	1.8	Sn	2.2
K	7.8	Ba	3
Ca	4.1	Bi	0.8
Ti	10.9	P	0.03
Fe	4.2	C, O	Balance

Table 2
Concentrations and relevant tribological role of the ingredient phases present in brake pad material.

Components (role)	wt%	Components (role)	wt%
Zirconium Oxide (abrasive)	31.0	Calcium carbonate (filler)	2.5
Silicate of Al, Mg and Zr (reinforcement and/or abrasive)	9.5	Tin sulfide (solid lubricant)	2.5
Low-C steel (reinforcement)	8.0	Zinc (reinforcement)	2.0
Copper (heat conduction, reinforcement, solid lubrication at high temperature)	7.5	Aluminum oxide (abrasive)	3.0
Vermiculite (filler)	6.0	Iron sulfide (solid lubricant)	0.5
Barite (filler)	5.0	Organic resin, graphite fibers and carbon-based	Balance
Potassium titanate (solid lubricant)	5.0		