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WEAR-FRICTION PROPERTIES OF FRICTION PAIRS IN DISC-PAD BRAKES

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This paper reports data on the dynamic coefficient of friction and wear of materials of different types of friction pads and brake discs obtained from experimental research during braking under bench conditions. It was established that on the basis of the chemical composition of the materials of the friction pads with codes, in the temperature range of 100–450 °C with a step of 50 °C, the ratio of the maximum to the minimum wear of the disc varies from 6.0 to 10.0. The value of the disc wear ratio at 800 and 1000 brakings, respectively, in the temperature range of 100–250 °C and 100–450 °C was 7.6 and 14.0. This indicates that for pad materials of type A, B, C, and D under the second thermal regime, the linear wear of the working surfaces of the discs is greater than under the first thermal regime. And for the pad materials of type E and F, the wear of the discs was the same. This indicates that the use of traditional pads is characterized by a higher thermal tension of the disc brake friction pair; the absolute temperature values are in the unfavorable zone of 400–700 °C. That, in turn, could lead to both phase changes and thermal fatigue aging of materials and, as a result, to the deterioration of their tribological and thermophysical characteristics in operation. Thus, the implementation of the method of selecting pad components could improve the performance of disc brake devices of cars

Keywords: disc-pad brake, friction pair, wear and tear, codes of friction materials

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1. Introduction

The energy load on the friction pairs of braking devices during their frictional interaction significantly affects the processes, phenomena, and effects that occur during thermoelectromechanical contact. Therefore, the thermal conditions of the surfaces of friction pairs significantly affect the mechanics of their contact interaction. This is expressed in the form of thermoelastic movements of the points of the surfaces of the contacting elements, which leads to a change in the areas of interaction and a redistribution of specific contact loads and stresses. In addition, the dynamic coefficient of friction and physico-mechanical properties, such as the modulus of elasticity, the limit of strength on friction surfaces, etc., depend significantly on the surface-bulk temperature. The type and intensity of wear of friction elements are also largely determined by their temperatures in the contact area. Given the above, research aimed at further improving the wear and friction characteristics of friction pairs of disc-pad brakes is important. Therefore, a study to devise a method for selecting components of friction pairs pads is relevant.

2. Literature review and problem statement

In work [1], when determining the dynamic coefficient of brake friction pairs, the principle of superposition in relation to processes, phenomena, and effects in the near-contact zone of frictional interaction was not considered.

The analysis of the percentage ratio of dustiness of the transport flow and its component share from friction pads is reported in [2, 3]. The studies have shown that the volume and intensity of the formation of wear particles of friction pads depend on their composition, the design of mechanisms, and modes of movement of vehicles. It is shown that with frequent sharp braking, the effect increases due to greater wear of the pads, and even driving at a leisurely pace is dangerous. But the question of how exactly the surface-volume temperature affects the wear of pads with different materials of friction pairs remained unsolved. This may be due to the fact that the pads are made of materials with different chemical compositions, which have not been investigated before to improve the wear-friction characteristics of friction pairs of disc-pad brakes. According to [4], the wear of friction pads is the cause of approximately of 20 % of emissions of air pollutants in road traffic; but no study of the influence of various factors on this wear has been conducted.

A list of requirements is put forward to the elements of the braking systems of motor vehicles, which must collectively ensure the safety of movement and braking, fulfill the regulatory requirements of the amount of braking distance, braking time, and deceleration that is allowed. Under the conditions of increased driving speeds and axial loads, drum brake mechanisms exhaust their capabilities due to insufficient heat dissipation capacity. Also, the tendency to lose efficiency during heating and instability of the braking moment due to a change in the dynamic coefficient of friction affects the decrease in the efficiency of the braking mechanisms [5, 6]. At the same time, a more detailed study was not conducted.

In [7], in order to stabilize the thermomechanical properties of disc brake pads made of TIIR-202 and TIIR-240 materials, the working surface of the friction pads was subjected to a short-term high-temperature treatment. The technique of high-temperature treatment of the working surface of pads is a "thermo-shock", which is widely known both in Ukraine and abroad. The given technological operation makes it possible to stabilize the indicator of braking efficiency without preliminary finishing of the pads, and also leads to additional thermal stabilization of the material when working in the high temperature zone. Carrying out the "thermal shock" operation requires strict adherence to the temperature-time regime of processing, ensuring reliable and uniform adhesion of the processing surface to the heating surface; moreover, the problem of disposal of gas emissions arises. In addition, this technique allows reducing the chemical action of the predominant components on other surface layers of polymer pads [8, 9].

The numerous composition of friction materials is designed to meet strict and contradictory requirements for the safety and efficiency of braking systems. There is still no optimal composition of materials for friction pads in friction pairs. The priority should be the one that would reduce the amount of wear products by strictly observing the ratio of maximum to minimum wear of various material codes in the temperature range of 100–450 °C. At the same time, special attention should be paid to the operation of the disc-pad brake friction pair before and after the permissible surface-volume temperature of the polymer pad [10].

Our review of literary sources showed that the wear-friction properties of different types of friction materials (material with codes C, B, A, F, E, D, which contains a different chemical composition) of disc-pad brake pads under bench conditions have not been determined as yet.

3. The aim and objectives of the study

The purpose of this study is to determine the wear-friction properties of various types of friction materials of disc-pad brake pads under bench conditions. This will make it possible to improve the performance of disc brake devices for cars.

To achieve the goal, the following tasks were solved:

– to investigate changes in the dynamic coefficient of friction during the frictional interaction of the brake;

– on the basis of experimental studies under bench conditions, evaluate the wear of materials of friction pads of different codes.

4. The study materials and methods

The object of our research is brake friction pairs.

The hypothesis of the study assumes the possibility of improving in the future the performance indicators of disc brake devices for motor vehicles by establishing and taking into account the influence of the surface-volume temperature on the wear and friction properties of the materials of friction pairs of disc-pad brakes.

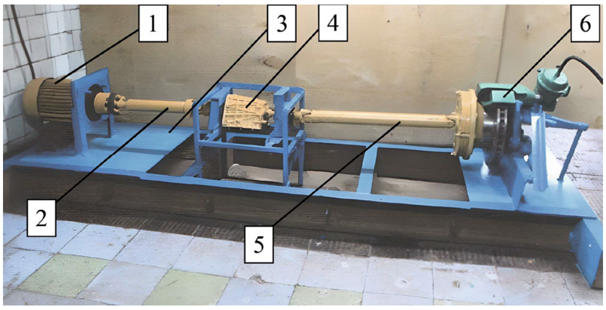
The following assumptions were accepted during the research. Instead of the surface temperature of friction pairs, the surface-bulk temperature was considered. From 100 to 250 °C, the friction properties of the pads do not change at a lower electrical potential, and from 250 to 450 °C, the binding component of the friction pads burns out, which could lead to an increase in the electrical potential.

Experimental studies were carried out in the laboratory at the bench of a model disc-pad brake (Fig. 1).

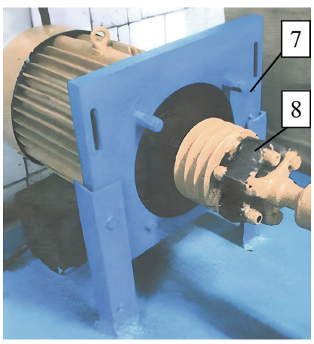
A bench for testing disc-pad brakes of vehicles with a brake disc diameter of 0.43 m was made of cast iron SCH 150 DSTU 8833:2019. The rotation of the brake disc is carried out with the help of a three-phase short-circuited electric motor with a power of 3.0 kW with a shaft rotation speed of 1500 min^{-1}.

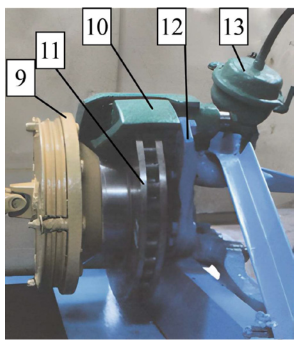
Owing to the gearbox of the bench, the angular speed of rotation of the brake disc was, respectively, 25, 50, 75, and 100 s^{-1}, which corresponded to a linear speed of vehicles of 10.0; 20.0; 30.0; and 40.0 m/s (36.0; 72.0; 98.0; and 134.0 km/h).

The material with code C, B, A, F, E, D, which contains a different chemical composition, was chosen as the pad material. The material of the brake disc was cast iron SCH 150 DSTU 8833:2019. The surface temperature of the pads at the beginning of braking was measured by a non-contact thermometer of the Baltech company and was 100 °C (Fig. 2); the characteristics are given in Table 1. Subsequently, the surface temperatures of the friction pairs were measured with ribbon chromel-copel thermocouples. After every 200 brakings and an increase in the surface temperature by 50 °C, the wear of the pads was measured using resistor sensors of the wear values of the internal surfaces of the friction elements directly during braking, as well as by micrometering along their width after removing the pads from the brake disc. The final surface temperature was 450 °C. At the same time, the number of brakings reached 800–1200. Based on the results of the tests, a diagram of the wear ability of brake discs with the frictional interaction of different pad materials was constructed.



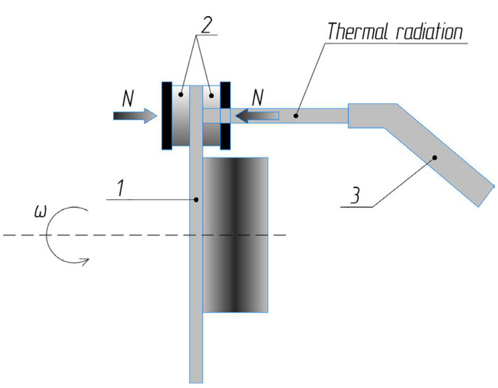
a





b *c*

Fig. 1. General view: *a* — brake bench; *b, c* — fragments of brake bench; 1 — electric motor, 2 — 1st cardan transmission; 3 — bench frame; 4 — gearbox; 5 — 2nd cardan transmission; 6 — disc-pad brake; 7 — electric motor support; 8 — elastic coupling; 9 — hub; 10 — brake caliper; 11 — self-ventilated brake disc with spikes; 12 — rotary cam; 13 — pneumatic cylinder



a *b*

Fig. 2. Schematic measurement of volume temperature: *a* — brake disc; *b* — pyrometer of the company "Baltech"; 1 — brake disc; 2 — friction pads; 3 — pyrometer; 4 — infrared radiation energy receiver; 5, 6 — scoreboard and handle

In order to evaluate the performance of designed friction devices of tribosystems, the methods of mechanical, electrical, thermal, and chemical fields are widely used. Using them enables the methods of thermal dynamics and modeling with the principles of superposition function, which make it possible to calculate their wear and friction characteristics based on the parameters of friction and wear. However, all of them require quite complex calculations.

Table 1

The main characteristics of the non-contact thermometer by "Baltech"

Characteristic name	Indicator
Temperature range of measurements, °C	–50...+1000
Limit of permissible basic error, %, in temperature range:	
(–50...–20) °C	0.3±
(–20...+100) °C	0.2±
(+100...+800) °C	0.2±
Time of readout setting, sec	0.5
Recurring readouts, °C	0.1±
Voltage, V	9
Laser designator	Yes, you can turn it off
Measurement memory	Yes, 10 points
Display of the set and current temperature	Yes
Temperature measurement: maximum, minimum, average, and difference	Yes
Audible warning when the set temperature is reached	Yes

In our studies, it was necessary to establish the effect of permissible surface temperatures, the use of different textures of friction materials under certain codes for metal friction elements that cause thermal stress in their bodies. Application of analysis of uniformity and principles of superposition to the processes of "polarization – depolarization", "heating – cooling", etc. makes it possible to correctly assess the patterns of changes in the dynamic coefficient of friction as a function of temperature in the zone of frictional interaction.

5. Results of the study of factors that affect the dynamic coefficient of friction and evaluation of the wear of friction materials

5. 1. Evaluation of wear of friction pad materials during experimental studies under bench conditions

There are a number of requirements for friction pads:

– high dynamic coefficient of friction, which varies little with temperature, pressure, speed of skidding (μ=0.28–0.62);

– high wear resistance and strength (the pads must withstand an angular speed twice the maximum angular speed of the engine without breaking);

– a smooth, proportional to the compressive force, increase of the friction force;

– sufficient heat resistance and thermal conductivity (the temperature of pads should not exceed 200 °C during long-term operation, 350 °C during short-term operation).

In their composition, friction materials based on thermoreactive resins should contain components that perform certain functions:

– increased wear resistance – resin particles and graphite;

– increase of thermal conductivity and smoothness of inclusion – copper, brass, bronze, aluminum (in the form of powder, shavings, or wire);

– increasing the stability of the dynamic coefficient of friction – zinc;

– reduction of wear and burring – lead;

– titanium (Ti) has a high specific electrical resistance;

– nickel (Ni) in an alloy with iron (Fe) has a low coefficient of thermal expansion.

The codes of pads E and F did not include chemical components: Ti, Sb, Ba, Ca, Mn, Mg, Na, Sr, the percentage of which is negligible (Table 2).

Analysis of the chemical composition of the codes of the friction pads revealed:

– free nitrogen (N) is found in almost the same amount in all pad codes;

– sulfur (S) is present in the largest quantities in codes E and F;

– there is the most aluminum (Al) in the code, and the least in D;

– copper (Cu) was observed the most in code C, and the least in B;

– iron (Fe) is found in the greatest quantity in code D, and the least in A;

– silicon (Si) is the most in code A, and the least in code E;

– zinc (Zn) had the most amount in code A, and the least in code H;

– lead (Pb) was the most in code A, and the least in code H;

– a change in nickel (Ni) in all material codes ranges from 0.01 to 0.26.

The isolation of a large number of chemical elements, which are in the above codes of materials, indicates that their reactions take place under their auspices.

Table 2

Chemical composition of materials of friction pads

Pad code	Content of elements, %							
	N_{fr}	S	Al	Cu	Fe	Si	Zn	Pb	Ni
B	24.20	2.95	3.95	3.34	14.90	1.08	2.23	0.08	0.260
C	18.10	–	0.84	11.80	27.40	–	3.28	0.13	–
A	22.70	–	1.97	5.84	14.30	1.12	3.67	0.16	0.023
H	19.60	–	0.24	5.13	19.50	0.34	1.10	0.01	0.004
D	19.10	–	0.13	11.77	35.20	0.29	3.52	0.05	0.008
E	19.4	19.4	0.67	8.23	19.4	0.11	2.41	0.09	0.01
F	19.0	19.0	0.82	9.85	19.6	0.24	3.56	0.16	0.05

Therefore, their neutralization requires pulse heat treatment of the working surface of the pad from its thickness to acceptable wear.

Analysis of the wear ratios of the frictional interaction of discs with pad codes showed that in the range of surface temperatures from 100 to 300 °C, the value of the wear ratio increases slightly. In the temperature range from 100–450 °C (Table 3), an increase in the wear ratio of pads was observed due to the processes of destruction of their working surfaces (Fig. 3).

Initial data and data at the end of braking cycles:

– brake disc diameter – 432 mm;

– disc thickness, 45 mm;

– brake disc weight – before braking, 350 N; after braking – 344.5 N;

– brake disc material – gray cast iron SCH 150;

– area of friction belts – before braking, 147340.7 mm^2; after braking, 145769.9 mm^2;

– the length of the pad – 249.3 mm;

– pad width – 118.2 mm;

– pad thickness – before braking, 30 m; after braking, 29 mm;

– number of friction pads – 2;

– friction pad weight – before braking, 51 N; after braking, 47 N;

– friction pads material – Retinax FK-24 A.

Table 3

Analysis of brake disc and friction pad wear ratios with codes in the range of surface temperatures from 100 to 300 °C and from 100 to 450 °C

Pad code	Surface temperature of the disc at the beginning of braking							
	100	150	200	250	300	350	400	450
	Pad wear for 200 brakes at each temperature, mm							
C	0.010	0.005	0.005	0.005	0.005	0.005	0.020	0.025
	0.010	0	0	0.005	0.010	0.010	0.010	0.015
B	0.010	0.010	0.020	0.020	0.030	0.030	0.070	0.050
A	0.025	0.025	0.030	0.035	0.040	0.040	0.060	0.055
F	0.010	0.010	0	0.010	0	0	–0.025	0.025
	0.005	0.010	0.010	0.025	–0.020	–0.020	–0.020	0.065
E	0.020	0.010	0.010	0.010	0	0	–0.015	0.020
D	0.015	0.015	0.035	0.025	0.005	0.005	–0.015	0.025
Ratio	5	5	7	7	8	6	7	10

As for the wear of the working surfaces of discs in the indicated temperature ranges, with the number of brakings 800 or 1200, the wear ratio was 7.6 and 14.0. The ratios characterize the ratio of maximum and minimum disc wear (Table 4).

Table 4

Analysis of the ratio of wear of the working surfaces of discs with the number of braking 800 or 1200

Pad code	Disc wear for 800 braking cycles, 100... 250 °C, mm	Disc wear for 1200 braking cycles, 100...450 °C, mm
C	0.025	0.045
	0.015	0.035
B	0.050	0.150
A	0.055	0.210
F	0.020	0.030
	0.065	0.015
E	0.020	0.040
D	0.025	0.085
Ratio	7.6	14

Bench full-scale tests make it possible to determine the wear ability of materials of friction pads (Fig. 4).

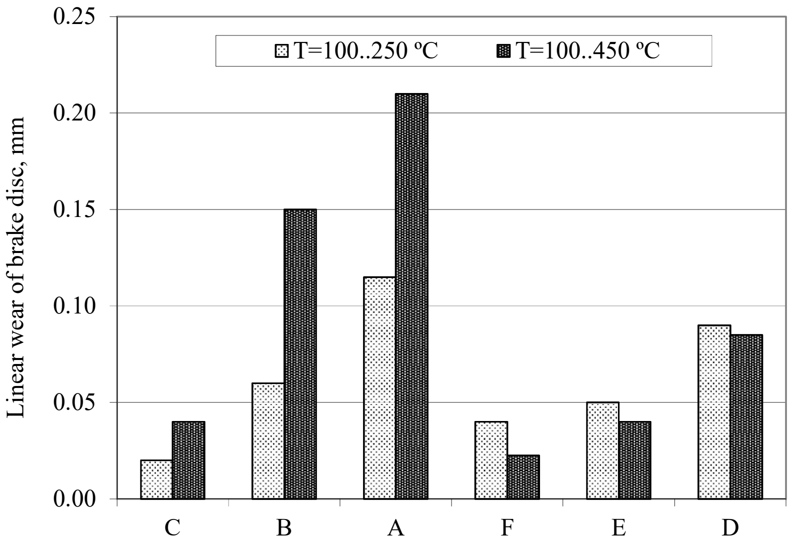


Fig. 3. Wear ability of brake discs (cast iron SCH150) in the friction interaction of various pad materials (results of full-scale bench tests)

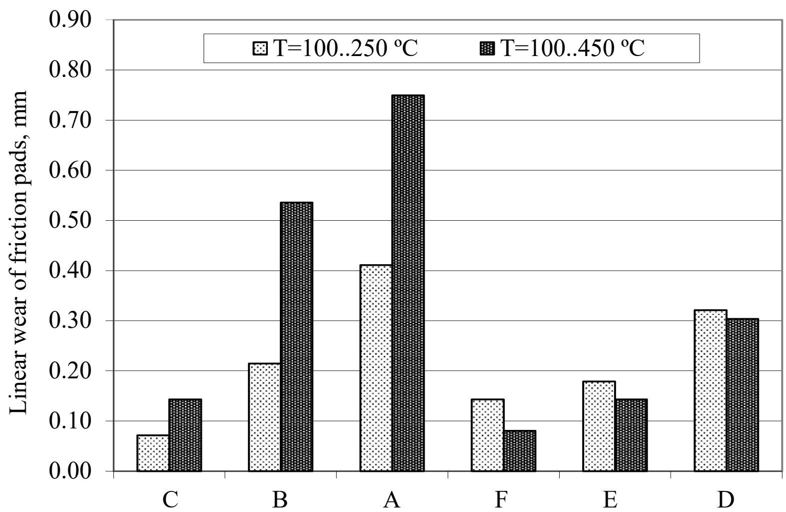


Fig. 4. Wear ability of various pad materials during friction interaction (results of full-scale bench tests)

It should be noted that pad materials with different chemical compositions (Table 2) in the temperature range of 100–450 °C with a step of 50 °C wear differently. In this sense, the interpretation of the results of the wearability of friction pad materials based on the results of bench field tests is of particular interest (Table 3). This is how the ratio of maximum to minimum disc wear was established, which ranges from 6.0 to 10.0. In addition, the value of the disc wear ratio at 800 and 1000 brakings, respectively, in the temperature range of 100–250 °C and 100–450 °C, was 7.6 and 14.0.

According to Fig. 4, it was determined that for pad materials of type A, B, C, and D under the second thermal regime, the linear wear of the working surfaces of the discs, respectively, was 1.76; 2.35; 2.0; and 1.1, that is, more than under the first thermal regime. For pad materials of type E and F, the wear of the discs was the same. This is explained by the different content of components of friction pads.

Such conclusions may be considered expedient from a practical point of view because they allow a reasoned approach to the selection of optimal pad materials, which would be lead to a decrease in their wear and, as a result, to a decrease in the energy load on the brake discs and an improvement in their operational parameters. From a theoretical point of view, it is possible to design new types of friction assemblies of disc-pad brakes. But all this does not make it possible to claim that this particular material will wear out the least during prolonged braking. Such uncertainty imposes certain restrictions on the use of our results, which can be interpreted as the shortcomings of this study.

Eliminating the indicated shortcomings within the framework of this study creates a potentially interesting direction for further research. It, in particular, can be focused on identifying an even more optimal pad material where at surface-volume temperatures that exceed the permissible wear value the pad wear will be the smallest. Such detection could reduce the energy load on the brake discs, which would lead to their longer use.

It is not possible to determine the optimal pad material since each has a different chemical composition. The designer decides which of the materials suits him/her when designing certain friction pairs under certain conditions. In the current article, we have only specified the materials of friction pads and their parameters. And the designer then chooses which brand of pads to use.

6. Discussion of results of studying the wear-friction properties of disc-pad brake friction pairs

When determining the influence of the dynamic coefficient of friction on the wear process of a disc made of cast iron SCH150, as can be seen from Fig. 3, the influence of the surface-volume temperature is also natural. This is due to the fact that it is evaluated taking into account the principles of superposition to the processes of "polarization – depolarization", "heating – cooling", "expansion – compression", "restoration – destruction", "strengthening – unstrengthening", as well as the action of electric double layers.

The fact is that during braking there is polarization, expansion, destruction, unstrengthening, and when the process of braking ends, there is a process of depolarization, compression, restoration, strengthening. Therefore, the surface-volume temperature was estimated based on the above considerations. As regards double electrical layers, they are constantly changing, as the geometry of discs and pads changes, and measuring them is a complex process.

7. Conclusions

1. Our research has made it possible to establish that the use of traditional disc brake pads is characterized by a higher thermal tension of the friction pair, and the absolute temperature values are in the unfavorable zone of 400–700 °C.

This can lead to both phase changes and thermal fatigue aging of materials and, as a result, to the deterioration of their tribological and thermophysical characteristics in operation. Therefore, the implementation of the method of selecting pad components should be considered a promising measure, the implementation of which could improve the operational performance of brake disc devices in cars.

2. The wrong choice of friction material code for a disc-pad brake can be a very important factor and noticeably negatively affect the operational characteristics of its friction pairs. Therefore, for the material of the disc, cast iron СЧ SCH15 was chosen, which contains graphite, which is a heat insulator. And for pads, the material may be different due to the different content of components. The only thing is that the value of the wear ratio at a temperature of 100–450 °C will vary from 5 to 10.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

All data are available in the main text of the manuscript.

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