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INVESTIGATION OF THE HYDROABRASIVE WEAR OF EPOXY COMPOSITES WITH TWO-COMPONENT FILLER

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We study the influence of the content of a two-component filler $(Al_2O_3 + B)$ on the wear rate of epoxy composite coatings. We produced coatings with the optimal characteristics of wear that can be used in aqueous abrasive media. It is shown that the materials containing aluminum oxide (60 m.p.) and crystalline boron (40 m.p.) per 100 m.p. of the ED-20epoxy oligomer and 10 m.p. of a polyethylenpolyamine hardener are characterized by the minimum intensity of wear $I = 0.36\%$ and the coefficient of wear resistance $K_{wr} = 3.66$ as compared with the epoxy matrix.

Keywords: epoxy composite, wear intensity, coefficient of wear resistance, hardness.

The traditional procedures used for the solutions of the problems of materials science enable us to save significant amounts of the power resources as a result of the development of modified materials with improved operating characteristics. At present, functional protective and wear-resistant coatings on the epoxy basis are extensively used for the purposes of hardening of the surfaces of machine parts and the mechanisms of technological equipment. In this connection, special requirements are imposed on the coatings operating under the conditions of hydroabrasive wear. The improvement of the operating characteristics of composite materials (KM) is attained by introducing in the matrix various plasticizers, modifiers, and fillers of different nature with different ranges of particle sizes.

As a result of detailed investigation of the physicochemical processes running in the process of hydroabrasive wear of composite materials, it was established [1–3] that the main factors determining the mechanism of their fracture are as follows: the mode of operation of the material, the angle between the vector of the velocity of particles and the surface of a workpiece (attack angle), the ratio of the microhardnesses of particles of the hydroabrasive material and the material of the coating, and (directly) the properties and structure of the worn material. It is worth noting that the service life of the friction units of the parts of machines, mechanisms, and aggregates is, in numerous cases, determined by the physicomechanical properties of the surface layers of materials from which these parts are produced. If dust, sand, and other foreign admixtures penetrate into the friction zone, then the hydroabrasive wear of the working surfaces becomes more intense [4, 5]. Therefore, as one of directions of the improvement of the properties of composite materials, we can mention the optimization of their components, including the content of the two-component filler.

The aim of the present work is to study the wear resistance of the epoxy composites with two-component fillers.

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Materials and Method of Investigation

As the main component of the matrix in the process of formation of composite materials, we used an epoxy-diane (4,4′-isopropylidenediphenol) oligomer of the ED-20 grade (GOST 10587-84) characterized by a high cohesive strength, low shrinkage, and high technological efficiency of its application to the surfaces with complex profiles. To cure the epoxy compositions, we used a polyethylene-polyamine (PEPA) curing agent (TU 6-05-241-202-78), which enables one to cure materials at room temperature. The composite materials were cured by introducing a curing agent in the composition with a stoichiometric ratio of the components ED-20 : PEPA = 100 : 10 (m.p.). As fillers in the course of formation of the composite material, we used an aluminum-oxide (Al_2O_3) powder with particle sizes of 63 μm and a powder of crystalline boron (CB) with the range of particle sizes 8–12 μm.

The epoxy composite containing particles of the two-component filler was formed by using the following technology: preliminary dosing of ED-20 epoxy-diane resin, its heating up to $T = 353 \pm 3°K$, and holding at this temperature for 20 ± 0.1 min; dosing of the fillers and their subsequent introduction in the curing agent; hydrodynamic mixing of the ED-20 oligomer with the two-component filler for 1 ± 0.1 min; ultrasound treatment of the composition for 1.5 ± 0.1 min; cooling of the composition down to room temperature for 60 ± 5 min; and introduction of the PEPA curing agent with subsequent mixing of the composition for 5 ± 0.1 min. Then the composite material was cured in the following experimentally established mode: formation of specimens and their holding for 12.0 ± 0.1 h at a temperature of $293 \pm 3°K$, heating with a rate $v = 3°K/min$ up to $T = 393 \pm 3°K$, holding of the composite material for 2.0 ± 0.05 h, and slow cooling down to a temperature of $293 \pm 2°K$. To stabilize the structural processes in the matrix, the specimens were held for 24 h in air at a temperature of $293 \pm 2°K$ prior to subsequent experimental investigations.

The relative resistance of the composite material to the action of hydroabrasive materials was found by the method of testing of materials and coatings for the gas-abrasive wear with the help of a centrifugal accelerator (GOST 23201-78). This method enables one to model the actual process of wear of parts of the mechanisms under the action of hydroabrasive materials (Fig. 1) [1]. The rate of rotation of the rotor of the centrifugal accelerator was equal to 3000 rpm. As a hydroabrasive suspension, we chose a mixture of technical water and abrasive particles of quartz sand (with volume ratio 5 : 1). We tested specimens $30 \times 20 \times 4$ mm in size for an attack angle of the hydroabrasive mixture equal to 45°. The mass of quartz sand consumed in our investigations was 9 ± 0.1 kg.

The relative intensity of wear is given by the formula

$$I = \frac{m_0 - m_{\text{end}}}{m_0} \cdot 100\%, \tag{1}$$

where m_0 and m_{end}, kg, are the masses of the specimen at the beginning and at the end of the tests, respectively.

The coefficient of wear resistance is given by the formula

$$K_{wr} = \frac{I_E}{I}, \tag{2}$$

where I_E and I, %, are the relative intensities of wear for the reference (45 steel) and composite materials, respectively.

The specimens were weighed prior to and after the tests in a DRS-8000 “SHIMADZU” electronic balance with an accuracy of 0.02 ± 0.001 g.

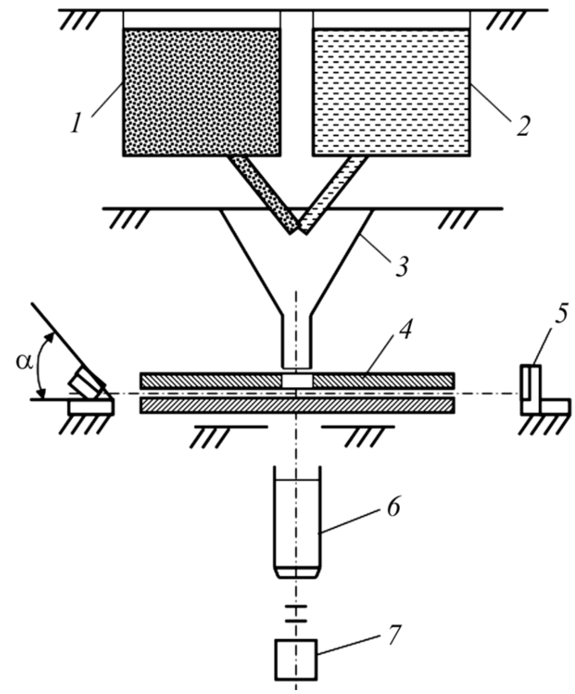

Fig. 1. Schematic diagram of a centrifugal accelerator: (1) tank with abrasive particles, (2) tank with industrial water, (3) vessel for mixing abrasive particles with water, (4) rotor, (5) sample with coating, (6) electric motor, (7) tachometer.

The hardness of the investigated materials was measured by the Brinell method according to GOST 9012-59 by using a TShP-4 device at a temperature of $293 \pm 2°K$. The level of hardness was found by the formula

$$HB = \frac{0.102 \cdot 2F}{\pi D(D - \sqrt{D^2 - d^2})}, \quad (3)$$

where D is the diameter of the ball, mm, d is the diameter of indentation in the studied material, mm, and F is a load acting upon the ball, N.

Results and Discussion

For the sake of comparison, we studied the hydroabrasive wear resistance of the following materials: 45 steel, epoxy matrix subjected to the ultrasound treatment, KM-1 [Al_2O_3 (60 m.p.) + CB (40 m.p.)], KM-2 [Al_2O_3 (70 m.p.) + CB (35 m.p.)], and KM-3 [Al_2O_3 (80 m.p.) + CB (30 m.p.)].

It is known [5–7] that, in the process of hydroabrasive wear, there are two cases of interaction of abrasives with the analyzed material: impacts for the right attack angle ($\alpha = 90°$) and skew impacts ($0 < \alpha < 90°$). We studied composite materials in the case of skew impacts, namely, for an attack angle $\alpha = 45°$. In this case, the character of damage of the surface strongly depends on the tangential component of the momentum and on the resistance of the material to the action of tangential forces upon the surface.

In this case, tangential stresses are formed on the surface of the material. These stresses are responsible for the appearance of micro- and macroshears and normal stresses, which induce plastic strains in the surface layer of the composite material.

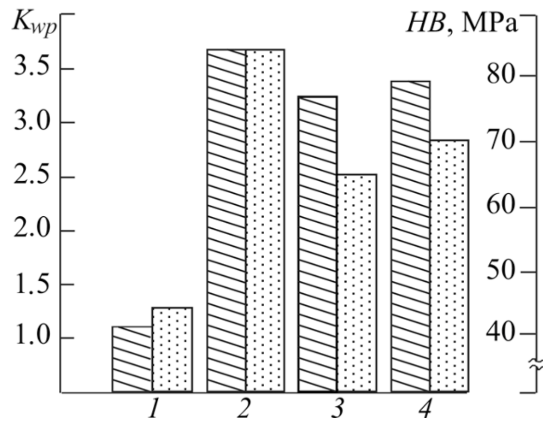

Fig. 2. Dependences of the wear-resistance coefficient (▧) and hardness (⬚) on the content of the two-component filler: (1) matrix (reference sample), (2) KM-1, (3) KM-2, (4) KM-3.

The analysis of the relative intensity of wear of the investigated materials makes it possible to conclude that the highest intensity of wear (I = 1.32%) is exhibited by the reference specimen made of 45 steel. As for the developed materials, the maximum value was observed in the epoxy matrix modified by the ultrasound treatment (I = 1.23%). It is possible to assume that, in this case, the intensity of wear depends not only on the contact interaction of the material surface with abrasive particles and the angle of their attack but also on the hardness of the coating surface. It is worth noting that the composites containing the two-component filler are characterized by lower degrees of wear (I = 0.36% for KM-1, 0.41% for KM-2, and 0.38% for KM-3).

On the surfaces of the composites, we discovered insignificant scratches, which reveals the chaotic microshears of the materials. This is typical of the wear of hard and rigid heterogeneous composite materials. The least intensity of wear (I = 0.36%) was observed for the KM-1 composite in which the contents of particles of aluminum oxide and crystalline boron were 60 and 40 m.p., respectively. The results of previous investigations demonstrate that the material with the indicated two-component filler has improved adhesive, physicomechanical, and thermal properties. Thus, the intensity of wear of this material is lower as compared with the epoxy matrix. An important role is also played by the absence of deformation action of abrasive particles upon the surface of the coating (these particles do not scratch the surface but create pits or grooves and induce, in the case of multiply repeated action, local fatigue fractures). It is possible to assume that this is one of the main causes of the increase in the intensity of wear of the KM-2 and KM-3 composites, as compared with KM-1, under the identical conditions of investigations. Therefore, we can state that the KM-1 composite with two-component filler can be used for the operation under the conditions of action of hydroabrasive media.

As a result of the investigation of the dependence of the coefficient of wear resistance (K_{wr}) on the content of the two-component filler, we managed to confirm the results of previous experimental studies. It was established that the epoxy matrix has the lowest coefficient of wear resistance (K_{wr} = 1.07) (Fig. 2). We proved that the introduction of a two-component filler in the epoxy oligomer noticeably increases the indicated coefficient. The highest value of K_{wr} is observed for the KM-1 material (K_{wr} = 3.66). It is worth noting that the coefficients of wear resistance of the KM-2 and KM-3 composites are lower (3.21 and 3.47, respectively) than for the KM-1 material but much higher than for the epoxy matrix. Hence, the produced materials can be used as coatings for the protection of the technological equipment under the conditions of influence of hydroabrasive media.

As one of the main criteria in the analysis of the operating characteristics of composites, one can use the characteristics of hardness of coatings. It was established that the matrix has the lowest hardness (HB = 45 MPa) among all studied specimens (Fig. 2). The maximum hardness is observed for KM-1 (HB = 84 MPa), which is in good agreement with the results of testing for the wear resistance of the same specimens. It is worth noting that the KM-2 and KM-3 composites have lower hardnesses (65 and 70 MPa, respectively) than the KM-1 material. However, we note that the former materials can also be used as protective coatings operating under conditions of action of the hydroabrasive media.

CONCLUSIONS

We determine the intensity of wear of some epoxy composites with two-component fillers under the conditions of action of hydroabrasive media. It is shown that the mechanism of wear of composite materials is determined by the physicomechanical fracture processes and insignificant microshears in the surface layer of the materials under the action of abrasive particles for a certain angle of attack of the hydroabrasive mixture ($\alpha = 45°$). In this case, the material containing aluminum oxide (60 m.p.) and crystalline boron (40 m.p.) per 100 m.p. of the ED-20 epoxy oligomer and 10 m.p. of the PEPA curing agent is characterized by the lowest intensity of wear ($I = 0.36\%$) as compared with 45 steel. In addition, the developed composite material with two-component filler is characterized by the high coefficient of wear resistance (from $K_{wr} = 1.07$ to $K_{wr} = 3.66$) and high hardness (from HB = 45 MPa to HB = 84 MPa) as compared with the epoxy matrix. This composite is recommended for the protection of the parts of units and mechanisms with complex profiles of the surfaces against the hydroabrasive wear.

REFERENCES

1. A. V. Buketov, P. D. Stukhlyak, and I. V. Chykhira, *Properties of Epoxy Plastics Modified by Ultrasound* [in Ukrainian], Krok, Ternopil' (2011).
2. A. P. Kudrin, V. F. Labunets, O. A. Vishnevskii, and A. Rizk, "Wear resistance of coatings under the conditions of hydroabrasive wear," *Promyslov. Hidravl. Pnevmat.,* No. 4 (6), 67–72 (2004).
3. J. Wang, "Abrasive waterjet machining of polymer matrix composites: cutting performance, erosive analysis, and predictive models," *Int. J. Adv. Manufactur. Technol.,* **15**, 757–768 (1999).
4. D. Shanmugam, T. Nguyen, and J. Wang, "A study of delamination on graphite/epoxy composites in abrasive waterjet machining," *Compos. Part A,* **39** (6), 923–929 (2008).
5. P. D. Stukhlyak, A. V. Buketov, and O. I. Red'ko, *Epoxy-Diane Composites: Technology of Formation, Physicomechanical and Thermal Properties* [in Ukrainian], Krok, Ternopil' (2011).
6. P. N. Bogdanovich, "Specific features of wear of the epoxy polymers," *Tren. Iznos,* **9**, No. 6, 1000–1006 (1988).
7. A. I. Burya, "Friction and wear of carbon plastics based on aromatic polyamides," *Tren. Iznos,* **22**, No. 6, 677–683 (2001).