Experimental evaluation of the effect of cryogenic treatment of brake discs of the vehicle on the performance characteristics

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Abstract. The article presents the conclusions and prerequisites of the experimental evaluation of friction pairs in the aspect of fading. The most part of kinetic energy of the vehicle with ABS is extinguished at the expense of friction work in the brake mechanism. Thus, the overheating of the brake mechanism, namely its pair of friction is peculiar to vehicles not equipped with ABS (for example, ATV) and leads to the phenomenon of critical fading, accompanied by a sharp decrease in braking torque. The reduction of the influence of this phenomenon is a very difficult task in terms of both taking into account the cost of the braking mechanism and its minimal complication. The authors suggest the use of cryogenic processing of brake disks to reduce the impact of thermal loading on the emergence of fading.

Introduction
The widespread use of automated braking systems in vehicles, in addition to the obvious benefits in terms of active safety, also causes a number of problems due to changes in the workflow [1]–[7]. This increases the amount of kinetic energy that needs to be extinguished during braking.

As against the traditional method of the braking and skidding, the main part of the kinetic energy of a car with ABS is extinguished by friction in the braking mechanism during ABS operation, which inevitably leads to an increase in their thermal load, especially when used by manufacturers of vehicle braking systems, traditional elements of basic models.

The problem of increased heating of friction pairs of brakes is also relevant for such specific vehicles as ATVs, even in spite of the absence of ABS [8], [9]. And this is due to the movement of these vehicles on the terrain with complex terrain, which requires frequent use of brakes. The situation is aggravated by moisture penetration on friction vapors, which in case of their high temperature can lead to accelerated failure (for example, warping of brake discs), despite the fact that the brake discs are made of stainless steel instead of sliding cast iron. The statistics shows that the friction pair life of the ATV is several times lower than that of a car with comparable mileage. Another reason for this is the penetration of sand and soil particles between the friction pairs and in the ventilation holes of the disc, which affects both the wear and tear of the friction pairs and their temperature conditions.
It is known from the literature that the overheating of brake friction pairs contributes to the emergence of critical fading, accompanied by a sharp decrease (up to 50%) in the friction coefficient of brake linings, as well as increased wear of counter bodies, with the formation of macroscopes [10].

The carried out analysis of the influence of the principal change of the working process of braking of the car wheel with ABS on the distribution of work required to extinguish the kinetic energy of the vehicle as an example is shown in Fig. 1. It is designated: change of kinetic energy of the vehicle with ABS at braking from initial speed of 60 km/h on dry asphalt concrete in the course of braking (Wk), the work spent on a friction in contact of the all-terrain tire (ATR) with road and on hysteresis losses in the tire (AFF), and also absorbed in the brake mechanism of aggregate trailer mass (ATM).

Figure 1. Distribution of the work required to extinguish the kinetic energy of an ABS vehicle during braking

The graph shows that when braking a car with ABS, in contrast to braking and skidding, most of the kinetic energy is damped by friction in the friction couples of the brake mechanism.

It is necessary to make changes in the design to solve the problems associated with fading, after the designer with the help of calculation methods has revealed a problem connected and increased heat loaded braking system. The calculation methods of evaluation were considered by the authors in [11]–[14]. One of the ways may be to change the surface area of the friction pairs of the brake mechanism, which may entail a change in the neighboring components (hub, wheel rim), which leads to a rise in the cost of the finished structure. The next approach to solving the problem of increased thermal loading of brakes can be the use of friction pairs of materials whose properties allow to avoid these problems. But materials with higher characteristics have a higher cost. For example, brake discs made of composite materials instead of antifriction grey cast iron used in production vehicles. The authors suggest cryogenic processing of brake discs made of grey sliding cast iron as a cheaper way to improve the material properties.
Test Methods
The article [15] presents the test results after cryogenic processing of cutting tools for turning. There was a decrease in thermal EMF in comparison with untreated tools. From this it is possible to draw a conclusion that the change of properties of a material of a cutter after cryogenic processing influences thermal processes in a cutting zone. In order to be sure of the positive effect on the properties of the brake mechanism of the cryogenic treatment of the brake disk, it is necessary to test the samples by comparison and to draw conclusions on the measured parameters.

There are various normative documents for friction pair testing, for example, RD 50-662-88. Where a set of methods for assessing friction compatibility of lubricants and (or) structural materials used in friction materials is installed.

The tests were carried out using the following main test equipment:
1. SMC-2 friction machine;
2. Inductive friction torque sensor;
3. Laptop for capturing the video signal from a thermal imaging camera;
4. SAT HotFind-L thermal imaging camera.
5. Electronic analytical scales

Materials used for testing
As a rotating sample were used discs with a diameter of 36 mm and a thickness of 6 mm obtained from the original brake disk of the Lada Granta by waterjet and turning. This made it possible to obtain a roughness and accuracy of the test surface comparable to the working surface of the original brake disk.

Results and discussion
One of the factors that confirms the adequacy of the tests is that they are friction pair materials. The chemical analysis of these brake discs (Table 1) has been carried out, which showed full compliance of the chemical composition with the requirements of the regulatory documentation for this grade of cast iron, all parameters were in the middle of the permissible ranges. ASF-4 cast iron grade, which means grey sliding cast iron with lamellar graphite.
Table 1. Results of chemical analysis of Lada Granta's brake discs

| Parameter    | Significance     | Requirements of GOST 1585-85 |
|--------------|------------------|------------------------------|
| Material     | Antifriction cast iron ASF-4 |                              |
| Carbon       | 3.46%            | 3-3.5%                       |
| Manganese    | 0.79%            | 0.4-0.8%                     |
| Silicon      | 2.06%            | 1.4-2.2%                     |
| Chrome       | 0.06%            | is not regulated             |
| Phosphorus   | 0.05             | no more than 0.3             |
| Sulphur      | 0.05             | 0.12-0.2                     |

Figure 3. A still from a thermal imaging camera. Symbols: 1 — Temperature at the center of the viewfinder, 4 — Maximum temperature in the captured area.

The movable sample is a disc that rotates at a constant speed of 1000 rpm (16.6 s⁻¹). It is pressed against a fixed specimen fixed in the carriage, which is a rectangular segment of the brake shoe. In the experiment, two manufacturers of brake pads were used slightly lower than average (company Riginal) and the upper price segment with confirmed authentication (company Ferrodo).

According to RD 50-662-88 "Methods of experimental assessment of friction compatibility of friction materials of rubbing interfaces" it is said that if the wear of a moving sample is less than 0.02 mm, the duration of the tests is doubled. Thus, this thesis should be taken into account with the accuracy of measuring the weight of the moving sample, because the wear of the stationary sample (pad) is greater.

The heat load of friction pairs during the test was assessed using a SAT HotFind-L thermal imaging camera.

The temperature of the surface of a moving sample is of great interest. The coefficient of correction for emissivity was chosen to be 0.7, which, according to the documentation for the thermal imaging camera, corresponds to the treated grey cast iron.

According to the test results, it was possible to show the influence of modes, braking time, properties of materials on fading. It was noted that the brake pad material has a significant influence on the torque with the same contact force and comparable areas, even though the surface temperature of the brake disk is too high.

The influence of pad material on the surface temperature of the brake disc is less than that of the cryogenic treatment of the disc. In a vehicle with cryogenically treated brake discs that work in
conjunction with quality brake pads (Ferodo), fading may not occur for a sufficiently long braking time or may reduce the risk of braking, as shown in these tests. An increase in braking torque with the same brake pad pressure can be achieved by using quality brake pads.

![Figure 4. Thermogram processing in SatIrReport](image)

Figure 4. Thermogram processing in SatIrReport

![Figure 5. Test torque sensor values for 5 minutes for a combination of different moving and stationary samples.](image)

Figure 5. Test torque sensor values for 5 minutes for a combination of different moving and stationary samples.

One of the most important features of the brake system is its reliability. A particular case of faultless braking is the stability of the braking system, e.g. the brake torque. For this purpose, we will use the parameter of stability of the friction coefficient of the pad disk in accordance with PD 50-662-88.
They calculate the coefficient of friction and the stability of the coefficient of friction by the formula

\[ a = \frac{\sum_{i=1}^{n} M_i}{\sum_{i=1}^{n} M_{\text{max}}} \]  \hspace{1cm} (1)

where \( n \) — number of re-tests.

After calculating the coefficient of friction stability, we obtain the friction coefficient for different combinations of test samples of the disc and pad:

– for standard disc and standard shoe 0.968,
– for cryogenically processed disc and standard block 0.974,
– for standard disc and Ferodo pad 0.959,
– for cryogenically processed disc and Ferodo 0.969 pads.

**Figure 6.** Maximum temperatures of moving samples within 5 minutes for a combination of different moving and stationary samples.

The results of the calculation of a show that the moving cryogenically processed sample has a more stable coefficient of friction and therefore a more stable braking torque. The decrease in the coefficient of friction pairs with Ferodo pads can be explained by the higher values of the realized braking torque at the same clamping force of the stationary sample to the moving one (see Fig. 6) and the high surface temperatures of the moving sample (see Fig. 7).

That is, the braking torque range increases proportionally with the increase in its values. But just as with a standard Ferodo pad, so too, does a cryogenically processed sample have a higher coefficient of friction stability than a pair of Ferodo pads and a standard disc.

**Conclusions**

The brake lining wear depends on the temperature according to the literature, although the results of the tests have shown the ambiguity of this statement. For the untreated moving sample, which had a higher temperature, the wear of the pads of the standard and Ferodo was significantly lower than for the treated sample, which had a lower surface temperature.
Table 2. Results of wear measurement of moving samples in combination with different pads.

| №  | Sample type                        | Disk weight before testing | Disk weight after testing | Disc wear and tear | The weight of the pads before the tests | The weight of the pads after the tests | Wear pads |
|----|-----------------------------------|---------------------------|--------------------------|--------------------|----------------------------------------|---------------------------------------|----------|
| 1  | standard disc, standard pad       | 33,417                    | 33,409                   | 0,008              | 278,506                                | 277,973                               | 0,533    |
| 2  | processed disk, standard pad      | 33,370                    | 33,366                   | 0,004              | 277,917                                | 277,765                               | 0,152    |
| 3  | standard disc, standard pad       | 33,373                    | 33,363                   | 0,01               | 283,945                                | 283,777                               | 0,168    |
| 4  | processed disk, standard pad      | 33,192                    | 33,183                   | 0,009              | 283,752                                | 283,613                               | 0,139    |
| 5  | processed disk, Ferodo pad        | 33,368                    | 33,359                   | 0,009              | 286,154                                | 286,120                               | 0,034    |
| 6  | standard disc, Ferodo pad         | 33,334                    | 33,316                   | 0,018              | 286,064                                | 286,035                               | 0,029    |
| 7  | standard disc, standard pad       | 33,401                    | 33,397                   | 0,004              | 278,072                                | 278,019                               | 0,053    |
| 8  | processed disk, standard pad      | 33,288                    | 33,286                   | 0,002              | 277,973                                | 277,910                               | 0,063    |

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