Increase of the resource of machine parts working by combined methods using plasma electrolytic oxidation

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Annotation. The paper presents the results of a study of the physicomechanical properties of oxide-ceramic coatings formed by plasma electrolytic oxidation on various aluminum alloys. It has been found that filling the pores of an oxide-ceramic coating with oil or applying a copper layer to its surface with a friction-mechanical method increases the wear resistance of movable joints of machine parts by 1.7 times and 4.5 times, respectively. Based on the complex of studies carried out, combined methods are proposed that significantly increase the life of reinforced parts of machines in operation.

1. Introduction

During operation 85...90% of cars goes down not because of broken parts, and due to the wear of their working surfaces. To increase the resource it is necessary to create hardened layers with high physical and mechanical properties on wear surfaces of parts. One of the methods that allow to realize this is electro-spark and plasma – electrolytic [1-19]. Among these methods, plasma-electrolytic oxidation (PEO) is the most common. The method of PEO does not have many disadvantages inherent in other technologies of surface hardening of parts. The main advantages of PEO include: obtaining multifunctional coatings with high physical and mechanical properties of the specified composition, structure and thickness, the availability of chemical reagents, environmental friendliness of the process and the lack of special treatment facilities using silicate-alkaline electrolytes. Formed coatings have high adhesion strength to the substrate material, hardness, wear resistance, corrosion resistance, heat resistance and controlled porosity.

At the same time, the coatings formed by PEO are not devoid of drawbacks. Firstly, due to the limited thickness only minor wear of parts (up to 0.10...0.13 mm) can be compensated with their help. Secondly, the peo technology is comparatively well developed for a group of so – called valve metals and their alloys-aluminum, titanium, magnesium, tantalum, etc., while a significant proportion of machine parts are made of steels and cast irons.

For elimination of the specified shortcomings it is perspective to use the combined technologies of increase of durability including increment of working surfaces of details for the purpose of compensation of their wear by one of the known methods, hardening of the restored surfaces of PEO and the subsequent modification of the hardening covering.
2. Methods of research

The thickness of the coating formed by PEO was measured by eddy current thickness gauge VT-201 with an error $\delta=+(0,03 S+1,0)$, microns, where $S$ is the measured value, microns. The hardness of coatings formed by PEO was measured on the computerized hardness testing PMT-3M-01 according to GOST 9450-76. The evaluation of the thermal conductivity of the coating formed by PEO was carried out with a monotone one-sided heating of the sample with an oxide coating on a dynamic $\lambda$-calorimeter, allowing an error of not more than 10% in the temperature range -196...377°C to measure the thermal conductivity of materials with $\lambda=0,1...5$ W/(m·°C). When estimating the specific heat of the coating formed by PEO, a comparative method was used, realized by means of a dynamic $C_{p}$-calorimeter with a heat meter and an adiabatic shell. The through porosity of the coatings was determined by the color defectoscopy method. After PEO and removing the loose coating layer, the samples were washed in cold running water, then immersed for 30 seconds in a warm (35...40 °C) solution of caustic soda (20 g / l) and for 1 minute in a clarification solution (nitric and hydrofluoric acid in the ratio 1: 1). For pore staining the samples were placed for 5 min in a solution containing 20 g/l of copper sulfate and 20 ml/l of hydrochloric acid. Washed and dried samples with areas of pink spots of copper on the coating were investigated under a microscope, 20x. The through porosity of the coatings was determined as the percentage ratio of the areas of the painted areas to the area of the site under consideration.

Wear resistance was determined in the conditions of boundary lubrication in accordance with GOST 23.224-86 in group A on the friction machine SMT-1M, reproducing the friction scheme when rotating the counterbody in the form of a sleeve relative to the fixed sample in the form of a ring. Samples for research were made of aluminum alloys Ak7ch, AO3-7, D16, PA12, AK9M2, AMg6, AK5. After that, on their surfaces by PEO coatings were formed, which were then polished to remove the loose layer and roughness $Ra=1,05...1,25$ microns. Further, a copper layer was applied to the surface of oxide-ceramic coating by porosity of 3...4% by friction-mechanical method. The hardened layer with porosity of 14 ... 15% was filled with oil. The porosity of the coatings was changed by varying the temperature of the electrolyte. The material for the manufacturing of the counterbody was steel 45, hardened to HRC 40...45 and having a working surface roughness $Ra=0,63$ mm. When forming coatings by PEO method, an installation operating at an alternating electric current of industrial frequency of 50 Hz, from a network of 380 V voltage, providing an anode-cathode formation of coatings with a ratio of the amplitude of the cathode and anode currents $I_{A} / I_{C}=1,0$, was used. In the formation of coatings used silicate-alkaline electrolyte type "CON-Na$_2$SiO$_3"$. The content of potassium hydroxide CON in the electrolyte was 3 g/l, sodium liquid glass Na$_2$SiO$_3$ – 10 g / l, distilled water – the rest. PEO modes: current-20 A / dm$^2$, the duration of oxidation – 2 h, the electrolyte temperature ranged from 20 °C to 60 °C.

Tested the following connection: "steel – coating formed by PEO, porosity 3...4%, steel – coating formed MAO, porosity 14...15%", "steel – coating formed MAO, porosity 14...15% filled with oil", "steel – coating formed MAO, porosity 3...4% with copper layer". When applying the copper layer, the contact pressure was 15 MPa, sliding speed-0.5 m / s, the thickness of the rubbing plate of copper – 0.05...0.10 mm, the duration of application – 230...240 s, lubrication of the contact surfaces – technical glycerin. The exact oil flow was regulated by a metering valve. To accelerate wear, an abrasive was added to the oil, which was used as quartz sand, corresponding to GOST 2138-91, dispersion of 5 microns. The abrasive concentration was 3±0,5% by weight of oil. Tests were carried out at room temperature. Before carrying out researches carried out an operating time of the tested mobile connection at smooth change of loading from 20 to 200 N with an interval of 20 n which completion was fixed on stabilization of coefficient of friction in a contact zone. The loading was carried out through the lever system of the friction machine. Wear was determined by changing the mass of samples and contrabass with the use of analytical weights ADV-200M. The error in weighing was not more than 0.002 g.

Before measurements, the sample and the counterbody was thoroughly washed in benzene for 10 minutes, then dried in a drying Cabinet SNOL-3,5 at a temperature of 60...70 °C for 40 minutes,
followed by air cooling. After the measurements, the test sample and the counter-body were placed on the friction machine according to the coincidence of the pre-applied marks. The wear was determined after every 10 hours of testing. The total test duration of each mobile unit was 60 hours. All experiments were carried out with a fivefold repetition.

3. Research results and their discussion

Physical and mechanical properties of coatings formed by PEO obtained in the course of research on various materials are presented in the Table 1. Studies have shown that the thickness and hardness of coatings on foundry, antifriction alloy and surfaces obtained using welding wires, rods and solders is lower than on the deformable alloy D16. This is consistent with the research of other scientists and is explained by the different chemical composition of oxidized aluminum alloys, which affects both the thickness of the hardened layer and its hardness, which is provided by the phase composition of the coating [3, 10, 13, 14].

The results of the wear tests showed the following. The wear and tear of movable joints "steel - coating formed by PEO, porosity 3 ... 4%" and "steel - coating formed by PEO porosity 14 ... 15%" differs insignificantly (no more than 2 ... 3%) and accordingly makes from 15.5 to 14.9 mg (Figure 1).

Obviously, the excess porosity (14 ... 15%) does not have a significant effect on wear in the initial period of work. The movable compound "steel - coating, formed by PEO, porosity 14 ... 15% filled

### Table 1. – Physical and mechanical properties of coatings formed by PEO

| Indicator                        | De-formable alloy D16 | Foundry alloy Ak7ch | Foun-dry alloy Ak7ch after compression | Antifriction alloy AO3-7 after compression | The aluminum-containing solder ПА12 | Aluminium-containing welding wire Svamg6, Svak5 and rod AK9M2 |
|----------------------------------|-----------------------|---------------------|----------------------------------------|-------------------------------------------|-----------------------------------|----------------------------------------------------------|
| Thickness, µm                    | 15 0                  | 120                 | 120                                    | 120                                       | 120                               | 120                                                      |
| Hardness, GPa                    | 22 9                  | 10                  | 12                                     | 8                                         | 11 10 9                           |                                                          |
| Coefficient of thermal conductivity, W/m·°C | when the temperature varies from 0 to 380 °C, it varies within the interval 0.42 .... 1.12 |                                                          |                                                          |                                                          |                                                          |
| Specific heat capacity, j/kg·°C  | when the temperature varies from 0 to 380 °C, changes in the range 800 .... 1300 |                                                          |                                                          |                                                          |                                                          |
Figure 1 - Ratio of wear of movable joints in the initial period of work $W_{i.p.}$: "steel-coating formed by PEO, porosity 3 ... 4%" (1), "steel - coating formed by PEO, porosity 14 ... 15%" (2), "steel - coating formed by PEO, porosity 14 ... 15% filled with oil "(3)," steel - coating formed by PEO porosity 3 ... 4% with a copper layer "(4)

with oil", this figure is reduced and is 10.6 mg. This is facilitated by the formation of an oil film between the test samples. The oil in this case protrudes from the pores of the coating due to a sharp increase in temperature in the friction zone at the beginning of the test and helps to reduce the wear rate. The minimum wear in the initial period of operation (6.5 mg) is provided by the movable compound "steel - coating formed by PEO, porosity 3 ... 4% with a copper layer", which is facilitated by a copper layer that reduces the coefficient of friction between the sample and the counterbody.

The lowest wear rate after running-in was observed in the movable compound "steel - coating formed by PEO, porosity 3 ... 4% with a copper layer" (Figure 2). It was 6.7 times lower than the mobile compound "steel - coating formed by PEO, porosity 3 ... 4%." The results obtained are consistent with the studies of other authors who found that the formation of a PEO-coating compound on one of the parts leads to intensive wear of the response part of the compound [15-18]. Filling the coatings with a porosity of 14 ... 15% with oil reduced the wear rate by 1.6 times. The presence of a porosity coating of 14 ... 15%, compared to a porosity of 3 ... 4%, had no negative effect on the wear rate of the test compounds.
Figure 2 - Ratio of wear rates $v$ and wear resistance of U mobile joints: "steel - coating formed by PEO, porosity 3 ... 4%" (1), "steel - coating formed by PEO, porosity 14 ... 15%" (2), "steel - coating formed by PEO, porosity 14 ... 15% filled with oil" (3), "steel - coating formed by PEO, porosity 3 ... 4% with a copper layer" (4).

The wear resistance of the investigated mobile compounds was:

1) "steel - a coating formed by PEO, porosity of 3 ... 4%":

$$U = \frac{1}{0.40} = 2.5 \text{ h/mg}$$

2) "steel - coating formed by PEO, porosity 14 ... 15%":

$$U = \frac{1}{0.36} = 2.78 \text{ h/mg}$$

3) "steel - coating formed by PEO, porosity 14 ... 15% filled with oil":

$$U = \frac{1}{0.24} = 4.17 \text{ h/mg}$$

4) "steel - coating, formed PEO, porosity 3 ... 4% with a copper layer":

$$U = \frac{1}{0.09} = 11.1 \text{ h/mg}$$

Thus, the pore filling of the oxide-ceramic coating with oil or the application of a copper layer on its surface increases the wear resistance of movable joints, respectively, by 1.7 times and 4.5 times in comparison with the conventional coating formed by PEO, porosity of 3 ... 4%. Therefore, it is advisable to use such technological methods as finishing operations when restoring worn working surfaces of parts with reinforcement of PEO, since not only wear in the initial period of work depends on them, but also the wear rate of the movable joint during the operation of the machine.

On the basis of the research, combined methods for increasing the life of machine parts using PEO have been developed. The parts are first cleaned and defective. Then, depending on the wear, the area of damage, the size and type of the renewable working surfaces, the material of the parts, and the
availability of the necessary technological equipment at a particular plant, they perform their restoration. To compensate for wear, you can use: surfacing, spraying, soldering, plastic deformation, an additional repair part. Further, depending on the required resource of the mobile connection after repair, the restored working surfaces strengthen the PEO and modify the oxide-ceramic coating by one of the methods considered in the article.

After performing the recovery operations, the parts are degreased in an aqueous solution containing 5 ... 10 g / l NaOH, 40...50 g / l Na₃PO₄ and 3 ... 5 g / l Na₂SiO₃, at a temperature of 60 ... 70 ° C for 1.5 min. Then rinse with water, heated to a temperature of 40 ... 50 ° C, for 3 ... 5 minutes. Prefabricated parts are mounted in special devices, install electrodes, mount on a suspension bracket and place in an electrolytic bath [11]. When using hollow electrodes with ceramic sprayers, compressed air is supplied to them. The use of such electrodes promotes the initiation of burning of microarc discharges and the mixing of electrolyte in PEO, which provides an improvement in the quality and increase in the thickness and hardness of the strengthening oxide-ceramic coating [3, 11].

Oxidation of parts is advisable to implement in devices that are simple to manufacture. To prevent the electrolyte from falling into the PEO under protective devices and cases, which contributes to damage to the non-hardened surfaces of the parts, a silicone sealant is used.

PEO is carried out in a silicate-alkaline electrolyte of the "KOH-Na₂SiO₃" type, the rest - distilled water. Oxidation must be started at a current density of 30 ... 35 A / dm², and after the process is exited to a mode, reduce it to a working one - 20 A / dm². The duration of oxidation is usually 1.5 ... 2 hours. Depending on the purpose of the coating, the electrolyte temperature in the cooler is regulated. When coatings are used as antirust coatings and to increase the wear resistance of movable joints by means of a copper layer, their porosity should be 3 ... 4%. To increase the wear resistance of mobile compounds due to the filling of coatings with oil their porosity should be 14 ... 15%. The porosity of the coatings is regulated by the temperature of the electrolyte and the modes of PEO. After the PEO, the parts are removed from the demountable blocks, washed with running water at room temperature, dried and the coating obtained is monitored.

To remove the technology layer of the coating and give the desired time-mers and geometric shapes hardened working surfaces of parts subjected to mechanical processing. At the same time, an elastic abrasive tool is used, consisting of petals of a sandpaper sandwiched between two discs. The processing is carried out by the peripheral part of the petals of the skin when the tool rotates.

Further on the part with a hardening coating formed by PEO, a porosity of 3 ... 4%, operating under conditions of boundary lubrication or friction without lubricant, a copper layer is applied by a friction-mechanical method with a special device [9, 11].

The reinforcing coating formed by PEO, the porosity of 14 ... 15% of the working surfaces of parts operating under hydrodynamic or semi-liquid (mixed) lubricants is filled with oil. For this purpose, the parts are laid in a wire basket and lowered into a bath with a spindle AU GOST 1642-75 or transformer GOST 10121-76 heated with oil (or a mixture of oil with 5 ... 8% graphite or molybdenum disulfide) heated to 100 ... 110°C and kept 1, 5 ... 2.0 h. After completing the oil coating, the parts are taken out of the bath, the residual oil is drained and dried dry.

When choosing any of the combined methods, it should be borne in mind that during operation of the parts, the contact pressure on the coating should not exceed 15 MPa. Otherwise, because of the possible deformation of the metal base, the hardened layer may break down [9, 11].

4. The conclusion

On the basis of the results of the conducted studies, it was established that the greatest thickness and hardness of oxide-ceramic coatings formed by PEO is ensured by using a deformable aluminum alloy D16. Filling the pores of the oxide-ceramic coating with oil or applying a copper layer to its surface with a frictional-mechanical method increases the wear resistance of movable joints of machine parts by 1.7 times and 4.5 times, respectively. Based on the results of the studies, combined methods have been suggested that allow significantly increasing the life of reinforced parts of machines in operation.
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