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PRELIMINARY EXPERIMENTAL RESEARCH OF TRIBOLOGICAL PROPERTIES OF BUS BRAKES FRICTION LININGS

WSTĘPNE BADANIA EKSPERYMENTALNE WŁAŚCIWOŚCI TRIBOLOGICZNYCH OKŁADZIN CIERNYCH HAMULCÓW AUTOBUSOWYCH

Key words:

car brakes, friction materials, durability, reliability

Słowa kluczowe:

hamulce samochodowe, materiały cierne, trwałość, niezawodność

Abstract

Experience gained from the use of buses in urban conditions showed that the working conditions of friction elements of the braking system, ensuring traffic safety, are associated with high loads. This leads to the intensive wear and

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premature replacement of the worn friction components, which reduces the overall reliability of the brake system and road safety. On the other hand, the friction linings of brake mechanisms may act as abrasives that cause the wear of brake discs or drums. Their replacement during operation is associated with a significant increase in the cost of spare parts. Therefore, it is assumed that the determination of the tribological properties of the brake linings in the brake mechanisms, before their exploitation, will increase the efficiency and safety of the vehicles' operation, which justifies the choice of the research subject matter for its real and practical significance. The paper presents the preliminary results of the research into the main elements of the brakes in a city bus on a test stand mapping the real working conditions. For the testing, brake shoes of different manufacturers were used. Their tribological characteristics, reasons for their wear, and operational recommendations were determined.

INTRODUCTION

The reliability of a vehicle's braking system is affected by a number of factors. Exploitation of the vehicle in difficult road conditions results in greater wear of the friction elements, and their delayed replacement is dangerous for the safety of traffic. The tribological properties of the friction lining material determine the wear resistance of the brake pad and its abrasive action on the cooperating element of the friction couple, namely on the brake drum or disc, depending on the design of the brake mechanism. In the aftermarket, there is quite a wide range of brake pads differing in their quality and price, which depends on the manufacturer. A selection of friction materials in terms of the optimum combination of frictional properties and the minimum abrasive wear enables a rational choice of spare parts, reduces downtime for repairs and reduces the cost of spare parts, and also ensures the required level of transport safety. Studies on the brakes wear have been carried out for a long time, and their goal is to identify the factors and mechanisms of wear that lead to an increase in their durability and in the scope of their application **[L. 1, 2]**. In the Department of Machine Design and Tribology of the Wroclaw University of Science and Technology, these issues have also been extensively examined, which made it possible to gain considerable experience in conducting experimental research into the tribological properties of friction materials **[L. 3–7]**. The main focus of the research was on the tribological properties of the friction linings in contact with the steel and cast iron brake components.

The exploitation experience shows that the work of vehicles on urban routes in fairly difficult road conditions with high loads on brakes that causes their intensive wear **[L. 8]**. In particular, the high intensity of the wear of friction blocks, brake drums (discs), and their premature replacement reduce the reliability of their work and traffic safety. Furthermore, frequent replacement of wearing elements of the mechanisms of brakes entails higher costs. Not sufficiently high abrasive wear resistance and improved materials of the friction lining lead to a reduced life of the brake mechanism and the reduction of the vehicle's safety. The brake pads available on the market feature no information on the consumption and abrasion of their friction linings. The study is aimed at the improvement in the effectiveness of vehicle braking mechanisms based on the experimental research into the tribological properties of the friction pads. Comparative evaluation of wear resistance and abrasion of the friction pads on the test stand for the durability testing of samples will allow a selection, from a list of similar spare parts, of the best solution, thereby ensuring the stability of the brake mechanism and safety of the system used in the automotive industry.

METHOD AND TEST CONDITIONS

To assess the nature of the work and loads of the braking system, observation of a city bus in the city of Ust-Kamienogorsk was carried out, which showed that the time of driving the bus was 1,950 sec. In that time, an average of 20 repetitions of incomplete braking, and 38 full braking repetitions at bus stops were carried out. The path length was 20.133 km, and the average speed on the route (not taking into account the time at the stops) amounted to 10.325 m/s. Based on that data, the input parameters for laboratory tests were defined as follows:

- Friction velocity (relative velocity of the friction surface) = 1.177 m/s (which reflects the speed of the friction of the brake pad on the brake drum).
- Load at a contact of the brake pads = 20 MPa (2 * 107 N/m^2), which corresponds to the clamping force of the brake pads to the brake drum.
- The duration of the test for one sample = 75 seconds.

The value of the brake linings' wear was determined by directly measuring the change (before and after each test cycle) in the thickness of the friction-lining sample and in the thickness of the brake disc-working surface, using a micrometre. The measurement was repeated eleven times for each material.

To evaluate the tribological properties of the friction linings and their abrasiveness in relation to the brake drum, a test stand was designed that allowed the reconstruction of the operational conditions of the brake mechanism's friction elements. The project of the test stand has been patented in the Republic of Kazakhstan **[L. 9]**, and it relates to a device for testing the research wear resistance and abrasion linings of car brake mechanisms. The device allows one to objectively evaluate and compare the abrasion resistance of friction materials for brake linings, which are tested under very similar conditions to real operation. The resistance to abrasion test consists in the observation of the controlled wear of a friction node composed of the friction lining–brake drum pair, loaded with a corresponding force pressing the brake pads to the brake drum at a relative speed of movement corresponding to the speed of moving the brake pads after the drum brake in the car brake mechanism while braking.

Friction materials of brake mechanisms provide efficient braking of vehicles. The braking effect is characterized by the operation of the friction couple (friction linings – brake disc/drum) accompanied by a low thermal load (in a normal mode until the wear of the working layer of the friction lining). In the process of friction, the linings wear as a result of separating the particles from the pad material, but the more durable brake drum is also worn.

Figure 1 shows a diagram of the test apparatus. The stand for the abrasion resistance testing of the lining friction materials samples includes an electric motor (1), belt transmission (2), a reducer (3), a clutch (4), a brake drum (5), a loading node (6) for fixing the test sample of a friction lining (7), a limiter (8) for fixing the load node, supporting rollers (9), and a sensor (10).

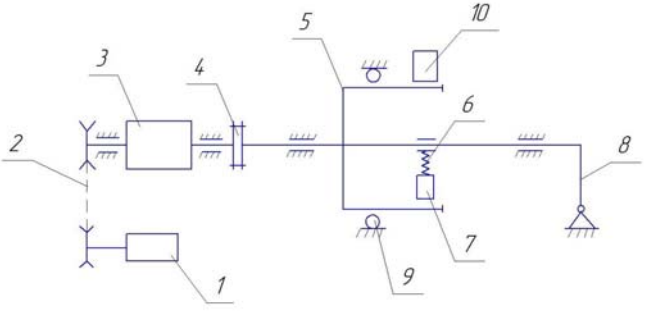

Fig. 1. Diagram of the test stand (description in the text)
Rys. 1. Schemat stanowiska badawczego (opis w tekście)

The operation principle of the stand is such that a sample made of the friction linings of the brake pads rubs against the brake drum (5) and rotates at a speed corresponding to an average vehicle speed during braking. The brake drum is driven by the electric motor (1) via the V-belt of the belt transmission (2). The belt transmission (2) allows one to change the speed of the brake drum and protects the motor from overload by blocking the friction pads–brake drum pair.

The reducer (3) is intended to transform the rotational speed of the drum (5) of the brake and increase the torque on it. The clutch (4) is used to connect the brake drum (5) with the reducer (3) and the dampening of the torsional vibration resulting from irregular work of the friction pads–brake drum friction node. The loading node (6) is used for the permanent mounting of the sample of the friction lining (7) and for generating contact pressure on the sample from the lining (7) onto the working surface of the brake drum (5).

In this way, the load node (6) is arranged on the limiter (8) in such a manner that the position of the load node (6) with the mounted sample of friction lining (7) can be regulated relative to the working surface of the brake drum (5). The supporting rollers (9) compensate the clamping force of the sample from the friction lining (7) onto the working surface of the drum (5). The sensor (10) can keep a record of the test cycle time by counting the number of revolutions of the drum brake.

The research on the stand includes three stages. In the first stage (to start the rotation of the drum (5) in contact with the sample of the friction lining (7)), the size of the sample from friction linings (7) and the thickness of the brake drum's wall (5) in the area of contact with the lining (7) is measured. Then, by the load node (6) and the limiter (8), the inner space of the drum (5) was loaded and a clamping force on the sample (7) and on the working surface of the brake drum (5) was generated.

In the second stage (during rotation of the drum (5) in contact with the sample of the friction linings (7)), a proper abrasion test is carried out.

The wear test is conducted in cycles determined by a number of revolutions of the brake drum in contact with the sample of the loaded friction lining. The actual duration of the test cycle is determined by the sensor (10). After completion of the test cycle, the rotation of the drum (5) stops.

In the third stage, after removal of the load from the loading node, the size of friction lining (7) sample and the thickness of the drum (5) brake wall in the zone of contact with the sample of the lining (7) are measured. The difference in dimensions before and after the test allows one to evaluate the wear of the friction lining and the brake drum.

MATERIALS AND THEIR CHARACTERISTICS

To study the tribological properties of the friction pairs, the materials applied in the construction of the brakes for Youtong 6108 HGH bus were used. The study involved the materials for friction linings of various producers, both original Chinese parts as well as their replacements manufactured by companies from Russia and Japan. The chemical composition of the materials was determined based on the quantitative analysis by means of the scanning electron microscopy, and they are shown in **Table 1**. In order to avoid advertising the producers, the materials are labelled with numbers 1, 2, and 3.

As a cooperating part, the original drums for the bus were used. **Figures 2a** and **2c** show the microstructure of the tested materials.

Table 1. Chemical composition of the materials for the brakes of YTONG 6108 HGH bus
Tabela 1. Skład chemiczny materiałów na hamulce autobusu YOUTONG 6108 HGH

	O	Na	Mg	Al	Si	P	S	K	Ca	Cr	Mn	Fe	Ba	Zn	Cu
Material 1	42.92	0.47	9.19	0.80	15.32	0.37	3.22	0.30	9.07	0.70	1.78	14.68	39.77		
Material 2	33.54		1.27	17.19	3.91		2.80	0.61	0.53			17.13	11.62	5.20	6.20
Material 3	23.82		0.58	2.15	1.18		2.08		5.14		1.74	58.73	3.73	1.74	

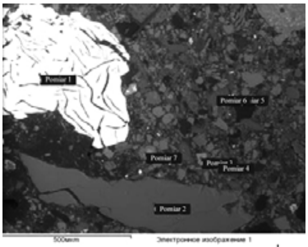	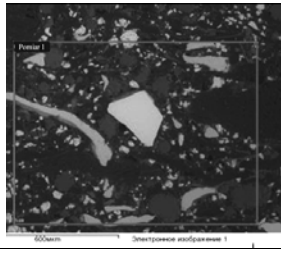	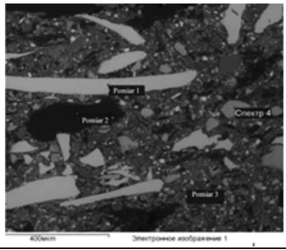
a) Material 1 a) materiał 1	b) Material 2 b) materiał 2	c) Material 3 c) materiał 3

Fig. 2. Microstructure of the tested materials
Rys. 2. Mikrostruktura badanych materiałów

RESULTS AND CONCLUSIONS

The test results are shown in **Figures 3–5**. In order not to decrease the legibility of the drawings, the confidence intervals have not been marked on them, even though they have been determined as the test for each brake lining material was repeated eleven times, and the results were analysed statistically at the variation coefficient of less than 0.23.

Studies have shown that the friction linings made of Material 1 are characterized by a high wear rate, and the friction material of the lining plate has increased abrasiveness in relation to the drum.

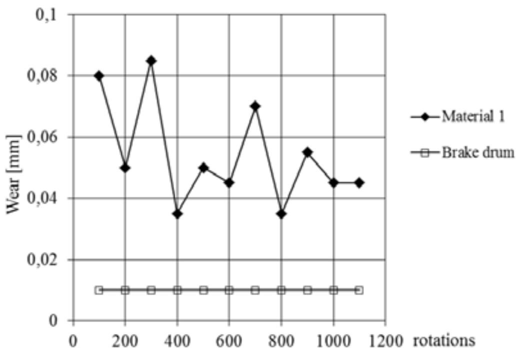

Fig. 3. Wear of Material 1 and of the cooperating brake drum
Rys. 3. Zużycie materiału 1 i współpracującego bębna hamulcowego

The analysis of the working surface of the brake pad by means of the scanning electron microscopy showed that the durability and abrasion results depend on the composition of the friction material. The macrostructure of the material shows a composition consisting of a mixture of the basic material and various additives that provide the lining with specific friction properties. On the surface, they are presented in a form of dislocations of uniformly distributed inclusions of different dimensions. **Table 1** shows that the composition of friction Material 1 predominantly contains iron, oxygen, calcium, and barium. These compounds ensure a high coefficient of friction for the material. The presence of silicon in friction Material 1 resulted in a high abrasion resistance of the material. In the composition of the material, copper containing inclusion of impurities was not detected. In addition, the cooperating element (drum brake) naturally is subject to intense wear.

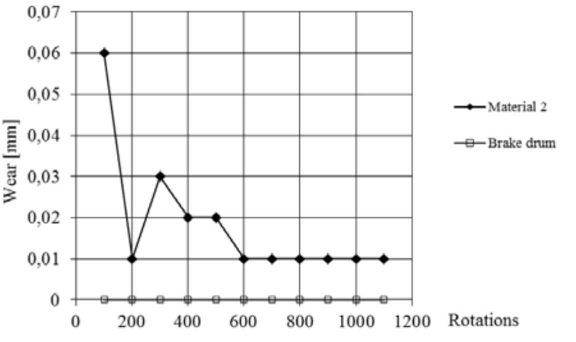

Fig. 4. Wear of Material 2 and of the cooperating brake drum
Rys. 4. Zużycie materiału 2 i współpracującego bębna hamulcowego

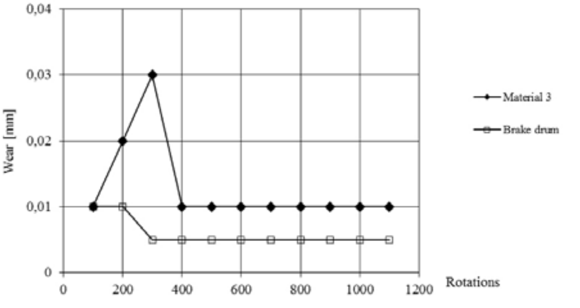

Fig. 5. Wear of Material 3 and of the cooperating brake drum
Rys. 5. Zużycie materiału 3 i współpracującego bębna hamulcowego

The test results show that friction Material 2, containing inclusions of copper, has a lower resistance to abrasion compared to its friction counter sample. In addition, the stability of the frictional properties provides a more homogeneous structure of the material mixture of the friction brake linings. Similar results are observed for Material 3; however, it does not contain copper in its composition, and the good wear resistance results may be caused by the heat treatment.

The best results of wear and wear resistance test of the friction lining are shown for comparison in **Figure 6**, and the wear of the cooperating element (drum brake) in **Fig. 7**. In terms of the wear resistance (durability), the best result was observed for the friction linings made of Material 3, and, from the point of view of the impact on the abrasion of the mating surface (cooperating element – brake drum), the best result was observed for the friction linings made of Material 2.

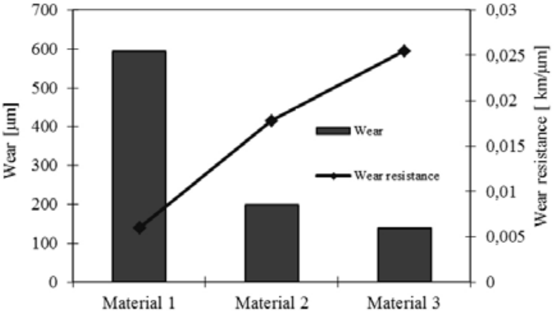

Fig. 6. Results of wear and wear resistance of the friction lining
Rys. 6. Wyniki zużycia i odporności na zużywanie okładzin ciernych

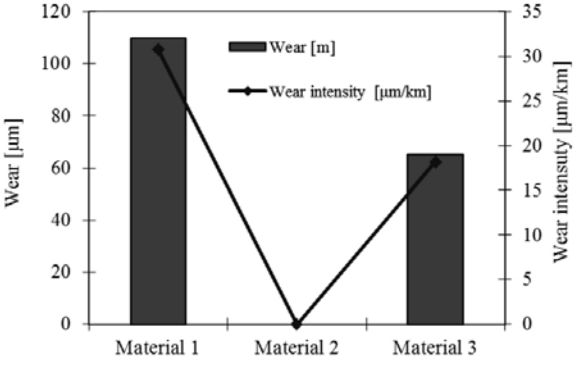

Fig. 7. The test results of the brake drum wear and wear intensity depending on the friction lining
Rys. 7. Wyniki zużycia i intensywności zużywania bębna hamulcowego w zależności od zastosowanej okładziny ciernej

The carried out technical and economic evaluation of brake efficiency maintenance cost depends on the type of friction material for the brake linings. The calculation results are shown in **Table 2**. Because of the limitations on the paper length, the calculation method has not been presented, but the hourly labour cost and the material prices applicable in Kazakhstan were adopted (the obtained values were calculated according to the NBP exchange rate), and it has been assumed that the time needed to replace the brake pads is 0.5 h, and the time needed to replace the drum is 1.5 hours. Apparently, the lowest unit cost of maintaining the reliability of the brakes, measured by the consumption of the brake pads and of the drum brake, is reached when friction Material 2 is used.

Table 2. Specific expenses for the replacement of worn parts of the brake mechanism
Tabela 2. Szczególne wydatki na wymianę zużytych części mechanizmu hamulcowego

	Material 1	Material 2	Material 3
Wear indicator of the brake pads [PLN/km]	5.11	3.05	2.08
Unit cost of brake pads replacement [PLN/km]	0.87	0.29	0.21
Wear indicator of the brake drums [PLN/km]	1.71	0	1.01
Unit cost of the brake drums replacement [PLN/km]	0.36	0	0.22
The total unit cost of the brakes replacement [PLN/km]	8.07	3.34	3.51

Thus, in the context of the technical and economic indicators of the operational efficiency of the bus braking system, it is advisable to opt out of the original brake pads in favour of the components made of friction Material 2, since they have desirable properties of friction and a minimal abrasive impact on the brake drum. This allows the easiest way to raise the braking performance and durability of the braking system of the bus.

To provide clear conclusions, it will be necessary to make a complete metallographic analysis of the materials used, because there are big differences in the structure of materials made by different manufacturers, which considerably affects the results of tribological research.

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Streszczenie

Doświadczenie uzyskane podczas użytkowania autobusu w warunkach miejskich wykazały, że warunki pracy elementów trących układu hamulcowego zapewniające bezpieczeństwo ruchu są związane z wysokimi obciążeniami. Prowadzi to do ich intensywnego zużycia i przedwczesnej wymiany zużytych elementów ciernych, co zmniejsza ogólną niezawodność układu hamulcowego i bezpieczeństwo ruchu drogowego. Z drugiej strony okładziny cierne mechanizmów hamulcowych mogą mieć działanie ścierne, które powoduje zużycie tarcz hamulcowych lub bębnów. Ich wymiana w czasie eksploatacji wiąże się ze znacznym wzrostem kosztów części zamiennych. W związku z tym założono, że określenie właściwości tribologicznych okładzin ciernych mechanizmów hamulcowych przed ich eksploatacją zwiększy efektywność i bezpieczeństwo eksploatacji pojazdów, co potwierdza celowość podjęcia tego tematu pracy z uwagi na rzeczywiste i praktyczne znaczenie. W pracy przedstawiono wstępne wyniki badań głównych elementów hamulców autobusu miejskiego na stanowisku badawczym odwzorowującym rzeczywiste warunki pracy. Do badań wykorzystano szczęki hamulcowe różnych producentów. Określono ich charakterystyki tribologiczne, powody ich zużywania oraz podano zalecenia eksploatacyjne.