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Effect of synthesis modes on the properties of microarc oxide coatings

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Abstract. The article presents studies of the physical patterns of formation of oxide coatings on aluminum substrates by microarc oxidation. Correlation dependences of the influence of technological modes, such as current density and time, on the properties of microarc oxidation coatings have been established. A method for monitoring the quality parameters of formed oxide coatings in real time is proposed, based on the analysis of the deviation of the voltage–time curves from the traditional piecewise linear form. The results of the study can be used in the development of intelligent algorithms for creating a digital twin of the microarc oxidation process.

Keywords: microarc oxidation, oxide coating, coating parameters, controlled synthesis, technological modes

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Исследование влияния режимов синтеза на свойства микродуговых оксидных покрытий

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Аннотация. В статье представлены исследования физических закономерностей формирования оксидных покрытий на алюминиевых подложках методом микродугового оксидирования. Установлены корреляционные зависимости влияния технологических режимов, таких как плотность тока и время, на свойства покрытий, полученных микродуговым оксидированием. Предложен метод контроля параметров качества формируемых оксидных покрытий в режиме реального времени, основанный на анализе отклонения формовочной кривой от традиционного кусочно-линейного вида. Результаты исследования могут быть использованы при разработке интеллектуальных алгоритмов для создания цифрового двойника процесса микродугового оксидирования.

Ключевые слова: микродуговое оксидирование, оксидное покрытие, параметры покрытия, контролируемый синтез, технологические режимы

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Introduction

Microarc oxidation (MAO) is a plasma–chemical method of hardening valve metals, which synthesizes coatings with high microhardness (up to 25 GPa), wear resistance, corrosion resistance, electrical strength and heat resistance, and at the same time has good adhesion to the substrate, which contributes to the widespread use of the method in various industries [1, 2]. However, the spread of microarc oxidation technology Production is still limited due to insufficient fundamental study of the coating forming process. There is no single systematic assessment of the effect of technological conditions on the properties of coatings made of valve metals and their alloys [3, 4]. This leads to difficulties in choosing optimal technological modes that take into account many different factors, which reduces the quality of coatings and complicates the management of the technological process [5].

Materials and Methods

To form the MAO coatings, a galvanic cell with an anode (aluminum billet AD31T1 measuring 23×15×1.5 mm) and a stainless steel cathode was used, to which a process current source was connected via a current line made of aluminum wire insulated with a polyolefin heat shrink tube. For the purity of the experiment, the surface of the samples was preliminarily adjusted to a roughness of Ra ≈ 0.1...0.2 microns. The oxidation was performed in the anode-cathode mode with the ratio of anode and cathode current equal to 1. Studies of the patterns of the MAO process, the development and debugging of new technological modes were carried out by registering the voltage–time curves. The parameters of the microarc oxidation process are shown in Table.

Table

Parameters of the MAO process

#	Na_2SiO_3, g/l	NaOH, g/l	current density, A/dm^2
1	50	0.5	10
2	25	0.5	50
3	25	0.5	25
4	25	0.5	10
5	40	0.5	5
6	30	0.5	5

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Results and Discussion

The voltage–time curves of the samples obtained under different modes of the microarc oxidation process are shown in Fig. 1.

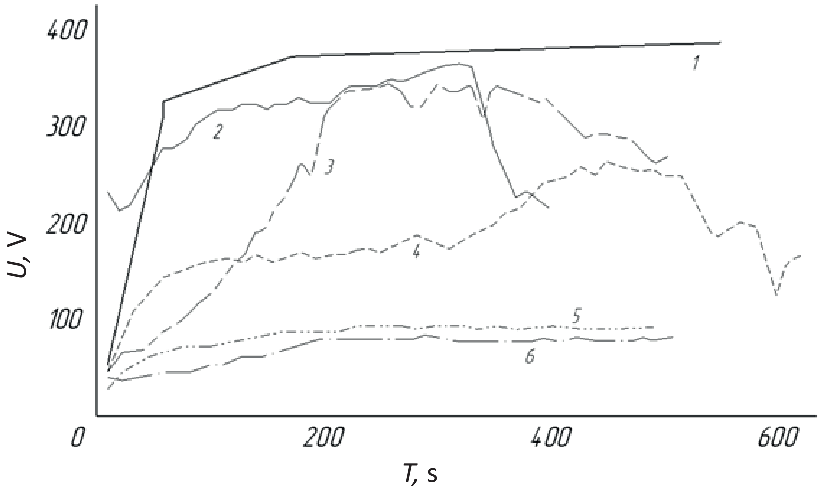


Fig. 1. The voltage–time curves

Analyzing the forming curves, the following factors can be established that affect the quality of the coating being formed:

– destruction of the coating by powerful arc discharges (curve *2*) due to too high current density;

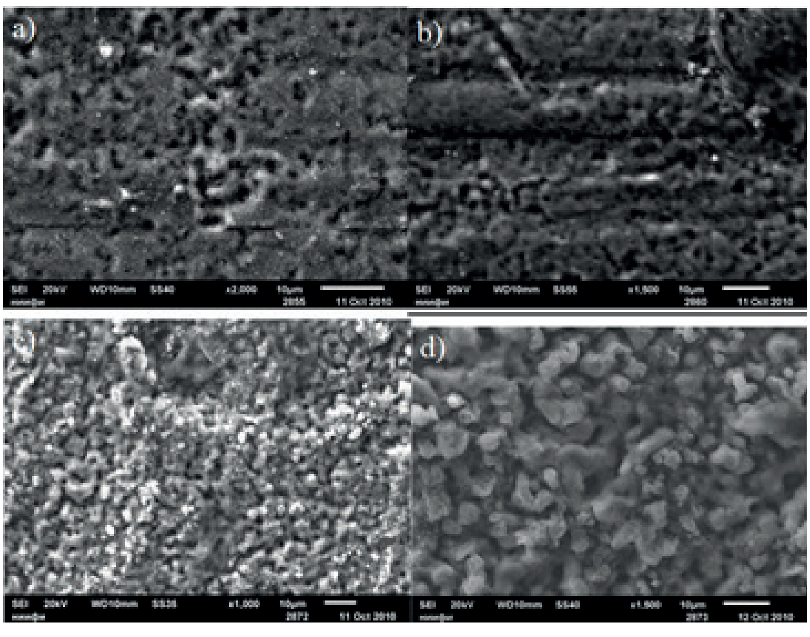
– low rate of increase in forming voltage at the beginning of the process and a rapid transition to the stage of arc discharges (curve *3*);

– low forming voltage (curves *4–6*). At the same time, for curves *4–6*, the process did not enter the stage of spark discharges and was only electrochemical in nature.

High-quality MAO coverage was obtained according to the modes corresponding to curve *1*.

Thus, it can be concluded that a piecewise linear curve can serve as a reliable sign of the formation of a high-quality coating. The structure of the coatings was studied on a VEGA 3 scanning electron microscope using SBH surface topography. The results of the analysis are shown in Fig. 2.

a) *b*)



c) *d*)

Fig. 2. MAO coating in various stages of oxidation: 60 s (*a*); 120 s (*b*); 240 s (*c*); 480 s (*d*)

From those shown in Fig. 2 images of the surface of MAO coatings, it can be seen that with an increase in the processing time of aluminum plates, the surface development increases, the size and number of pores increase. Thus, we can talk about the layering of the resulting ceramic coating. Also, the image taken after the minimum processing time shows that the coating is not porous and repeats the structure of the substrate. Such a coating can be attributed to the basic adhesive sublayer. Further exposure time leads to the appearance of small pores, the coating structure gradually develops. Such layers have a well-developed structure. At the last stage, the fourth sample has a highly porous structure.

The study of surface roughness was carried out on a Mitaka FS150 3d laser conturograph profilometer. Examining the values of the arithmetic mean of the absolute values of the profile deviations within the base length Ra, it turns out that after the minimum processing time, before the start of the spark discharge stage, they are within 0.1 ...0.3 microns. This indicates that the coating at the initial stages of growth repeats the structures of the substrates, since the surface roughness of the samples was adjusted to the same values. As the time of the MAO process increases, the roughness gradually increases due to an increase in porosity and the development of relief. The data shows values in the range of 0.4...0.7 microns.

To assess the effect of current density, a sample was made in the same electrolyte, but at a current density of 15 A/dm^2. Micrographs of the sample taken at various processing stages are shown in Fig. 3.

a) *b*)

c) *d*)

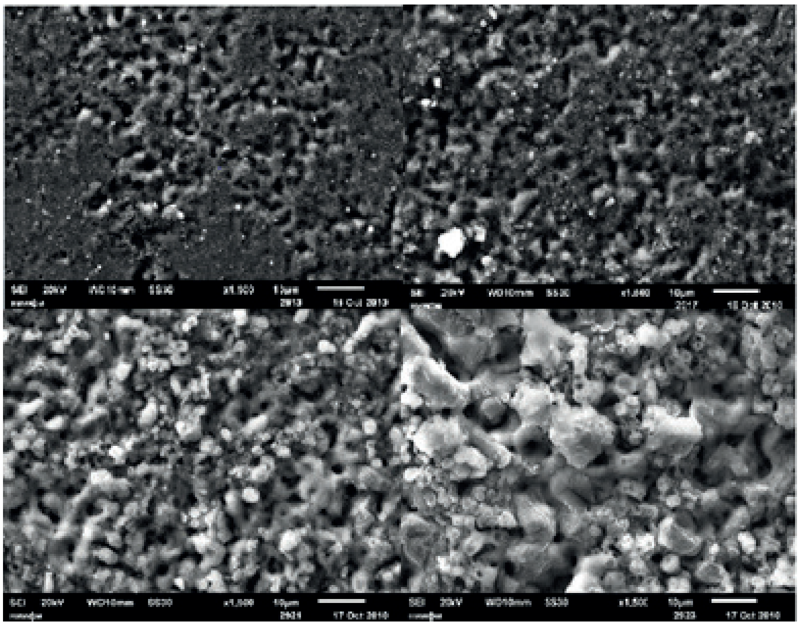


Fig. 3. MAO coating at a current density of 15 A/dm^2 at various stages of oxidation: 60 s (*a*); 120 s (*b*); 240 s (*c*); 480 s (*d*)

Based on the image obtained, it can be concluded that an increase in current density to 15 A/dm^2 leads to an even more complex surface development and an increase in porosity, which is associated with a higher power of microarc discharges and increased dissolution processes in the cathode half-life. This is also confirmed by roughness measurements, according to which the arithmetic mean is Ra = 1 micron.

Conclusion

The forming curves of all the samples are shown on the slide and they all have a piecewise linear appearance. The above makes it possible to establish a quality criterion for MAO coatings, which can be used for an express assessment of the suitability of the technological regime in production conditions: the coating will be of inadequate quality if the voltage–time curves has a distorted shape.

The formed MAO coatings obtained according to these methods can be characterized as multilayer, consisting of a base adhesive layer, an intermediate porous layer and a highly porous layer with a developed surface microstructure.

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