DIELECTRIC PROTECTION OF ALUMINUM ALLOYS OF DIAMOND WHEEL FRAMEWORKS BY PLASMA-ELECTROLYTIC COATINGS WITH FORMING IN GALVANOSTATIC MODE

Sen. Staff Scientist Elena SEVIDOVA, Nat. Tech. Univ. “Kharkov Polytech. Inst.”, Kharkov, Ukraine, nangara55@gmail.com
Sen. Staff Scientist Yury GUTSALENKO, Nat. Tech. Univ. “Kharkov Polytech. Inst.”, Kharkov, Ukraine, yu.gutsalenko@gmail.com
Prof. PhD. Eng. Cătălin IANCU, C-tin Brâncuşi Univ. of Tg-Jiu, Targu Jiu, Romania ciancu@utgjiu.ro
Prof. Dr. Eng. Valeria SUBBOTINA, Nat. Tech. Univ. “Kharkov Polytech. Inst.”, Kharkov, Ukraine, subbotina.valeri@gmail.com
Sen. Staff Scientist Oleh VOLKOV, Nat. Tech. Univ. “Kharkov Polytech. Inst.”, Kharkov, Ukraine, volkovoleh1978@gmail.com

ABSTRACT: *The study was carried out within the framework of the field of technological solutions for local electrical insulating coatings of the tool of highly efficient processing technologies with the introduction of electric discharge energy into the cutting zone to maintain the performance of grinding wheels with a diamond-metal composition of the working part. The development of plasma electrolyte oxidation of aluminum alloys with the aim of using the dielectric properties of coatings is presented. Investigations of oxide coatings formed by the anode galvanostatic regime in alkali-silicate solutions are presented and discussed. The data on the roughness, radiology and dielectric properties of the coatings are used for joint consideration.*

KEYWORDS: electrolyte, alkali-silicate solution, microarc electric discharge, current density, surface roughness, specific volume resistance, dielectric strength

1. INTRODUCTION

Plasma electrolyte oxidation (PEO) technology, carried out due to the microarc effects of electric discharges, is a promising process of surface finishing, which makes it possible to obtain a wide range of polyfunctional coatings (wear, heat, corrosion-resistant, dielectric, catalytic, etc.) on the surface of valve metals. Despite the extensive experience in the use of PEO coatings and the development of numerical modifications of the method [1], in recent years the technology has become intensively developed due to the widespread use of light metals and alloys (aluminum, titanium, magnesium) in different industrial sectors [2].

Today's interest in investigating the dielectric properties of micro-arc oxide coatings on aluminum alloys is related to the instrumental application of such alloys in diamond grinding wrameworks, which require electrical protection in high-performance technologies with direct current feed to the treatment area [3].Their bore surface R_a roughness index must meet specific requirements and be equal to 2.5 μm, according to the drawings. Similar requirements can be also applied to other parts with rigid joint connections.

In the context of this problem, with the formation of a coating in the mode of an auto-falling power (AFP) using an anode-cathode (alternating) current, our works [4, 5] present some studies of the dielectric capabilities of PEO, which are decisive when used in diamond-abrasive a tool with a direct current supply to it in combined electrophysical grinding processes [6].

The purpose of this work is to present the results of a galvanostatic technology for producing dielectric coatings on aluminum alloys, alternative to the AFP regime, and to determine the qualitative relationships between the established numerical data of the performed physical studies.

2. RESEARCH TECHNIQUE

The experimental samples were made of deformable aluminum alloys D16T (1360) and AK6 (2124) GOST 4784-97 (ISO 209-1) which are used for the manufacturing of the diamond grinding wheels wrameworks.

We investigated the anodic galvanostatic (GS) mode of PEO, which is widely used in modern technologies, as well as the mode of AFP at the anode-cathodic (alternating) current. The processes were carried out using a transformer current source.

The investigations in the GS mode involved the influence of anode current density on the dielectric properties of the formed PEO coatings. The current density amounted to 5, 7.5, 10, and 15 $A \cdot dm^{-2}$. The duration of the electrolysis was determined using the principle that in each experiment, the same charge of electricity flow through the electrolysis unit. Following the calculations, durations of oxidation of 40, 26.6, 20, and 13.3 min were used.

On the basis of preliminary experiments, for research have been taken three electrolytes of the alkaline-silicate group: first – 12 $g \cdot l^{-1}$ LG (LG is a technical solution of the sodium liquid glass (sodium silicate) with the specific mass of 1.4 $g \cdot sm^{-3}$); second – 2 $g \cdot L^{-1}$ KOH + 12 $g \cdot L^{-1}$ LG; third – 1 $g \cdot L^{-1}$ KOH + 6 $g \cdot L^{-1}$ LG. For the sake of simplicity, the electrolyte compositions are hereinafter denoted as 0:12, 2:12, and 1:6, respectively. The temperature of the solutions was maintained within a range of 20–35 ºC.

The thickness of coating was determined by a nondestructive method, using the eddy current thickness indicator NOVOTEST TP-1.

The specific volume resistivity ρ_V and electric strength E were adopted as main characteristics of insulating properties. The volume resistivity was measured according to GOST 6433.2 using a teraohmmeter E6-13 at an operation voltage of 100 V. The reading of parameters was accomplished over a minute after the voltage was switched on.

The breakdown voltage was determined for an alternating current (50 Hz) using a laboratory set-up that included a high voltage transformer, a protective resistor 5 kΩ, and a scheme for smooth regulation of the voltage. The measurtments started from the high voltage value.

X-ray diffraction analysis of the coatings was performed using an X-ray diffraction meter DRON-3 with monochromatic radiation of a copper anode in the range of angles 2θ within 15 to 50º, chosen taking into account the most probable phase composition of the coatings that can be expect on the basis of previous investigations [7].

Surface roughness, the arithmetic mean profile deviation R_a, was measured by Surtronic 3+ profilograph-profilometer (Taylor Hobson) on the base length of 0.8 mm. The reference (initial) surface roughness R_a was 1.2 μm.

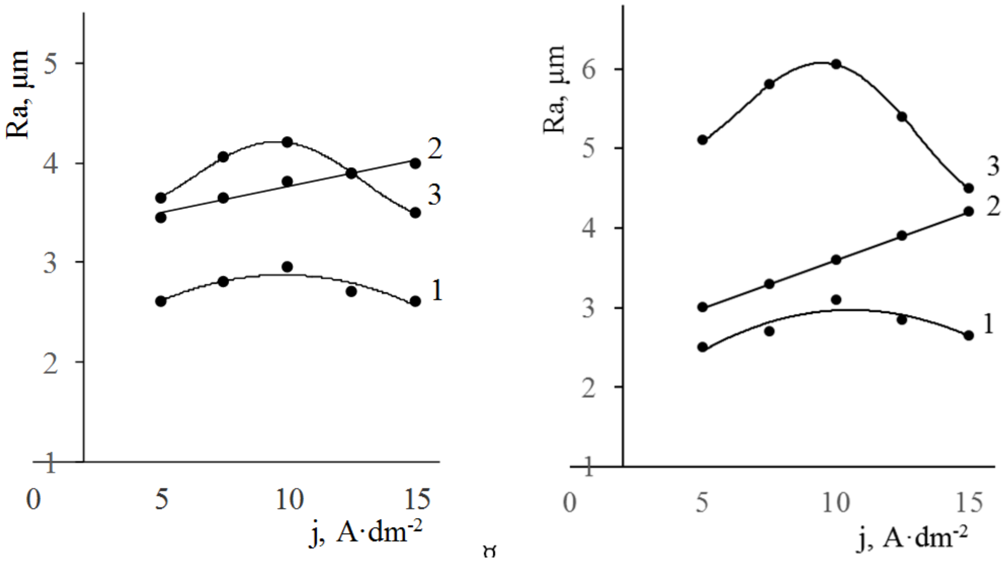
3. RESULTS AND DISCUSSION

The thickness of the coatings prepared in the GS mode does not in fact depend on the current density, but it depends on electrolyte composition. As in the AFP mode (see [4]): the minimal thickness of the coatings forms in a diluted alkaline-silica 1:6 solution, and the maximal thickness forms in a 2:12 solution (see Table 1 for the constant of the GS mode: (electrolysis time)·(current density) = 200 $A \cdot min \cdot dm^{-2}$). Obviously, the silicate component plays a decisive role in the rate of growth of PEO layers (see also [5]).

Table 1. The thickness of PEO coatings on aluminum alloys under various electrolysis conditions, μm

Grade of alloy	Electrolyte					
	0:12		2:12		1:6	
	Current density, A·dm^{-2}					
	5	15	5	15	5	15
D16T	42	43	44	45	36	38
AK6	33	34	37	37	30	29

On Fig. 1, R_a values demonstrate that the surface roughness of both studied alloys after PEO increases significantly compared to the baseline R_a value.



a *b*

Fig. 1. Dependences of surface roughness of the PEO coatings on the current density in the GS mode of AK6 (a) and D16T (b) alloys in different electrolytes: *1* – 0:12; *2* – 2:12; *3* – 1:6

Under conditions of indifference of the coating thickness to a change in current density шn the GS mode (Table 1), R_a dependences not only from the electrolyte composition but also of current density are manifested (Fig. 1). Last mentioned dependency is not monotonic, but extremal in 0:12 and 1:6 solutions. In fact, R_a index increases in the range of 5…10 A·dm^{-2} and subsequently drops as current density increases till 15 A·dm^{-2}.

The smoothing effect could be well observed even with no auxiliary optical devices: the structure and color of the oxidated surface became significantly more homogenous with this current density.

The enhancement of R_a index at j = 15 A·dm^{-2} can be accounted for the Joule's heat release (~ j^2), which is sufficient at this current density for fusion and melting to occur both within the coating layer and on the surface structures, in particular, fusion and melting of aluminum oxides and silica.

A presence of concentrated alkali in 2:12 solution can offset this effect due to an increased etching action of the harsh component (KOH), which results in the monotonic R_a increase proportional to the current density.

Similarly to the alternating current oxidation under the AFP mode (see also [5]), the minimum roughness value of dielectric coatings produced under the GS mode is achieved in the 1:6 electrolyte.

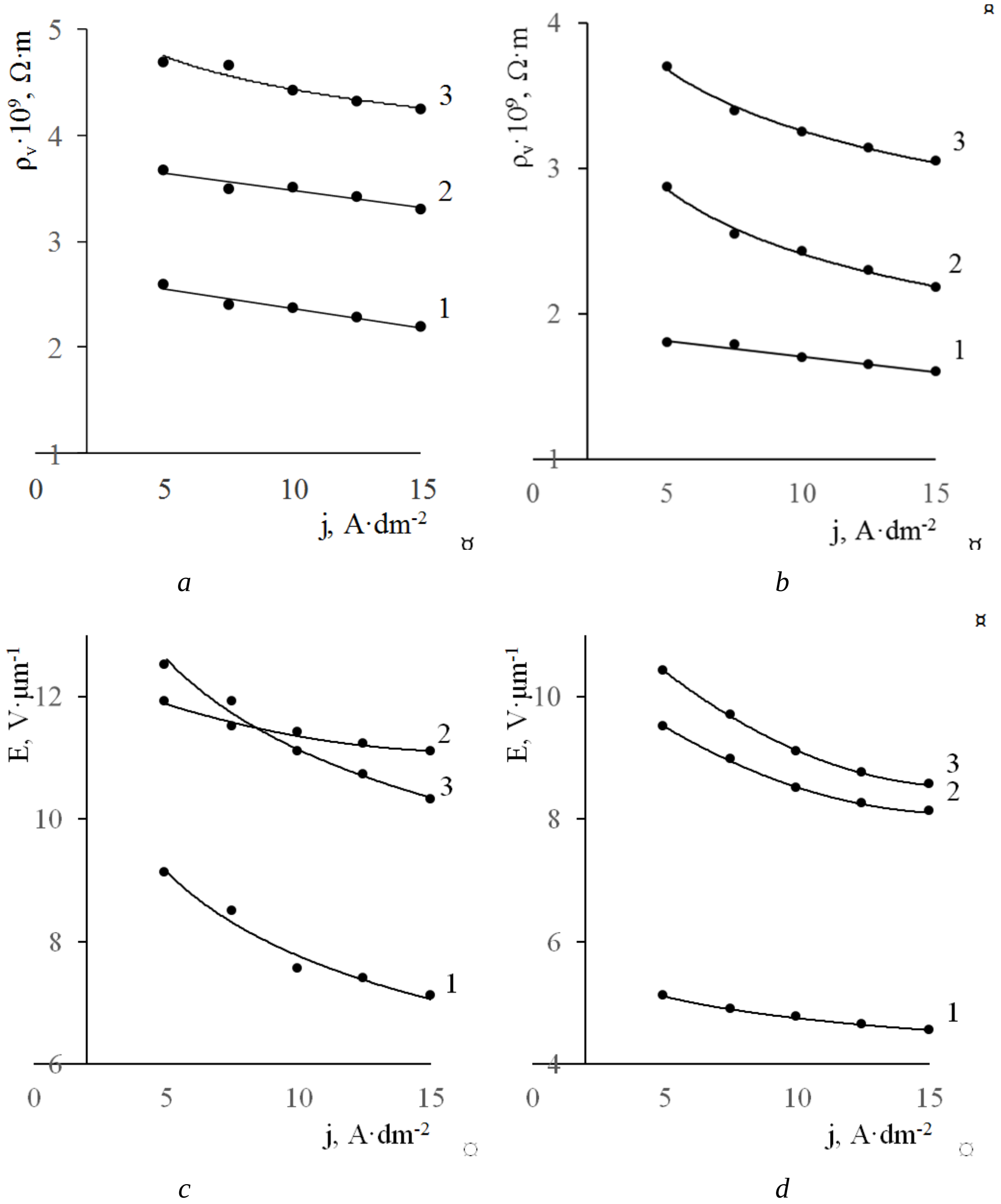


Fig. 2. Dependence of specific volume resistance (a, b) and electric strength (c, d) of the PEO coatings of AK6 (a, c) and D16T (b, d) alloys from the anode current density under the GS mode in different electrolytes: *1* – 0:12; *2* – 2:12; *3* – 1:6

Analysis of the dielectric properties for the coating prepared in GS mode for both alloys, AK6 (Fig. 2, *a*, *c*) and D16T (Fig. 2, *b*, *d*) allowed to note tendency when the current density *j* increases. This can be associated with the increase in porosity that is typical for GS modes and the saturation of the composite coating by electrolyte elements.

The difference between the ρ_V values of the coatings formed in various electrolytes is more pronounced. The best result was found for the liquid glass solution 0:12; the worst result was obtained for solution 2:12, which was lower by a factor of 1.6–1.9.

The presented results are in qualitative agreement with the values of the forming voltage that become settled at the end of the PEO process in each solution independently of the current density. Respectively, the greatest voltage was observed in the silicate 0:12 electrolyte – 560 V on AK6, and 580 V on D16T; the least one of 520 V in the alkaline-silicate 2:12 electrolyte on both alloys.

One of the reasons that the parameter ρ_V becomes worse in the 2:12 solution may be noted also in the analysis of results in the AFM mode (see [5]) the elevated concentration of ions of alkaline metal, in it that leads to a relatively greater concentration of these ions in the composition of the coating.

The character of the variation of the electric strength of the coatings versus the investigated factors for both alloys – AK6 (Fig. 2, *c*), and D16T (Fig. 2, *d*), as could be expected is similar to the dependence of the specific resistance on them. In particular, for electrolitytes 0:12 and 2:12 the tendency of diminishing of the parameter with the increasing of the current density (curves *1* and *3*) is retained or becomes even stronger; the influence of the qualitative and quantitative composition of the electrolytes is to some degree smooth (curves *2* and *3*).

The best values of the electric strength of the coatings in GS mode were obtained in 1:6 and 0:12 solutions.

In general, from comparison the electrophysical parameters of PEO coatings formed on both alloys using the two electric modes (AFM and GS), see also [5], it can see that the results related to the choice of the efficient electrolyte composition correlate. In all cases, the 1:6 and 0:12 solutions exhibit distinct advantages.

Analysis of the results of X-ray diffraction investigations shows that the phase compositions of the coatings, in particular, the quantity of γ-Al_2O_3 and its relationship to the mullite phase by radiation intensity (I_γ / I_m), are not the determining parameters for the dielectric properties.

Obviously, these parameters of PEO coatings respond to the integral influence of all the components of the composite substance, including the radiotransparent and unidentified ones. This first of all relates to the ions of alkaline metals that worsen the dielectric properties of the coatings [8]; the quantity of the ions can be determined using an X-ray spectral microanalysis.

4. CONCLUSIONS

In electric anode GS mode with a transformer (up to 600 V) current source with a current density of up to 15 $A \cdot dm^{-2}$ in the experiments, the technological capabilities of electrical insulating PEO as applied to deformable aluminum alloys of grades D16T (1360) and AK6 (2124) GOST 4784-97 (ISO 209-1) used in the manufacture of frameworks of diamond grinding wheels in the tool industry were studied. Formation of PEO coatings provide sufficiently high parameters for ρ_V and E.

It is established that the best results of the dielectric properties on both alloys provides moderately concentrated alkaline-silicate electrolyte 1:6 with relative mass contents of potassium alkali and sodium silicate respectively 1 $g \cdot L^{-1}$ and 6 $g \cdot L^{-1}$. At the same time, in terms of the absolute values of ρ_v and E at comparable thicknesses, the coatings of GS mode are noticeably inferior to the coatings formed on the anodic-cathodic (alternating) current in AFM mode [5].

Established results do not contradict the conventional knowledge, since studies of other features of the functional quality of coatings at comparable thicknesses have established that the MAO layers obtained at alternating current are more homogeneous and less defective [9], and this obviously also has a positive effect on the barrier electrophysical parameters.

The extreme nature of the dependence of the average microroughness height on the anode current density during PEO in the GS mode in electrolytes with a low concentration of the alkaline component was revealed and explained from thermophysical positions.

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