INVESTIGATION OF COATING THICKNESS OBTAINED BY PLASMA ELECTROLYTIC OXIDATION ON ALUMINIUM ALLOYS IN ELECTROLYTES OF TYPE «KOH-H₃BO₃»

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Abstract: Plasma Electrolytic Oxidation (PEO) is one of advanced methods of obtaining thin layer oxide ceramic coatings on machine elements of different functional purpose providing considerable increase their resource. The work is devoted to the investigation of coating thickness formed by Plasma Electrolytic Oxidation on different aluminium alloys in electrolyte of type «KOH-H₃BO₃». Plasma Electrolytic Oxidation is recommended to be implemented at different engineering and repair and technical enterprises, dealing with production, restoration and hardening of elements.

KEY WORDS: plasma electrolytic oxidation, electrolyte, oxide ceramic coating, sample, element, thickness, wear resistance, current density.

1. Introduction

Element life growth by their restoration and hardening is the basic reserve of material saving, cost savings under machines repairing and one of the most important problems in the conditions of cost increase of raw materials and energy resources. One of the most advanced methods allowing considerable life growth of elements produced from aluminium alloys (pistons of internal combustion engines, cases of hydraulic gear type pumps, etc.) is plasma electrolytic oxidation [1].

The essence of Plasma Electrolytic Oxidation is in element surface formation of thin layer high tenacity wear resistant ceramic coatings consisting foremost of solid phase aluminum oxides in the conditions of microplasma discharges impact [2-4].

The main advantages of Plasma Electrolytic Oxidation are:
- the possibility of coatings applying on the complex-profiled products, inner surfaces and hidden cavities;
- the obtaining of coatings with width to 0.3 mm with adhesion is compared with base material hardness;
- low price and availability of chemicals and materials;
- environmental friendliness.

Fig. 1 presents morphology and typical micro structure of coatings being formed by Plasma Electrolytic Oxidation on aluminium alloys.
Figure 1 – Morphology (a) [5] and micro structure (b) [1] of coatings being formed by plasma electrolytic oxidation. Magnification 600\(^\times\) and 400\(^\times\).

Today many aspects of mechanism of Plasma Electrolytic Oxidation process are not studied yet: there is no systematic information about influence of internal and external factors on this process, many new electrolytes are not tested.

Hereafter the results of investigations of wear resistance of coatings obtained by Plasma Electrolytic Oxidation on different aluminium alloys in electrolyte of type «КОН-H\(_3\)BO\(_3\)» are presented.

2. Experimental procedures

Aluminium alloys of trademarks 1520 (AMr2), 1235 (AD1) and 2024 (Д16) were considered as material for sample production. They are widely used for production of elements of different nomenclature in processing industry. Aluminium alloys chemical content is presented in Table 1. Plated samples of size 50x15x5 mm were used to carry out the investigations.

Table 1 – Mass fraction of elements in the alloy content (base – aluminium), %

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Mg</th>
<th>Si</th>
<th>Mn</th>
<th>Cu</th>
<th>Ti</th>
<th>Fe</th>
<th>Cr</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>1520 (AMr2)</td>
<td>1.7-2.4</td>
<td>0.4</td>
<td>0.1-0.5</td>
<td>0.15</td>
<td>0.15</td>
<td>0.5</td>
<td>0.05</td>
<td>0.15</td>
</tr>
<tr>
<td>1235 (AD1)</td>
<td>0.05</td>
<td>0.3</td>
<td>0.025</td>
<td>0.05</td>
<td>0.15</td>
<td>0.3</td>
<td>-</td>
<td>0.1</td>
</tr>
<tr>
<td>2024 (Д16)</td>
<td>1.2-1.8</td>
<td>0.5</td>
<td>0.3-0.9</td>
<td>3.8-4.9</td>
<td>0.15</td>
<td>0.5</td>
<td>0.10</td>
<td>0.25</td>
</tr>
</tbody>
</table>

It is suggested that the aluminium alloys data application provides the realization of method of installation of the hardened extra repair element (ERE) at the restoration of elements produced from different materials (for example, made of different materials (for example, bronze, corrosion-resisting steel) and contacting with liquid food mediums (milk, fruit extracts, etc). The main task being solved in this case is obtaining of hardened oxide ceramic layers, formed inward of base of oxidized aluminium alloy.

To form coatings on above mentioned aluminium alloys electrolyte of type «КОН-H\(_3\)BO\(_3\)» with the following components concentration for liter of distilled water: KOH – 5 g/l, \(H\(_3\)BO\(_3\)– 15-30 g/l was used.

The sample oxidation was done on the Plasma Electrolytic Oxidation installation functioning in anode-cathode mode. Current density was 10-30 A/dm\(^2\); processing time – 120 min; electrolyte temperature was supported in the range of 30-35 \(^\circ\)C.

Coating thickness was determined on disks by means of device Buehler Micromet 2100 microhardness tester.
3. Results and discussion

The results of the researches showed that thickness of oxide ceramic coating obtained in electrolyte of type «KOH-H3BO3», depends on the modes of Plasma Electrolytic Oxidation and trade mark of aluminium alloy (Fig. 1, 2, 3).

Concentration KOH increase at other constant factors results in deeper penetration into alloy base, increasing thickness. Obviously it can be explained that for the sake of more intensive etching of the oxidized alloy surface, in coating formation the greater number of formed connections that had reacted with alkalis. Concentration KOH increase being more than 6 g/l does not sufficiently influence on coating thickness, because electrolyte aggressiveness increases. Obtained coatings turn out to be soft. At KOH concentration being less than 2 g/l electrolyte has low dispersive capacity and obtaining of thick uniform coatings is difficult.

Boric acid concentration increase at other constant factors of Plasma Electrolytic Oxidation does not sufficiently influence on change of coating thickness. In our case boric acid is used as anode inhibitor, increasing break down strength. Boric acid concentration increase being more than 25 g/l is not rational from economic point of view. At boric acid concentration being less than 15 g/l to switch into Plasma Electrolytic Oxidation is not possible. The above mentioned is well coherent with the data of other scientists [3, 5].

![Figure 1 – Influence of current density (Dt) on the thickness of the hardened coating layer (h) on aluminium alloy 1520. Modes: t = 120 min; a) CKOH = 2 g/l; b) CKOH = 4 g/l; c) CKOH = 6 g/l.](image)

- CH3BO3 = 15 g/l;
- CH3BO3 = 20 g/l;
- CH3BO3 = 25 g/l;
- CH3BO3 = 30 g/l.
Current density growth at other constant factors of Plasma Electrolytic Oxidation results in increase of hardened layer thickness (Figures 1, 2, 3). It provides more intensive
Carrying out plasma electrolytic oxidation at low current densities is not rational from technological point of view, because to obtain the required thickness all three factors were controlled. Therefore, they were not included in the model. Coatings obtained on alloy 1520, have maximum thickness, because magnesium in alloy with aluminium form uniform oxide connections (Figure 1). Coatings obtained on alloys 1235 and 2024, do not differ sufficiently (Figures 2, 3).

To maintain the main factors influence on coating thickness change and also taking into consideration their interaction the investigation was done according to the method of full factorial experiment planning $2^3$.

Matrix of planning $2^3$ and mean real values of optimization parameter are presented in Table 2.

The experiment data processing, creation of mathematical model of process and check of its adequacy were done using PC by means of software product MS Excel. As the result the following regression equations were obtained:

For 1520: $h = 121.95 + 11.7X_1 + 2.85X_2 + 1.75X_3 + 0.3X_1X_2X_3$; (1)

For 1235: $h = 118.4 + 10.81X_1 + 0.95X_2 + 2.26X_3 + 0.5X_1X_2X_3$; (2)

For 2024: $h = 114.16 + 10.49X_1 + 1.96X_2 + 2.39X_3 + 1.06X_1X_2X_3$; (3)

<table>
<thead>
<tr>
<th>Number of plan point</th>
<th>Code factor designations</th>
<th>Geometry parameters (process factors)</th>
<th>Mean real values of optimization parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$X_1$ $X_2$ $X_3$</td>
<td>$D_t, A/dm^2$</td>
<td>C H$_3$BO$_3$, g/l</td>
</tr>
<tr>
<td>1</td>
<td>- - -</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>+ - -</td>
<td>25</td>
<td>20</td>
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<tr>
<td>3</td>
<td>- + -</td>
<td>15</td>
<td>30</td>
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<td>4</td>
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<td>5</td>
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<td>+ - +</td>
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<td>7</td>
<td>- + +</td>
<td>15</td>
<td>30</td>
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<tr>
<td>8</td>
<td>+ + +</td>
<td>25</td>
<td>30</td>
</tr>
</tbody>
</table>

Considering their ratios importance for obtaining the required thickness all three factors were controlled.

Then the experiment results were processed using the least square method by means of software product MS Excel. As the result the process mathematical models in the form of linear equations were obtained:

For 1520: $h = 54.15 + 2.34D_t + 0.57C H$_3$BO$_3$ + 1.35 C KOH; (4)

For 1235: $h = 59.04 + 2.16D_t + 0.19C H$_3$BO$_3$ + 2.26 C KOH; (5)

For 2024: $h = 50.45 + 2.09D_t + 0.39C H$_3$BO$_3$ + 2.4 C KOH; (6)

For final check of the obtained models adequacy the results of coating thickness measurements obtained in the pilot experiment were used. Substituting into equation $D_t = 20 A/dm^2$; C H$_3$BO$_3$ = 25 g/l; C KOH = 5 g/l, we will get: for 1520 alloy: $h = 122$ µm, for A1: $h = 118$ µm, for D16: $h = 114$ µm. Comparison of these calculated values with experimental values points to the mathematical model adequacy.
4. Conclusions

Taking into account that the thickness of coating necessary to provide high wear resistance, corrosion resistance, low porosity must be no less than 90-120 µm and according to the recommendations [5,7-9], to harden surfaces of extra repair element (ERE) (for example, repair bushings) in electrolyte of type «KOH-H₃BO₃», it is possible to recommend the following:

- to produce repair bushings ERE one should use alloy 1520;
- to use electrolyte of the following content,: 4-6 g/l KOH, 20-25 g/l H₃BO₃;
- the recommended electrolyte temperature 30-35 ºC;
- the current density during the process one should maintain about 20-25 A/dm²;
- the recommended duration of Plasma Electrolytic Oxidation – 110-130 min.

This method of elements surface hardening can be recommended for implementation at engineering and repair and technical enterprises, dealing with production, restoration and hardening of elements. The expected life growth of hardened elements will correspond to not less than 150-200% in relation to new elements.

REFERENCES