Controlled Synthesis of Multifunctional Coatings by Micro-Arc Oxidation Method

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ABSTRACT

The article is devoted to the development of the methodology for the controlled synthesis of protective coatings by the micro-arc oxidation method in order to improve the efficiency of this technology and the quality of the obtained oxide layers. Methodology includes a mathematical model of a galvanic cell based on an equivalent electrical circuit, as well as a model of the interconnections between the technological parameters of the micro-arc oxidation (MAO) process and the properties of the obtained oxide layers based on graph theory. The indicated dependences are formalized using methods of regression and correlation analysis of experimental data. A technique for the controlled synthesis of MAO coatings using the obtained regression equations is proposed. The structure and functioning algorithm of an intelligent automated system for the controlled synthesis of MAO coatings are developed. A prototype of this system was used to obtain experimental dependences of reaction parameters on the influence parameters of the micro-arc oxidation process.

KEYWORDS

Controlled Synthesis Technique, Electrophysical Model, Graph Theory Model, Hardware, Intelligent Automated System, Micro-Arc Oxidation, Operation Algorithm, Software and Information Support

INTRODUCTION

The article is devoted to the development of theoretical principles, practical methods, and technological equipment that allow implementing the controlled synthesis of multifunctional coatings of metals and alloys by the method of micro-arc oxidation (MAO) (Golubkov, Pecherskaya, Karpanin et al., 2020).

BACKGROUND

A large number of theoretical (Clyne & Troughton, 2019; Ao et al., 2020) and experimental studies (Wang et al., 2020; Bordbar-Khiabani et al., 2019) have been devoted to the study of a promising area of surface treatment of light metals and alloys (aluminum, magnesium, titanium, etc.) under the name micro-arc oxidation. This is due to the fact that the ceramic oxide coatings obtained by this method have improved performance characteristics: micro-hardness, wear resistance (Haghighat-Shishavan et al., 2019), corrosion resistance (Buling & Zerrer, 2019), biocompatibility (Nabavi & Aliofkhazraei,

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2019), magnetic (Rudnev et al., 2020), and antifouling properties (Zhang et al., 2020). In addition to the traditional fields of this technology application (mechanical engineering, the aerospace, rocket and space industries, prosthetics in medicine), new ones (dosimetry (Zolotarjovs et al., 2019), production of ferroelectric ceramics (Teng & Lu F.-H., 2020)) appear or existing ones (prostheses with antibacterial properties (Santos et al., 2019)) expand, which in the long term can lead to great demand for products with such coatings among citizens not only of Russia but also of other countries.

It should be noted, however, that in order to successfully obtain multifunctional coatings by the micro-arc oxidation method on an industrial scale, optimal technological conditions must be developed to guarantee high quality of the finished product at the minimum cost of its production, which is associated with some difficulties. Firstly, this is a large number of heterogeneous factors that simultaneously affect the properties of the formed oxide layer (Golubkov, Pecherskaya, Shepeleva et al., 2018); secondly, the variety of possible directions of use, for which the requirements for the properties of the finished coating can vary widely; thirdly, insufficient knowledge of the MAO process, the lack of an analytical description of a number of interconnections between influencing factors; and fourthly, the imperfection of technological and measuring equipment, the inability to control and register the oxide layers properties in the process of their formation. All this greatly complicates the development of the technological process and leads to the need to create an automated system that realizes the production of MAO coatings with the required properties.

Currently, works of this kind are being conducted both in Russia (Bolshenko et al., 2014) and abroad (Progress industrial systems SA, 2012; Plasma Technology Ltd., n.d.), however, these systems have limited control capabilities, as they do not allow measuring the properties of MAO coatings during their formation. In (Golubkov, Pecherskaya, Karpanin et al., 2017), the concept of an intelligent automated system for the controlled synthesis of MAO coatings was proposed but theoretical positions on which the intelligent application of controlled synthesis is based, as well as methods for choosing the optimal technological mode, were not considered. This article proposes theoretical models that make up the methodology for the controlled synthesis of oxide coatings, and also presents the structure and functioning algorithm of an intelligent automated micro-arc oxidation system.

MODELS USED IN THE DEVELOPMENT OF A METHODOLOGY FOR CONTROLLED SYNTHESIS OF MAO-COATINGS

The mathematical models of the MAO process considered below are designed to solve two main problems: theoretical (study of the interconnections between the parameters of the MAO process and the properties of the obtained oxide layers) and practical (controlled synthesis of MAO coatings with desired properties for various applications in industry). To solve the first problem the MAO process model based on the equivalent electrical circuit, to solve the second - based on graph theory.

Electrophysical Model of the Mao Process

As it is known, the MAO process has a pronounced staging. The anodizing stage is characterized by the formation of a dense barrier layer of metal oxide (in this case, aluminum), and then a porous layer. As the anode oxide film thickness increases, the voltage drop on it increases, which leads to its breakdown and the appearance of sparks on the part surface - the sparking stage begins. In this case, the heating of the pore walls (discharge channels) accelerates the electrochemical processes in them, the pore is overgrown with oxide, and breakdown occurs elsewhere. As the coating thickness increases, the power of micro-discharges increases, which contributes to the occurrence of plasma-chemical reactions in the pores and the phase transition of amorphous alumina (γ-Al_2O_3) to the crystalline modification corundum (α-Al_2O_3), i.e., the stage of micro-arc discharges begins. The higher the proportion of corundum in the coating, the better are its mechanical, chemical, and electrical characteristics. With an even greater increase in the power of micro-discharges, the coating is destroyed (stage of arc discharges).