INFLUENCE OF THE FORM OF COPPER IN THE FRICTION MATERIAL OF DISC BRAKES ON THE COEFFICIENT OF FRICTION AND WEAR IN RIG TESTS

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Summary

More than 15 components occur in the friction materials for disc brake pads. Copper in the form of powder or fibres is counted among reinforcers and it plays an important role in the braking process. The brake pads tested, reinforced with a 2% admixture (by weight) of copper powder or fibres, were manufactured in a normal production process at the TOMEX Company. The tests were carried out on a T-11 ("pin-on-disc") test machine for small specimens prepared from the friction material under consideration and on a Kraus test machine, where finished brake pads were examined. The test conditions were close to the normal brake operation conditions. The brake discs used as counter-specimens were made of grey cast iron with flake graphite.

According to the test results obtained from both test machines, the values of the coefficient of friction were higher and the wear was bigger for the material reinforced with fibres as against those recorded for the material where powder was used as the reinforcer.

Observations of the material structure carried out on a scanning microscope JEOL JSM-6360LA and the nature of the material wear observed on an optical profiler BRUKER Contour GT have confirmed the test results.

Keywords: friction materials, friction pair, friction, wear

1. Introduction

The material components used to manufacture friction materials for motor vehicle applications are classified into five groups: reinforcers, binders, fillers, friction materials proper (abrasives), and lubricants. Copper in most cases is counted among reinforcers, which give adequate mechanical strength to the friction material. Apart from copper, other materials such as aramid glass fibre, metals (steel, brass), and ceramic materials are also

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used as reinforcers. Copper in friction materials has the form of fibres or powder. It has good heat conduction characteristics, which help to reduce temperature in the contact area; unlike steel fibres, it has good corrosion resistance properties [5], [8].

2. Purpose of the work

The work was undertaken to determine the conditions of interaction between the friction material and a brake disc made of grey cast iron with flake graphite, depending on the form of copper used in the friction material [7].

3. Materials used at the tests

3.1. Material of the test specimens

The test specimens were made on the production process line of the TOMEX Company, based on friction material 14A reinforced with Cu fibres (specimen 1a) and Cu powder (specimen 2a).

The test specimens made from friction material samples and prepared for tests were subjected to identification carried out with the use of a scanning microscope JOEL JSM-6360LA, which offered a possibility of observations at 30 kV with a resolution of 3 nm and 4 nm in the high vacuum and low vacuum mode, respectively (Fig. 1) [1].

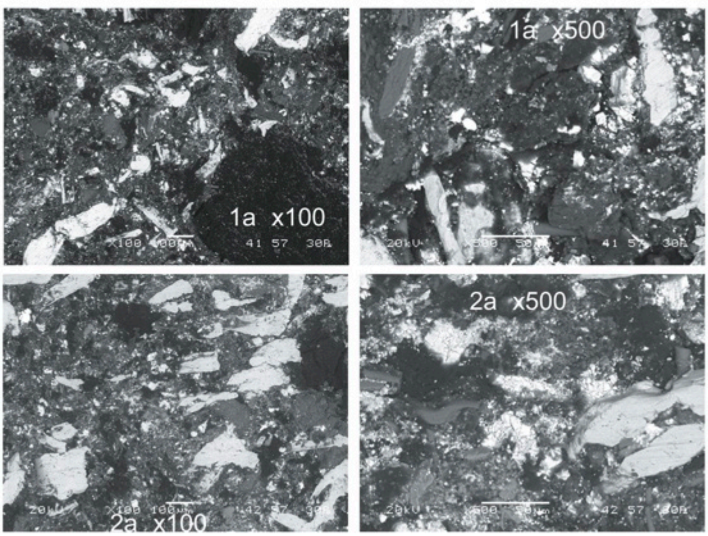


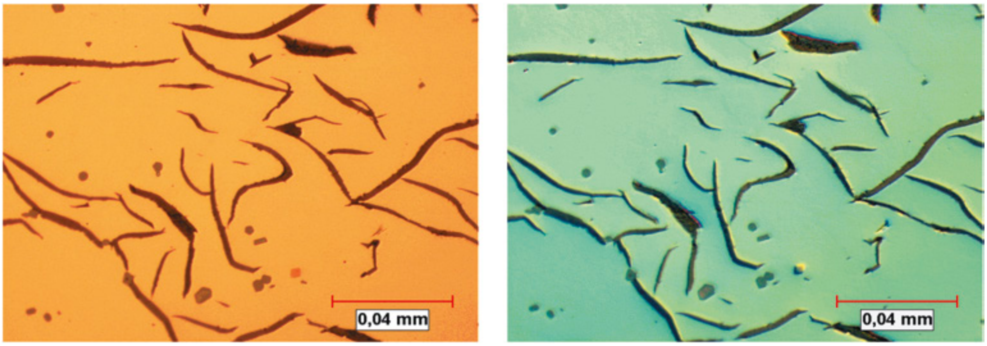
Fig. 1. Structures of specimens 1a and 2a, magnification: 100× and 500×

3.2. Material of the counter-specimens

Brake discs are most frequently made of cast iron, which is an alloy with iron matrix and 2.0–3.8% carbon content, with Si, Mn, P, and S also used as alloy additions.

Grey cast iron with flake graphite is the most conventional material among the cast iron grades used for the manufacturing of brake discs.

The counter-specimens prepared were subjected to microscopic observations without etching (Fig. 2) [6], [7].



Conventional light, magnification 500×, unetched specimen

Phase contrast, magnification 500×, unetched specimen

Fig. 2. Grey cast iron with flake graphite (Br)

4. Tests

The tests to determine the friction properties of the materials under examination were carried out at the micro-scale on a T-11 ("pin-on-disc") test machine and at the natural (full-size) scale on a Krauss test machine.

4.1. Micro-scale examining of friction properties on a T 11 ("pin-on-disc") test machine

The T-11 test machine of the "pin-on-disc" type is used to determine tribological properties of materials for friction pairs in micro-scale tests aimed at preliminary assessment of e.g. friction materials. The vertical load was applied to the test specimen with the use of test weights and the fiction force was measured with a dynamometer. The values of these quantities provide a basis for determining the coefficient of friction of the friction pair under test. During the tests, the friction force, temperature, and friction path of the friction pair were continuously recorded. For the test conditions to be made as close to the natural conditions as possible, test specimens with diameter changed to 8 mm were allowed thanks to the use of a specially designed adapter, with the counter-specimen diameter being also changed so that the friction radius was 9.5 mm (Fig. 3). The specimen was loaded with a vertical force of up to 50 N.

The tests of the T 11 machine [2] were carried out at predetermined test parameters specified in Table 1.

Table 1. Test parameters

Dimensions		Rubbing area	Test parameters	
Specimen diameter	Friction radius			
8 mm	9.5 mm	50.26 mm^2	Rotational speed:	525 rpm
			Rubbing speed:	0.522 m/s
			Friction path:	3 130 m
			Unit contact pressure:	about 1 N/mm^2
			Ambient temperature	25±5 °C

Fig. 3. Specimen (a) and counter-specimen (b), in the form of a pin and a disc, respectively

4.1.1. Test program

During the tests on the T-11 machine, the friction pair elements were to rub continuously against each other, according to the test program adopted. Based on previous experience, the time of a single test run was decided to be 6 000 s, with the friction pad bedding-in period taking the first 2 000 s of that.

4.2. Natural-scale examining of friction properties on a Krauss test machine

The natural-scale tests of friction properties of the materials under tests were carried out on a Krauss test machine at the TOMEX Company. The machine design makes it possible to test full-size brake mechanisms. The friction material test loading conditions in a brake mechanism are simulated with the use of a DC motor. The Krauss test machine is commonly used by friction material manufacturers for ongoing production quality assessment in accordance with the requirements laid down in Annex 9 to UN ECE Regulation No. 90 [4].

Dynamic tests on inertia dynamometers, which enable the obtaining of a wide range of test parameters, are usually carried out within the process of developing new friction materials.

Parameters of the machine testing (Annex 9 to UN ECE Regulation No. 90):

Disc or drum rotational speed without load	660±10 rpm
Disc or drum rotational speed with full load	min. 600 rpm
Rubbing speed	about 0.9 m/s
Hydraulic pressure acting on the piston	0.9 MPa
Number of brake applications	50 (in the brake fade test cycle)
Cooling air supply rate	600±60 m^3/h

4.2.1. Test program

The test program covered four test cycles (bedding-in, cold performance test, fade test, and recovery). Each brake application lasted 5 seconds, which was followed by a brake release for 10 seconds.

The program of the test carried out on the Krauss test machine has been presented in Table 2.

During each brake application, the quantities recorded were brake disc temperature and brake torque converted into the coefficient of friction. The friction properties of the friction pairs under tests were evaluated during the fade test cycle. The parameters subject to evaluation were operational coefficient of friction (μ_{op}), maximum coefficient of friction (μ_{max}), and minimum coefficient of friction (μ_{min}).

Table 2. Test program

Cycle No.	Cycle	Number of brake applications in the cycle	Brake disc temperature at the beginning of the first brake application [°C]	Maximum brake disc temperature [°C]	Forced cooling
1	D – bedding-in	2×(5×3)	100	300	yes
2	Z – cold performance test	1×10	50	–	no
3	F – fade test	5×10	100	–	no
4	R – Recovery	1×10	100	–	yes

The friction pair consisted of a brake pad with 2 275 mm^2 rubbing area and a ventilated brake disc with 239 mm diameter for the Daewoo Lanos passenger car (Fig. 4).

Fig. 4. Brake pad and brake disc for the Daewoo Lanos passenger car

4.3. Wear examinations

The T-11 test machine made it possible to record the linear wear of the friction pair. The wear was evaluated after bedding-in of the friction pair, for the test period from 2 000 s to 6 000 s.

On the Krauss test machine, the friction material wear was determined by mass.

4.4. Qualitative examination of the working surface of the friction pair

For the specimens tested on the T-11 test machine, the working surface of the friction pair was qualitatively examined with the use of a BRUKER profiler, model Contour GT (Fig. 5), at the Motor Transport Institute (ITS).

Fig. 5. Optical profiler BRUKER Contour GT

5. Test results

5.1. T-11 test machine

The evaluation of friction and wear characteristics was based on the average values of the measurement results recorded during the test period from 2 000 s to 6 000 s. The parameters subject to evaluation were the coefficient of friction and the total wear of the friction pair.

The test results have been shown in Fig. 6.

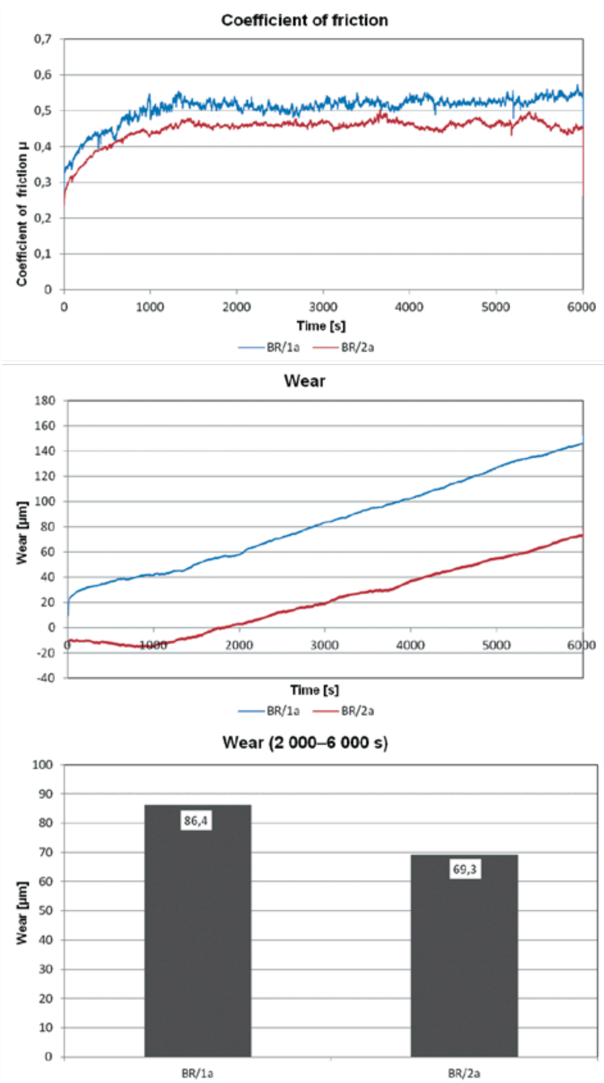


Fig. 6. Results of the tests carried out on the T-11 test machine

As it can be seen in the graphs in Fig. 6, the coefficient of friction vs. time curves had a similar nature in both cases. The values of the coefficient of friction for the material with copper fibres exceeded those determined for the material with copper powder by about 10 %. The linear wear values measured, taken for the specimen and counter-specimen in aggregate, were found for the former material to be higher by 20 % than those for the latter [3, 4].

5.2. Krauss test machine

At the tests carried out on the Krauss machine, the friction pair performance was evaluated during the fade test cycle because of the most severe operating conditions encountered by the friction pair in such a case. This part of the test consisted of 5 cycles of 10 brake applications each at a constant rubbing speed of v= ok. 7 m/s and a constant hydraulic line pressure of 0.9 MPa. The brake disc temperature at the beginning of each cycle of brake applications was 100 °C. During each brake application, the brake disc temperature and coefficient of friction were recorded.

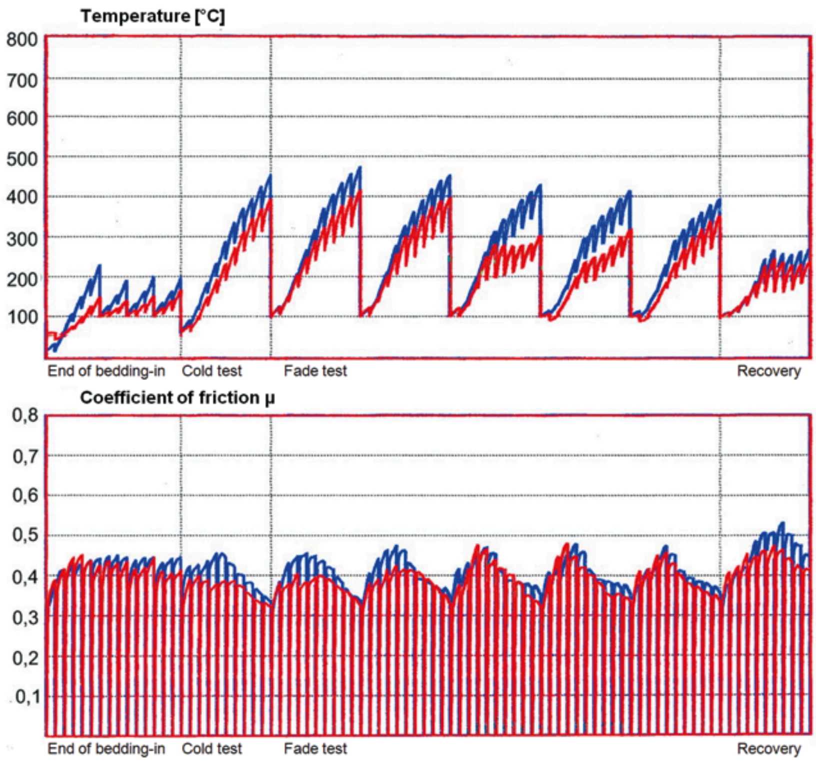
The test results have been presented in Fig. 7, where the time histories of friction characteristics have been shown in the graphs and the values of the coefficient of friction have been tabulated.

The test results have confirmed the fact observed at the micro-scale tests that the coefficient of friction for the material with copper fibre reinforcer exceeded that of the material reinforced with copper powder.

The wear of the friction materials was measured by mass. For the friction material with copper fibre reinforcer, the loss in mass was 0.89 %, while the loss of mass for the material with copper powder was lower by about 30 %.

5.3. Examination of the counter-specimen surface

For the influence of the form of copper additive in the friction material on the counter-specimen wear to be determined, the counter-specimen surface was examined with the use of a BRUKER Contour GT optical profiler (Fig. 5). The surface roughness was measured at selected cross-sections and quantitative evaluation of the roughness over the bearing area (Sa) was carried out. The examination results, concerning cross-section 1 (Fig. 8), have been presented in Figs. 9 and 10.



Coefficient of friction		Specimen 1a	Specimen 2a	Difference [%] (1a = 100 %)
Operational	μ_{op}	0.322	0.321	-0.3
Cold performance	μ_{zimno}	0.369	0.325	-12
Minimum	μ_{min}	0.311	0.311	0
Maximum	μ_{max}	0.531	0.480	-10

Fig. 7. Results of the tests carried out on the KRAUSS test machine: blue – specimen 1a; red – specimen 2a

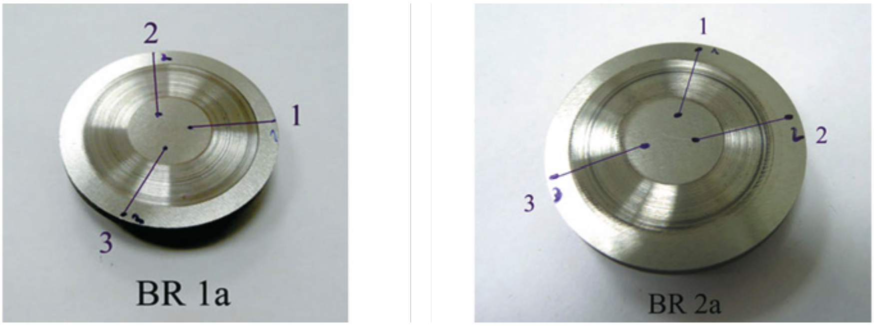


Fig. 8. Counter-specimens after tests with specimen 1a and specimen 2a

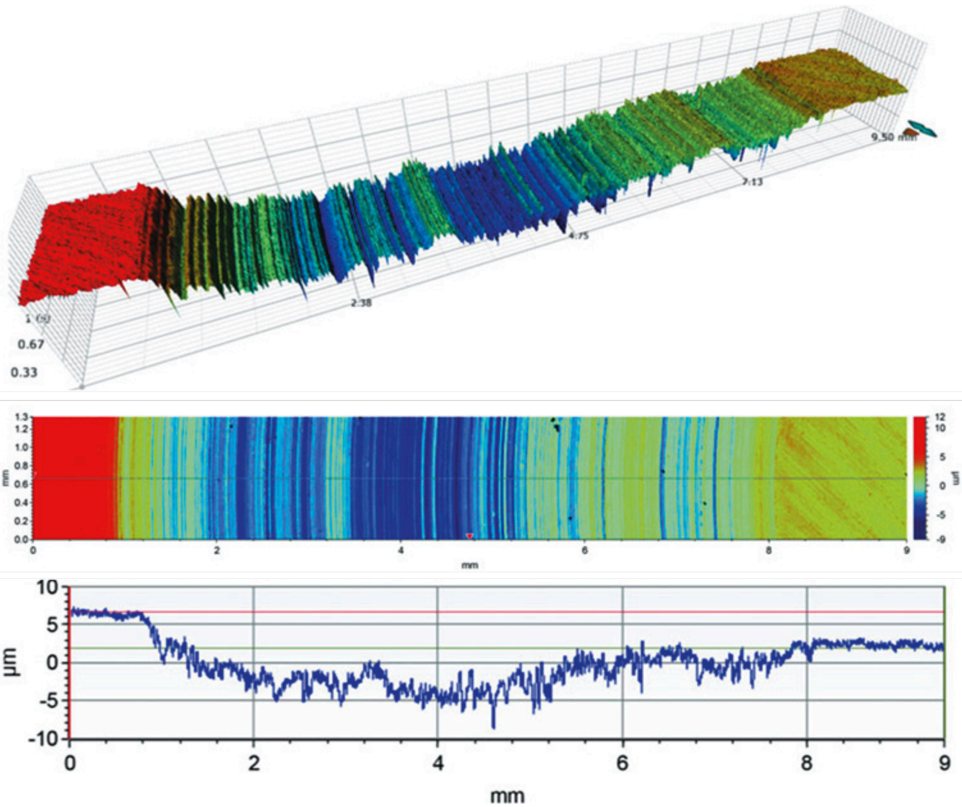


Fig. 9. Counter-specimen after tests with specimen 1a – surface structure

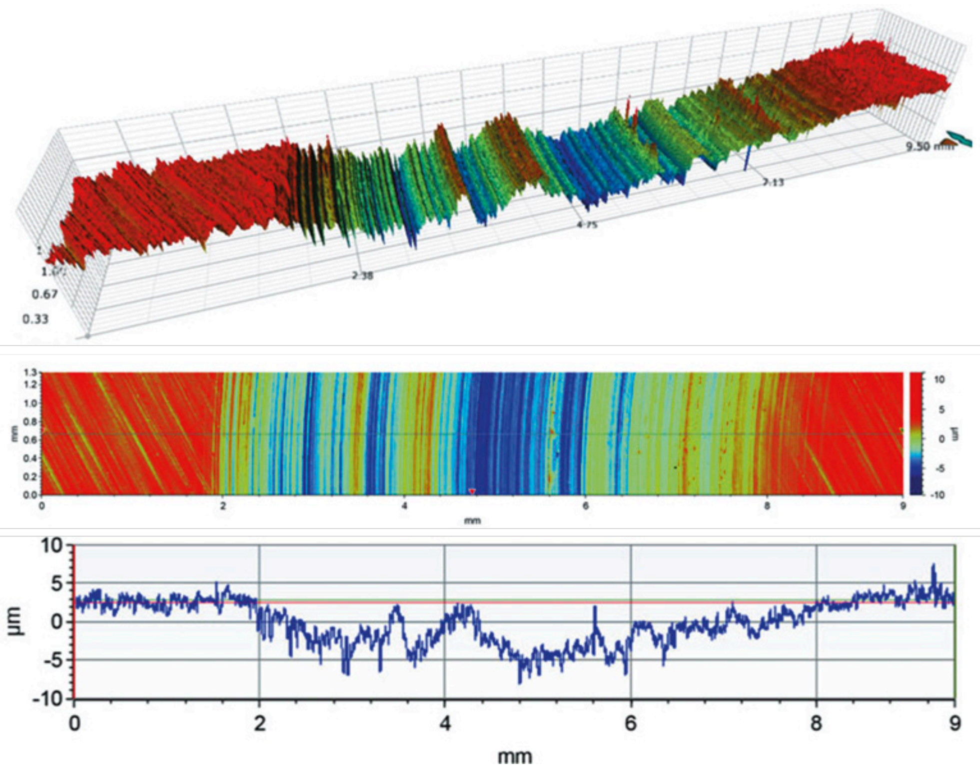


Fig. 10. Counter-specimen after tests with specimen 1b – surface structure

The examinations of the surface wear degree have shown that the counter-specimen mating the specimen reinforced with copper powder was less worn than the one used with the specimen with copper fibres. Based on an analysis of the surface profile, the surface roughness of the former counter-specimen was estimated at about 5 µm while for the specimen with copper fibres, the counter-specimen surface roughness was about 8 µm.

6. Conclusions

In result of the tests described above, the following was ascertained:

- The coefficient of friction (at the cold performance test), determined from the tests carried out on both the KRAUSS and T-11 test machines, was lower by 10–12 % for the friction pair with copper having the form of powder.
- The maximum coefficient of friction, determined from the tests carried out on both the KRAUSS and T-11 test machines, was lower by about 10 % for the friction pair with copper having the form of powder.

- The specimen and counter-specimen wear, determined from the tests carried out on the KRAUSS and T-11 test machines, was lower by about 30% and about 20%, respectively, for the friction pair with copper having the form of powder.

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