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Effect of electrospark doping on mechanical properties of Al-Si-Cu alloys*

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Влияние электроискрового легирования на механические свойства Al-Si-Cu сплавов***

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Introduction. Microhardness and wear resistance of the aluminum alloy (AK5M7) after its surface treatment through electrospark doping (ESD) using A (Cu) and P (Cu+P) electrodes with different applied energy is considered. The work objective is to study the relationship of the physicomechanical and strength properties of the surface of AK5M7 alloy obtained after ESD with copper and copper-phosphorus electrodes.

Materials and Methods. X-ray diffraction and X-ray fluorescence analysis methods were used to determine the phase composition, coherent-scattering regions (CSR), and the surface microstrain.

Research Results. It is established that with increasing energy, the values of microhardness and wear resistance increase when using both electrodes. The sample was modified by P electrode with the energy of 0.79 J. In this case, the maximum value of microhardness increased 5.3 times, wear resistance - 1.6 times. It is found that with ESD, new intermetallic phases of Al2Cu and Cu3P are formed on the surface of the alloy under study. If the value of the energy used is maximum (0.79 J), the concentration of the Al2Cu phase increases 5 and 9 times with A and P electrodes, respectively, and the concentration of the Cu3P phase increases more than 4 times when using P electrode. The experimental data obtained suggest size reduction of the CSR and an increase in the microstrain values for all the Al, Al2Cu, and Cu3P phases on the surface.

Discussion and Conclusions. An increase in energy with the ESD involves an increase in the defective factors and a change in the phase composition of the newly obtained surfaces. This may explain the increase in wear resistance of the surface.

Введение. Статья посвящена исследованию микротвердости и износостойкости алюминиевого сплава (АК5М7) после обработки его поверхности электроискровым легированием (ЭИЛ) электродами **А** (Cu) и **Р** (Cu + P) с разной приложенной энергией.

Цель работы — исследование взаимосвязи физико-механических и прочностных свойств поверхности сплава АК5М7, полученной после ЭИЛ медным и медно-фосфорным электродами.

Материалы и методы. Использованы методы рентгенодифракционного и рентгенофлуоресцентного анализа для определения фазового состава, областей когерентного рассеяния (ОКР) и микродеформации поверхности.

Результаты исследования. Установлено, что при использовании обоих видов электродов с увеличением энергии возрастают микротвердость и износостойкость. Образец был модифицирован электродом Р с энергией 0,79 Дж. В этом случае максимальное значение микротвердости увеличилось в 5,3 раза, износостойкости — в 1,6 раза. Установлено, что при ЭИЛ на поверхности исследуемого сплава образуются новые интерметаллические фазы Al_2Cu и Cu_3P. Если значение используемой энергии максимально (0,79 Дж), то концентрация фазы Al_2Cu увеличивается в 5 и 9 раз с электродами А и Р соответственно, а концентрация фазы Cu_3P увеличивается более чем в 4 раза при использовании электрода Р. Полученные экспериментальные данные свидетельствуют об уменьшении размеров ОКР и увеличении значений микродеформации для всех имеющихся на поверхности фаз Al, Al_2Cu и Cu_3P.

Обсуждение и заключения. Увеличение энергии при ЭИЛ приводит к повышению дефектности и изменению фазового состава вновь полученных поверхностей. Этим можно объяснить повышение износостойкости данной поверхности.

Keywords: electrospark doping (ESD), coherent-scattering region (CSR), microstrain, aluminum alloys, wear rate.

Ключевые слова: электроискровое легирование (ЭИЛ), область когерентного рассеяния (ОКР), микродеформация, алюминиевые сплавы, интенсивность изнашивания.

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Introduction. Various coatings and surface modification methods are used to increase the wear resistance of workpieces. One of them is electrospark doping (ESD) of conductive materials (authors: B.R. Lazarenko and N.I. Lazarenko [1–4]).

Al-Si-Cu alloys are widely used in the automobile industry. They are well molded, have all the necessary mechanical properties, and are characterized by a low coefficient of thermal expansion and a high ratio of strength and weight. However, the hardness and wear resistance of aluminum alloys are relatively low. This is the reason for the urgency of the problem of improving these properties through surface hardening [5–10]. The point is that it is required to create hardened layers with improved mechanical-and-physical properties. In the present paper, the results of ESD by various electrodes at different energies to harden the surface of AK5M7 alloy are shown.

Materials and Methods. Samples of AK5M7aluminum alloy with dimensions of 15×15×4 mm were made for research. Their surfaces were processed through the ESD method with copper and copper-phosphorus electrodes. The elemental composition of the alloy and electrodes was determined through X-ray fluorescence analysis on an ARL Perform’X 4200 instrument. The results are shown in Table 1.

Table 1

Elemental composition of alloy and electrodes

	Al, %	Cu, %	Si, %	P, %
AK5M7alloy	88	7	5	
P-electrode		92.9		7.1
A-electrode	0.1	99.9		

Electrospark doping was carried out on ALIER-31 installation (SCINTI, Moldova), which allows performing the ESD in a wide energy range.

X-ray phase analysis was performed to determine the phase composition of coatings applied to aluminum alloy through the ESD technique.

The PANalytical EMPYREAN X-ray diffractometer with CuKα radiation equipped with a nickel filter with an automatic primary beam divergence slit was used for the survey. The radiograph was decoded using the HighScorePlus program. We studied:

- quantitative content of phases detected on the surface;
- the average dimension of coherent-scattering regions (CSR);
- values of microdeformations after ESD of samples.

The microhardness of the modified layer was measured on the surface obtained after ESD. The research complex based on HVS-1000 microhardness meter and a digital video camera were used. The measurements were carried out according to GOST 9450–76 with the Vickers pyramid indenter (the load was P = 25 g). At least ten measurements were performed for each sample. The base alloy and the surfaces of its samples after the ESD treatment were subjected to tribological tests (a lubricant was preliminarily applied on the surfaces of the samples).

Research Results. The results obtained are presented in Table 2 and in Fig. 1–4.

Table 2

Phase concentration of base alloy and surfaces after ESD depending on energy

Energy, J	Phase concentration									
	AK5M7alloy			A-electrode			P-electrode			
	Al	Al_2Cu	Si	Al	Al_2Cu	Si	Al	Al_2Cu	Si	Cu_3P
0	92	2	4							
0.07				97	2	1	94	3	2	1
0.2				96	3	1	70	22	5	3
0.39				94	5	1	65	25	5	5
0.79				89	10	1	59	28	5	8

Table 2 shows phase concentrations found on the surfaces of the base alloy and samples after the ESD at various energies.

The base alloy has three phases: Al, Al_2Cu and Si. With increasing the ESD energy, an increase in the Al_2Cu concentration is observed when using both electrodes, and a decrease in the Al phase, while the Si phase remains constant for the A- electrode at all energies. In this case, Si concentration increases 2.5 times with the energy rise for the P-electrode. In the samples treated with the P-electrode, the Cu_3P phase appears. Its concentration increases 8 times with the pulse energy rise to 0.79 J.

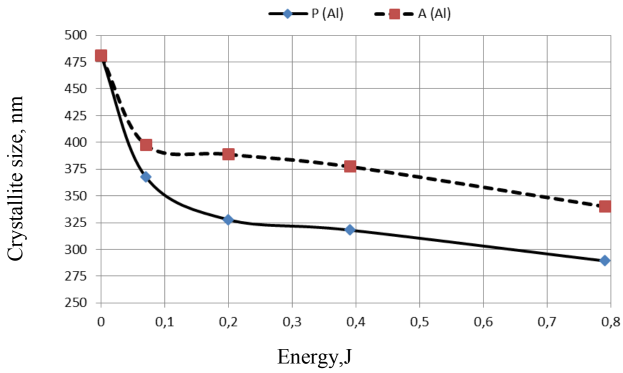

Fig. 1. Dependence of CSR Al-phase size on energy for A and P electrodes

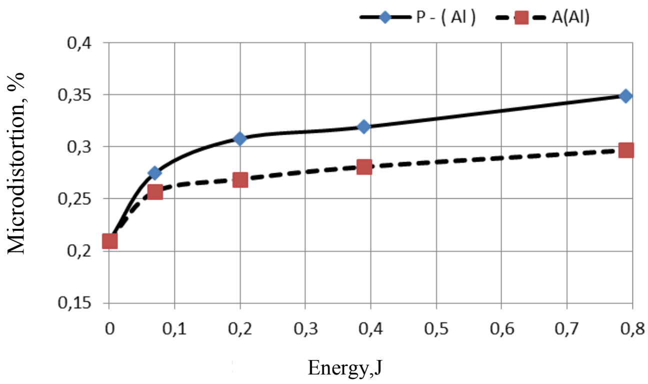

Fig. 2. Dependence of Al-phase microstrain value on energy for A and P electrodes

Fig. 1 and 2 show that when using both electrodes, the CSR decreases with the ESD energy rise, and the microstrain grows. The coherent-scattering regions are practically faultless surface areas. Therefore, an increase in CSR indicates improvement in the microstructure of the modified layer, and reduction of its defect level. However, it is known that a change in the structure imperfection of metallic materials causes a change in their mechanical-and-physical properties [11, 12]. The microstrain value indicates the degree of the crystal lattice distortion, and thus, the structure imperfection ratio can be defined by its value [13, 14]. Similar CSR dependences and microstrain were obtained for the Al_2Cu and Cu_3P phases after the ESD of AK5M7 alloy surface with A and P electrodes. It is found that the patterns of changing the CSR and microstrain are the same as for the Al-based phase. Therefore, the data in Fig. 1, 2 suggest that with increasing energy, the structure of the resulting surface is distorted more heavily.

Fig. 3 shows the measurement results of the surface microhardness after the ESD by the copper and copper-phosphorus electrodes.

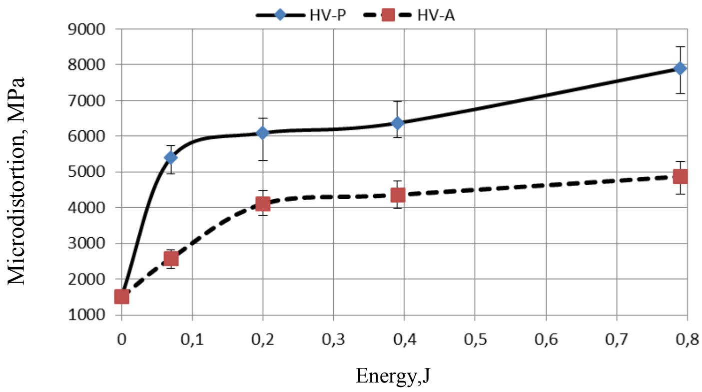

Fig. 3.Ddependence of microhardness on energy for A and P electrodes

It is seen that the microhardness increases with the energy rise, and for A-electrode, at the peak value of energy, nearly 3-fold increase is observed, for P-electrode — 5-fold.

It is known that during the ESD, melting of materials of the anode and the sample surface occurs, and then rapid cooling (quenching). As a result, new phases (in our case, Cu_3P), dislocations, point defects, high degree of surface stress, fine-grained structure, etc., can form on the surface. Accordingly, it can be assumed that with increasing energy, the microhardness grows due to the above-mentioned distortions arisen during the ESD process (see Fig. 3).

Fig. 4 shows the measurement results of the wear rate of AK5M7 alloy and the sample surfaces after the ESD with copper and copper-phosphorus electrodes at the energy of 0.79 J.

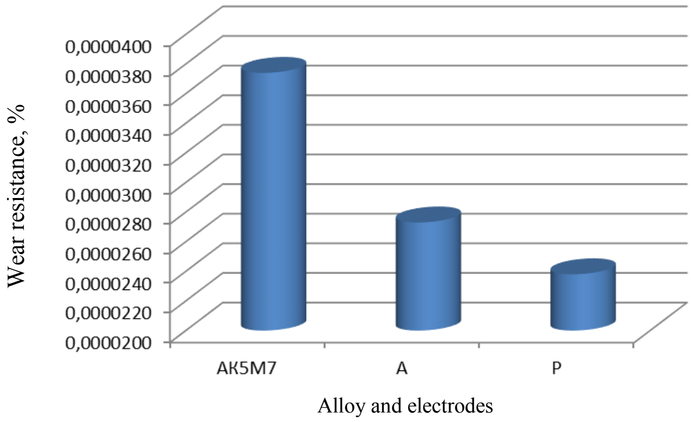

Fig. 4. Wear resistance rate of base AK5M7 alloy and its surface after coating at energy of 0.79 J

Fig. 4 shows that the sample surfaces treated by copper-phosphorus and copper electrodes are worn out much less than the surface of AK5M7alloy.

Discussion and Conclusions. The results obtained validate the efficiency of the ESD of AK5M7 alloy surface by various electrodes and with different energies. Surfaces obtained by this method wear out less. When using a copper electrode, the wear is reduced by 1.37 times, when using a copper-phosphorus electrode — by 1.57 times.

Upon reaching the minimum value of wear after the ESD, the surfaces have the maximum values of microhardness and microstrain, as well as the lowest CSR values. At the same time, there is a significant increase in the concentration of intermetallic phases formed after the ESD: Al_2Cu — from 5 to 9 times with copper and copper-phosphorus electrodes, respectively; Cu_3P — 8 times with a copper-phosphorus electrode. The reason for the increase in wear resistance of surfaces after the ESD can be various distortions and defects formed after melting, as well as the formation of new intermetallic phases.

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