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EVALUATION OF POSSIBILITIES TO IMPROVE FUNCTIONALITY OF BRAKE PADS THROUGH MODIFICATION OF THE HEAT DISSIPATION METHOD

OCENA MOŻLIWOŚCI POPRAWY FUNKCJONALNOŚCI NAKŁADEK HAMULCOWYCH POPRZEZ MODYFIKACJĘ SPOSOBU ODBIORU CIEPŁA

Key words: anisotropic brake pad, ventilated brake pad, brake disc, wear, inertia dynamometer.

Abstract: From a social perspective, providing motor vehicle users with high quality brake lining assemblies, which additionally help to prevent the braking system from overheating by dissipating heat into the atmosphere, is a matter of great importance. Overheated brakes may cause failure of the braking system and, as a result, lead to a car accident. Heat dissipation during operation helps to cool the braking system and prevent overheating. The article presents two patented brake pad structural solutions – anisotropic and ventilated brake pads – designed to boost the effectiveness of heat dissipation. The tests described in the article were performed using the T-33 inertia dynamometer developed at the Łukasiewicz – Institute for Sustainable Technologies in response to a demand presented by a Polish brake pad manufacturer. As part of the tests, various functional properties of the newly-designed and classic brake pads (i.e. the friction coefficient, the temperature of the brake pad, and the wear of the brake pad and brake disc) were compared.

From the tests it follows that the new pads with the heat dissipation system have an advantage over classic pads, depending on the method of brake pad's material and structural modification.

Słowa kluczowe: anizotropowa nakładka hamulcowa, wentylowana nakładka hamulcowa, tarcza hamulcowa, tarcie, zużycie, stanowisko bezwładnościowe.

Streszczenie: Ze społecznego punktu widzenia bardzo istotnym zagadnieniem jest zapewnienie użytkownikom samochodów wszystkich typów wysokiej jakości zespołów okładzin hamulcowych, które dodatkowo zapobiegają przegrzewaniu się układu poprzez odprowadzanie ciepła do atmosfery. Przegrzanie hamulców może doprowadzić do nieskuteczności układu hamulcowego, a w następstwie do katastrofy samochodowej. Zdolność układu do odprowadzania ciepła w trakcie jego funkcjonowania wpływa na chłodzenie układu hamulcowego i zapobiega jego przegrzewaniu się.

W artykule przedstawiono dwa opatentowane rozwiązania konstrukcyjne nakładki hamulcowej, które mają umożliwić lepsze odprowadzanie ciepła: ze strukturą anizotropową oraz dodatkową wentylacją. Do badań wykorzystano stanowisko bezwładnościowe T-33, opracowane w Łukasiewicz – Instytucie Technologii Eksploatacji dla potrzeb jednego z krajowych producentów klocków hamulcowych. Dokonano porównania szeregu cech funkcjonalnych nowych nakładek do cech wykazywanych przez nakładki hamulcowe o konstrukcji klasycznej. Były to: współczynnik tarcia, temperatura klocka hamulcowego, zużycie klocka i zużycie tarczy hamulcowej.

W wyniku przeprowadzonych badań stwierdzono, że nowe nakładki z systemem odbioru ciepła wykazują przewagi nad klockami klasycznymi, przy czym jest to uzależnione od sposobu modyfikacji klocka, zarówno materiałowej, jak i konstrukcyjnej.

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INTRODUCTION

A great disadvantage of all brake pads available on the market is the transfer of heat to braking system elements, which results in excessive heating of the brake cylinder, potential boiling of the brake fluid, and loss of braking power **[L. 1–5]**. When the boiling point of the brake fluid is exceeded, “vapour locks” may be created in the braking system, and in such a case – as a result of highly compressed gases – the brake pedal will go to the floor. This may happen particularly when travelling on mountain roads. Cases of car accidents caused by braking system failures resulting from overheated brakes are known.

In the completed project implemented as part of the Polish Smart Growth Operational Programme (POIR), the authors developed innovative brake lining assemblies enabling heat dissipation through anisotropic and ventilated brake pads. The assemblies are intended to dissipate the heat generated at the time of braking to the surrounding environment, and thus to prevent overheating of the braking system and loss of braking power.

As regards anisotropic brake pads, ways to improve the transfer of heat through the brake lining are known. For this purpose, metal shavings were added to the Ferodo mixture. What constitutes a disadvantage of this solution is the fact that the shavings disperse in the mixture chaotically. During pressing, an isotropic structure characterised by a constant heat transfer coefficient is produced. Other ways of strengthening the connection between the friction pad and the steel washer by means of embedding several perpendicular metal pins in the washer that pierce through the friction pad are also known. In this solution heat dissipation from the layer of the pad distant from the friction surface through pins to the steel washer is only locally facilitated, which constitutes a disadvantage. Another solution to reinforce the connection between the friction pad and the steel washer, known from sports car design, consists in welding an expanded hard drawn steel wire mesh to the steel washer, which allows heat transfer in an even more restricted area. High temperature leads to the degradation of the friction pad and its much quicker wear.

In the anisotropic brake pad developed in the project, metallic fibres create heat flow channels between the friction surface and the steel washer, as a result of which heat is dissipated to the steel washer and the surrounding environment (**Fig. 1**).

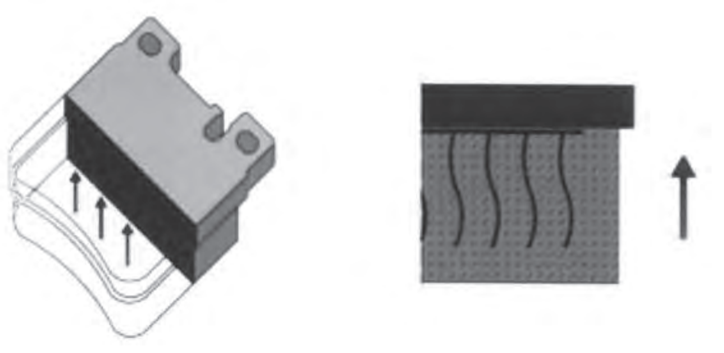


Fig. 1. Model of an anisotropic brake pad with heat flow channels [L. 6]
Rys. 1. Model anizotropowej nakładki hamulcowej z pokazaniem sposobu przepływu ciepła **[L. 6]**

In the case of ventilated brake pads, different washers and steel washers (including thick steel washers with holes filled at the time of pressing with the Ferodo mixture) can be used, which makes the pad-washer connection more durable. Additionally, thick steel washers with metal pins that pierce through the friction pad may also be used. What constitutes a disadvantage of all the above-mentioned solutions is the fact that heat is transferred to braking system elements. This may cause excessive overheating of the brake cylinder, potential boiling of the brake fluid, and loss of braking power.

In the ventilated brake pad developed as part of the project carried out by the authors, heat is actively dissipated when the vehicle is moving – air flows through the space between the steel plates of the ventilated brake pad, as a result of which heat is effectively dissipated to the surrounding environment. This prevents excessive overheating of the brake cylinder and loss of braking power (**Fig. 2**).

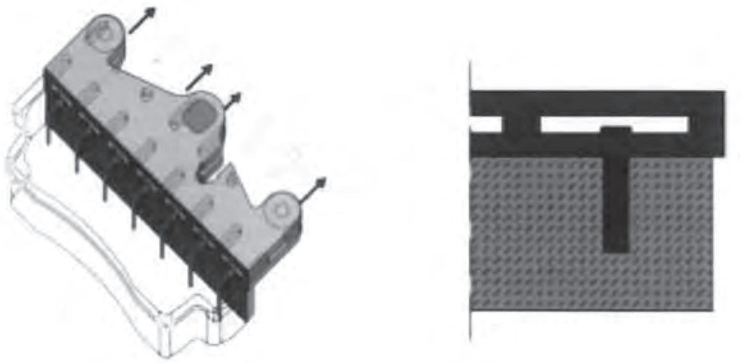


Fig. 2. Model of a ventilated brake pad with heat flow channels [L. 7]
Rys. 2. Model wentylowanej nakładki hamulcowej z pokazaniem sposobu przepływu ciepła **[L. 7]**

Currently carried out experimental tribological analyses of friction pads employ two approaches. In the first (employed, among others, by the authors of publications **[L. 8–13]**), tests are carried out on model cylindrical samples cut out from a friction pad and rubbing against a disc imitating a brake disc.

In the second (employed, among others, by the authors of publications **[L. 14–19]**), tests are most commonly performed on pad-disc configurations with the use inertia dynamometers.

Many publications **[L. 20, 21]** revolve around modelling of processes taking place in the friction pad-brake disc configuration.

In authors' experience, the industry prefers tests carried out on real brake elements. In general, model sample tests may only be used as screening tests for different mixtures selected as friction pads.

To meet the industry's requirements, in the aforesaid POIR project, the authors developed at the Łukasiewicz–Institute for Sustainable Technologies the T-33 inertia dynamometer, discussed in detail

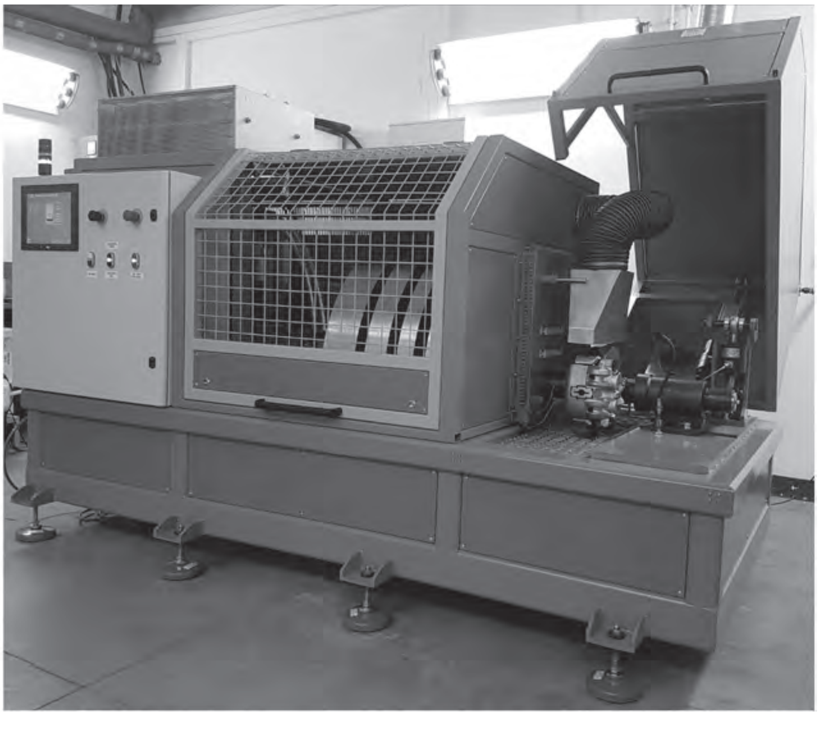


Fig. 3. T-33 inertia dynamometer with a lifted brake element assembly chamber casing
Rys. 3. Stanowisko T-33 z uniesioną osłoną komory montażu elementów hamulca

in publication **[L. 22]**. The dynamometer is implemented at the plant of a Polish brake pad manufacturer. The T-33 inertia dynamometer was used to compare the characteristics of new and classic brake pads described in this article.

TEST METHODOLOGY

T-33 inertia dynamometer

The T-33 inertia dynamometer **[L. 22]** allows brake pad and brake disc tests at the time of braking. It is designed to test brake pads and discs of cars with the gross vehicle weight (GVW) range from a light passenger car to a heavy van, at the simulated car speed at the time of brake application of 40 km/h. During the test, at a given brake application, based on many measured parameters, the maximum and mean friction coefficients, and braking deceleration are automatically calculated. The temperature of the brake pad friction pad is also measured at two points, as well as the temperature of the brake disc. All measured values are collected in the memory of the dynamometer system and transferred to a computer for further data analysis. They are also displayed in real time on the operator‘s screen. The test is fully automated.

The T-33 inertia dynamometer with a lifted brake element assembly chamber casing is presented in **Fig. 3**.

Tested brake pads

The tested brake pads and discs are presented in **Table 1**. Each test was carried out on a new brake disc and brake pads compliant with geometrical requirements of a Fiat Ducato III van and with the friction pad (U9) selected because of its physical and mechanical as well as friction and wear properties during initial tests based on the criteria adopted for 4 classes of vehicles: passenger cars, vans, lorries and sports cars.

The composition of the U9 friction pad is reserved to the manufacturer.

Table 1. Tested brake pads and discs
Tabela 1. Zbadane klocki i tarcze hamulcowe

Brake pad	Image	Brake disc
Classic brake pad		BOSCH 0 986 478 842 – 7XR BD742
Anisotropic pad (friction pad radiation)		
Ventilated brake pad		

Test method and parameters

The test was divided into three phases:

- Phase 1: Initial burnish.
- Phase 2: Control burnish.
- Phase 3: Friction tests.

Table 2 presents test parameters recorded for all phases of tests carried out with the use of the T-33 inertia dynamometer.

It should explained that the methodology used is an original methodology developed by the authors based on the three procedures included in the SAE J2522:2003 standard, i.e.: the "Cold application section," "Characteristic value 3 section," and the "Recovery 1,2,3 section."

Table 2. Test parameters
Tabela 2. Parametry badań

Parameter	Phase 1 Initial burnish	Phase 2 Control burnish	Phase 3 Friction tests
Pressure	30 bar		
Inertia [kgm^2]	147		
Rotational speed of the brake disc [rpm]	302		
Simulated car speed at the start /end of brake application	40/≤5 km/h		
Cooling air speed	3.7 m/s		
Cooling air temperature	10°C		
Initial brake disc temperature	≤100°C	≤100°C	≤40°C
Initial brake pad temperature	≤200°C		
Number of stops	500	18	15
Cleaning procedure (before burnish)	Brake disc: washing with petroleum ether Brake pad: blowing with compressed air		

As part of each test, the following parameters were determined:

- the maximum friction coefficient,
- the mean friction coefficient,
- the brake pad temperature,
- the linear wear of the brake pad,
- the weight loss of the brake pad,
- the linear wear of the brake disc, and
- the weight loss of the brake disc.

Method for determining friction characteristics

The maximum and mean values of the friction coefficient were identified during friction tests (Phase 3).

The maximum values of the friction coefficient were determined automatically – from the moment the pressure in the brake pump reached 90% (27 bars) until the rotational speed of the brake disc dropped to 1/8 of the initial value (which corresponds to the simulated vehicle speed of 5 km/h).

The mean values of the friction coefficient were determined for each brake cycle based on momentary values.

The momentary friction coefficient was calculated with formula (1):

$$f = 5000 * \frac{F}{p \quad \pi \quad d^2 \quad R \quad k} \tag{1}$$

where:
f – friction coefficient,
F – braking force measured by the strain gauge [N],
p – pressure at the outlet of the master cylinder [bar],
d – brake piston diameter [mm],
R – average friction radius of the brake pad [mm], and
k – number of brake pistons in the caliper,
5,000 – coefficient resulting from the conversion of units of particular quantities, also taking into account the arm, with a fixed length (250 mm) on which the force F is measured.

For Fiat Ducato III, the following values were adopted: d = 48.6 mm, R = 121 mm, k = 2.

What decides on friction properties is also the temperature of the pad. As a reference, the temperature measured for the Outboard ("inner") pad was used. The temperature was measured with a thermocouple placed in the upper and bottom area of the brake pad in the last (500) cycle of the initial burnish process.

Method for determining wear characteristics

The weight loss and linear wear were determined based on the measurements of the thickness of brake pads and discs taken prior to and after the test.

The thickness of pads and discs was measured in points indicated in **Fig. 4**.

For Fiat Ducato III, the following values were adopted: I_1 = 5 mm, I_2 = 50 mm.

Before the measurement, the brake disc was washed in petroleum ether and air-dried, while the brake pad, once holes for thermocouples were drilled, was cleaned with compressed air. The post-test cleaning procedure was the same. The linear wear was determined with the accuracy of 0.01 mm, while the mass wear with the accuracy of 0.1 g.

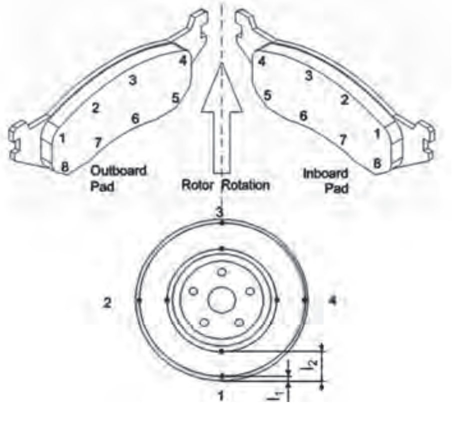


Fig. 4. Points of measurement of pads and discs' thickness
Rys. 4. Miejsca pomiaru grubości klocków i tarcz hamulcowych

TEST RESULTS

Analysis of the burnish process

Table 3 presents the maximum values of the friction coefficient during the initial burnish process (500 cycles).

The post-test analysis of the maximum values of the friction coefficient and of the surface of the friction pad shows that brake pads have been burnished, which means that the results of comparative friction and wear tests should be deemed reliable.

Maximum friction coefficient in friction tests

The test results are presented in **Fig. 5** along with confidence intervals for the probability of 95%.

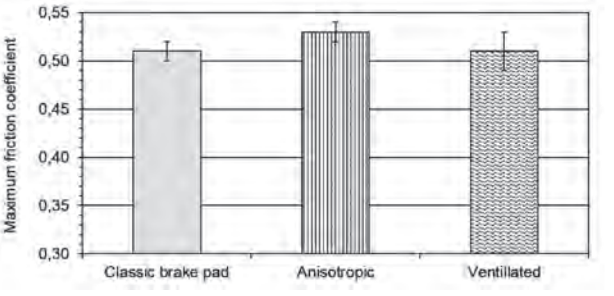


Fig. 5. Maximum friction coefficient in friction tests
Rys. 5. Wyniki badania maksymalnej wartości współczynnika tarcia w badaniach tarciowych

When anisotropic pads are used, the maximum friction coefficient is slightly higher than that recorded in the case of classic brake pads, while in the case of brake pads with the heat dissipation system in which the friction pad is ventilated, the maximum friction coefficient is similar to that recorded in the case of classic brake pads.

Mean friction coefficient in friction tests

The test results are presented in **Fig. 6** along with confidence intervals for the probability of 95%.

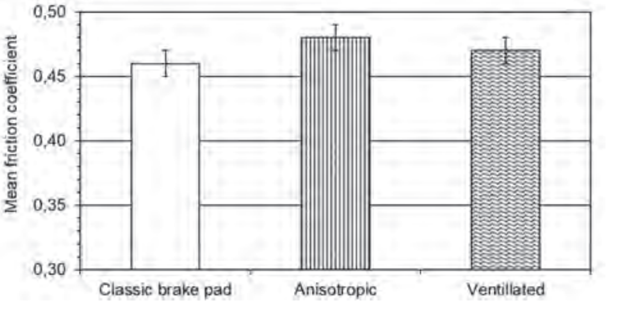
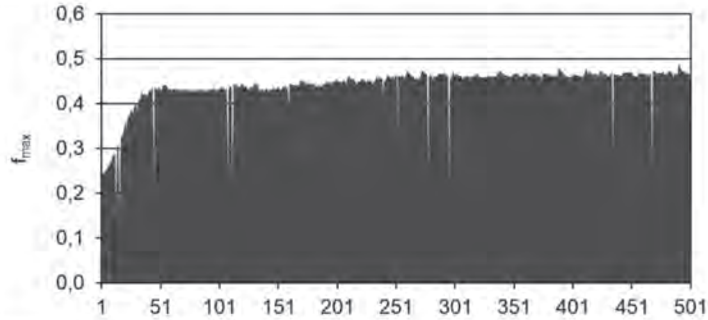
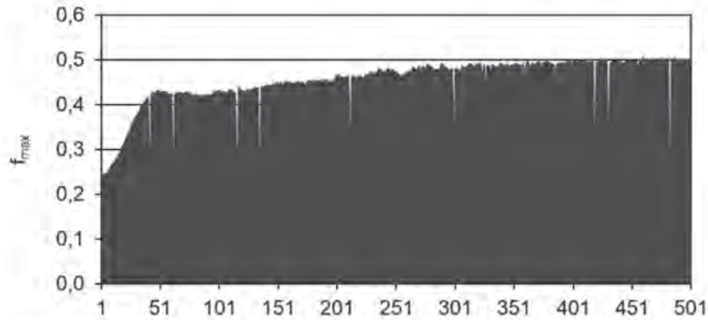
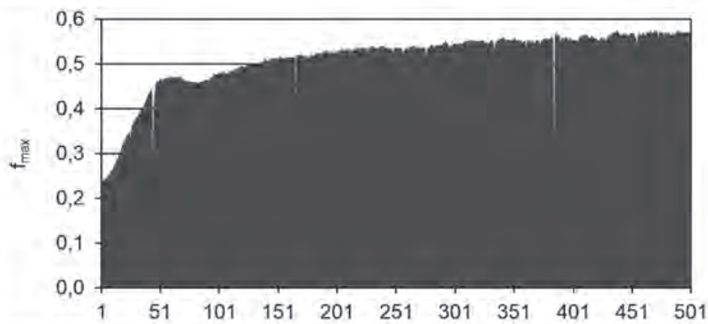


Fig. 6. Mean friction coefficient in friction tests
Rys. 6. Wyniki badania średniej wartości współczynnika tarcia w badaniach tarciowych

As in the case of maximum friction coefficient tests, when anisotropic pads (with the radiation system) are used, the mean friction coefficient is slightly higher than that recorded in the case of classic brake pads, while in the case of brake pads with the heat dissipation system in which the friction pad is ventilated, the mean friction coefficient is similar to that recorded in the case of classic brake pads.

Table 3. Maximum friction coefficient values during initial burnish

Tabrla 3. Przebiegi maksymalnej wartości współczynnika tarcia podczas docierania wstępnego

Brake pad	Maximum friction coefficient values (f_{max}) versus number of cycles
Classic brake pad	
Anisotropic brake pad (friction pad radiation)	
Ventilated brake pad	

Brake pad temperature towards the end of the burnish process

The test results are presented in **Fig. 7**. The friction pad temperature of the Outboard ("inner") brake pad was measured with thermocouples placed in the upper (T_{kl1}) and bottom (T_{kl2}) area of the pad.

The radiation system (anisotropic brake pads) makes it impossible to reduce the temperature of the friction pad. On the other hand, the ventilation system helps to reduce the temperature (in the bottom area of the pad even by 14°C).

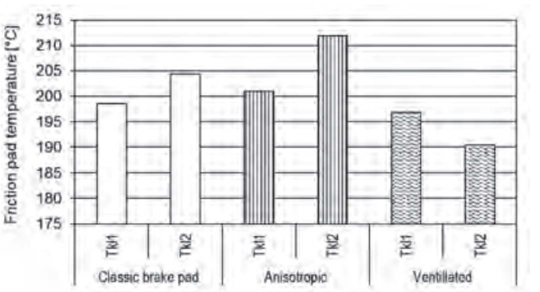


Fig. 7. Friction pad temperature test results towards the end of the burnish process

Rys. 7. Wyniki badania temperatury materiału ciernego klocka pod koniec docierania

Linear wear of brake pads

The test results are presented in **Fig. 8** along with confidence intervals for the probability of 95%.

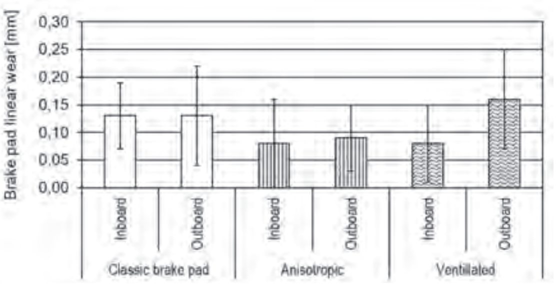


Fig. 8. Brake pad linear wear test results

Rys. 8. Wyniki badania zużycia liniowego klocków hamulcowych

The linear wear of both types of brake pads with the heat dissipation system is comparable to the linear wear of classic brake pads – the test results are scattered and error bars overlap.

Weight loss of brake pads

The test results are presented in **Fig. 9**.

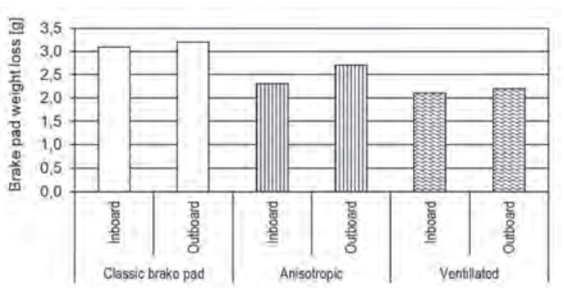


Fig. 9. Brake pad weight loss test results (one weighing cycle only – no test result scatter)

Rys. 9. Wyniki badania zużycia masowego klocków hamulcowych (wykonano po jednym ważeniu, stąd brak rozrzutu wyników)

The weight loss of both types of brake pads with the heat dissipation system is lower than in the case of classic pads, with pad wear more effectively reduced when ventilated pads are used.

Linear wear of the brake discs

The test results are presented in **Fig. 10** along with confidence intervals for the probability of 95%.

The linear wear of brake discs in which brake pads with a new heat dissipation system have been used is comparable to the linear wear recorded in the case of classic brake pads.

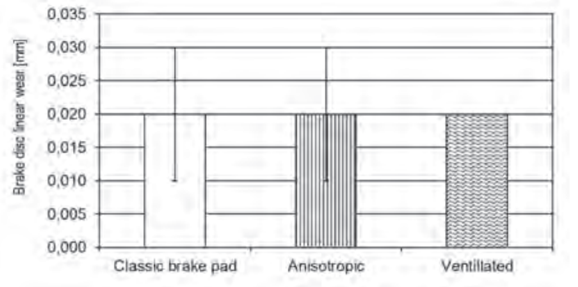


Fig. 10. Brake disc linear wear tests results (no test result scatter was recorded for a ventilated brake pad – all results were the same)

Rys. 10. Wyniki badania zużycia liniowego tarcz hamulcowych (w przypadku nakładki wentylowanej nie odnotowano rozrzutu wyników – były identyczne)

Weight loss of brake discs

The test results are presented in **Fig. 11**.

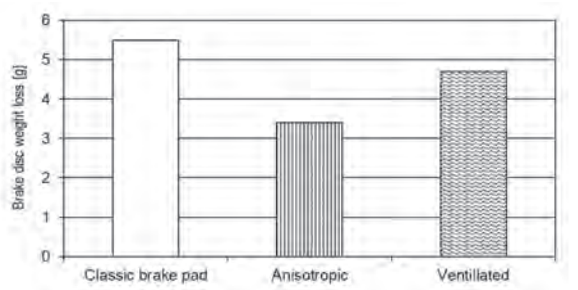


Fig. 11. Brake disc weight loss test results (one weighing cycle only – no test result scatter)

Rys. 11. Wyniki badania zużycia masowego tarcz hamulcowych (wykonano po jednym ważeniu, stąd brak rozrzutu wyników)

The weight loss of brake discs in which brake pads with a new heat dissipation system have been used is lower than in the case of classic pads, with the brake pad radiation system more effectively reducing the disc wear in anisotropic pads.

SUMMARY

The test results obtained allow the following conclusions:

- When anisotropic brake pads (with the radiation system) are used, the friction coefficient measured during friction tests is higher than in the case of classic brake pads.
- The radiation system does not allow to reduce the friction pad temperature, while the ventilation

system helps to reduce this temperature even by 14°C.

- The wear of brake pads with the heat dissipation system is lower than in the case of classic pads, with pad wear more effectively reduced when ventilated pads are used.
- The wear of brake discs in which brake pads with a new heat dissipation system have been used is lower than in the case of classic pads, with the brake pad radiation system more effectively reducing the disc wear in anisotropic pads.

To sum up, brake pads with a new heat dissipation system have an advantage over classic pads (but this depends on the pad modification method). The concurrent application of both systems would be an interesting solution as it would lead to a synergistic effect.

This article was prepared based on the results of the work carried out in an R&D project with a fixed schedule. Many issues need to be further analysed (e.g. whether the temperature to which the friction pad heats up affects the shear stress and wear, or what the impact of ventilation on fading and noise levels is).

The authors plan to centre their future publications around some of these issues, using as the foundation the results of other research carried out in the aforementioned project.

Acknowledgements

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The Institute for Sustainable Technologies – National Research Institute (currently Łukasiewicz – Institute for Sustainable Technologies[1]) was the subcontractor in the R&D project in question.

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[1] The Łukasiewicz Research Network – Institute for Sustainable Technologies is the third biggest research network in Europe. It delivers attractive, comprehensive and competitive technological solutions, also those tailored to the needs of and requested by companies as part of the "challenge us" campaign – a company's request is analysed by a group of 4,500 scientists within no more than 15 business days and an effective solution that is ready to implement is proposed. In doing so, Łukasiewicz, at no extra cost to be incurred by a company, engages recognised and highly-qualified researchers and unique scientific equipment, which enables the network to meet companies' needs and expectations. A business owner may choose to contact the network via an on-line form available on https://lukasiewicz.gov.pl/en/for-business/, or visit one of its affiliated institutes or branches in more than 50 locations across Poland, and they may be sure that they will always be provided with the same high-quality product or service, no matter which entity they contact. Łukasiewicz's scientific potential is concentrated in the following research areas: Health, Smart Mobility, Digital Transformation, and Sustainable Economy and Energy.

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