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Study of frictional properties, long-term (cyclic) strength of materials of brake pads of motor vehicles

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Abstract

Fractogram analysis shows that deep scratches, particles of titanium and chromium carbides and other elements were found on the friction surfaces. Moreover, in the braking devices there was damage to the large size of the brake pads of trucks. The transfer of particles of borides and carbides to the surface of the wheels can be explained by the processes of metal flooding with their subsequent embrittlement, which inevitably leads, as a rule, to the destruction of friction wheel pairs. It is established that such types of wear as fretting corrosion significantly (by 1.5-2 times) reduce the fatigue limit of parts. Also significantly reduce the cyclic strength of metal friction pairs oxide films on their surface in the absence of lubricant. The service life of friction wheel pairs has a particularly strong impact on fatigue strength. The main reason for the decrease in endurance due to the processes of setting on the working surfaces of friction units is a high concentration of stresses caused by deep tears, cuts, microcracks. The process of destruction of brake pads from fatigue begins from the surface of the part. In this regard, the quality of the surface, its structural-phase composition, physical and mechanical properties of the surface layer in most cases are decisive for the intensity of the development of wear processes of parts from fatigue of the tribosystem (friction wheel pairs), which are operated under cyclic loads. The peculiarity of the influence of friction and wear processes on the fatigue strength of metal is that at the time of running-in there is a change in surface roughness, structure and properties of surface layers. As the analysis of literature sources has shown, the effectiveness of the influence of friction and wear processes on the characteristics of fatigue resistance in the case of repeatedly alternating (cyclic) loads is essential, and therefore ignoring this effect during the traditional assessment of the reliability of parts by individual criteria, for example, wear resistance, often leads to an incorrect assessment of the operational durability of the elements of the tribological system of road or rail transport. The long-term (cyclic) strength of brake pads was determined on a specialized unit model 1251 by Instron company (Great Britain). The basis for spraying and surfacing of different types of coatings was normalized steel 35. Tensile-compressive deformations at zero average stress and a cycle frequency of 20 Hz were studied on the laboratory unit. Most of the tests were carried out in salt solutions (NaCℓ of industrial purity was used).The process of destruction of brake pads from fatigue begins with the surface of the part. In this regard, the quality of the surface, its structural-phase composition, physical and mechanical properties of the surface layer in most cases are decisive for the intensity of the development of wear processes of parts from fatigue of the tribosystem (friction wheel pairs), which are operated under cyclic loads. Endurance limits in the case of simultaneous exposure to friction forces and cyclic loads will depend on the sliding speed of the tangent surfaces of the normal contact load, which determines the friction force, and the composition of the environment.

Keywords: fractograms, friction, destruction, wear, structural-phase composition, physical and mechanical properties, wheel pair, tribology, cyclic strength, microcracks.

Introduction

Currently, the industrial industry of Ukraine faces the problem of creating the basic foundations for the development of transport technology, in particular, the issues of friction and wear in transport machines. The relevance is due to the fact that the current state of development of technology is characterized by harsh operating conditions of various transport systems, which is associated with an increase in: specific loads; increase in power; speed; the effect of complex loads of static cyclic and dynamic nature; the influence of various corrosive environments and temperatures. It is known from operational practice that the violation of normal functioning or complete failure of technical systems by 70-80% is caused by the failure of elements of their tribosystems due to surface destruction as a result of wear and other related processes - erosion, fretting, etc. Therefore, increasing the durability of friction units has been and remains one of the most important technical problems of our time in terms of increasing the reliability and extending the service life of transport machines. Despite the large volume of publications on this subject, it can be noted that the diversity of a large amount of experimental material, uncertainty and inconsistency of information about the tribological properties of the material involved in friction and wear pairs leads to the need to find additional resources to improve the wear resistance of brake pads, in particular transport trucks.

Therefore, we have conducted additional studies of the friction properties of brake pads in the conditions of experimental benches that were closest to the real kinematic and dynamic conditions of operation of transport trucks.

The purpose and objectives of the study – conducting systematic experimental studies of the frictional properties of brake linings made of different materials.

Materials and methods of the study

In the experiments, an improved unit of the MFK-1 model was used, which is schematically shown in Figure 1, (which does not show the information system for determining the necessary information and computer processing). To select the material of brake linings, express dry friction tests were carried out together with the specialists of NPO "Powder Metallurgy" and the Institute of Electric Welding named after E.O. Paton of the National Academy of Sciences of Ukraine (a possible case of braking wheelset operation in dry friction mode was simulated on the stand).Tests of samples of coated linings for wear resistance at dry friction were carried out for 45 minutes at a specific pressure of 0.6 MPa and a counterbody rotation speed of 80 min-1, the counterbody was a disk made of hardened steel 40HN. The reference sample of brake linings was steel 45. The lining was made of three types: FMK-8 - metal-ceramic friction (based on iron); "carbon - carbon" - composite materials CCCM and powders of eutectic alloys of the TH system (for coating used powders of eutectic alloys of the 12X18H9T-TiB system).Moreover, it should be noted that the metal matrix of the alloy corresponds to steel 12X18H9T, and the strengthening compounds are titanium and chromium borides. Spraying was carried out by plasma method. The fractograms of the friction surface, which were subjected to wear, were studied by X-ray spectral analysis using a scanning electron microscope model "JSM-35CF" of the company "Geol" (Japan).

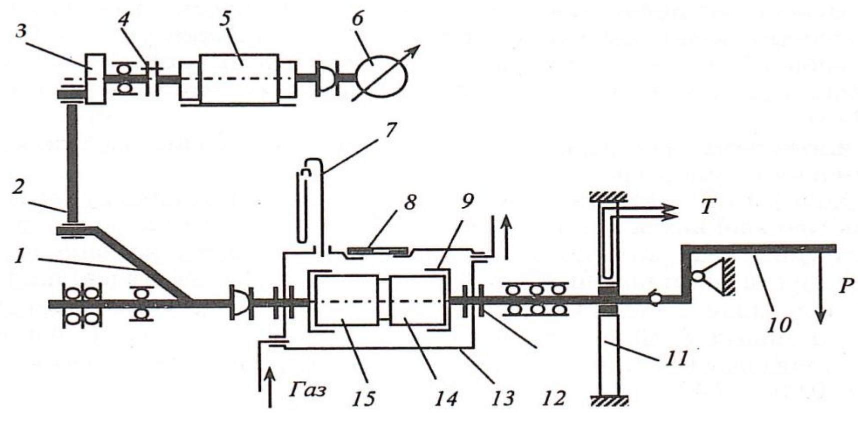

Fig.1. Schematic diagram of MFKU-1 unit:
1 - horizontal connecting rod, 2 - vertical connecting rod, 3 - adjustable eccentric, 4 - coupling, 5 - electric motor, 6 - counter of the number of cycles, 7 - pressure gauge, 8 - inspection window, 9 - collet, 10 - loading device, 11 - strain beam, 12 - seal, 13 - camera, 14 - fixed sample, 15 - moving sample.

Long-term (cyclic) strength of brake pads was determined on a specialized model 1251 unit of the Instron company (Great Britain). Normalized steel 35 served as the basis for filing and surfacing various types of coatings.Tensile-compressive deformations at zero average stress and a cycle frequency of 20 Hz were studied on a laboratory unit. Most of the tests were carried out in salt solutions (NaCℓ of industrial purity (above 99%) was used).

The results of experimental studies are shown in Figures 2-10.

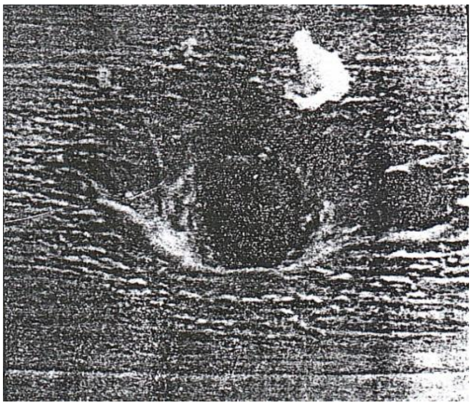

Fig.2. Microstructure of plasma TN coating (cross grinding - base carbon steel U7 - x400).

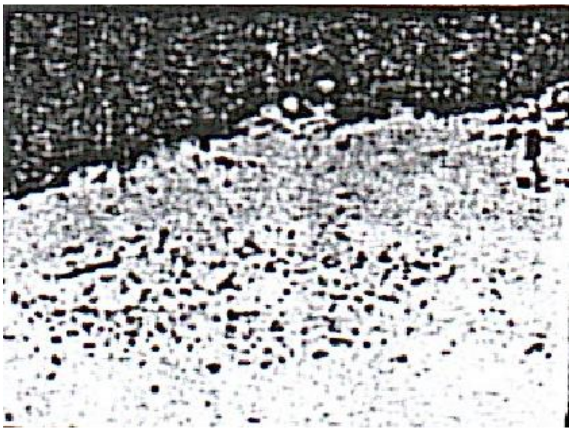

Fig.3. Microstructure of plasma coating of TN type (general view of the coating surface - base steel 35 (x500))

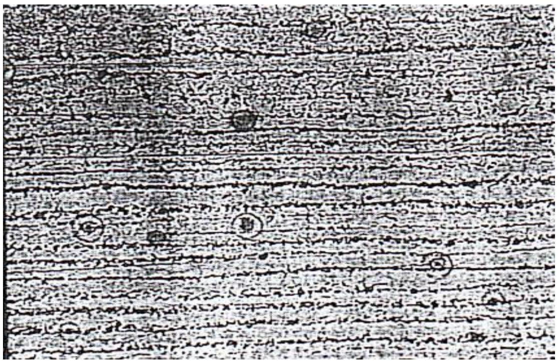

Fig.4. Microstructure of plasma deposited TN coating (x300). Titanium boride inclusions are circled.

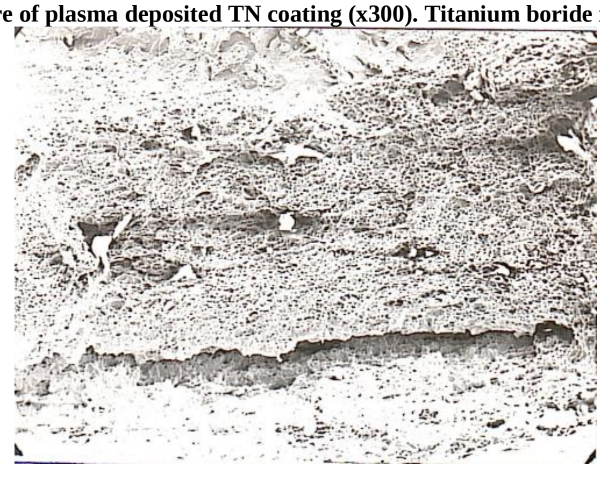

Fig. 5. Fractogram of the surface with surfacing composite coating CCCM. Base - steel 45

The results of tests of brake pads for cyclic (long-term) strength are shown in Figures 6 and 7.

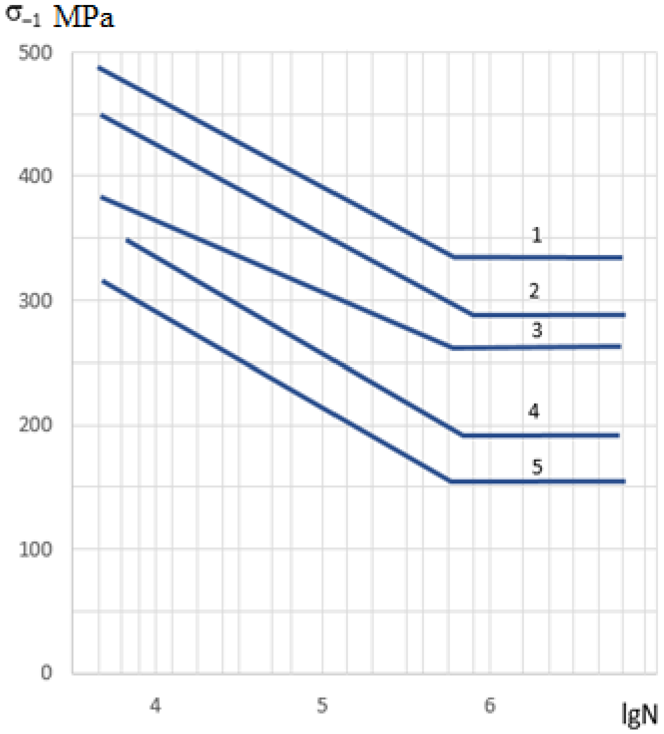

Fig.6. Cyclic strength (fatigue) curves of carbon steel 35 samples.
1 - unused steel; 2 - service life is 5 years; 3 - service life is 10 years; 4 - service life is 15 years; 5 - service life is 20 years.

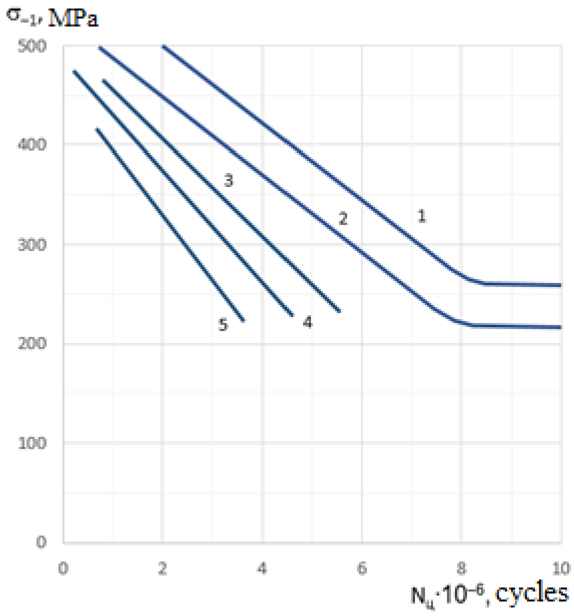

Fig.7. Effect of fretting corrosion on fatigue (cyclic) strength of carbon normalized steel 35.
1 - fatigue curve without fretting corrosion (service life is 5 years); 2 - fatigue curve without fretting corrosion (service life is 10 years); 3-5 - fatigue curves with fretting corrosion (service life is 5, 10 and 15 years, respectively).

The process of destruction of brake pads from fatigue begins with the surface of the part. In this regard: the quality of the surface; its structural-phase composition; physical and mechanical properties of the surface layer in most cases are decisive for the intensity of the development of wear processes of tribosystem parts (friction wheel pairs) from fatigue, which are operated under cyclic loads. Many parts of motor vehicles operate in such conditions. A feature of the influence of friction and wear processes on the fatigue strength of metal is that at the time of running-in, there is a change in surface roughness, structure and properties of surface layers. As the analysis of literary sources [18,19,20] has shown, the effectiveness of the influence of friction and wear processes on the characteristics of fatigue resistance in the case of repeatedly variable (cyclic) loads is essential, and therefore ignoring this effect during the traditional assessment of the reliability of parts according to certain criteria, for example, wear resistance, often leads to an incorrect assessment of the operational durability of elements of the tribological system of road or rail transport.

The endurance limits in the case of simultaneous exposure to friction forces and cyclic loads will depend on: sliding speed; contact surfaces; normal contact load, which determines the friction force; composition of the environment.

The data of Figure 6 shows that such types of wear as fretting corrosion significantly (by 1.5-2 times) reduce the fatigue limit of parts. Also significantly reduce the cyclic strength of metal friction pairs oxide films on the surface of friction pairs in the absence of lubricant. Especially strong influence on fatigue strength has the service life of friction wheel pairs (Fig.6).

The main reason for the decrease in endurance due to the processes of setting on the working surfaces of friction units is a large concentration of stresses caused by deep tears, cuts, microcracks (Fig.2 and 5).

The decrease in fatigue strength of steel 35 is characterized by the data in Figure 7. According to the recommendations of Prof. Kindrachuk M.V. [19], if we extrapolate the fretting fatigue curves to the abscissa axis corresponding to the limited endurance based on N=107 cycles, and then project the intersection points onto the fatigue curve without fretting corrosion, we obtain the value of the equivalent stress. The higher the values of these equivalent stresses compared to the nominal stress, the more fatigue (cyclic) strength is reduced by fretting corrosion.

So, for example, according to the curves, we have the following σeq value: $\sigma 2$ = 255MPa; $\sigma 3$ = 151MPa; $\sigma 4$ - 248MPa; $\sigma 5$ = 245MPa (σ-1 = 200MPa), that is, the excess of equivalent stresses over σ-1 is in the range from 20 to 40%.

Analysis of the fractograms presented in Figures 3 and 4 shows that deep scratches, particles of titanium and chromium carbides and other elements were found on the friction surfaces. Moreover, in the braking devices there was damage to the large size of the brake pads of trucks. The transfer of particles of borides and carbides to the surface of the wheels can be explained by the processes of flooding the metal with their subsequent embrittlement, which inevitably leads, as a rule, to the destruction of friction wheel pairs.

Conclusions

1. Fractogram analysis shows that deep scratches, particles of titanium and chromium carbides and other elements were found on the friction surfaces. Moreover, in the braking devices there was damage to the large size of the brake pads of trucks. The transfer of particles of borides and carbides to the surface of the wheels can be explained by the processes of flooding the metal with their subsequent embrittlement, which inevitably leads, as a rule, to the destruction of friction wheel pairs.

2. It is established that such types of wear as fretting corrosion significantly (by 1.5-2 times) reduce the fatigue limit of parts. Also significantly reduce the cyclic strength of metal friction pairs oxide films on their surface in the absence of lubricant. The service life of friction wheel pairs has a particularly strong impact on fatigue strength. The main reason for the decrease in endurance due to the processes of setting on the working surfaces of friction units is a high concentration of stresses caused by deep tears, cuts, microcracks.

3. The process of destruction of brake pads from fatigue begins with the surface of the part. In this regard, the quality of the surface, its structural-phase composition, physical and mechanical properties of the surface layer in most cases are decisive for the intensity of the development of wear processes of parts from fatigue of the tribosystem (friction wheel pairs), which are operated under cyclic loads. The peculiarity of the influence of friction and wear processes on the fatigue strength of metal is that at the time of running-in there is a change in surface roughness, structure and properties of surface layers. As the analysis of literature sources has shown, the effectiveness of the influence of friction and wear processes on the characteristics of fatigue resistance in the case of repeatedly alternating (cyclic) loads is essential, and therefore ignoring this effect during the traditional assessment of the reliability of parts by individual criteria, for example, wear resistance, often leads to an incorrect assessment of the operational durability of the elements of the tribological system of road or rail transport.

4. The long-term (cyclic) durability of brake pads was determined on a specialized installation model 1251 of the company "Instron" (Great Britain). The basis for spraying and surfacing of different types of coatings was normalized steel 35. On the laboratory unit was investigated under tensile-compressive deformation at zero average stress and cycle frequency of 20 Hz. Most of the tests were carried out in salt solutions (NaCl of industrial purity was used.

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Макаренко В. Д., Клюєв О. І., Войтович О. А., Мєшков Ю. Є., Макаренко Ю.В. Дослідження фрикційних властивостей, тривалої (циклічної) міцності матеріалів гальмових колодок автотранспорту

Аналіз фрактограм показує, що на поверхнях тертя було виявлено глибокі подряпини, частинки борідів (карбідів) титану і хрому та інших елементів. Причому, у гальмових пристроях мали місце пошкодження великих розмірів гальмових колодок вантажних автомобілів. Перенесення частинок борідів та карбідів на поверхню коліс можна пояснити процесами наводнення металу з подальшим їх окрихченням, що неминуче спричиняє, як правило, руйнування колісних пар тертя. Встановлено, що такі види зношування як фретинг-корозія значно (в 1,5-2 рази) знижують межу втоми деталей. Також значно знижують циклічну міцність металу пар тертя оксидні плівки на їх поверхні у відсутності мастильного матеріалу. Особливо сильний вплив на втомну міцність має термін експлуатації колісних пар тертя. Основною причиною зниження витривалості внаслідок процесів схоплювання на робочих поверхнях вузлів тертя є велика концентрація напружень, спричинена глибинними виривами, надрізами, мікротріщинами. Процес руйнування гальмових колодок від втоми починається з поверхні деталі. У зв’язку з цим якість поверхні, її структурно-фазовий склад, фізико-механічні властивості поверхневого шару у більшості випадків є визначальним для інтенсивності розвитку процесів зношування деталей від втоми трибосистеми (колісних пар тертя), які експлуатуються в умовах циклічних навантажень. Особливість впливу процесів тертя та зношування на втомну міцність металу полягає в тому, що в момент припрацювання відбувається зміна шорсткості поверхні, структури і властивостей поверхневих шарів. Як показав аналіз літературних джерел, ефективність впливу процесів тертя і зношування на характеристики опору втоми в разі повторно-змінних (циклічних) навантажень мають істотне значення, а тому ігнорувати цим ефектом під час традиційного оцінювання надійності деталей за окремими критеріями, наприклад, зносостійкості приводить часто до невірної оцінки експлуатаційної довговічності елементів трибологічної системи автомобільного чи залізничного транспорту. Тривалу (циклічну) міцність гальмових колодок визначали на спеціалізованій установці моделі 1251 фірми “Інстрон” (Великобританія). Основою для напилювання і наплавлення різних типів покриттів слугувала нормалізована сталь 35. На лабораторній установці досліджували деформації розтягування – стискання при нульовому середньому напруженні і частоті циклів 20Гц. Більшість випробувань проводили в розчинах солі (використовували NaCℓ промислової чистоти). Процес руйнування гальмових колодок від втоми починається з поверхні деталі. У зв’язку з цим якість поверхні, її структурно-фазовий склад, фізико-механічні властивості поверхневого шару у більшості випадків є визначальним для інтенсивності розвитку процесів зношування деталей від втоми трибосистеми (колісних пар тертя), які експлуатуються в умовах циклічних навантажень. Межи витривалості в разі одночасного впливу сил тертя і циклічних навантажень будуть залежати від швидкості ковзання дотичних поверхонь нормального контактного навантаження, яке визначає силу тертя, і складу навколишнього середовища.

Ключові слова: фрактограми, тертя, руйнування, зношування, структурно-фазовий склад, фізико-механічні властивості, колісна пара, трибологія, циклічна міцність, мікротріщини.