UDC 629.083

V.V. Shchepetov[1], O.V. Kharchenko[2], S.D. Kharchenko[1].
([1]General Energy Institute of NAS of Ukraine)
([2]National Aviation University, Ukraine)

Regulations of the formation of heat-resistant coatings at elevated temperatures

The choice of Cr–Si–B–MgC_2 composition is justified and its optimal composition for spraying wear-resistant coatings loaded with friction at high temperatures are justified. It is shown that the main influence on the properties, structure and stability of heterogeneous coatings is exerted by alloying elements at certain concentrations, as well as technological parameters of coating application.

Introduction

A characteristic feature of most parts of machines and mechanisms of energy facilities that work under conditions of high technological loads is the need to maintain performance at elevated temperatures. Among a number of indicators of operational factors, temperature occupies one of the main places and is an important characteristic of friction conditions, and the thermal processes that occur during this directly affect the formation of physical, chemical and mechanical properties of surface layers.

One of the modern technological methods that allows you to apply high-quality coatings, which significantly increase the service life of parts in conditions of friction at high temperatures, is detonation-gas spraying. The development of heat-resistant coatings that minimize friction parameters at elevated temperatures is one of the priority areas of modern tribotechnical materials science.

The purpose of the work is to summarize the results of theoretical and applied research on the tribological resistance of heat-resistant Cr-Si-B-MgC_2 coatings intended for the protection of machine parts operating under conditions of high-temperature friction.

Materials and methods

In this work, the patterns of friction and wear of coatings of the Cr–Si–B–MgC_2 system obtained by the detonation-gas method from powder materials of the resource-raw material base of Ukraine [1] were investigated. A coating with a thickness of 0.25–0.30 mm with a roughness of Ra=0.55–0.35 was applied on the modernized Dnipro-3 installation on ring samples made of steel 45 (sorbitol-trostite structure). The tests were carried out on a universal friction machine of the UMT-2 type at elevated temperatures (V=1.5 m/s, P=5.0 MPa).

X-ray phase analysis of coatings was carried out using a DRON-UM1 diffractometer in Co radiation (voltage 25 kV, current 15 mA). The structure was studied using a Camscan electron scanning microscope. The ZAF-4FLS program was used for chemical analysis of secondary structures. Metallographic research was performed on a MIM-8 microscope and a PMT-3 microhardness tester under a load of 0.5 N. The temperature was measured at a distance of 1-2 mm from the friction surface with chromel-drop thermocouples.

Results and discussion

Reasoned selection of the components of the Cr-Si-B-MgC_2 composition [2] meets the basic conditions of stable manifestation of structural adaptability and minimization of friction indicators. The choice of the optimal composition of coatings involves the assessment of the influence of components on the structure and properties [3]. The choice of raw material for chromium powder, which is a certified material, is due to the possibility of its stepwise alloying, especially elements with limited solubility [4].

The data of micro-X-ray spectral analysis of Cr-Si-B-MgC_2 coatings made it possible to classify the structure as a thin conglomerate (>75% of the volume), which consists of ultradispersed inclusions enriched with boron and carbides.

The characteristics of coatings are mainly influenced by the structure and phase composition of the surface layer and the surface films formed during friction. The test data, showing the functional dependence of the wear intensity of the coatings on the temperature near the friction surfaces, are presented in Fig. 1.

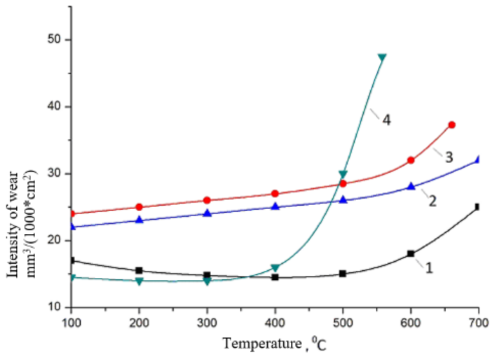

Fig. 1. Dependence of the intensity of wear of coatings: Cr-Si-B-MgC2 (1), Al2O3-Cr2O3 (2), Ni-Cr-Al-B (3), WC-Co (4).

It has been confirmed that the surface films shielding the adhesive interaction in the tribocontact zone have an ultradispersed structure and consist of a mixture of phases of the composite coating and the products of their interaction with air oxygen. According to their stoichiometric composition, they are a complex, difficult-to-activate complex in the form of a finely dispersed mixture of $Cr2O_3$, SiO_2, B_2O_3 oxides and complex phases such as silicide oxides $CrSi_2O_4$ and $SiCrO_2$ chromates, which under the conditions of contact pressures and temperatures that cause heat-resistant surface structures Thus, the formation of secondary structures is determined by the phase and chemical composition of the surface layer, with a microhardness of 10–21 hPa (at the initial 15±0.5 hPa). This is due to the influence of mechanical and thermal pulses, as well as the diffusion of alloying elements and atmospheric oxygen, which cause phase transformations, redistribution of structural components and changes during friction of the highly dispersed heterogeneous quasi-equilibrium wear-resistant structure. It should be noted that in terms of their structure, thin-film objects are close to dispersion-reinforced composite material. In fig. 2 presents an electronic photograph of the surface structure of the coating. The nature of the distribution of dispersed inclusions is oriented in the direction of force effects during friction loading, which is a confirmation of the formation of wear-resistant surface structures by self-adaptation mechanisms.

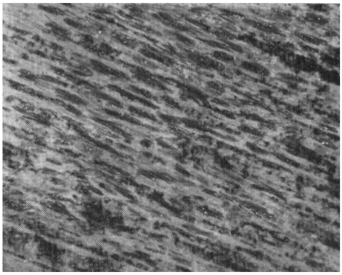

Fig. 2. Electron microscopic friction surface of the Cr-Si-B-MgC2 coating after testing at a temperature of 500°C: x20,000

Metallographic analysis of the samples shows that there are no visible damages on the friction surface, and individual sticking points arising under the given friction conditions are localized in the thinnest surface layers.

From the energy point of view, this transformation of secondary structures can be considered as adequate elementary mechanisms of adaptation of surface layers in the process of structural adaptability of the friction system.

As the temperature rises, the complex of surface phenomena intensifies, which is due to the distortion of crystal lattices during plastic deformation due to fluctuating stresses arising during friction. In addition, the appearance of point and multidimensional defects activate tribochemical reactions. As a result, when the critical temperature is reached, which for the tested coating (Fig. 1, curve 1) is ~700°C, destructive processes develop, which lead to the transition to unacceptable damage, with subsequent strengthening and possible destruction. A thin-film conglomerate of oxide phases, which prevents adhesive-molecular interaction of contact surfaces, is a complex object, the integral properties of which, in turn, depend on the individual properties of simple oxides. The microhardness of chromium oxide monotonically decreases as the temperature increases. At the same time, metastable chromium oxide CrO_3 at a temperature of ~350–400 °C turns into Cr_2O_3, which is evidenced by a change in microhardness. The formation of Cr_2O_3 is also accompanied by a decrease in volume. The microhardness of thermally stable boric anhydride gradually decreases up to the melting point.

The microhardness of the surface films, which are oxides of double spinel-type compounds, such as MgO-Cr_2O_3, MgO-SiO_2, Cr_2O_3-SiO_2, and Cr_2O_3-B_2O_3, monotonically decreases with increasing temperature; in addition, it can be assumed that spinels are prone to the formation of solid solutions with simple oxides of divalent and trivalent metals. It was established that the microhardness of MgO-SiO_2 magnesium silicates decreases at all temperatures if chromium is dissolved in them.

Conclusions

The composition, structure, tribo and heat resistance of Cr-Si-B-MgC_2 coatings obtained by gas-thermal methods from elements of the resource-raw material base of Ukraine were studied. High adhesion, physical and mechanical characteristics, heat resistance and wear resistance of such coatings when working at elevated temperatures correspond to similar properties of heat-resistant high-alloy alloys.

Oxide structures, carbides formed under conditions of high-temperature wear on the friction surfaces of detonation coatings, depending on the chemical composition, can be in different states. At elevated temperatures, the oxide structures enter a more stable state, which causes a change in their mechanical properties.

The temperature dependence of the microhardness of the surface structures is monotonic, but jumpiness is also observed if there are polymorphic transformations or transformations of metastable states into more stable and stable ones upon heating and cooling. Indicators of microhardness are uniform, because particles of inclusions and impurities are dissolved in the oxide structures, which significantly affect the microhardness, and therefore, the properties of oxides of both simple and complex compositions.

References

1. Patent No. 125777 of Ukraine. Composite wear-resistant material; C22C 27/06 Babak V.P., Shchepetov V.V., Kharchenko S.D. those others // Appl. from 01.06.2022; Bul. No. 22.
2. Variations in strain affect friction and microstructure evolution in copper under a reciprocating tribological load / S. Becker, K. Schulz, D. Scherhaufer et al. // Journal of Materials Research. – 2021. – 36. – P.970–981.Скороход, В.В., Уварівa, І.В., Рагуля А.В. Фізико-хімічна кінетика в наноструктурних системах. К.: Академперіодика, 2001, 180 с.
3. Residual Life of Metal Structures under Complex Dynamic Deformation Stresses / P. Louda, A. Sharko, D. Stepanchikov // Materials. – 2021. – 14. – P. 2090.Yu-Lei Zhang, He-Jun Li, Xi-Yuan Yao, et al. Oxidation protection of C/SiC coated carbon/carbon composites with Si-Mo coating at high temperature. Corrosion Science. 2011, v. 53, p. 2075-2079.
4. Microgeometrical characteristics of electrospark coatings in the initial state / V.V. Tokaruk, O.O. Mikosianchyk, R. G. Mnatsakanov, N.O. Rohozhyna // Problems of Tribology. – 2020. - V. 25, No 4/98. – P.33-39.