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Tribotechnical coatings

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Abstract

Wear and tear limits the possibilities and shortens the operational life of modern technical systems. Therefore, the importance and necessity of consideration of issues aimed at reducing frictional forces and increasing wear resistance cannot be doubted. The paper summarizes the theoretical and applied results of triboresistance studies of detonation coatings of the Nb-Zr-V-Si-C-MgC2 system under conditions of constant loading in the field of sliding velocities. It has been established that the ratio of the quality of the components that make up the surface modified structures changes. It is noted that at the initial test speeds the presence of lower metal carbides that are part of the coating dominates, with an increase in speed under the current load due to solid-phase and diffusion processes, higher ones are formed in the graphite matrix carbides with enhanced thermodynamic properties.

Key words: detonation coatings, wear intensity, structural-phase composition, graphitization.

Introduction

The problem of durability and reliability of moving joints of machine parts stands out against the background of general technical and industrial achievements. The unshakable existence of the problem is based on the phenomenon of friction, which is associated with one of the most pressing situations in modern technology - wear and tear of machine parts and structures. Wear, as a universal phenomenon of degradation due to friction, limits the capabilities and shortens the service life of modern technical systems. Hence the importance and necessity of considering issues aimed at reducing friction forces and increasing wear resistance.

Objective

The purpose of the work is to generalize the theoretical and applied results of studies of tribological resistance of detonation coatings of the Nb-Zr-V-Si-C-MgC_2 system under constant load conditions in a sliding velocity field.

Materials and methods of research

The preparation of the powder mixture was carried out by mechanochemical synthesis using a laboratory attriter of the “IES-1-0.5” type. To prevent sticking of powders to the chamber walls and to optimize the spheroidization process, an anti-adhesive additive in the form of zinc stearite was added to the mixture.

The study of the features of friction surfaces in which activation processes occur, affecting the intensity of mechanochemical reactions, was carried out using a complex method of physical and chemical analysis, including metallography (optical microscope "Neofot-32"), durometric analysis (hardness tester M-400 from LECO), scanning electron microscopy (scanning electron microscope JSM-840), X-ray structural phase analysis (diffractometer DRON-UM1).

The tribological properties of the coatings were assessed by friction of model samples according to the end pattern under conditions of distributed contact. The tests were carried out in continuous sliding mode at a load of 15 MPa, the thickness of the coatings after finishing was 0,750-0,80 mm, roughness Ra = 0,32-0,63.

Tests of detonation coatings were carried out according to a program in which, under similar conditions, coatings of the VK15 type and coatings dusted with alloyed nichrome powder were tested for comparison.

Research results

The main factors determining the course of friction and wear processes are external influences, which determine the degree and gradients of elastoplastic deformation, temperature, level of activation, a number of derivative phenomena and ultimately determine the leading type of wear.

Based on the test results, averaged graphical dependences of wear intensity and friction coefficients in the sliding velocity field are presented at a constant load of 15 MPa (fig. 1). With a monotonous increase in sliding speed under constant load conditions throughout the entire operating test range, the lowest values of wear intensity (curve 1) and friction coefficients (curve 1'), corresponding to normal mechanochemical wear, are found in coatings of the Nb-Zr-V-Si-C-MgC_2 system.

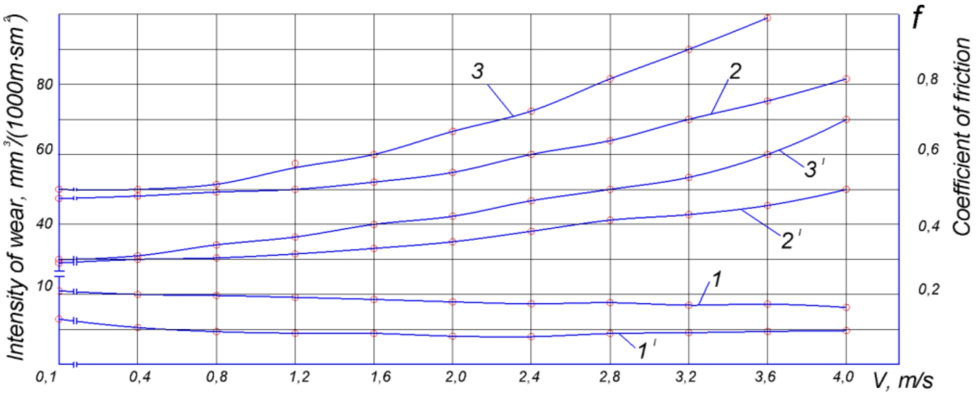


Fig. 1. Dependence of wear intensity (1, 2, 3) and friction coefficient (1', 2', 3') on the sliding speed of coatings: 1, 1' – Nb-Zr-V-Si-C-MgC_2 systems; 2, 2' – VK15 (WC-Co); 3, 3' – based on nichrome (Ni-Cr-Al-B). At P = 15 MPa.

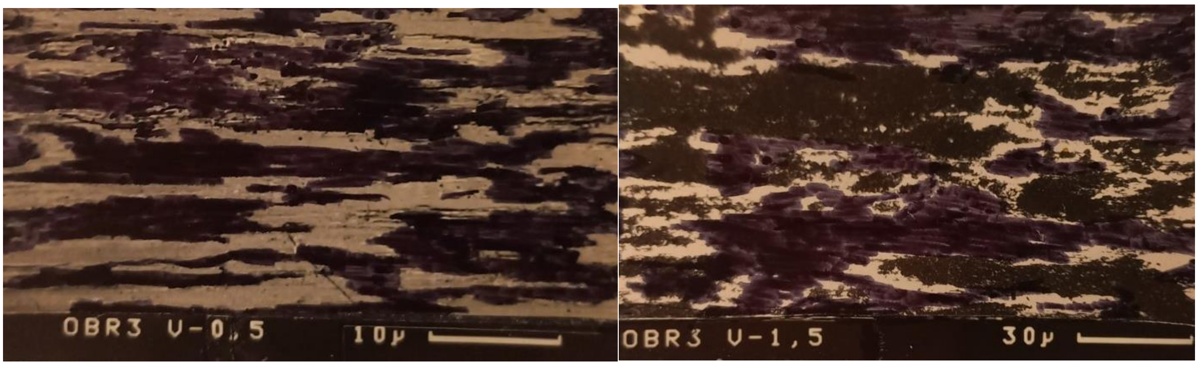
Studies of the composition and structure of coatings have made it possible to establish that their structure consists mainly of a finely dispersed mixture, in which strengthening formations are presented in the form of carbide and silicide phases and intermetallic compounds, which are distributed in a solid solution matrix and, thus, represent a structure close to structure of dispersion-strengthened materials. The nature of the interaction of the coating components was determined using the Lanscan program, and it was found that the distribution spectra of Nb, Zr and V along the scan line correlate with the phases of silicon and carbon, which confirms their interaction with the production of the corresponding carbides and silicides, and also determines the possibility of the formation of both solid solutions and ternary compounds.

Analysis of oxygen scanning lines with elements included in the nanocoating showed their phase alignment, which indicates their chemical interaction, causing passivation of the working surface due to the formation of secondary oxide structures. Thus, the obtained research results, supplemented by X-ray diffraction analysis data, allow us to conclude that the initial coatings are an ultradisperse conglomerate of almost uniformly distributed particles of silicides NbSi, $NbSi_2$, ZrSi, Zr_2Si, VSi_2, V_5Si_3 and extensive colonies of carbides NbC, Nb_2C, ZrC, VC, V_2C in a fine-grained matrix of solid solutions of Nb in β-Zr, β-Zr in Nb, V in Nb and Zr.

Under conditions of structural activation under friction loading, the passivating role of secondary structures is played by surface films of oxides and, first of all, SiO_2 and V_2O_5, which are characterized by increased density and adhesive strength, as well as high-quality compact oxides that form Nb and Zr. In addition, the formation of solid solutions of oxygen in niobium and zirconium occurs. Thus, according to X-ray diffraction analysis, a slight increase in the density and lattice period of zirconium has been established, which is, in our opinion, a consequence of the introduction of oxygen atoms into the octahedral pores of the hexagonal lattice and, as a result, the formation of a solid solution. However, the main factor that minimizes molecular adhesion interaction, preventing setting and destruction, is the formation of a surface film of structurally free α-graphite, the formation of which is caused by the thermal decomposition of magnesium carbide [1].

Moreover, the higher the temperature, the greater the amount of carbon converted into graphite and the more graphite is formed. The process is similar to graphitizing annealing. Thus, under friction loading, the running-in of surfaces whose composition includes magnesium carbides, in a certain sense, can be considered as a specific type of heat treatment, accompanied by graphitization.

In figure 2 shows the topography of friction surfaces coated with a graphite film. In fig. 2.b (at V = 1,5 m/s and P = 15 MPa) the graphite film occupies almost the entire working surface, which helps to increase the actual contact area, reduce the specific load due to filling and smoothing surface microroughnesses, microcracks, and causes the fixation of particles graphite in microcavities of contact interfaces and ensures a reduction and stabilization of the friction coefficient, in addition, it helps to lower the temperature, level out and reduce deformation fields. The contact zone, which directly forms the friction surface, is a thin plastically deformable layer, which, according to micro-X-ray spectral analysis performed on a MAP-3 device (probe diameter 1 μm), is a conglomerate of dispersed phases of complex and simple oxides and compounds of silicides and carbides components included in coating composition.



a b

Fig. 2. Topography of friction surfaces coated with a graphite film P = 15 MPa:
a - V=0,5 m/s; b - V=1,5 m/s

In figure 3 shows an electron diffraction pattern from the surface of the contact layer. The presence of diffusion halos with textured maxima indicates that the structure corresponds to a directional orientation in the friction field. According to the authors, the pattern of its formation can be represented as a process of amorphization and mechanochemical alloying, including dispersion, grinding of a dispersoid with particles of oxides, silicides and their transformation under the influence of local temperatures and pressures into an oriented ultradisperse structure, which represents a substance with liquid-like properties.

Fig. 3. Electron diffraction pattern from the surface of the contact layer
at V=0,5m/s and P=15 MPa.

In figure 4 shows the qualitative distribution of chemical components over the working surface area. The results of physicochemical phase analysis of secondary structures in the form of surface films based on graphite made it possible, by analyzing the diffraction pattern, to identify carbide, silicide and oxide phases with a significant degree of probability. At the same time, it was possible to establish the patterns of structural changes in the identified phases during their reorganization, which is accompanied under friction conditions by both the transformation of the structural-phase composition of secondary structures, caused by varying external influences (sliding speed, load, temperature), and the stability of the dynamic sequence of the processes of their destruction and formation during friction. Thus, the ratio of the quality of the components that make up the surface structures changes, but their general order (the dynamics of formation and destruction) remains constant.

Thus, in the testing area up to 2,0 m/s, the dominant factor is the presence of low metal carbides included in the coating composition and the presence of their oxide reagents. With an increase in sliding speed under the influence of increased shear strains, temperatures and effective load, as a result of solid-phase tribochemical and diffusion processes in the graphite matrix, a balanced presence of higher carbides is formed, characterized by increased thermodynamic stability, which corresponds to the manifestation of the structural adaptability of materials during friction [2].

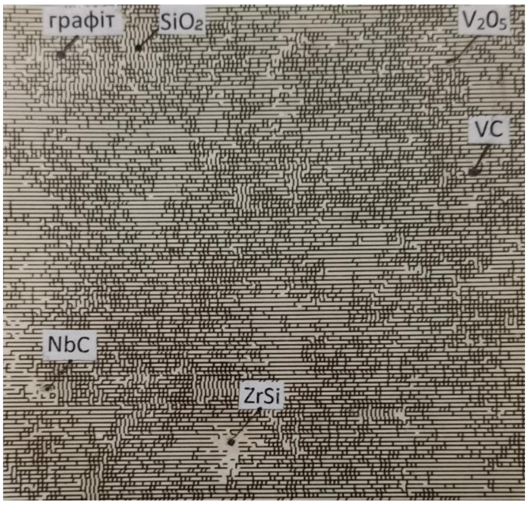


Fig. 4. Qualitative distribution of chemical components over the working surface area.

The nature of the change in the friction coefficient (fig. 1, curve 1') is consistent with the established wear pattern. The decrease in its value and stability with increasing sliding speed confirm the high performance of the studied coatings of the Nb-Zr-V-Si-C-MgC_2 system.

In accordance with the presented test results, the developed niobium-based coatings meet high tribological characteristics. The possibility of increasing the operational reliability of coatings through the use of magnesium carbide in their composition, which promotes the formation of carbide graphite under friction loading, has been theoretically substantiated and experimentally confirmed. It should be noted that the presence of magnesium carbide is an effective means of regulating wear and ensuring service life through the formation of modified surface films based on carbide graphite, which, in cooperative mutual consistency with secondary structures, ensure a stable manifestation of minimizing the tribological properties of coatings. Based on this, the amount of magnesium carbide in the coating material may influence the stability of normal mechanochemical wear.

Also tested under similar test conditions were VK15 coatings (fig. 1, curve 2), which are the most widely used tribological material for wear protection of a large range of critical parts of various designs and purposes. However, under the conditions of these tests at sliding speeds of more than 1,7 m/s, the temperature factor begins to influence the tendency to reduce wear resistance.

Coatings based on nichrome (fig. 1, curve 3) alloyed with aluminum and boron, starting from 0,4 m/s, are characterized by a monotonous increase in wear intensity with increasing speed. The structure of the coatings is represented by a nickel-based solid solution and a dispersed mixture of strengthening phases of nickel aluminides, chromium borides, and complex boride compounds. The microhardness was about 10,6 GPa. The protective functions of secondary structures representing heterophase oxide thin-film objects are suppressed by the development of plastic deformation with increasing sliding speed.

Niobium-based coatings containing magnesium carbide and not containing expensive and scarce components meet environmental safety requirements and, due to their operational capabilities, have the prospect of widespread use for the production of competitive tribotechnical equipment.

The most effective use of the studied coatings is to improve the quality of operation of friction units when strengthening and restoring moving joints of control mechanisms, hinges of guide surfaces, cams, sliding supports, lever parts, high-speed and heavily loaded units in which the use of traditional oils and lubricants is undesirable.

It should be noted that the development of coatings containing modified films of carbide graphite, the results of their tests in various friction and wear modes will significantly expand the arsenal of achievements of modern tribological technology.

The studied niobium-based coatings can be used to restore and strengthen worn parts using any technological methods using powder materials.

Conclusions

1. Through theoretical premises and experimental studies, the optimal structural-phase composition of coatings of the Nb-Zr-V-Si-C-MgC_2 system was realized. A high level of performance characteristics of coatings was noted, achieved by optimizing the chemical composition and spraying technology.

2. Using modern methods of physicochemical analysis, the structural-phase composition of coatings was studied, the structure of the surface modified layer based on carbide graphite, which prevents molecular adhesion interaction and minimizes friction parameters, was determined.

3. It has been established that the ratio of the quality of the components that make up the surface modified structures changes, it is noted that at the initial test speeds the presence of lower metal carbides that are part of the coating dominates, with an increase in speed under the current load due to solid-phase and diffusion processes, higher ones are formed in the graphite matrix carbides with enhanced thermodynamic properties.

4. The test results form the basis for the development of composite coatings with improved tribological characteristics, which will expand the arsenal of achievements of modern tribological technology. In addition, the developed powders, which do not contain scarce and expensive components, can be used for restoration and strengthening by any technological methods using powder materials.

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Зємляной А.О., Бись С.С., Щепетов В.В., Харченко С.Д., Харченко О.В. Триботехнічні покриття

Зношування обмежує можливості та скорочує строки експлуатації сучасних технічних систем. Тому важливість та непохідність розгляду та вирішення питань зниження сил тертя та підвищення опру зношуванню не викликає жодного сумніву. В роботі зроблено узагальнення теоретичних та практичних результатів досліджень трибостійкості детонаційних покрить системи Nb-Zr-V-Si-C-MgC_2 в умовах постійного навантаження ковзанням. Встановлено, що змінюється співвідношення якості компонентів, що входять до складу поверхнево модифікованих структур. Відмічено, що на початкових швидкостях випробування домінує наявність нижчих карбідів металів, які входять до складу покриття, при збільшенні швидкості під струмовим навантаженням за рахунок твердофазних і дифузійних процесів вищі утворюються в карбідах графітової матриці. з підвищеними термодинамічними властивостями.

Ключові слова: детонаційні покриття, інтенсивність зношування, структурно-фазовий склад, графітизація