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SUGGESTED RESEARCH METHOD FOR TESTING SELECTED TRIBOLOGICAL PROPERTIES OF FRICTION COMPONENTS IN VEHICLE BRAKING SYSTEMS

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Abstract: The braking system is one of the most important systems in any vehicle. Its proper functioning may determine the health and life the people inside the vehicle as well as other road users. Therefore, it is important that the parameters which characterise the functioning of brakes changed as little as possible throughout their lifespan. Multiple instances of heating and cooling of the working components of the brake system as well as the environment they work in may impact their tribological properties. This article describes a method of evaluating the coefficient of friction and the wear speed of abrasive wear of friction working components of brakes. The methodology was developed on the basis of Taguchi's method of process optimization.

Key words: Brakes, Taguchi's Method, Friction

1. INTRODUCTION

Brakes are one of the most important components of any vehicle. Their proper and effective work determines the life and health of drivers, passengers, and other road users. That is why a lot of research is conducted in order to identify the problems connected with the construction and work of brakes, and making them more effective.

The most common types of brakes in today's vehicles are friction brakes. This type of brake uses friction in order to transform mechanical energy into thermal energy. The amount of heat produced during braking, as well as the speed of its distribution depends, among other things, on the material that was used to manufacture the brake system components. Results of simulations (performed using MES) show, that the elements that get heated the most during braking are brake discs and pads (Yevtushenko et al, 2014, 2015, 2016). Thermal energy is then released into the atmosphere and to other parts of the brake system, as well as the vehicle's suspension.

Multiple instances of heating (to temperatures of up to several hundreds degrees Celsius) and cooling may change the tribological properties of brake pads and discs. Consequently, this may reduce the braking force (Śnieżka, 1998). The corrosive environment brake systems work in (salt and water, especially during winter) are also significant. Increasing the braking distance has a direct influence on the level of danger in traffic. Therefore it is important to determine if and how the tribological properties of brake friction components change.

2. METHODOLOGY

Proper planning of the test is not an easy task. However, it allows obtaining the best results with minimum work (Polański, 1984), which contributes to limiting the time and costs generated by the research. Among numerous possibilities used by researchers (Kamiński, 2013; Borawski, 2015; Szpica, 2015a, 2015b), Taguchi's method of process optimisation was used to plan the experiment. The experiment itself will be conducted using the ball cratering test which allows examination of abrasive wear resistance (Osuch-Słomka et al, 2013).

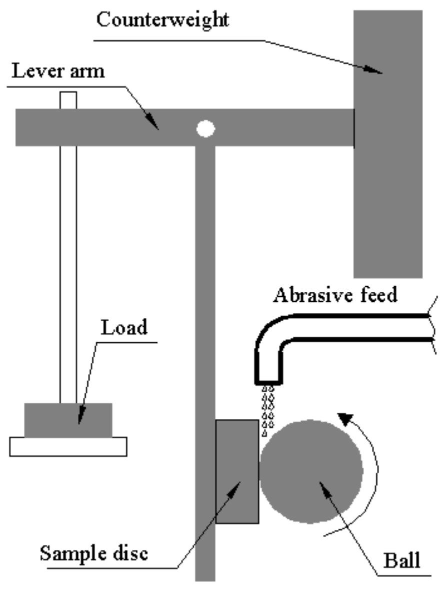

Fig. 1. Abrasive wear testing set

In this method, the friction pair is composed by the studied material's sample and a counter sample, a 1" (25.4 mm) ball. When the ball is moving it grinds against the sample causing it to wear (Fig. 1). Its smooth, polished surface may influence the tests

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results (Allsopp et al, 1998). In extreme cases it may turn out that no results were obtained (no abrasive wear occurred). That is why in order to enhance the effect of abrasive damage it is suggested to use hard abrasives suspended in water and fed onto the friction surface (Fildes et al, 2012).

As a result of the test, a crater is formed in sample. The diameter of the crater depends on, among other things, the working parameters of the friction pair (load, rotational speed and sliding distance). Proper adjustment of these elements determines obtaining accurate test results (Cozza, 2014).

2.1. Test object

In accordance with the applicable standard (PN-EN 1071-6:2008) the test objects are samples which are 1” (25.4 mm) in diameter and 10 mm thick. It is recommended to cut 2 samples from each studied component of the braking system (from each disc and each pad). The samples should be prepared using a method that prevents the material from heating, such as water-jet cutting. This prevents further changes in the structure of the material. Next, the sample should be sanded, remembering about minimizing the temperature of the sample during sanding. Otherwise, the obtained results will not correspond with the actual value of the K_C factor. Fig. 2 shows samples that were first cut from a brake disc and then sanded.

Fig. 2. Examples of samples prepared for ball-cratering tests

2.2. Planning the experiment

The first step of planning the experiment should involve conducting preliminary research. The obtained results will allow to evaluate what ranges of input parameters produce satisfying craters. Recommended input parameters (based on the norm and results of preliminary research) that produce reliable results in most cases are presented in Tab. 1. Experience shows, however, that setting these parameters does not produce satisfactory results for some materials. In such cases, the parameters should be adjusted, for example by increasing the load or the sliding distance (resulting in extending the time of the experiment) (Cozza, 2014). Increasing the ball’s speed of rotation is not recommended, as it tends to result in increased relative error of the measurements. The preliminary parameters of the experiment will be set properly if the relative error of the crater diameters created in the preliminary tests do not exceed 0.01.

Tab. 1. Recommended input parameters based on the norm (PN-EN 1071-6:2008) and own preliminary research

Load [N]	Distance [m]	Speed of rotation [rpm]
0.2	50	38
0.4	100	80
0.6	150	150

In the example presented in Fig. 3, the relative error for all friction distances obtained in 5 tests fits into the assumed value. If the relative error exceeded 0.01 for any distance, this value should be rejected and replaced with the arithmetic mean of the other two values.

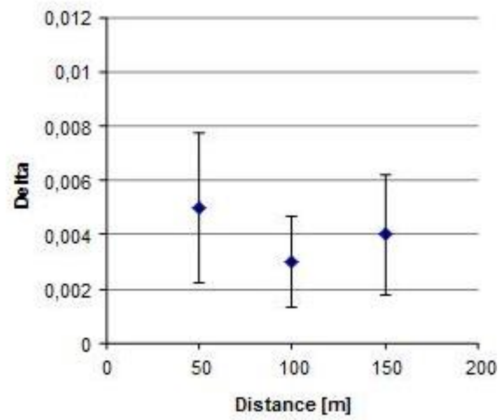

Fig. 3. Example diagram showing the relative errors of measured crater diameters (results of five tests, minimum, maximum and mean values).

After finding the preliminary ranges for input parameters of the experiments, the next step is to find their optimal values. This is done with an orthogonal array. In the discussed case there are three entry parameters, and each of theses has three values. Therefore, the orthogonal array will have the form presented in Tab. 2.

Tab. 2. Example orthogonal array of the experiment

Experiment no.	Load [N]	Distance [m]	Speed of rotation [rpm]
1	0.2	50	38
2	0.2	100	80
3	0.2	150	150
4	0.4	50	80
5	0.4	100	150
6	0.4	150	38
7	0.6	50	50
8	0.6	100	150
9	0.6	150	80

Each of the nine tests should be conducted at least three times. In accordance with the “less is best” criterion and using the results obtained previously, the next step is finding the ETA function following the relation:

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$$\eta = -10\log_{10}\left[\left(\frac{1}{n}\right)\right]\sum {y_i}^2 \qquad (1)$$

where: n – number of measurements, y_i – value of analysed parameter.

Example graphs of ETA functions for particular parameters are presented in Fig. 4.

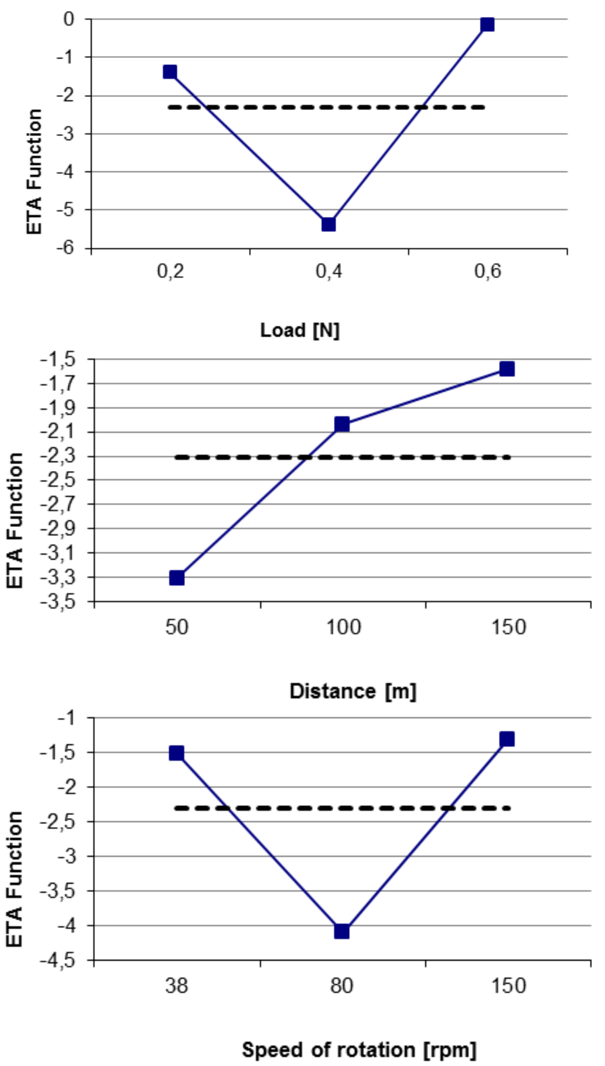

Fig. 4. Example ETA function graph based on preliminary research

After analysing the value of ETA functions, the optimal parameters for the experiment are:
- load: 0.6N;
- distance: 150 m;
- speed of rotation: 150 rpm.

2.3. Course of the experiment

Using the optimal input parameters for the experiment that were determined using Taguchi's methodology, it is possible to plan the proper experiment (Tab. 3). Its results will make it possible to determine the abrasive wear factor (K_C). In order to avoid random errors, it is recommended to repeat every test at least three times (for each sample, 1÷i). It is also necessary to calculate the relative error of the crater diameters which, as mentioned earlier, should not exceed 0.01.

Tab. 3. Example plan of the proper experiment, aiming at determining the K_C factor

Sample no	Parameters		Number of repetitions
1	Load:	0.6 N	≥3
	Distance:	150 m	
	Speed of rotation:	150 rpm	
2	Load:	0.6 N	≥3
	Distance:	150 m	
	Speed of rotation:	150 rpm	
...	Load:	0.6 N	≥3
	Distance:	150 m	
	Speed of rotation:	150 rpm	
i	Load:	0.6 N	≥3
	Distance:	150 m	
	Speed of rotation:	150 rpm	

For the purpose of this article, the tests were carried out using a T-20 slurry abrasive testing machine, which allows testing friction pairs with abrasive suspensions (Fig. 5). The recommend abrasive is a silicon carbide water suspension.

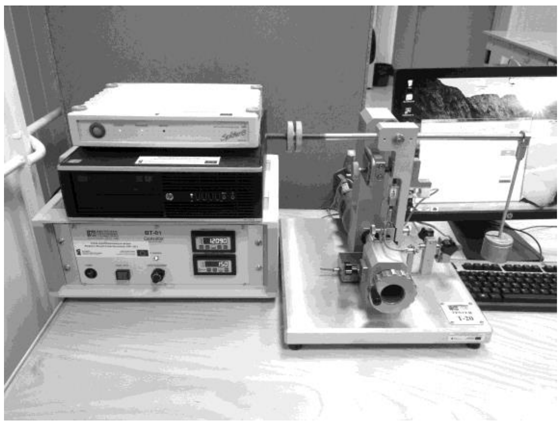

Fig. 5. T-20 Workstation

The machine is capable of recording the coefficient of friction during the test. In order to keep the measured value as close as possible to the actual value (unlike in tests aimed at determining K_C) it is recommended to perform a "dry" run, without feeding the abrasive suspension to the friction pair. This is because the slurry may underestimate the results of the test.

3. COMPILING THE RESULTS

The direct results of the tests are craters created in the samples. Examples of grooves created by ball friction are presented in Fig. 6.

The diameter of the crater should be measured in two planes (Fig. 7) to calculate the arithmetical mean:

$$b = \frac{b1+b2}{2}. \qquad (2)$$

The volume of the crated can be calculated using the relation:

$$V = \pi\frac{b^4}{64R}, \qquad (3)$$

where: R – Ball radius.

$$V = K_C SN \, , \quad (4)$$

where: K_C – Abrasive wear factor, S – distance, N – load.

Transformation of Archard's equation (4) produces the formula for the rate of abrasive wear:

$$K_C = \pi \frac{b^4}{64RSN} \, . \quad (5)$$

The K_C factors and the coefficients of friction should be calculated and measured for each sample cut from the brake system component and then compared.

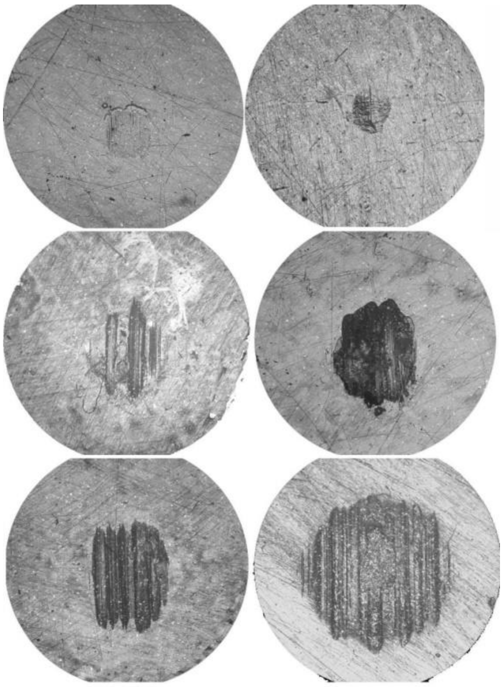

Fig. 6. Examples of craters created in the samples as a result of ball-cratering tests, photographs taken with an OLYMPUS BX51M microscope, 10x zoom.

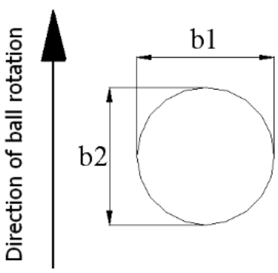

Fig. 7. Crater diameter measurement diagram

4. SUMMARY

1. The developed method is a quick, economical and effective way of measuring abrasive wear.
2. The method is characterised by repeatability and reproducibility, and it requires significantly less testing time than other methods, such as ball-on-disc.
3. Proper planning of the experiment requires conducting preliminary research in order to determine input parameters (ball rotation speed, load and sliding distance).
4. Precision in preparing the sample determines the quality of the results. Specialised equipment, such as water-jet cutting, is helpful at this stage.
5. The results of K_C factor calculations and the results of the coefficient of fraction measurements enable the comparison of tribological properties of the samples taken from the components of the brake system.

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