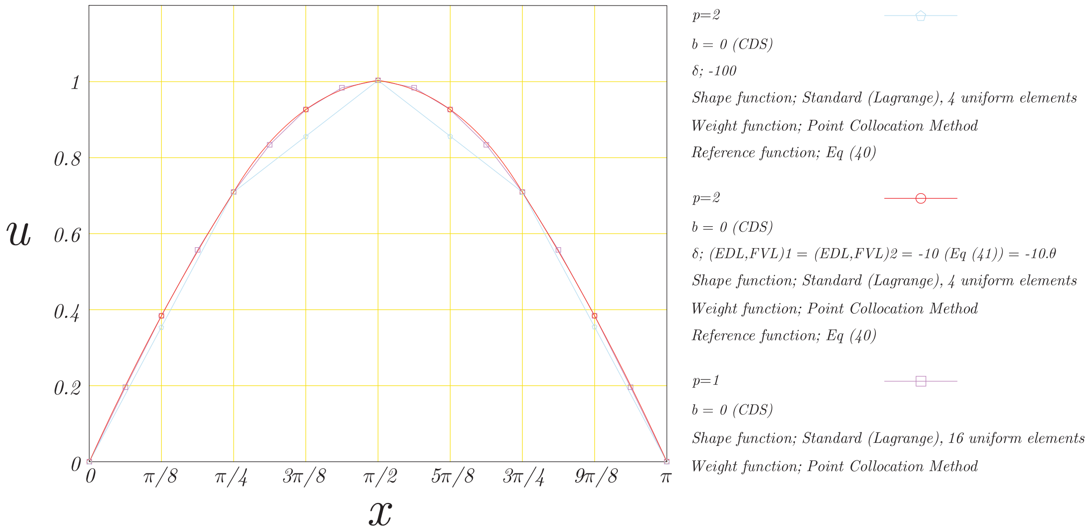

Fig. 22. 1D convection equation with source term, $au_x = \cos(x)$ on $[0, \pi]$ and $a = 1$

Conclusions

The best criterion for evaluate a numerical method is the results of the method and as can be seen in the examples were solved, the result of RFEM comparable to the best results were obtained by other methods is (for these examples, because of the small size of the elements, the difference between the results from different methods can not be seen) and given that the system of equations resulting from this approach similar (in terms of density) Finite Difference Method (FDM) is its efficiency can be compared with finite difference methods (although the use of the Legendre shape functions gives an efficiency much higher than FDM) so do not think other methods that are used in CFD be able to compete with it. Also, due to the similarity of relations many of the techniques used in the FDM can be used to RFEM [Hoffmann, and Chiang (1998)].

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RESEARCH OF INFLUENCE OF MICRO-ARC OXIDATION MODES ON OXIDE COATING PROPERTIES

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Currently search for new efficient coatings with high wear resistance, corrosion resistance, thermal resistance for spare parts of machines and mechanisms of different purpose is an ongoing process. Due to the above a comparatively new method for treatment of valve metals surface – micro-arc oxidation method – is of interest. This method allows obtaining fundamentally new coatings, which are characterized through different physical, chemical and mechanical properties. Pulse mode of performing micro-arc oxidation is of great interest. When forming oxide coating under the pulse mode by micro-arc oxidation method the value of current anode pulse duration has a significant impact on roughness of the coating. The work studies influence of current anode pulse duration on properties of oxide coating obtained by micro-arc oxidation method.

Aluminum, titanium, zirconium alloys and other materials are widely used as structural materials in modern engineering and airspace industry. Search for new efficient coatings with high wear resistance, corrosion resistance, thermal resistance for spare parts of machines and mechanisms of different purpose is an ongoing process. Due to this micro-arc oxidation method (MAO) [1–3], which is comparatively new method for treatment of valve metals, is of interest. The method allows obtaining brand new coatings with unique complex of properties characterized through high performance indicators. The peculiarity of micro-arc oxidation method is that the process runs under high electric field intensity and is accompanied by formation of micro-plasma and micro-regions with high pressure due to appearing gases, which leads to developing of high temperature chemical transformations and transportation of the substance in the arc. Micro-plasma charges activity results in formation of coating layer consisting of oxidized forms of metal elements of electrolyte basis and components. The coating basis predominantly consists of α-Al_2O_3 (corundum) [3].

Topical is the issue of obtaining oxide coating in MAO mode with low roughness in order to exclude additional mechanical treatment of surface layer.

In this regard research of influence of current anode pulse duration on properties of oxide coatings obtained by micro-arc oxidation method is of interest.

Materials and methods. Samples for application of oxide coating were made out of A0 aluminum with dimensions of 2x2 cm and thickness of 3 mm, area of the surface to be treated was 8 cm^2. The samples prior to application of oxide coating by MAO method underwent mechanical polishing and had roughness of Ra = – 0,098 μm.

Oxide coating was formed in electrolyte solution consisting of, g/l: $Na_2HPO_4 \cdot 12H_2O$ – 40; $Na_2B_4O_7 \cdot 10\ H_2O$ – 30; H_3BO_3 – 20, NaF – 10. Electrolyte was prepared out of distilled water and analytically pure and chemically pure reagents. Micro-arc oxidation was carried out in a 700 ml capacity tub made of stainless steel. With the purpose of cooling the electrolyte the tub was provided with water cooling system. Tub body served as cathode in the process of MAO.

MAO process was performed using pulse power source, which allowed obtaining voltage pulses of rectangular, trapezoidal form with pulses flow frequency of 50 Hz and current density of 114–130 A/dm^2.

Roughness of coatings was measured with application of proximity MICRO MEASURE 3D station 3D-profiler. Micro-hardness of coatings was identified by means of Nano Hardness Tester by indenting the penetrator with diamond tip under maximum load of 20 mN. Wear resistance of coating was measured on high temperature friction gauge THT-S-AX0000. Identification of coating durability was based on friction principle of ball indentor made of ВК alloy against surface. Whereas the load was equal to 1N, linear velocity – 2,5 cm/s, measurements were taken under temperature of 250 °C, 50 % air humidity. Durability value was identified by track area measured on three-dimensional profiler using Mountains Map Universal software and obtaining three-dimensional images of sample surface with track. For each sample 9 values of track area were obtained and arithmetic average was found. Coatings thickness was measured on QuaNix-1500 thickness gauge. The thickness was calculated as an average among 15 measurements, from both sides of the sample. Porosity, form, distribution of pores by dimension were analyzed by processing microphotos of surface of samples being studied, which photos were obtained on Quanta 200i 3D raster type electronic microscope using planimetry, secant and dots methods as a ratio of pore image area to total area of a section under observation [4].

Discussion of results. Conducting of MAO process in constant current mode causes intense warming up of near-electrode layer, which leads to formation of partial melting on the sample surface, destruction and peeling of coating, formation of coatings with high roughness.

It is known that when forming oxide coating by micro-arc oxidation method in the pulse mode the value of current anode pulse duration has a significant impact on coating roughness [5]. In case the process is carried out with small values of current anode pulse duration the micro-arc charges arise during short period of time. In this case the material under treatment is not overheated and in the interval between pulses the heat is able to flow to the solution. Small values of pulse duration lead to appearance of small oxide buildups and to significant quantity of pores per unit of area. This facilitates formation of uniform coatings with low roughness.

Voltage value influences final thickness of the coating. Values of current anode pulse duration influences coating quality, in particular, roughness thereof, whereas pulse amplitude influences the coating formation rate. Changes of thickness and roughness of coatings formed under polarizing voltage Up = 300V under different duration of current anode pulse are in table 1.

As it is seen from the obtained data with increase in current anode pulse duration the coating thickness grows, coating roughness increases. The latter is related to the fact that with growth of coating thickness increases power, intensity of micro-plasma charges. Whereas increase in dimensions of individual micro-arc charges is observed, warming up takes place in near-electrode layer of the solution.

In the process of study of these coatings for wear resistance (durability) three dimensional images of samples surface with track were obtained; on these pictures it is seen that track width of initial sample without coating exceeds the width of tracks of samples with oxide coating obtained under different current anode pulse duration.

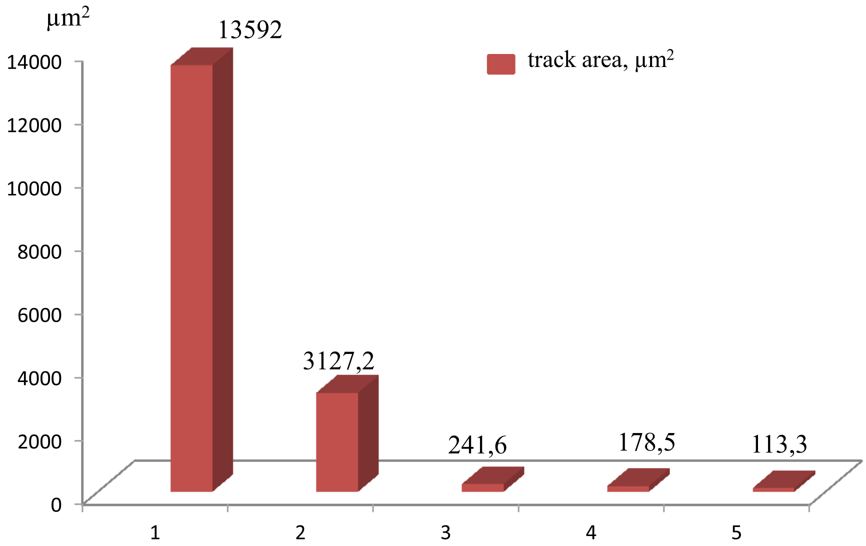
Track areas values for samples without coating and with oxide coating are shown in form of a diagram in figure.

As it is seen from the diagram track areas of samples with oxide coating are significantly less than track area of initial sample, which testifies of high wear resistance of samples with oxide coating. As anode pulse duration increases with coating thickness growth the coating wear resistance increases. Since coating roughness is related to friction ratio, along with roughness increase friction ratio increases as well (table 2).

Table 1

Dependence of thickness and roughness of coatings on current anode pulse duration

№	Current anode pulse duration, ms	Time, min	Coating thickness, µm	Roughness Ra, µm
1	50	20	7,8	0,34
2	100	20	11,1	0,57
3	150	20	19,7	0,92
4	200	20	26,5	2,21



Track areas values when performing durability test of samples without coating and with oxide coating obtained under different durations of current anode pulse. 1 – initial sample; 2 – 50 ms; 3 – 100 ms; 4 – 150 ms; 5 – 200 ms

Table 2

Micro-hardness of coating

№	Polarizing voltage, V	Current anode pulse duration, ms	Micro-hardness, MPa	Friction ratio
1	300	50	1522,7	0,85
2	300	100	1888,2	1,12
3	300	150	3775,7	2,16
4	300	200	33543,9	3,68

An important physical and mechanical feature of coating is its micro-hardness. Micro-hardness values on surface of samples depending on coating obtainment modes are shown in table 2.

Study of micro-hardness deep into the sample showed that in the MAO process a transient layer deep into the metal is generated from oxide layer with gradual decrease of micro-hardness value. For instance, when pulse duration is 100 ms the micro-hardness of transient layer gradually decreases from 1047,4 MPa to 846,2 MPa when measuring at depth of 15 to 40 µm deep into the metal. Micro-hardness of initial material is equal in this case to around 150 MPa. In this depth interval also Young module increase is observed, which is below 89 GPa in average, whereas initial material has Young module of 70 GPa.

Research of coating surface morphology by means of raster electronic microscope showed that with 50 ms anode pulse duration a thin coating is formed due to low productivity of the process. Whereas formation of basic external functional layer is not complete, coating is formed in spots. With current anode pulse duration of 50 ms formation of significant quantity of round shaped pores per unit of surface area is observed. As current anode pulse duration increases to 200 ms the nature of micro-plasma charges change. Small spark charges are replaced with large ones. Coating thickness growth leads to of refilling pores, quantity of pores decreases. As a result of spark charges enlargement the average dimension of pores increases with current anode pulse duration of 200 ms. Surface porosity values are shown in table 3.

Table 3

Surface porosity of oxide coatings

№	Current anode pulse duration, ms	Coating thickness, µm	Porosity ΔS, %	Quantity of pores per 1 cm2 of coating	Average diameter of pores, µm
1	50	7,8	6,4	$1{,}1\cdot10^{6}$	2,72
2	100	11,1	11,7	$7{,}3\cdot10^{5}$	4,5
3	150	19,7	5,6	$3{,}5\cdot10^{5}$	4,5
4	200	26,5	8,7	$3{,}02\cdot10^{5}$	6,06

Conclusions

Impact of current anode pulse duration on properties of oxide coatings has been studied. It has been shown that current anode pulse duration has significant impact on coating roughness. As pulse duration increases coating roughness, friction ratio increase as well.

Tribometric research of coatings showed that as a result of micro-arc oxidation durable coatings are formed, whereas with increase of anode pulse duration and thickness of coating the durability of the coating increases. Micro-hardness on coating thickness of 19,7 and 26,5 µm is equal to 3,8 and 33,5 GPa respectively. It has been found out that as a result of micro-arc oxidation a transient layer is formed deep into the metal with high value of micro-hardness in comparison with untreated aluminum. Micro-hardness of transient layer is gradually decreasing deep into the metal.

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