Study of the Surface Structure Variations of AK5M7 Alloy after Electro Spark Alloying and Annealing

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Abstract: The current work presents the results of studying surface structure of the AK5M7 aluminum alloy hardened by the Electro Spark Alloying (ESA) technique with subsequent annealing. Analysis of crystallite size (CS) values, microdistortion of phase crystal lattices found on the surface, microhardness, and wear resistance allows concluding that the degree of defectiveness of the surface structure plays a decisive role in its wear resistance.

Keywords: annealing, electro spark alloying, crystallite size, microdistortion, microhardness and wear intensity.

1. Introduction
The issues of improving the operational properties of machine parts and mechanisms by surface alloying and hardening methods are becoming increasingly important. To increase the wear resistance of parts, various surface modification methods were usually used. One of these methods is the Electro Spark Alloying (ESA) of conductive materials created by B.R. Lazarenko and N.I. Lazarenko [1-4]. At the same time, from a physical point of view many issues of surface hardening remain not fully understood. Due to their ability to cast, Al alloys are widely used in the automotive industry, since it have sufficiently high mechanical properties, low thermal expansion coefficients, and high strength to weight ratios. At the same time, the hardness and wear resistance of aluminum alloys remains relatively low [12-14]. In this regard, the study of the surface structure of aluminum alloys after ESA remains very relevant. Such issues were studied by many authors [15, 16], in which the surface of the AK5M7 alloy was studied together with a number of parameters characterizing the surface structure were determined: likely phase composition, crystallite size CS, microdistortion of the lattices formed on the phase surface, microhardness, and wear intensity.

As a result of analyzing the experimental data, it was concluded that one of the main reasons for reducing the wear of the surface of the AK5M7 alloy is an increase in the defectiveness of its structure after ESA. Meanwhile, it is known that a decrease in the structure defect can be achieved by various ways, among which one of the most effective is annealing. Accordingly. The aim of this current study is to attempt of evaluation the influence of annealing temperatures (100, 150 and 200 C°) on the wear resistance of the AK5M7. The results obtained after ESA processing and annealing, were analyzed and a conclusion was drawn about the possible physical foundations of the influence of the structure of the alloy surface after ESAon the intensity of its wear.

2. Materials and methods
Two groups of samples (four samples per group) with dimensions of $15 \times 15 \times 4$ mm in size were made from AK5M7 aluminum alloy in order to investigate the phase formation and behavior of surface phases. The surfaces of samples of the 1st group were processed manually using an ESA technique by a copper electrode (A), while the samples of the 2nd batch were treated with an electrode of an alloy with phosphorus copper (P). The elemental composition of the electrodes and AK5M7 alloy are shown in Table 1.

| Table 1. The elemental composition of the alloy and electrodes in wt. % |
|-----------------------------------------------|
|                  | Al  | Cu  | Si  | P    |
| **Alloy AK5M7**  | 88  | 7   | 5   | ........|
| **P-Electrode**  | ........ | 92.9 | ........ | 7.1   |
| **A-Electrode**  | 0.1 | 99.9 | ........ | ........ |

Figure 1 shows the results of measuring the microhardness of surfaces after ESA A and P electrodes, as a function of annealing temperature.

Figure 1. Dependence of the microhardness of surfaces hardened by electrodes A and P on temperature and annealing time.

It can be seen that in both cases, the values of microhardness were continuously decreased with increasing time and annealing temperature stress relation / relief was highly expected to occur leading to the noticed behaviors. The phase composition results the surface with ESA under various temperatures and times of annealing given in the Table (2).

By a comparison of the results obtained from of studying the phase composition of surfaces with ESA before [16] and after annealing (Table 2), it was noticed that when electrode A was used after annealing, a similar phases remain on the surfaces as before annealing, but their concentrations changed: Al- from 87 to 53, Al$_2$Cu- from 11- to 39, Si- from 2 to 8%. When using the P electrode, it was observed that the previously existing phases were also preserved: Al and Al$_2$Cu with a change in their concentration from 60 to 72, and from 32 to 15% before and after annealing, respectively. Moreover the appearance of new phases: like AlP-3%, Cu$_3$Al - 4%, Al$_4$Cu$_9$ - 6%, were characterized on the treated surfaces.
Table 2: The composition of phases on the surface of the samples after ESA treatment.

| Energy, J | Phase consternation, % (wt %) |
|-----------|-------------------------------|
|           | Alloy AK5M7                   |
|           | A-electrode                   |
|           | P–electrode                   |
|           | Al   | Al\textsubscript{2}Cu | Si |
| 0         | 94   | 2            | 4  |
| 0.07      | 97   | 2            | 1  |
| 0.2       | 96   | 3            | 1  |
| 0.39      | 94   | 5            | 1  |
| 0.79      | 89   | 10           | 1  |

From the analysis of the phase composition at the studied surfaces, it can be noted that a change in the quantitative composition of the existing phases, as well as the appearance of new ones, did not lead to an increase in microhardness, but rather to a decrease in it. From these data, it can be concluded that: the presence of new phases on the treated surface after the ESA, as well as the conservation or change in their content after annealing, do not have a decisive influence on the surface microhardness. Figure 2 shows the results of a study of coherent scattering regions of the surface after annealing.

Figure 2. Crystallite size as a function of annealing time

It was seen that, as temperature and annealing time were increased, an increase in the CS sizes of the Al and Al\textsubscript{2}Cu phases was observed when using electrodes A and P. The results of microdistortion magnitude of the phase lattices on the surface show that with increasing temperature and increasing annealing time resulted in decreasing microdistortion as shown in Figure (3).

Thus, the results of studying the surface structure of the AK5M7 alloy after various annealing modes showed that the CS values of the crystal lattices of various phases increase, while microdistortion decrease. These data indicate a decrease in the defectiveness of the surface structure after annealing.

Figure 4 Presents the wear intensity after annealing compared with the correspond parameters after ESA. Thus, the results of a study of the surface structure of the AK5M7 alloy after various annealing temperatures showed that the CS values of the crystal lattices of various phases increase,
while the microdistortion decrease. These data indicate a decrease in the defectiveness of the surface structure after annealing. The present results are in good agreement with what concluded by ref [16].

![Figure 3](image1.png)

**Figure 3.** Microdistortion behavior for Al, Al$_2$Cu phases verses annealing temperature.

![Figure 4](image2.png)

**Figure 4.** Wear rate of the AK5M7 alloy after surface treated by ESA for electrodes A and P with energy of 0.79 J and annealing at 200°C for 11 hours.

3. **Conclusion**

Based on the analysis of research results for AK5M7 alloy hardened by the ES method, it was concluded that:

1. The surface structure of the AK5M7 alloy studied after the ESA and its subsequent annealing was in different modes.
2. It was established that after annealing, the phase composition of the surface changes both by the appearance of new phases and by a change in previously existing compositions.
3. It was shown that the CS values of the crystal lattices of the phases after annealing increase, while the microdistortion decrease, which indicates a decrease in the surface structure defectiveness.
4. That the physical basis for increasing the wear resistance of the AK5M7 alloy was assumed to be mainly a high level of surface structure defectiveness after its ESA.
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