Estimation of wear resistance of oxide and ceramic coatings in the hydroabrasive wear conditions

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Abstract. For wear compensation of the components made from aluminum alloys and operated in the conditions of hydroabrasive wear, we suggest the method of reconditioning and hardening, which combines the advantages of deposition in the argon medium and plasma electrolytic oxidation. The model of hydroabrasive wear of oxide and ceramic coatings obtained by plasma electrolytic oxidation is suggested. The requirements to the composition and structure of coatings at their usage in the hydroabrasive wear conditions are reasoned.

Key words: oxide and ceramic coating, hardened layer, electrolyte, plasma electrolytic oxidation, combined method, wear resistance, hydroabrasive wear.

1. Introduction.

One of the most advanced methods of considerable increase of wear resistance and component life is plasma electrolytic oxidation (PEO) [1-4].

To the main advantages of plasma electrolytic oxidation, we can refer the following: the applied equipment simplicity, possibility to obtain coatings of different composition and purpose, possibility to treat geometrically complicated products, versatility, environmental safety [3-5].

In spite of obvious advantages, the plasma electrolytic oxidation method is not free from disadvantages. One of them is impossibility to use plasma electrolytic oxidation (PEO) to recondition the worn components.\textsuperscript{[4-6]}

To eliminate the above-mentioned disadvantage at reconditioning of the components manufactured from aluminum alloys and operating in the conditions of hydroabrasive wear, we recommend the combined method, which consists in the combination of the advantage of deposition in the argon medium and plasma electrolytic oxidation.

It is important to note that wear resistance increase of the reconditioned components is possible on the ground of the reliable information about the mechanism of their surface destruction with abrasive particles and knowledge of the processes that take place in the wearing layer under the abrasive effect. The study of these processes nature allows determining the properties of the material of the oxide and ceramic coating, which maximally determine its capability to resist to the destruction when interacting with abrasive particles and to formulate the requirements to its composition and structure.
2. Materials and methods.

Estimation of wear resistance of oxide and ceramic coatings obtained by plasma electrolytic oxidation (PEO) was done on the deposited surfaces of aluminum alloy AK7ч. The material selection was determined with the fact that it is used to manufacture the components of self-priming pumps of type «СВН». These pumps are used for pumping water, milk, alcohol, gasoline, kerosene, diesel fuel.

For deposition, we used welding wires of trademarks: Св.АК10, Св.АМг3, Св.А97. Deposition in the argon media was done with the help of welding unit УДГ-180.

The hardening of the deposited coatings (after the corresponding machining) was performed on the installation of plasma electrolytic oxidation (PEO), performing in the anode-cathode mode.

As electrolyte we used the solution of the following composition, g/l of distilled water: KOH – 4…6, H3BO3 – 20…30, compositional material – 20…30. Fine powders of aluminum oxides, titanium, ferrum, chrome and silicium were used as the compositional material.

The test for wear was done according to GOST 17367 «Metals. Test method for abrasive wear at friction on fixed abrasive particles» on friction machine ИИ 5018 according to the scheme «disk-pad». An abrasive wheel ПП63×16×10; 25A CM-5-K ГОСТ 2424-83 was used as a «disk» sample. The sample and counter-body were located in the test chamber in the liquid medium. Water served as a test medium. Specific loading on the sample was 0,25…3 MPa. Every test was done for 1 min 35 sec, which corresponded to the rubbing path of 20 m. The wear was estimated by variation of sample mass on the analytical balance ВЛА-200g-M with accuracy of 0,00001 g.

3. The results of the research.

Figure 1 presents the structural scheme of the wear model of oxide and ceramic coatings, obtained by plasma electrolytic oxidation. As the basic interacting elements, we distinguished the following: wear medium, wear conditions and physical and mechanical properties of coatings.

![Diagram](image)

**Figure 1.** Structural scheme of the wear model of oxide and ceramic coatings formed by plasma electrolytic oxidation

It should be emphasized, that in the represented general scheme of the model, determining coatings wear it is impossible to distinguish the specific and the most important element. The influence of each of them is essential.

Among the present existing computational models of material wear, conditionally it is possible to differentiate the following models: empirical, semiempirical, energetical, kinetic and synergetic models [7-9].
Empirical models are mathematic approximation of experimental results. In them mechanical characteristics are combined with wear characteristics (wear resistance, wear rate) via non-dimensional empirical factors, without any definite physical meaning. Approximations in the form of lineal, degree or exponential functions are the most commonly used.

Semiempirical models include the parameters, for each of them the connection with physical and mechanical properties of materials, characteristics of processes, etc. is established. The experimental estimation of these parameters provides the analysis of real physical phenomena. Computational dependences in semiempirical models are based on physical reasons and with account of parameter.

Energetical models are developed on the ground of thermodynamic analysis wear. Energetical models parameters are the basic thermodynamic characteristics of surface layer are the following: energy, entropy, temperature, etc. Computational dependences of this type are based on energy equation (entropy).

Kinetic models of wear are based on thermofluctuation concept of solid body strength. The characteristic feature of these models is application of the Boltzmann approach for connection of wear rate and external factors and description of material properties via its activation features: activation energy and structure-sensitive ratio.

Synergetic models. Synergetic approach at wear modelling can consist in selection of criteria of system stability and determination of model critical data, in which the system attains bifurcation point – instability, antecedent to dissipative mechanism change.

It should be pointed out, that to obtain an abrasive wear model is reasonable to apply the phenomenological approach (empirical model of wear), because it is classical. It is distinct in simplicity and friendly for consideration of the majority of the factors of the given tribological system [7, 8].

Below, we present the developed theoretical statements on simulation of hydraobrasive wear of oxide and ceramic coatings, obtained by plasma electrolytic oxidation, in respect to the actual operating conditions of the pumps of type «СВН».

The main criterion of the long-term pump operation is the absence of mechanical impurities in pumped medium and observation of operation rules. Operating conditions of the pumps of the similar type are also determined with such factors as: temperature and process pressure, work time, drive type, etc.

For the concerned operating conditions of the pumps and wear simulation, hydrodynamic effects at friction in liquid medium should be considered reasonably in accordance with the methodology suggested in the paper [10]. Using common in contact hydrodynamics similarity criteria, hydrodynamics effect was estimated via the factor of hydrodynamic effect \( \delta \):

\[
\delta = B_r - \left( \frac{v}{V \cdot R_a} \right),
\]

where \( B_r \) – empirical factor; \( v \) – liquid viscosity, m\(^2\)/s; \( V \) – slide rate, m/s; \( R_a \) – height of abrasives, m.

In connection with high service properties of oxide and ceramic coatings, it is possible to neglect heat removal through working elements of the pump and friction in liquid medium, being a coolant, and temperature effect on wear value.

For appraisal of the influence of the technological parameters of plasma electrolytic oxidation on coating wear, we introduce empirical factor \( \gamma \), considering the material of the component and the process modes.

Accordingly, we obtain the equation, describing abrasive wear of oxide and ceramic coatings in liquid medium:

\[
U = \mu \cdot H_a \cdot P \cdot A_a \cdot L \cdot \beta \cdot \rho \cdot \gamma \cdot B_r \cdot \left( \frac{v}{V \cdot R_a} \right)
\]
where $\mu$ – friction factor; $H_a$ – abrasive particle hardness; $H_\mu$ – wearable material hardness; $P$ – nominal pressure, MPa; $A_a$ – contact area, m$^2$; $L$ – rubbing path, m; $E$ – elasticity module, MPa; $\beta$ – factor, displaying the influence of medium grain diameter of coarse fraction on material wear value; $\rho$ – wearable material density, kg/m$^3$.

With the help of this model the theoretical dependencies of mass wear of oxide and ceramic coatings from different external factors were calculated and constructed (fig. 2).

Figure 3 present the test results on hydroabrasive wear of oxide and ceramic coatings obtained by plasma electrolytic oxidation (PEO) in different modes.

**Figure 2.** Theoretical dependencies of mass wear of oxide and ceramic coatings obtained by plasma electrolytic oxidation from different external factors
Properties of coatings decrease in case of use of steel at abrasive wear. Production of ceramic coatings, V.V. Goncharenko, in combination with V.N. Vinogradov, L.S. Yu.A. Kuznetsov // IOP Conf. Series: Journal of Physics: Conf. Series 1058 (2019) 012065.

Figure 3. Sample wear variation (U), manufactured from alloy AK7у, deposited with materials Cб.A97, Cб.AМr3, Cб.AК10 and hardened by plasma electrolytic oxidation (PEO) depending on nominal loading (P).

Analyzing the results of the experimental testing it is possible to conclude that maximum wear resistance of oxide and ceramic coatings is provided in case of utilization of pure aluminum (Cб.A97) as a filler material at deposition. Physical and mechanical properties of coatings decrease in case of availability in the base material impurities and alloying elements.

4. Conclusion.
The test results of hydroabrasive wear of oxide and ceramic coatings obtained by plasma electrolytic oxidation (PEO) confirm adequateness of the suggested wear model. Oxide and ceramic coatings possess high wear resistibility and can be recommended for hardening the working surfaces of components (including the surfaces reconditioned by deposition) operating in the hydroabrasive wear conditions.

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