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Towards a better understanding of brake friction materials

W. Österle [a,*], H. Kloß [a], I. Urban [a], A.I. Dmitriev [b]

[a] BAM, Berlin, Germany
[b] Institute of Strength Physics and Materials Science, Tomsk, Russia

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Abstract

This work focuses on surface changes induced by repeated brake applications and tries to provide explanations, how such material modifications might affect friction and wear properties of automotive disc brakes. Surface films were investigated locally by transmission electron microscopy (TEM) after having prepared thin cross-sections with a focused ion beam instrument (FIB). Since the observed friction layers revealed a nanocrystalline structure, modelling with the method of movable cellular automata (MCA) was performed by assuming an array of linked nanometer-sized particles. In spite of complicated material combinations at the pad surface, two very characteristic features were always observed at both the pad and disc surface, namely a steel constituent—either ferritic (pad) or pearlitic (disc), partly covered with patches of nanocrystalline iron oxide, on a zone of severe plastic deformation with fragmented grain structure. When using an automata size of 10 nm, reasonable values for the mean coefficient of friction (COF) were obtained, namely 0.35 and 0.85 for oxide-on-oxide and metal-on-metal contacts, respectively. Immediately after brake application mass-mixing and bond-breaking was observed within a narrow zone at both surfaces.

Keywords: Brake pad; Brake disc; Composite material; Friction layer; Third body; MCA-modelling

1. Introduction

Pad materials for automotive braking usually are polymer matrix composites with a large number of constituents which provide certain functionalities, like COF-stabilization, disc-polishing or noise reduction. Though pad manufacturers know by experience how formulations must be changed in order to achieve certain properties, there is a lack of fundamental knowledge concerning the influence of pad materials on friction and wear properties. Certainly, features at the pad–disc-interface will control the latter properties, but it is difficult to find the appropriate length scale for the respective phenomenon. Though "Tribology at the Interface" was the topic of the 33rd Leeds-Lyon Symposium (Leeds, September 2006), there was no paper directly referring to brakes. During recent brake conferences, on the other hand, the importance of surface films was mentioned several times [1–3], but experimental evidence has been rarely provided [4,5]. A method for modelling dynamic phenomena, frequently observed during braking, was proposed by Ostermeyer's group [6,7]. The length scale of this approach is of the order of 10–100 μm. Such simulations can explain dynamic effects by regarding formation, growth and degradation of contact patches. But we must keep in mind that an even finer length scale exists, describing single asperity contacts. Since we know that tribologically induced surface films usually are of the order of 1 μm or even thinner, a much finer discretization is necessary to simulate the behaviour of such films during sliding operation. The method of movable cellular automata (MCA) has the potential to simulate events like topography modification, film degradation and mass mixing on the nanometer scale [8]. Therefore it is particularly suitable to check Godet's hypotheses that "all these events occur practically simultaneously and within a few cubic microns" and "indeed, film thicknesses are very small when compared with other contact dimensions" [9]. A particle approach to simulate the behaviour of third body layers was proposed shortly after Godet's statements [10]. Recently attempts have been undertaken first by Kemmer [11] and now also by our group to simulate friction and wear properties at micro-contacts of a brake with the MCA-method. Some preliminary results were published in Ref. [12].

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* Corresponding author at: Federal Institute for Materials Research and Testing (BAM), 12200 Berlin, Germany. Tel.: +49 30 8104 1511;
fax: +49 30 8104 1517.
E-mail address: Werner.oesterle@bam.de (W. Österle).

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Table 1
Composition of low-met pads (mass%)

	Rubber	Resin	Fibres	Metals	Fillers	Lubricants	Carbon
A1	1	7	3	38	23	13	15
A2	2	7	2	39	20	18	12

Wirth et al. were the first who regarded the chemical composition of transfer films on a rotor surface with a surface analytical technique [13]. Eriksson's PhD thesis revealed detailed information on the morphology and microstructure of so-called contact patches, which are actually areas covered by a third body formed from the wear debris [14–16]. The Swedish colleagues lead by Jacobson, mainly using scanning electron microscopy (SEM) and light optical microscopy (LM) concluded (i) contact patches are protruding from the surface and thus can be identified by topographic measurements and (ii) the third body is composed mainly of iron oxides. Approximately 5 years ago our group started to use transmission electron microscopy (TEM) and the focused ion beam (FIB) technique to reveal details of the third body on pads, discs and loose wear particles [17–20]. The first statement of Jacobson's group had to be slightly modified, since we did not find protrusions but rather wear troughs which interrupted the contact areas on a mesoscopic scale [19]. The formation of iron oxides has been confirmed for commercial pads for the European market which usually contain a high fraction of steel fibres [18,20], though for a model material containing no steel but a high fraction of barite, a different third body had been observed [17].

2. Experimental procedure

2.1. Materials

Only commercial pad materials developed for automotive braking after a series of brake stops against grey cast iron discs (European standard EN-GJL-250) will be regarded in this paper. Two typical formulations are shown in Table 1. Actually the main difference between both materials was revealed by Scanning X-ray Fluorescence Analysis (XFA) as described in more detail in Ref. [21]. Fig. 1 shows XFA sum-spectra after an area of several cm^2 had been scanned by an X-ray beam of 60 μm diameter. Since the penetration depth is about 50 μm, mainly the bulk composition is revealed. Obviously steel (Fe and some Mn) is the main constituent of both pads besides the organic binder phase and carbon, these are not shown in the spectra which reveal only elements of atomic numbers beyond 11. As communicated by the manufacturer the iron contents of pads A1 and A2 are 25 and 30 mass%, respectively. Further metallic constituents are Cu and brass for A1, but only Cu for A2. The latter finding was derived from elemental mapping which showed coincidence of Cu and Zn within some macroscopic particles for A1 but not for A2. The Zn content of A2 is due to sub-micron-sized ZnO particles, as revealed by SEM/EDX [12,21]. ZnO together with CaF_2, the latter one was also revealed by SEM/EDX, might serve as friction stabilizers at elevated temperatures. A major difference between both materials relates to the mixture of solid lubricants, namely Sb_2S_3 and MoS_2 for A1 and SnS and MoS_2 for A2, as revealed qualitatively by the spectra of Fig. 1. Since antimony in the brake dust is suspected to be carcinogenic [22], A2 formulation was developed with the aim to provide a more environmentally friendly material.

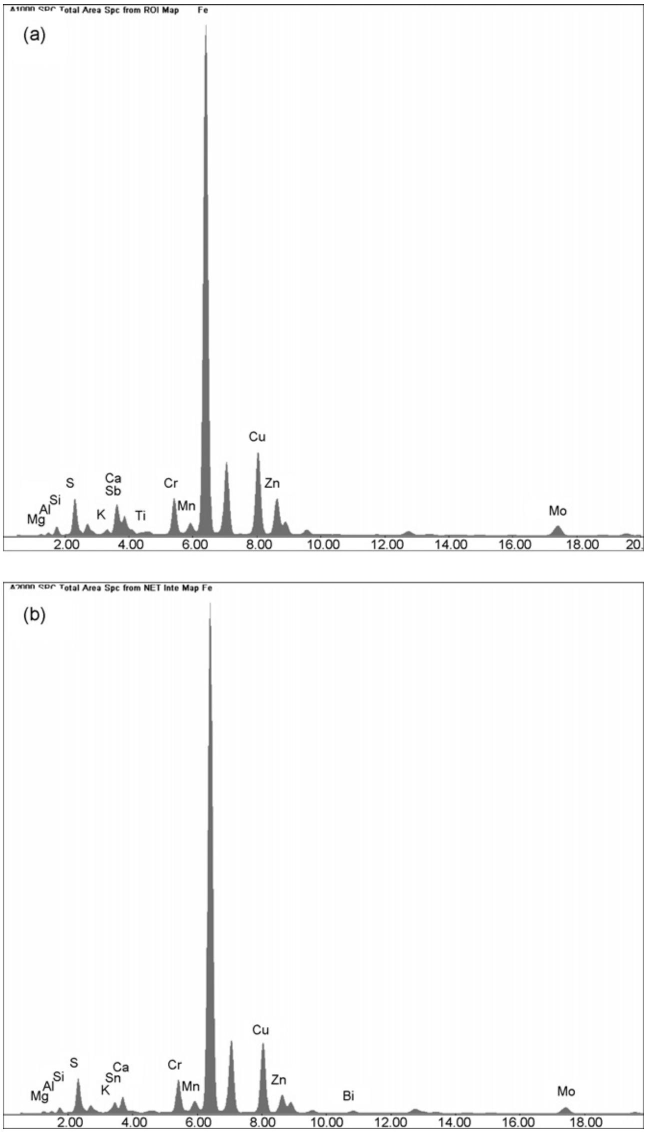

Fig. 1. XFA sum-spectra of pad A1 (a) and pad A2 (b).

2.2. Materials testing

Three different test facilities were used in the frame of our project for preparing surface states: (i) the 13 kW laboratory test rig of Bosch Company in Stuttgart, described in Ref. [11], (ii) the 40 kW laboratory test rig of Technical University Berlin (TUB), described in Ref. [23] and (iii) a 200 kW full scale dynamometer test rig which is installed at Honeywell company in Hamburg. The latter device was designed to simulate a large variety of real braking conditions according to the standard test procedures described, e.g. in Ref. [3]. Whereas laboratory test rig 1 had been down-scaled in such a way that real braking condi-