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Research on Tribological Features of Brake Friction Materials - Comparison of the Results Obtained with the Pin-On-Disc and Ball-Cratering Methods

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1. Introduction

Brakes are one of the most important vehicle systems as they are closely related to safety. However, the correct design of the working elements (pads and discs) is not easy [1, 2]. The friction materials currently used are composites of about 20 different materials for different purposes. During operation, they are subjected to very extreme factors - mainly changing temperature and humidity [3].

The friction elements of brake systems are subject to various types of wear. The most important is abrasive wear, i.e. destruction of the top layer of cooperating parts that move relative to each other. Loss of the pad material is caused by the separation of material particles as a result of scratching, micro-cutting and grooving [4]. It is this type of wear that was focused on later in the work. The most important criterion according to which research methods can be divided into the determination of abrasive wear parameters is the macrogeometry of the contact between the sample and the counter-sample. It is an important design feature of machines for measuring the value of the friction coefficient and the intensity of wear. The most common solutions are [5-7]:

a) point contact (ball-disk), e.g. Ball-cratering;

b) line contact (cylinder-disk), e.g. Pin-on-disc;

c) surface contact (plane-plane), e.g. inertial stations.

Two of the above research methods, Ball-cratering and Pin-on-disc, were used in this work. The aim of the study is to compare the obtained results and check whether these methods can be used interchangeably.

2. Materials and research methods description

Two test stands were used for the research, which are at the disposal of the Faculty of Mechanical Engineering of the Białystok University of Technology. They were:

1) based on point contact and using the Ball - cratering method. It is a method in which the friction pair is a cylindrical sample (1 "diameter and 10 mm high) and a ball (also 1" diameter) [8]. Fig. 1 shows a diagram of one of them, namely the T-20 test rig manufactured in Poland. In this device, the test sample *1* is mounted in a holder on the vertical arm of the rotary lever, and its mass is balanced by a counterweight *7* located at one end of the horizontal arm of the lever. At the other end, there is a pan on which a load *5* is placed, which presses the sample against the counter-sample *2*. The length of the swivel lever arms is the same, so the pressing force is identical to the gravity force resulting from the pressure of the given load on the pan. The counter-sample is mounted on the shaft of the electric motor *8* (with adjustable rotational speed). The strain gauge *4*, located above the sample holder, allows direct measurement of the friction force during the test. As the ball rotates, it rubs against the sample, the vertical position of which allows the material to fall freely, thus it does not interfere with the measurement [9]. As a result of friction, a crater is formed, the measurement of which in two planes allows to determine the average diameter and then the frictional wear intensity factor K_c in accordance with the Archard equation [10] (examples of craters and the method of measuring their diameter are shown in Fig. 4). The stand allows to measure the friction force in real time, thanks to which you can easily calculate the friction coefficient of the friction pair. The research problem may be the point nature of the contact - different than in the vehicle braking system, but it may be compensated by a properly designed experiment.

2) T11 - Using the Pin-on-disc method. It allows for the implementation of linear macrogeometry of the contact between the sample and the counter-sample. This method can be used both for testing dry friction, as well as under the operating conditions of a lubricant [11, 12]. The Pin-on-disc method enables the determination of the average coefficient of friction of the node and the examination of the wear intensity of the friction surfaces. The first parameter is measured directly during the tests as a function of time or number of disk revolutions, while the second is determined on the basis of the mass lost by the sample. The necessary data is obtained by weighing the sample before and after the test. In the vast majority of solutions, the disk rotates in the horizontal plane, although there are devices in which the disk is positioned vertically [13]. Due to the similarity to the disc brake system, the stands with the horizontal axis of rotation of the disc are good for testing brake discs and pads. As in the case of the Ball-cratering method, the horizontal positioning of the disc causes the pin to slide over loose fragments of the sample torn off during the test. For this reason, the same material tested several times may give different final results each time [14]. Despite this, the Pin-on-disc method in this configuration is commonly used to test samples taken from brake pads [15-19]. Fig. 2 shows a diagram of the Polish production stand used for the tests.

The test samples were taken from brake pads intended for passenger cars. Three types of brand new pads were used and in about 50 % of the wear. Few of samples used (before grinding) are presented on Fig. 3.

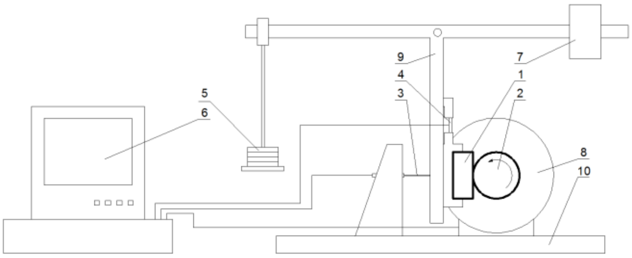

Fig. 1 Diagram of the T-20 test stand: *1* – sample; *2* - counter-sample (ball); *3* - displacement sensor; *4* - strain gauge for measuring the friction force; *5* – load; *6* – computer; *7* – counterweight; *8* - electric motor; *9* - swivel arm; *10* - base [20]

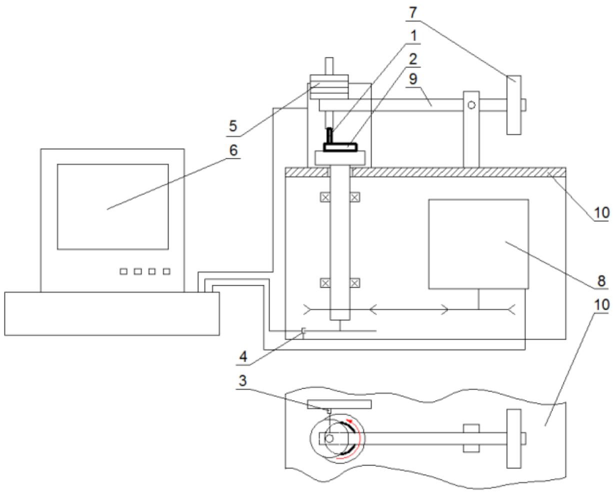

Fig. 2 Diagram of the T-11 test stand: *1* - fixed pin, *2* - rotating disc; *3* - strain gauge for measuring the friction force; *4* - rotational speed sensor; *5* – load; *6* – computer; *7* – counterweight; *8* - motor electric, *9* - swivel arm; *10* - body [20]

Fig. 3 Few of the samples taken from brake pads

This gave a total of 6 groups of samples. Four samples were cut from each group of pads, giving a total number of 24. This number allowed for testing each group of samples three times (three samples were Pin-on-disc, one Ball-cratering by rotating it around its axis). Samples and experiments were prepared as described in previous articles [21, 22].

3. Results and their analysis

Direct results recorded by both stands allowed the calculation of the values of the coefficients of friction using Amontons-Coulomb friction law [23]:

$$\mu_s = \frac{\overline{F}_s}{m \cdot g}, \tag{1}$$

where: μ is coefficient of friction *i* sample (where s=1…24); F is measured average friction force of s sample; g is gravitational acceleration; m is loading mass.

These, in turn, made it possible to calculate the arithmetic mean and standard deviation from the Eq. (2):

$$S_d = \sqrt{\frac{\sum_{s=1}^{3}(z-\overline{z})^2}{2}}, \tag{2}$$

where: z is COF value. Results and calculations are compiled in Table 1.

Table 1

Tested samples

Sample no.	Sample group no.	Samples descrition	Test method	Results, coefficient of friction	Arithmetical average	Standard deviation
1	I	Type 1, brand new	Pin-on-disc	0.47	0.466	±0.0251
2				0.49		
3				0.44		
4			Ball-cratering	0.48; 0.49; 0.45	0.473	±0.0208
5	II	Type 1, 50 % of wear	Pin-on-disc	0.43	0.41	±0.0251
6				0.38		
7				0.41		
8			Ball-cratering	0.44; 0.4; 0.39	0.41	±0.264
9	III	Type 2, brand new	Pin-on-disc	0.37	0.4	±0.03
10				0.43		
11				0.4		
12			Ball-cratering	0.39; 0.44; 0.38	0.403	±0.0321
13	IV	Type 2, 50 % of wear	Pin-on-disc	0.38	0.356	±0.0208
14				0.34		
15				0.35		
16			Ball-cratering	0.37; 0.39; 0.33	0.363	±0.0305
17	V	Type 3, brand new	Pin-on-disc	0.56	0.556	±0.0152
18				0.57		
19				0.54		
20			Ball-cratering	0.59; 0.57; 0.53	0.563	±0.0305
21	VI	Type 3, 50 % of wear	Pin-on-disc	0.52	0.503	±0.0208
22				0.51		
23				0.48		
24			Ball-cratering	0.49; 0.49; 0.53	0.503	±0.0230

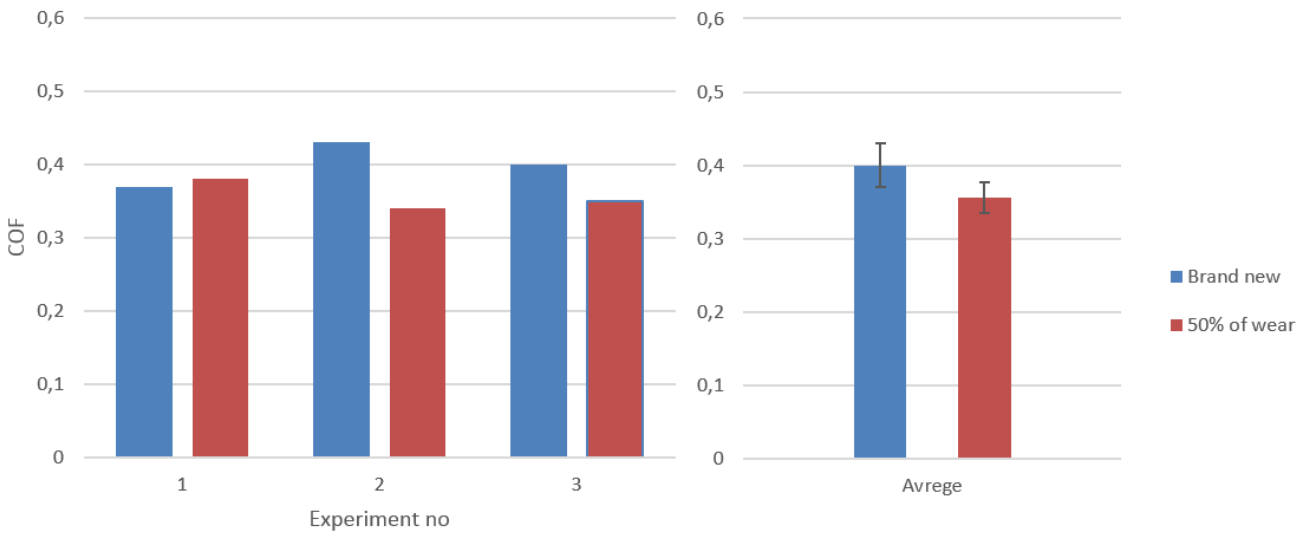

Fig. 4 Results for samples group no. I

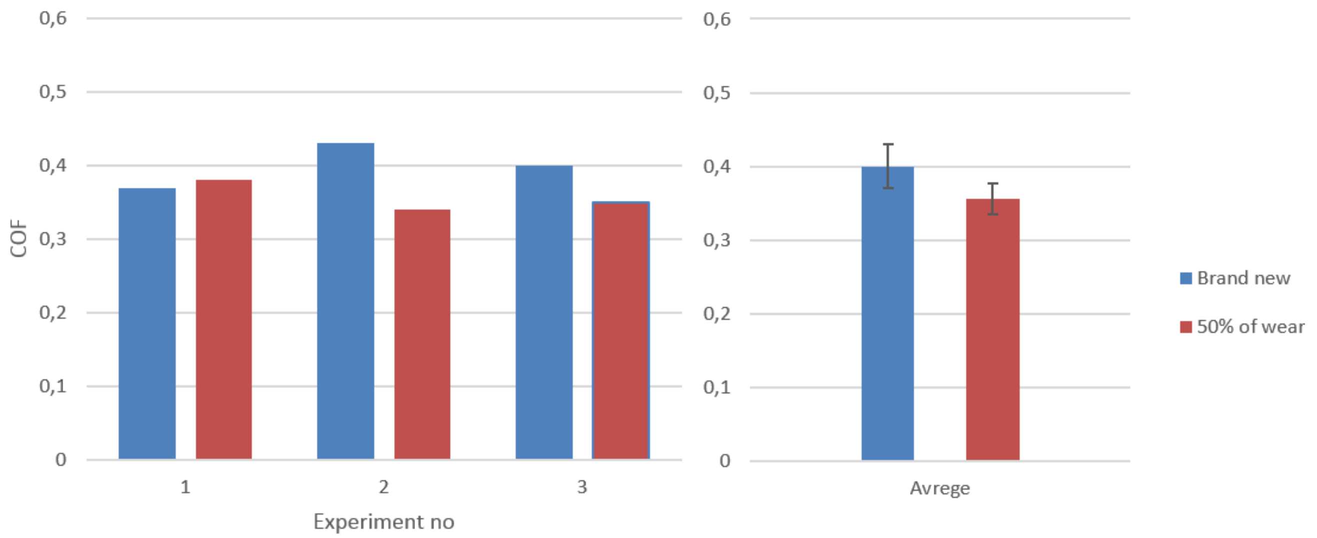

Fig. 4 Results for samples group no. II

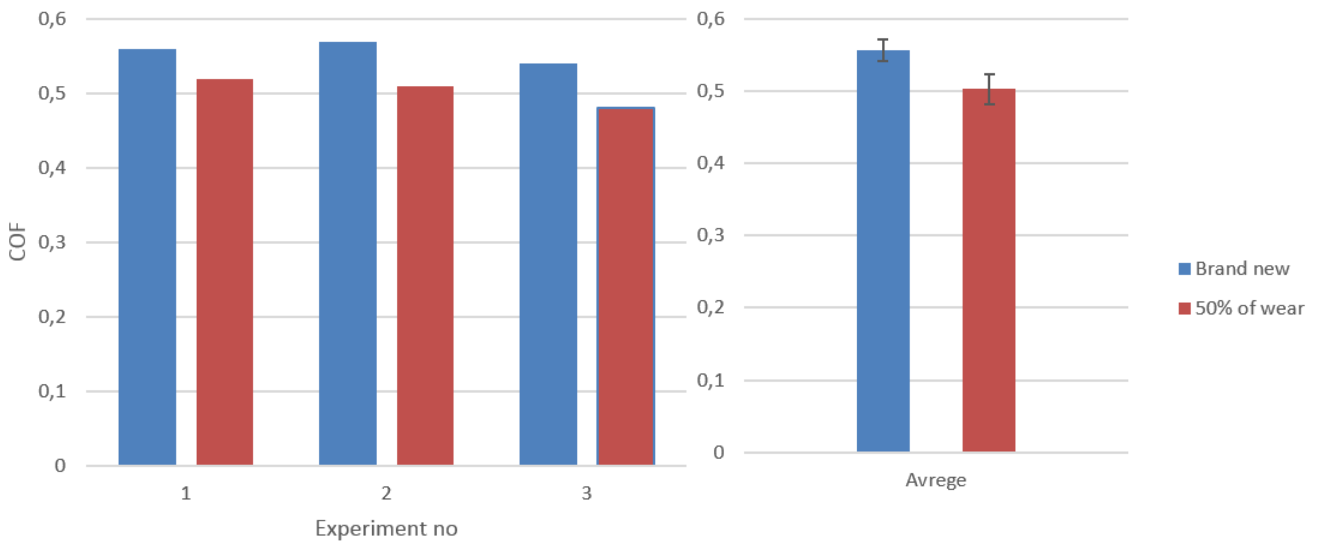

Fig. 5 Results for samples group no. III

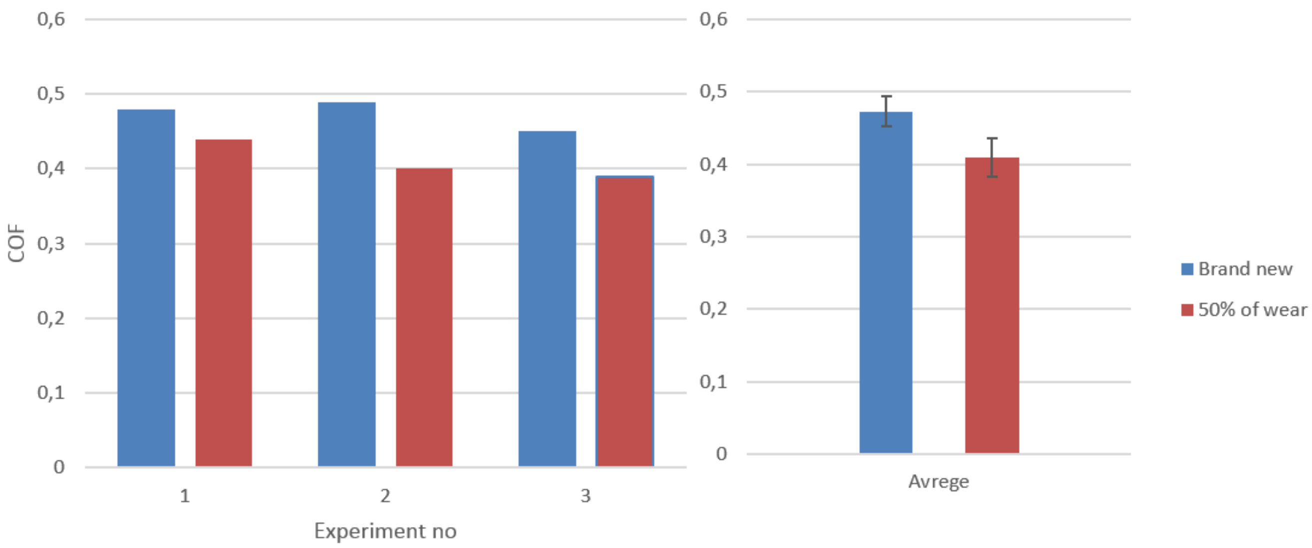

Fig. 6 Results for samples group no. IV

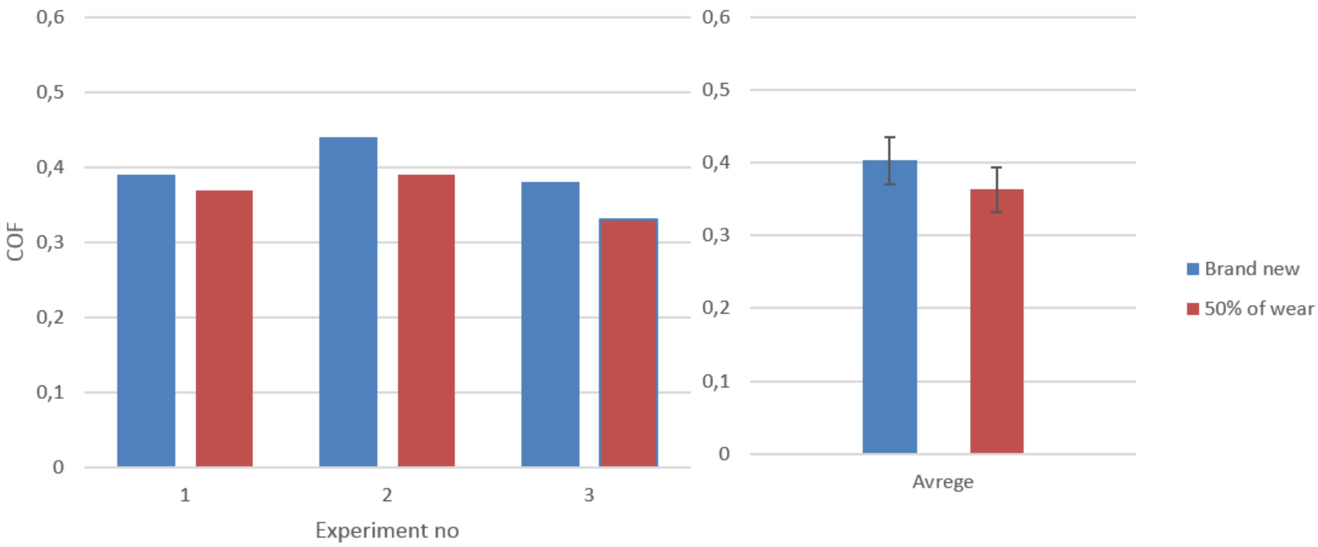

Fig. 7 Results for samples group no. V

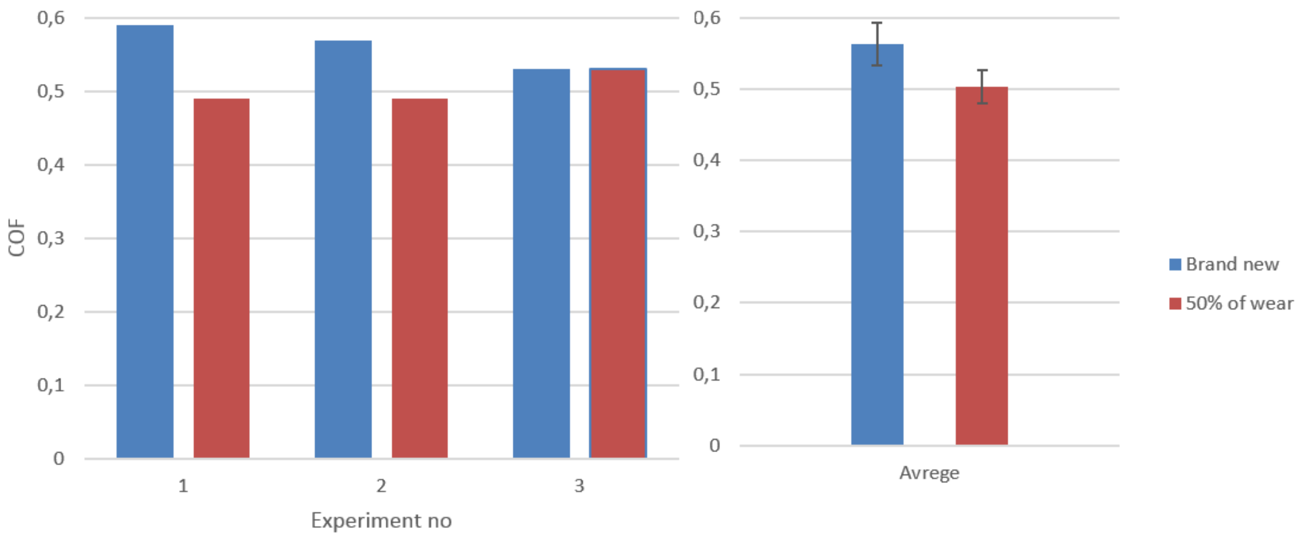

Fig. 8 Results for samples group no. VI

The chi-square test [24-26] was used to determine the influence of the research method on the obtained results. In this test, we compare the observed values with the expected values. The formula for this test is as follows:

$$\chi^2 = \sum_{i=1}^{k}\sum_{j=1}^{r}\frac{\left(n_{ij} - n_{ij}\right)^2}{n_{ij}}, \qquad (3)$$

where: k is number of research methods; r is number of measurements; n is total number of observations; n is expected values; i is test method number; j is measurement number.

The mean values of the measurements were used for the analysis. Ultimately, the data used for the analysis is presented in Table 2.

Table 2

Data used for analysis

Test method	Arithmetical average COF
Pin-on-disc	0.466
Ball-cratering	0.473
Pin-on-disc	0.410
Ball-cratering	0.410
Pin-on-disc	0.400
Ball-cratering	0.403
Pin-on-disc	0.356
Ball-cratering	0.363
Pin-on-disc	0.556
Ball-cratering	0.563
Pin-on-disc	0.503
Ball-cratering	0.503

For the test purposes, the following hypotheses were adopted:

H_0 – the test method does not affect the obtained result (Pin-on-disc results = Ball-cratering results);

H_1 – the test method influences the obtained results (Pin-on-disc results ≠ Ball-cratering results);

The calculation results allowed for the determination of the following values:

$$\chi^2 = 13.86294. \quad (4)$$

To correctly interpret the results, it was necessary to calculate the degrees of freedom:

$$df = (k-1)(r-1), \quad (5)$$

which after substitution gave:

$$df = 10. \quad (6)$$

Then using the inverse chi-square distribution and assuming the confidence level:

$$\alpha = 0.05, \quad (7)$$

value read [27]:

$$\chi^2_{1-\alpha;(k-1)\cdot(r-1)} = 18.3070. \quad (8)$$

Because:

$$\chi^2 < \chi^2_{1-\alpha;(k-1)\cdot(r-1)}, \quad (9)$$

there is no reason to reject the H_0 hypothesis. Therefore, it should be stated that the influence of the applied research method on the obtained results at the confidence level of 0.95 is not statistically significant.

4. Conclusions

Six groups of samples taken from three types of brake pads were tested in the study. Each pads group was in two different degrees of wear: brand new and 50 % worn. A series of tests were made with the use of two tribotesters: Ball-cratering and Pin-on-disc. Statistical analysis of the results allowed to establish that:

1. The value of the chi-square function is much lower than the critical value, which refuted the H_1 hypothesis.

2. No statistical significance was found, proving that the quality of the results depends on the choice of the research method when testing the friction materials of brake pads.

3. Appropriate (correct) design of the experiment allows the above research methods to be used interchangeably while maintaining their high quality.

4. The above methods, due to their interchangeability, can be used as a way to validate empirical results.

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RESEARCH ON TRIBOLOGICAL FEATURES OF BRAKE FRICTION MATERIALS - COMPARISON OF THE RESULTS OBTAINED WITH THE PIN-ON-DISC AND BALL-CRATERING METHODS

S u m m a r y

Brakes are one of the most important systems in each vehicle. For this reason, numerous studies are carried out in many scientific institutions that allow for better understanding of friction and wear phenomenon. Therefore, the correctness of the obtained results is of great importance. Hence, the choice of the research method is not without significance. In this paper, it was decided to check how the choice of the method will affect the quality of the obtained results. The chosen methods were Ball-cratering and Pin-on-disc. Six groups of samples taken from three different types of pads were tested. The pads were both brand new and used. The analysis of the results was performed using the chi-square concordance test. It was established that at the significance level of 0.95, the choice of the research method was not statistically significant. Both methods provide similar high-quality results.

Keywords: mechanical engineering, brake pads, friction, ball-cratering, pin-on-disc.

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