



Braking pad-disc system: Wear mechanisms and formation of wear fragments

Piyush Chandra Verma^a, Luca Menapace^a, Andrea Bonfanti^b, Rodica Ciudin^a, Stefano Gialanella^a, Giovanni Straffelini^{a,*}

^a Dipartimento di Ingegneria Industriale, Università di Trento, Via Sommarive 9, 38122 Trento, Italy

^b Brembo S.p.A., via Europa, 2, 24040 Stezzano (Bg), Italy

ARTICLE INFO

Article history:

Received 2 August 2014

Received in revised form

19 November 2014

Accepted 20 November 2014

Available online 29 November 2014

Keywords:

Brake systems

Wear tests

Pin-on-disc

Wear debris

Friction coefficient

ABSTRACT

The tribological phenomena that occur in brake systems are interesting even in other respects than just the braking action. One important issue, that is gaining increasing importance over the last years, concerns the environmental impact of wear debris produced by the braking action. In this context, the present study is focussed on the tribological behaviour of a commercial friction pad material dry sliding against a cast iron disc. Pin-on-disc tests were conducted at room temperature under mild wear conditions, as concerns load and rotating speed. The effect of some components of pad material, in particular of copper, on the dynamic of formation of tribological layer and wear debris is presented. The results obtained so, although referring to quite a simpler system than real brake systems, still may provide interesting indications, for instance in view of the development of novel brake pad materials and braking control systems.

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1. Introduction

Brake pads are an important part of braking systems for all those vehicles that are equipped with disc brakes. Brake pads are made of a steel backing plate with a friction material bound onto the surface facing the disc. Brake pads convert the kinetic energy of the vehicle into thermal energy by friction.

The performances of brakes are controlled to an important extent by the composition and microstructure of the pad material. Industrial pads usually contain a large number of different constituents, such as ceramic particles and fibres, minerals, metallic chips and fibres, solid lubricants and elastomers, all bound by, for instance, a phenolic resin [1,2]. In fact, brake material should maintain a relatively high, stable and reliable friction coefficient over a wide range of braking conditions, temperature and humidity. Metals, such as copper, steel and brass are used in order to affect the frictional characteristics and relevant wear behaviour of involved materials by a suitable selection of their type, morphology and hardness [3–5].

Nowadays, brake material manufacturers are regularly testing materials to develop new formulations for brake pads that might respond more efficiently to the end users demands for materials featuring steady frictional coefficient [6,7], low wear rates [8–10],

reduced emission of particulate matter (PM) in the atmosphere (hazardous debris) [11–13], and noise [7,9,11]. Particular attention has been recently paid to the environmental related problems, due to the release of fine particles produced by brake wear. For example, it has been estimated that around 35% of the break pad wear is emitted as airborne PM, and 86% of these particles are smaller than 2.5 μm [11]. The wear processes that take place at the interface between braking disc and pad are responsible for the production of the wear debris that is possibly released in the environment. Such processes are quite complex, reflecting the complex composition of brake pad materials, that may contain up to 30 different constituents held together by a phenolic resin [1,2]. Several investigations carried out so far have shown that wear processes are characterized by the formation of a friction layer, also called third body or mechanically-mixed layer, which bears the contact load and strongly influences the actual frictional and wear behaviour [14–16]. In particular, it has been shown that wear initially induces the detachment of particles from the phenolic matrix close to large and hard constituents, which thus form protruding primary plateaus. The components that may form such plateaus were found to be typically larger than 100 μm , and with hardness values greater than that of the counterface disc material, typically pearlitic cast iron. Tough pad constituents too, such as steel fibres and highly strain-hardened copper or brass particles, are involved in the formation of such primary plateaus [17]. Subsequently, micrometric and submicrometric wear particles tend to accumulate close to such plateaus, where they are even compacted to some extent, depending on the contact pressure and sliding shear stresses. In this

* Corresponding author. Tel.: +39 0461282458; fax: +39 0461281977.

E-mail address: giovanni.straffelini@ing.unitn.it (G. Straffelini).

way, the secondary plateaus will form, made of small compacted particles coming from wear of the pad as well as of the disc materials. Several investigations have shown that iron oxide particles, produced by oxidative mild wear of the cast iron disc, are typically present in the friction layer and often constitute the main part of it [7,12]. The friction layer at the interface between disc and pad is thus made of two contact plateaus, primary and secondary ones. It has been further shown that during sliding the outermost part of the friction layer may undergo microstructural transformations, including the formation of a nanogained structures [7,14,15]. Wear particles, including those emitted in the atmosphere, are mainly formed by the disruption of the friction layer (although a small contribution may also come from the wear of the so-called low-land regions following an abrasive interaction with the wear fragments [14,15]), even if the damaging mechanisms have not been fully elucidated as yet.

In the present work, a pin-on-disc equipment has been used for investigating the tribological properties and wear mechanism of commercial Non-Asbestos Organic (NAO) brake pad frictional material dry sliding against a cast iron disc, under different loading conditions and a constant sliding speed. Aim of the work is to deepen the understanding of the wear mechanisms that lead to the generation of wear particles, with particular regard for those mechanisms involving the degradation of the friction layer. In this regard, the experimental set up has not been designed with the intention to reproduce the real brake system action, for which specific equipments, like dyno-tests and bench test apparatuses are available. The main driving force has been rather focussed on the attainment of wear products that might be profitably investigated from a microstructural, compositional and crystallographic point of view. To achieve this goal, different techniques have been used to characterize the friction layer and wear fragments, including microscopy observations and X-ray diffraction analysis of wear particles and the subsequent quantitative evaluation of the phase concentrations using a full-pattern fitting procedure based on the Rietveld method.

2. Experimental procedures

2.1. Materials

In this work, a commercial NAO pad material and a grey cast iron discs were used for the wear tests. Table 1 provides the results of the elemental composition of the brake pad, as measured by X-ray fluorescence spectroscopy (XRF). The concentrations that do not sum up to one hundred as light elements, like carbon and oxygen, were not quantified, as their characteristic X-ray photons were not detectable. Fig. 1 shows an example of the complex microstructure of the brake pad material. The arrows indicate some of the components that were identified using EDXS analysis and by comparing the results with literature data [1,12,16–20]. All the identified phases are listed in Table 2, where the concentrations of the components are also indicated. They were calculated from data XRF data (Table 1), according to the stoichiometry of the various compounds. The presence of a quite large amount of zirconium oxide can be clearly noticed. In the same table its main role in the sliding performance of the pad is also specified [1,2]. As a counterface material, a pearlitic–bainitic grey cast iron disc with a hardness of 350 ± 11 HV60, was used.

2.2. Wear test set-up and characterization techniques

The dry sliding tests were carried out at standard room temperature and humidity, in a pin-on-disc testing device. Cylindrical pins were machined from the brake pad (Fig. 2a). They had a diameter of 6.2 ± 0.2 mm and a height of 7 ± 2 mm. The pins were

Table 1

Elemental compositional details of the brake pad material measured by XRF.

Element	Wt%
Mg	2.8
Al	3.2
Si	1.7
S	1.3
K	2.3
Ca	1.0
Ti	5.2
Fe	8.3
Cu	7.5
Zn	2.1
Zr	22.7
Sn	1.9
Ba	2.9
Bi	0.6
Sb	0.9

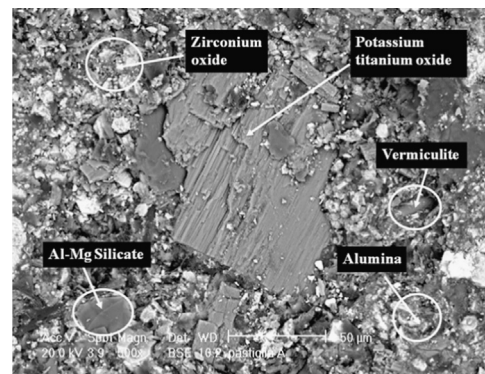


Fig. 1. Microstructure of starting brake pad material. Some of the components are indicated.

then abraded on the bottom side with a SiC 800 grit abrasive paper in order to render this surface as more planar as possible in order to have a stable contact with the pin-holder and a conformal contact with the disc. The initial roughness of the disc surface, as measured with a stylus profilometer, was $R_a = 0.18$ μm. Wear tests were carried out at a sliding velocity, v , of 3.14 m/s and for 50 min, for a total distance of 9000 m. Two average nominal contact pressures, p_o , were investigated: 0.5 and 2 MPa. The $p_o v$ values were then 1.57 and 6.24 MPa m/s, an adequate range to investigate the performance of these materials and systems, since in real brake systems the $p_o v$ values usually are in between 0.3 and 20 MPa m/s [1,2,18]. Pin wear was measured by checking its weight, W , 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 measured density of the pad material equal to 2.8 g/cm³. Disc wear was measured with a profilometer, used to evaluate the cross section of the wear trace. During each test, the friction coefficient was continuously recorded with the evolution of contact temperature. For this purpose, two chromel–alumel-type thermocouples were placed in two holes drilled in the pin holder at a distance of 4 and 6 mm from the contact surface of the pin with the disc (see Fig. 2b). To estimate the contact temperature, the frictional heat flow was considered to be unidimensional and temperature was then assumed to decrease linearly from the contact surface upward [21]. At least three tests were carried out for each experimental condition.

The surface morphologies of the worn pads were examined in a scanning electron microscope (SEM). To eliminate any surface charging effect, SEM samples were coated with thin layer of carbon or gold. SEM was also used to examine the microstructure

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