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Coefficient of Friction of a Brake Disc-Brake Pad Friction Couple

A.W. Orłowicz^{a,*}, M. Mróz^a, G. Wnuk^a, O. Markowska^a, W. Homik^a, B. Kolbusz^b^aRzeszow University of Technology, Al. Powstańców Warszawy 12, 35-959 Rzeszów, Poland^bUnion Parts Sp. z o.o. Bobrowa Wola 72, 39-203 Nagoszyn, Poland

*Corresponding author. E-mail address: aworlow@prz.edu.pl

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Abstract

The paper concerns evaluation of the coefficient of friction characterising a friction couple comprising a commercial brake disc cast of flake graphite grey iron and a typical brake pad for passenger motor car. For the applied interaction conditions, the brake pressure of 0.53 MPa and the linear velocity measured on the pad-disc trace axis equalling 15 km/h, evolution of the friction coefficient μ values were observed. It turned out that after a period of 50 minutes, temperature reached the value 270°C and got stabilised. After this time interval, the friction coefficient value also got stabilised on the level of $\mu = 0.38$. In case of a block in its original state, stabilisation of the friction coefficient value occurred after a stage in the course of which a continuous growth of its value was observed up to the level $\mu = 0.41$ and then a decrease to the value $\mu = 0.38$. It can be assumed that occurrence of this stage was an effect of an initial running-in of the friction couple. In consecutive abrasion tests on the same friction couple, the friction coefficient value stabilisation occurred after the stage of a steady increase of its value. It can be stated that the stage corresponded to a secondary running-in of the friction couple. The observed stages lasted for similar periods of time and ended with reaching the stable level of temperature of the disc-pad contact surface.

Keywords: Flake graphite cast iron, Brake discs, Abrasive wear resistance, Coefficient of friction

1. Introduction

The braking system is one of the most important constituents of any wheeled vehicle. The function of the system is to reduce velocity or stop a vehicle at any time in the course of its motion. It is assumed that both the braking distance and the system's response time should be as short as possible. Another important requirement is reliability and efficiency of the braking system which should remain on the same level regardless of length of the operating cycle [1-3].

Research effort on the above-mentioned issues is focused mainly on improvement of properties of the materials used to fabricate braking system components (discs and pads) in view of high values of parameters characterising service properties: high

resistance to abrasive wear, high value of the coefficient of friction, and low acoustic emission level.

Car components such as brake discs are operated in very difficult conditions which include high mechanical loads and the related abrasive wear, and moreover, seizing, thermal fatigue, and corrosion wear of the material. The corrosion wear of brake discs is affected by such ambient atmospheric conditions as air humidity and temperature, precipitation intensity, and sun exposure [4-6].

Analysis of spent brake discs shows that cast iron discs demonstrate different degree of wear depending on chemistry and microstructure of the material and the type of the used brake pads.

The objective of the present study was to examine changes of the friction coefficient values characterising a friction couple comprising a commercial passenger car cast-iron brake disc and a typical brake pad.

2. Description of the approach, work methodology, materials for research, assumptions, experiments etc.

The metallic charge metal prepared for casting the test brake disc were grey iron plates containing 0.01% S. The charge melting process was carried out in an induction furnace. The braking discs were cast in sand moulds.

The last stage of preparation of the liquid metal consisted in modification. The wide range of modifiers used currently include those based on rare earth elements, calcium, aluminium, silicon, and bismuth [7]. In the present case, ferrosilicon was used.

Chemical composition of the brake disc used in the experiment is given in Table 1.

Table 1.
Chemistry of the experimental brake disc's flake graphite grey iron

Element	Content, weight %
C	3,70
Si	1,60
Mn	0,78
P	0,04
S	0,02
Cr	0,02
Mo	0,01
Ni	0,01
Cu	0,31
Ti	0,01
Mg	0,010
Fe	To balance

Assessment of microstructure (as per PN-EN ISO 945-1) comprised analysis of shape, arrangement, and size of flake graphite precipitates. Based on visual examination, volumetric share of pearlite V_{vp} was assessed as well as the value of structural parameter λ_p (distance between cementite platelets in pearlite). The analysis was performed on 10 randomly selected fields with surface area of 0.76 mm^2 .

The test were carried out on modified experimental set-up equipped with two modules in which brake discs were set in rotational motion by means of independent motors via belt transmissions. The set-up was provided with a measuring module for evaluation of the friction force value necessary to determine the coefficient of friction.

A view of the set-up is shown in Figure 1.

The countersamples, in the form of cuboids with dimensions $30 \text{ mm} \times 30 \text{ mm} \times 16 \text{ mm}$, were cut out from a commercially available brake pad.

Linear velocity of the rotating disc as measured on the axis of trace of its contact with brake pad sample was 15 km/h . The force applied to the pad was 480 N . The total abrasion time was 33.3 hours .

In the course of abrasion tests, measurements of the brake disc surface temperature were carried out with the use of optical pyrometer and by means of NiCr-Ni thermocouple with $\varnothing = 0.25 \text{ mm}$ wires, measuring junction of which was mounted in the block

on the block-disc boundary (Fig. 2). The results could be considered comparable, but at temperatures much higher than those observed in the presented case, it is necessary to exclude contactless measurements as the obtained results become divergent with respect to the traditional measuring method with the use of thermocouples.



Fig. 1. A view of the set-up for brake disc abrasion resistance test

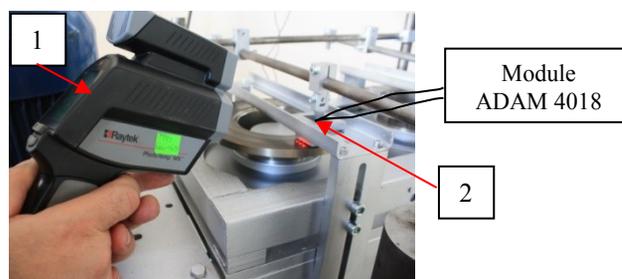


Fig. 2. Measuring the brake disc surface temperature in the course of the abrasive resistance test: (1) — noncontact temperature measuring instrument PhotoTemp MX (Raytek); (2) — thermocouple input module ADAM 4018 (Advantech)

The brake disc wear-out depth was determined based on the difference of average surface profile height within and outside the area of contact with the brake pad countersample. The 3D maps and profiles of these surfaces were examined with the use of HOMMEL-ETAMIC profilometer equipped with TKU 300 TSM probe. The measuring probe displacement speed was $V_t = 0.5 \text{ mm/s}$. The measurement was carried out over a surface area with dimensions $15 \text{ mm} \times 5 \text{ mm}$.

3. Description of achieved results of own researches

Microstructure of the brake disc material is shown in Figure 3.

Results of examination of microstructure of the flake graphite grey cast iron brake disc are presented in Table 2.

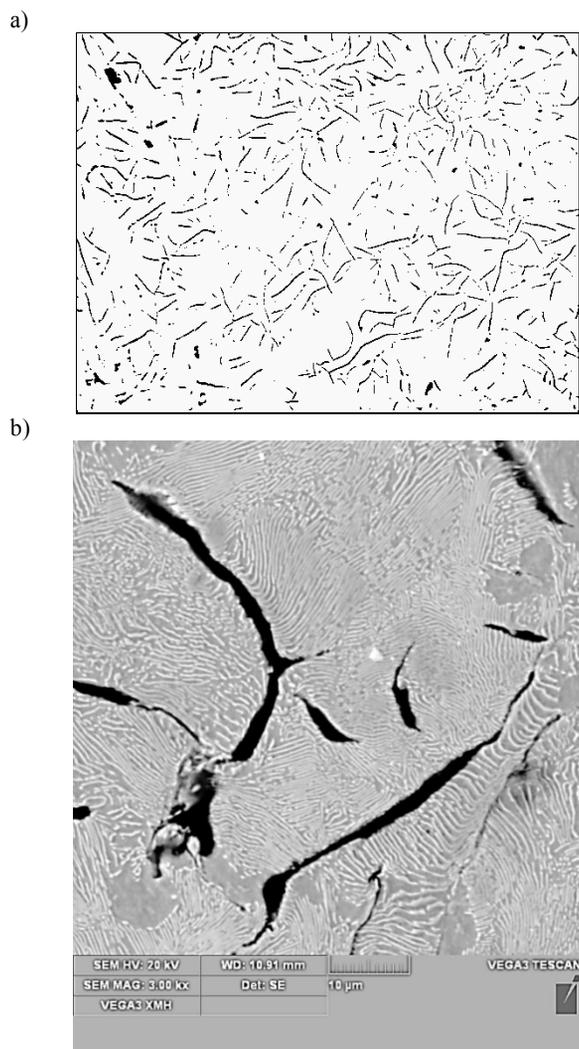


Fig. 3. Microstructure of a brake disc cast of flake graphite grey iron: (a) flake graphite precipitates, $\times 100$ magnification; (b) a view of cementite platelets in pearlite — a section etched with nital, $\times 3000$ magnification

Table 2.

Results of assessment of microstructure of a brake disc cast out of flake graphite grey iron

Graphite shape	I
Graphite arrangement	A - 80% B + C + D - 20%
Graphite precipitate size, μm	10-60
Pearlite share by volume, %	99
Average distance between pearlite platelets $\lambda_p, \mu\text{m}$	10-60

The course of the brake disc surface temperature value changes observed during abrasions tests, including one prolonged and two short-time trials carried out with the same friction couple, is presented in Figure 4.

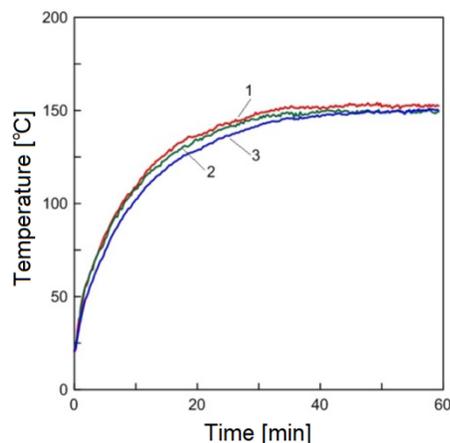


Fig. 4. The course of the brake disc surface temperature value changes in a disc-pad friction pair abrasion test; 1 - the first prolonged test, 2 - the second short-time test, 3 - the third short-time test

The obtained results indicate that under established abrasion conditions, the temperature value changes demonstrate similar character. The disc temperature reaches a stable value of 270°C after the friction couple interaction temperature of about 50 minutes.

A 3D map of a brake disc section after abrasion test is shown in Figure 5.

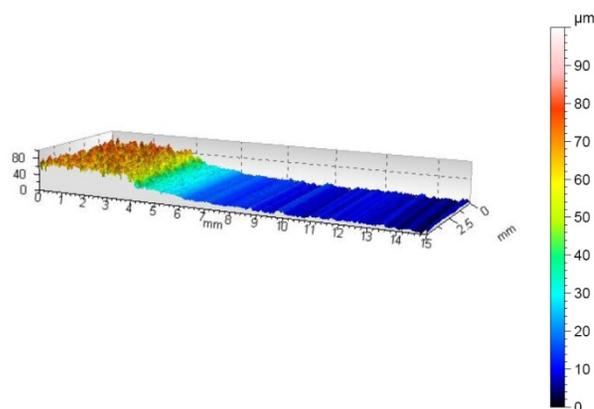


Fig. 5. A 3D map of a brake disc section after abrasion test

Figure 6 illustrates the method used to evaluate the brake disc wear-out depth after the abrasion test.

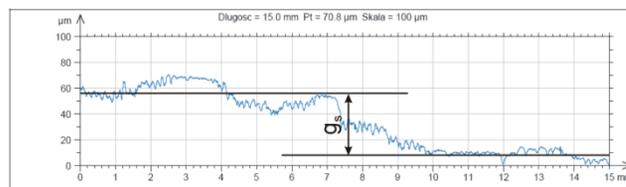


Fig. 6. The method of the wear-out depth measurement after abrasion test

The obtained results allow to conclude that the depth of the wear-out area in brake disc after 33-hour long test (corresponding to the friction path length of 500 km) was 18.4 μm .

The changes of the friction coefficient values in time for the disc-pad friction couple in the course of prolonged abrasion test (33.3 hours) is presented in Figure 7.

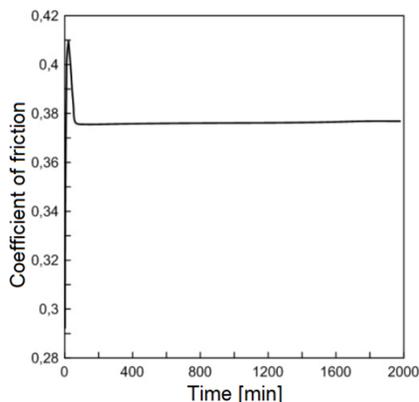


Fig. 7. The course of the disc-pad couple friction coefficient changes in time

The obtained results indicate that in the initial stage of the abrasion process, the friction coefficient value increases and reaches its maximum at $\mu = 0.41$ after 9 minutes from the start of the abrasion process, and then decreases to $\mu = 0.38$ and stabilises.

Such course of the friction coefficient value changes suggests the occurrence of the running-in process in the friction couple resulting in development of a stable tribological layers on both the disc surface and the pad surface. According to authors of papers [8] and [9], a friction film or a third body layer is produced incessantly by maintaining a certain thickness and it is composed of carbonaceous reaction products, unreacted constituents, oxide from metallic ingredients. Friction characteristics of the transfer layer between a brake disc and pads developed during subsequent braking influence the braking effectiveness at elevated temperature.

In view of the above it became an interesting issue to determine whether subsequent short interaction cycles would be characterised with a steady approach to a stable value of the coefficient of friction and whether such stable value would be reached for the same tribological interaction duration and for the same disc surface temperature value.

The results of examination of the friction coefficient value change as a function of the friction couple interaction time are presented in Figure 8.

The obtained results indicate that in the course of prolonged abrasion test, a running-in of the friction couple occurred. In view of the above, the second and the third short-time test were both characterised with a steady and similar increase of the coefficient of friction up to a stable final value. This specific value of the coefficient of friction was reached for the tested friction couple and for the applied experiment conditions after a period of time equalling 50 minutes elapsing at the moment when the friction face temperature reached the value of 270°C.

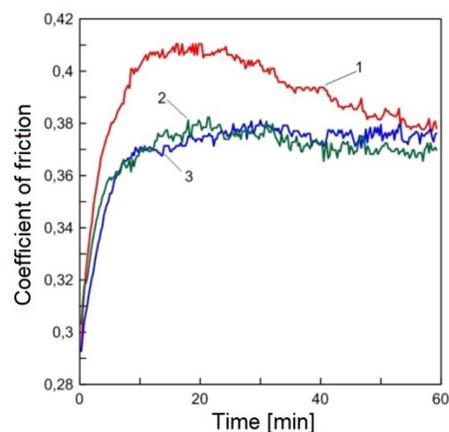


Fig. 8. The course of the friction coefficient value for the disc-pad friction couple as a function of abrasion time; 1 - the first prolonged test, 2 - the second short-time test, 3 - the third short-time test

On the other hand, authors of the paper [10] suggest that the change of the friction coefficient value is connected with development of an actual pad-disc contact surface, strength properties of the binding materials used in the pad manufacturing process, tribological properties of individual filling materials, and the progress in development of a tribological layer between pad and disc surfaces.

It should be concluded from the above that using the same brake pad and the same brake disc as well as the same operating conditions allowed to obtain similar course of the friction coefficient value changes vs. time (results of the second and the third test, Fig. 8) and the final value of the coefficient of friction after reconstruction of the tribological layer common for all test cycles.

According to authors of studies [11] and [12], the use of other organic binding materials, other fillers, or additives improving tribological properties has a decisive effect on development of the tribological layer. Therefore, even if brake pads coming from the same manufacturer are used in the experiment, possible differences in chemical composition will result in obtaining different friction coefficient values. It can be however assumed that the character of the coefficient changes reported in these papers will be the same as this presented above.

4. Conclusions

The obtained results allow to conclude that for conditions of friction prevailing between a brake pad and a brake disc cast of grey iron with pearlitic matrix and flake graphite precipitates applied in the present study, the course of the friction coefficient value changes depends on multiplicity of the braking test.

In case of using a brake pad in its original state, an increase of the friction coefficient value is observed up to a maximum value followed by a decrease to a lower stable value. This can be explained by the process of development of an actual friction couple contact surface until a tribological layer is formed which results in stabilisation of the friction coefficient value. The period

of coming to such stabilisation can be termed the primary matching of the friction couple.

In consecutive abrasion tests carried out with the same friction couple, a steady increase of the friction coefficient value is observed up to a stable value level. The time required to reach the value can be considered similar. This period of time can be described as the secondary matching of the friction couple.

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