Production of Transitional Diffused Layers by Electrospark Coating

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Abstract. The article presents a new method for production of diffused transitional layers with nano- and microthickness by local removal of nanofilms on aluminum alloys. This allows procuring of high-quality coatings on fusible alloys (for example, on aluminum ones) by materials, the melting point of which is 2-3 times higher than that of the basis (for example, of cast iron). This permits imparting new useful properties to workpieces made from light alloys with decent values for electrochemical working. The authors show that application of coatings provides minimum heating of workpieces. This enables the regulation in temperature condition of operating environment and permits efficiency improving during the process of electrochemical working by means of higher density current supply.

1. Introduction
During the design and fabrication of fixtures and tools, there are difficulties in selection of materials that are capable to combine the required physical mechanical and service characteristics. The main difficulties appear during the design and fabrication of working parts made of conductive materials that are used during electrochemical working, the radical departures of which are high conductivity of the material and minimum losses of impressed voltage. As a rule for fabrication of similar workpieces, the authors use as materials stainless steels, copper and copper alloys, graphite and copper graphite materials with a fine-grain structure, as well as alloys based on titanium and chromium [1-4]. But these materials have some disadvantages (high specific density and others) that have great influence on the capability of their application, especially in batch production.

At present during the design of equipment parts, draftsmen pay much attention to aluminum alloys possessing the property package favorably distinguishing them from other materials. Advantages of workpieces made of aluminum alloys permitting significant mass reduction and materials loss are well known. They can be easily treated either by cutting or by yielding, but their performance characteristics do not satisfy the requirements for equipment parts during electrochemical working [5]. At the presence of alkali ions produced by electrochemical working, aluminum alloys decompose because of uncontrolled anodic attack, this dramatically reduces the equipment endurance with accuracy loss in setting of processing datum surfaces and areas of current supply [6].
2. Availability of High-Temperature Coatings on Aluminum Alloys
The most promising coating for aluminum alloys is cast iron that has high oxidation stability, low resistance to part transfer in units, moderate voltage loss in current lead. But electrospark alloying and covering do not provide reliable bonding of cast iron coating because at low pulse energy the treatment process decayed, but the growth of discharge energy caused intensive melting in aluminum alloy under the high-temperature surface oxide film. In addition, the transitional diffused nanolayer holding the workpiece coating could not be produced. In response to this problem, it was necessary to remove oxide film with the thickness of several dozen nanometers before cast iron application. This will not lead to the change of rough part size and will not cause the workpiece accuracy loss. After that in contact areas of cast iron coating and aluminum alloy at temperatures that are lower than melting point of material basis, the transitional diffused layer with the thickness of more than 100-150 nanometers is formed, this ensures good adhesion of coating, resistant to cavitating influence during electrolytic flowing and current impulses during electrochemical working.

3. Transformations in Nanolayer when Applying Coating
Much heating during electrospark coating caused by the necessity of melting heat-proof (as compared to aluminum alloys) cast iron microdoses, as well as high electric field intensity, has influence on electron emission from cathode surface. In addition, at this stage one can face active destruction of the piece surface layer. The reason for such behavior of aluminum alloy during this process is active heating of cathode metal [7]. Taking into account that the oxide film covering work surface has high melting point and (in spite of little width) strength, for its destruction or separation one need heat that exceeds manifold the melting point of aluminum alloys or considerable force. It is possible to accept that increase in volume of the metal that is under oxide layer due to its heating, melting and boiling in film under expansive forces may cause the appearance of tensile strength, leading to clinks that could result in its destruction. But the moderate melting point of basis material does not allow the necessary heating of high-temperature film without local rupture of aluminum alloy in the discharge area. This sidelines production of the diffused transitional layer is necessary for production of sound deposit.

The presence of natural oxide nanofilm on the surface of aluminum alloys has not only negative effect on production of sound metal deposit, but also may cause destruction of workpiece surface during electrospark coating. For that matter, one of the tasks that the authors have to handle is removal of natural oxide $\text{Al}_2\text{O}_3$ film from the metal.

4. Production of Sound Deposits on Aluminum Alloys
For embodiment of covering aluminum alloys by cast iron, the authors used different techniques for destruction and removal of surface oxide film in the working area and for protection from metal reoxidation during technological cycle. But all of them were not enough effective.

After the study of peculiarities in coating the surface of aluminum alloys by cast iron, the authors found the method of oxide film removal from the surface of in-process part that eliminates heating of the covering area and associated with it reduction of accuracy and quality of the surface layer. It is the method of producing protective current-conducting metal coatings on the surface of aluminum alloys equipment.

The offered method of producing metallic current-conductive coatings is different because before coating the discharge area chemically-reactive fluxes are injected; they lower material thermal protection at the boundary of coating and as a consequence prevent the destruction of the basis surface layer.

The worked out method is carried out as follows. On the surface of the aluminum alloy workpiece, let us mark areas for metal coating, set the workpiece in position that allows holding the flux layer on the chosen places of the workpiece. Then let us pick flux grade recommended for example for aluminum alloy welding and apply a thin layer of the flux on the marked parts of the workpiece. The flux is put homogeneously until the continuous layer is received controlling the thickness by eye. Then the working part with flux is transferred to the plant for electrospark coating and application of the
continuous metal layer. This time the diffused nanolayer is made under the coating; it firmly connects the cast iron coating with the basis. This process can be accomplished at sparse process conditions when crack formation of coating does not take place. For the chosen flux content, let us recommend using operating voltage of (40-60) volt; short-circuit current of (2-7) ampere; pulse on time of (100-150) microsecond; vibration frequency of tool electrode of 100 hertz; specific time of coating application of (1-5) minute per square centimeter; the number of applied layers is up to 3-4. The choice of tool electrode feed velocity must be based on the guarantee covering of next droplets on 1/4 of their diameter.

The offered modes can be specified in the process of experimental adjustment, in order to find out the optimum values for further application.

5. Rationale for Choosing the Flux for Oxide Nanofilm Removal on the Place for Coating

For production of permanent joints, let us recommend the flux grades shown in Table 1.

Table 1 presents the composition of fluxes that are recommended for application in processing of aluminum alloys.

| Flux grade | Weight percent of the element, % |
|------------|----------------------------------|
|            | CaF₂ | Al₂O₃ | CaO | MgO | SiO₂ | C | Fe₂O₃ | S | P | other elements |
| ANF-1      | ≥ 90 | ≤ 3   | ≤ 5 | -   | ≤ 2.5 | 0.1 | 0.5 | 0.05 | 0.02 | ≤ 0.05 (TiO₂) |
| ANF-7      | 65-75 | -     | 18-30 | -   | ≤ 2 | - | - | 0.05 | 0.02 | - |
| ANF-6      | Oct. | 25-31 | ≤ 8 | - | ≤ 2.5 | 0.1 | 0.5 | 0.05 | 0.02 | ≤ 0.05 (TiO₂) |
| ANF-28     | 41-49 | ≤ 5 | 26-32 | ≤ 6 | 20-24 | 0.1 | 0.5 | 0.06 | 0.03 |

Application of such fluxes guarantees not only mail processing characteristics, but also steady behavior during brazing and coating; easy removal of slag coverage; production of quality coating, prevention of interstices and cracks in coating; corrosion resistance; conductivity and other properties. So for destruction of oxide film and prevention of sponginess, one may include into fluxes TiO₂, SiO₂, Cr₂O₃, Fe₂O₃; carbonates BaCO₃, K₂CO₃, and also sulfates, chlorides of non-ferrous metals, charcoal, etc.

6. Approbation of Coatings with Transitional Layer

The analysis of surface layers on pieces with coatings applied by the electrospark method under the layer of FS-71 flux proved the formation of diffused nanolayers at the basis-coating boundary. Pieces for processing were made of D-16 aluminum alloy in the form of slabs having 3 millimeter width with (15 × 10) millimeter areas marked for application of coating layers. The surface finish of initial face is \( R_a = 1.25 \) micrometer. Application of the coating was performed by the cast iron electrode made of SCH-20 material in the form of a spindle.

Metallographic testing of formed coating layers showed (Table 2) that during application of hard modes of \( A = (0.5-1) \) joule, the coating thickness is more than 40 micrometer, but when the mode is made still more intensive, \( A ≥ 1 \) joule, the thickness grows up to (150-200) micrometer. However in
all these cases, there is a transitional layer containing the diffused area with the thickness ranging from dozen nanometers to fractions of a millimeter. When the pulse energy increases, coating thickness increases as well (Table 2), but there may be damages of different types (networks of cracks, burns, nonuniformities), occurrence of gas micropores and blowholes that may become stress concentrators. The surface finish of such coatings is $R_a = (100-150)$ micrometer (in contrast to the ones produced in sparse modes where $R_a = (2-20)$ micrometer).

Table 2. Characteristics of coating layer produced on surface of D16 aluminum alloy by tool electrode made of SCh-20 cast iron

| Layer characteristic | Pulse energy ($A$), joule | Thickness of applied coating, micrometer |
|----------------------|---------------------------|------------------------------------------|
|                      | 20           | 50           | 100          | 150          | 200          |
| Uniformity, %        |              |              |              |              |              |
| < 0,5                | 40-50        | 75-85        | 85-95        | 80-90        | -            |
| 0,5-3,0              | 50-70        | 85-90        | 80-85        | 75-80        | 70-75        |
| Microcracks occurrence |              |              |              |              |              |
| < 0,5                | Absent       | Absent       | Casual occurrence | -            |
| 0,5-3,0              | Slight       | Occur        | Cracks network |
| Sponginess           |              |              |              |              |              |
| < 0,5                | Absent       | Absent       | Seldom occurrence | -            |
| 0,5-3,0              | Seldom       | Fractional open | Considerable |
| Surface finish, micrometer |              |              |              |              |              |
| < 0,5                | 2-8          | 8-20         | 20-35        | 45-70        | -            |
| 0,5-3,0              | 6-10         | 15-25        | 30-50        | 60-90        | 100-140      |
| Burns                |              |              |              |              |              |
| < 0,5                | Absent       | Absent       | Occur        | -            |
| 0,5-3,0              | Seldom       | Occur        | Often        | occurrence   |

Sparse modes ($A = (0,1-0,5)$ joule) lead to formation of a more homogeneous flawless layer although the thickness of the coating layer in this case decreases up to 20-35 micrometer.

Pieces surface inspection in terms of correspondence to operating factors showed that such pieces do not have microcracks network, voids and burns, and the surface finish value of the surface layer without the additional treatment has an interval of $R_a = (10-50)$ micrometers when the coating integrity is (75-95) %.

The tested empirical relations between characteristics of produced layers and operating conditions of the coating process prove the calculated results to a precision of 7-10 %.

7. Conclusion
The article shows that it is possible to receive sound deposits by applying cast iron on aluminum alloys with the help of the electrospark process, where the layer endurance is maintained by formation of the transitional diffused nanolayer after chemical removal of the oxide layer from the alloy surface.
This led to solution of the problem concerning effective replacement of hard-to-treat, heavy (difficult-to-obtain) engineering materials during production of industrial equipment for electrochemical working and other types of processing.

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