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PLASMA ELECTROLYTIC OXIDATION OF ALUMINUM PRESS MOLDS

Abstract. This scientific paper gives consideration to the statistical method used for the construction of the mathematical model for the plasma electrolytic oxidation (PEO) of hexagon blanks according to the Box-Behnkin design. A model of electrolytic plasma oxidation was developed for aluminum. The relationship of the finite surface porosity caused by PEO as a function of basic factors that influence the process course has been derived. The derived relationship was used to construct response surfaces of the test parameter depending on experiment factors.

Key words: Plasma electrolytic oxidation, roughness, electrolyte concentration, porosity, treatment time and Box-Behnken design.

Topicality. It is known that the hardening of aluminum alloys requires the quenching. However, with ageing the surface subjected to the quenching is oxidized and it requires the mechanical treatment and applied coatings fail to provide high wear resistance for the restored surface. The PEO is a rather promising methodology for the technology of electrochemical molding of fused and crystallized coatings.

The production of the specified coating is rather labor −consuming, expensive and often even difficult, especially when ecologically friendly methods of material treatment are used [1]. In this regard the plasma electrolytic oxidation is considered to be a highly efficient process of the treatment of items in nontoxic environments, because it has improved ecological and economic indices.

The objective of this scientific paper was to simulate physical and mechanical characteristics of anode-&- oxide coatings applied on press molds to obtain the specified porosity and to reduce energy inputs of the technological process.

Methodology of Experiments. The experiments were carried out using the developed plant with PEO control system (Fig.1). The hexagon blank 10x11 of 83 mm long made of aluminum alloy D16 with the original roughness Ra=0.63μm was used as test specimens. The oxidation was performed in the range of operation voltages U=390 to 400 V; the current density at the beginning of the treatment was equal to J_p=30A/cm^2, then the current density was reduced and the operating value was equal to J_p=10A/cm^2; in the water solution KOH 4%+Na_2SiO_3 4%; the electrolyte temperature was maintained constant t_c =30°C. Roughness parameters were measured and metallographic studies were carried out using contactless interference 3-D profile recorder “Micron-Alpha”. The PEO process was simulated using Box-Behnken 3-factor design.

Fig. 1. Experimental plasma electrolytic plant.

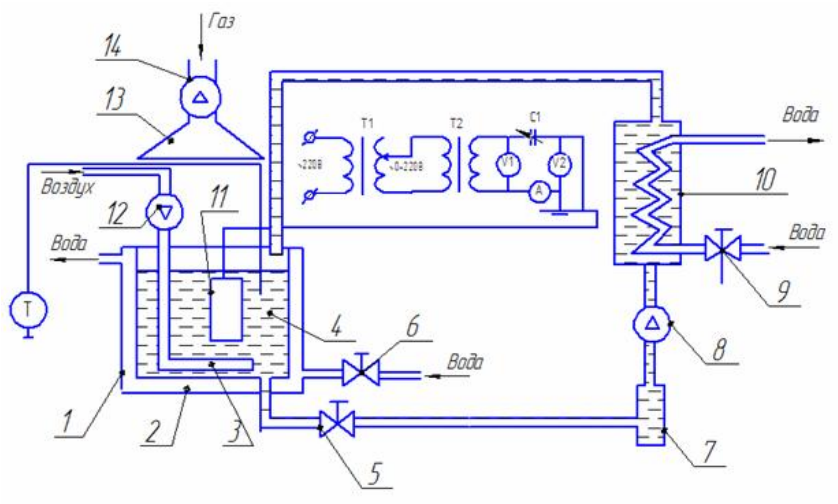


Fig. 2. Functional diagram of the PEO plant: 1 is the electroplating bath; 2 is the water cooling jacket; 3 is the bubbler; 4 is the electrolyte; 5,6,9 are the stop valve; 7 is the filter; 8 is the water pump; 10 is the tank with the heat exchanger; 11 is the part; 12 is the air compressor; 13 is the exhaust hood; and 14 is the exhaust fan.

The parameters that characterize the PEO process were the treatment time T, s; the electrolyte concentration, % and the initial roughness of the specimen Ra, mkm:

- the component composition of the electrolyte (in our case the electrolyte consists of KOH and Na_2SiO_3)
- concentration (the percentage ratio of electrolyte components is varied);
- pH (const≈9-10);
- Electrolyte temperature (t°C=const=30°C);
- Polarity (cathode and anode modes and alternating current, in our case we have the alternating current with the capacitor electrical network);
- Frequency (υ const=50Hz);

- Duty factor (in our case this parameter is not taken into consideration, because we take the alternating current);
- Current voltage pulse shape and the amplitude and their ratio;
- Treatment time (we use for the experiment the following treatment time: 30, 60 and 90 minutes);
- Alloy composition (in our case this is D16, which is heat strengthened and deformable aluminum alloy whose chemical composition meets GOST 4784-97);
- Thermal treatment (the specimens used for the experiment were not subjected to thermal treatment);
- Oxidized material roughness (Ra 0,63μm, Ra0, 48 μm, Ra32μm).

Table 1

Factors and the levels of their varying

Factor	Notation	Measurement unit	Factor varying levels		
			upper	zero	lower
			Coded notation		
			+1	0	-1
Electrolyte concentration	X1	%	KOH 1% Na_2SiO_3 10%	KOH 4% Na_2SiO_3 4%	KOH 4% Na_2SiO_3 3%
Treatment time	X2	min	90	60	30
Initial roughness of the specimen	X3	mkm	0,63	0,48	0,32

For the realization we accepted the D-optimal Box- Behnkin design of a dimensionality K=3, that allows for the mathematical and statistical data processing varying the three components at three levels. D-optimal designs provide a minimum volume of the dispersion ellipsoidal of estimated parameters; minimize a maximum dispersion in the prescribed domain of the design, they have the rototability property and they have the lowest determinant of the covariation matrix. The property of rototability is reduced to that design matrix points are selected providing simultaneously the identical accuracy of the prediction of the values of reply functions independently of the investigation area.

A total number of experiments according to the Box-Behnkin design for K=3 is equal to:

$$N_{tot}=N+N_o=12+3=15 \qquad (1)$$

where N_o is the number of experiments in the design center.

The regression equation in the general case is represented as:

$$Y = b_0 + \sum_{i=1}^{n} b_i x_i + \sum_{i=1}^{n} b_{ii} x_i^2 + \sum_{i=1}^{n} b_{ij} x_i x_j \qquad (2)$$

Regression factors were calculated using Box-Behnkin design matrix.

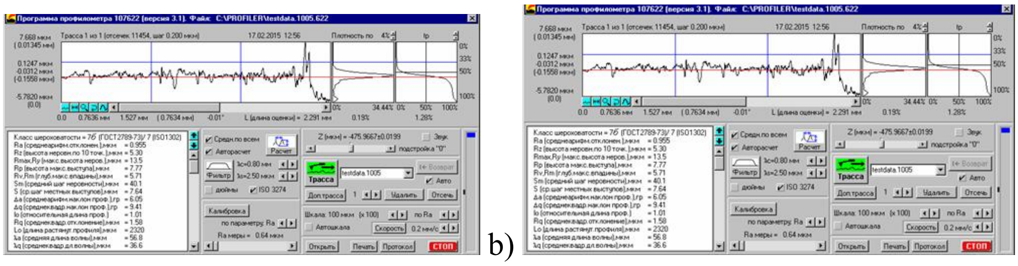
Table 2- Experimental results

Experiment No	Design of experiment			Experimental data			
	X1	X2	X3	Electrolyte concentration	Processing time	Initial roughness	Porosity
1	+1	+1	0	KOH 1%Na_2SiO_3 10%	90	0,48	5
2	+1	0	-1	KOH 1%$Na_2SiO_3$10%	60	0,32	8
3	+1	0	+1	KOH1%$Na_2SiO_3$10%	60	0,63	11
4	+1	-1	0	KOH1%$Na_2SiO_3$10%	30	0,48	6
5	0	-1	+1	KOH 4%Na_2SiO_3 4%	30	0,63	4
6	0	-1	-1	KOH 4%Na_2SiO_3 4%	30	0,32	3.6
7	0	0	0	KOH 4%Na_2SiO_3 4%	60	0,48	7,1
8	0	0	0	KOH 4%Na_2SiO_3 4%	60	0,48	7
9	0	0	0	KOH 4%$Na_2SiO_3$4%	60	0,48	7,2
10	0	+1	+1	KOH 4%Na_2SiO_3 %	90	0,63	10,2
11	0	+1	-1	KOH 4%Na_2SiO_3 4%	90	0,32	9
12	-1	+1	0	KOH 4%Na_2SiO_3 3%	90	0,48	11
13	-1	0	+1	KOH 4%Na_2SiO_3 3%	60	0,63	5,4
14	-1	0	-1	KOH 4%Na_2SiO_3 3%	60	0, 32	7
15	-1	-1	0	KOH 4%Na_2SiO_3 3%	30	0,48	4,9

The processing of experimental data resulted in the following mathematical relationship:

$$Y=7.1+0.2125x1+2.0875x2+0.375x3+3.9375x12+2.7875x22+3.9125x32-1.775x1x2+ +1.15x1x3+0.2x2x3 \quad (3)$$

The average error of the experiment was ε_{av}=0,000194 % and the maximum error was ε_{max}=0, 132%. The adequacy of the obtained mathematical model was checked using Fisher's F-criterion. According to the obtained mathematical model:



a) b)

Fig.3 Surface profilogram:
before the treatment; b- after the PEO

a) b)

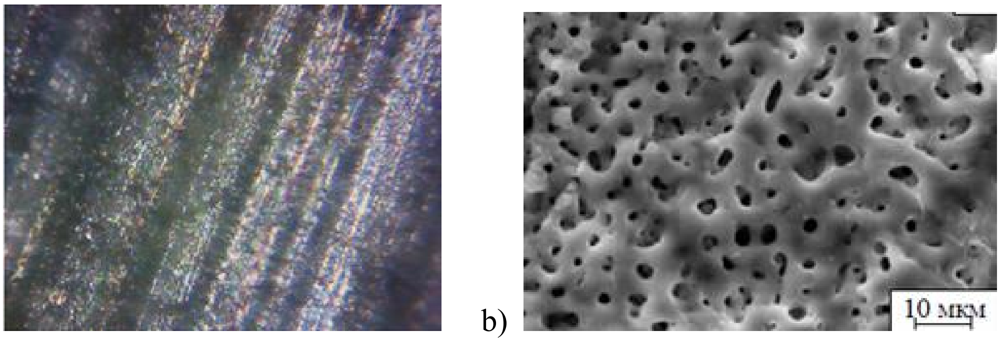


Fig. 4- Specimen surface topography:
before the treatment; b) – after the treatment

Conclusions.

1. As a result of the active experiment according to the 3-factor Box-Behnkin design the mathematical model of the process of plasma electrolytic oxidation was confirmed experimentally.
2. The use of the model allowed for the selection of the rational PEO mode with the parameters for the finite porosity of the specimen made of the aluminum alloy D16.
3. It has been proved experimentally that the model can efficiently be used to control the coating porosity and to reduce power inputs in comparison with the traditional methods of the treatment, by choosing rational PEO modes for the oxidation process of specimens made of the aluminum alloy D16.

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