Deposition of Al-Sn Nanostructured Coatings on Aluminum Surface Using Electrospark Alloying and Their Wear Resistance under Lubricated Friction

V.I.Agafii*, E.V.Yurchenko**, V.I.Yurchenko**, V.I.Petrenko*, A.I.Dikusar*,**

**Institute of Applied Physics, Academy of Sciences of Moldova, str. Academiei 5, Chisinau, MD2028, Republic of Moldova*

***Shevchenko Pridnestrov'e State University, str.25 Oktyabrya 128, Tiraspol, Republic of Moldova*

***Abstract* – Under certain modes of electrospark alloying (ESA) of aluminum surfaces using the Al-Sn tool-electrode (TE), nanostructuring of the manufactured surfaces occurs owing to the formation of SnO_2 fibers. Examining the tribological properties of these surfaces in a friction couple with a counterbody made of hardened steel showed that the wear of the counterbody during the friction in oil exceeds by an order of magnitude and above it the wear of such surfaces.**

***Index Terms* – Al-Sn alloy, electrospark alloying, nanostructuring, SnO_2 fibers, wear resistance**

I. INTRODUCTION

Works [1, 2] show that the possibilities for the nanofibers formation under the ESA, in particular, on the aluminum surfaces during treatment of the latter using the TE made of the alloy which is a hard matrix that contains an easily fusible component (e.g., Sn), provided that Al-Sn alloy is a mechanical mixture. If the dimensions of the easily fusible component are within the limits of several micrometers, then under the ESA, the drops of this component stretch into fibers of nanometric dimensions. Under the ESA in the air they become oxidized, forming tin oxide – SnO_2. The surfaces that are formed in this fashion have the unique abrasive properties [3]. During the contact with the counterbody from the hardened steel the wear of such surfaces is less by an order of magnitude (or even less) than that of the surface from the hardened steel, whose microhardness exceeds by several times the microhardness of the matrix of the treated surface. The results of [3] were obtained under the conditions of a manual variant of the ESA during the lubricated friction.

This work studies the conditions of manufacturing the surfaces using ESA under the feed rate control the TE movement against the treated surface (i.e., in the automatic mode). It also determines the tribological properties of these surfaces during the lubricated friction.

II. RESULTS AND DISCUSSION

Treatment of the specimen surfaces was carried out using the facility described in detail in [4]. The TE feed rate against the specimen changed from 0.3 to 2 mm/s. The ALIER-31 (Scinti, Moldova) generator working in mode 5 was used as a source of power (see [1–3] for the details). In the variant of specimen treatment used in the study the number of the TE passes along the treated surface was maintained constant, equaling 4. Depending on the TE feed rate V increase and a relative decrease in the surface treatment time, the value of the energy passed through the interelectrode gap also decreased proportionally to V increase.

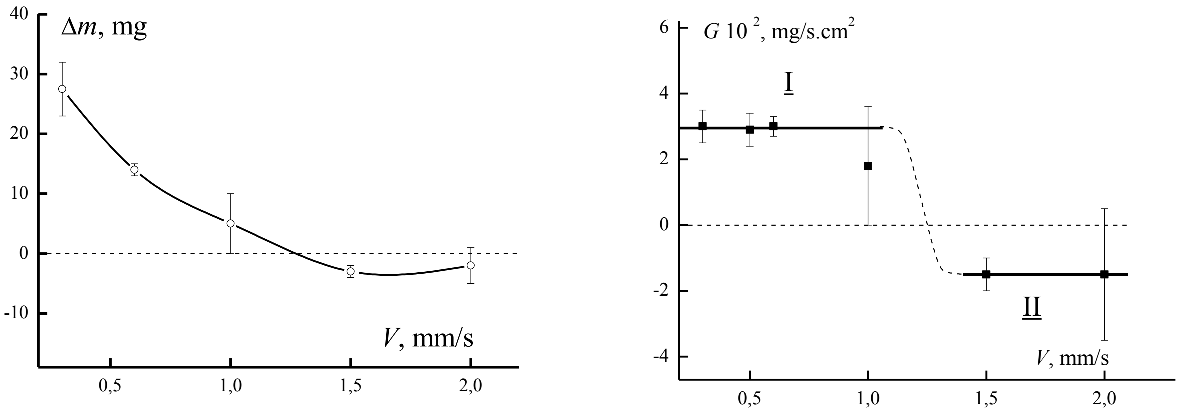
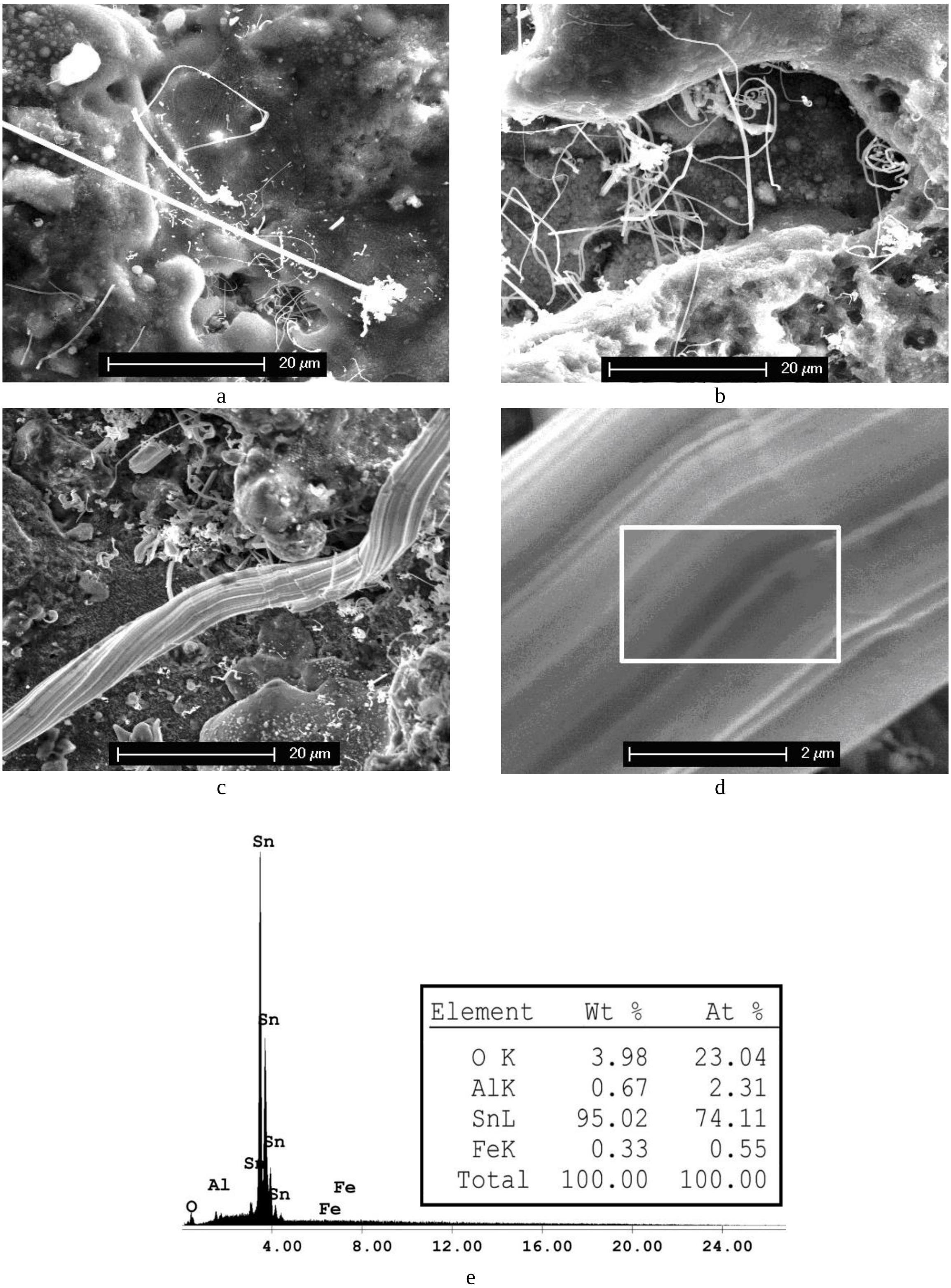


Fig. 1. Dependence of the absolute weight gain of the specimen (a) and the treatment rate *G* (b) on the TE feed rate against the treated surface



Element	Wt %	At %
O K	3.98	23.04
AlK	0.67	2.31
SnL	95.02	74.11
FeK	0.33	0.55
Total	100.00	100.00

Fig. 2. The morphology of the surface layers manufactured using method 1 at the TE feed rate of 0.6 mm/s (a, b), 1 mm/s (c, d), EDX spectrum and elemental composition of the surface segment (e) marked in Fig. 2d.

This, in turn, led to a decrease in an absolute weight gain of the specimen and intermittent change in the treatment rate *G* at V > 1 mm/s (Fig. 1). As is seen from Fig. 1, there are two modes of treatment depending on the TE feed rate, i.e., mode I (Fig. 1b) at a constant rate of deposition (in mg/cm^2) and mode II (Fig. 1b) which will further be referred to as the “sparkling” mode. Under the mode II treatment the weight loss of the treated surface is observed.

Figure 2 shows the images of the surface treated at various feed rates *V* (for mode I). The peculiarity of the results presented is the formation of fairly thick fibers that allow us to more accurately measure their elemental composition (Fig. 2e). As is seen, the fibers that are formed represent the Sn nucleus covered with tin oxide. This follows from the fact that the content of tin exceeds that needed for SnO_2 according to stoichiometry.

The change in the TE feed rate modifies roughness of the surface, however, it almost remains unchanged during the transition from mode I to the “sparkling” mode, remaining constant at V > 0.5 mm/s both in mode I of the treatment and “sparkling” mode (Fig. 3). At the same time, it is noteworthy that a decrease of Ra at an increase of V is observed in the range of small values of V (Fig. 3).

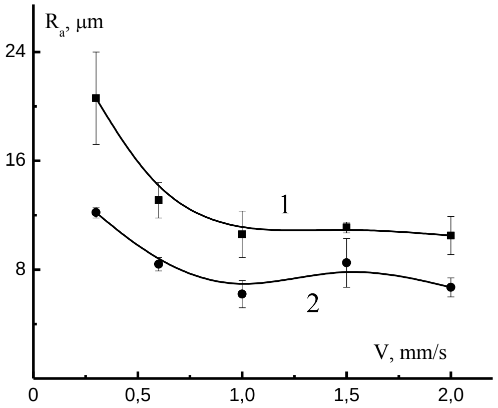


Fig. 3. The change in roughness of the ESA treated surfaces (1) and surfaces after the wear tests (2) depending on the TE feed rate against the surface treated during the manufacturing of coatings.

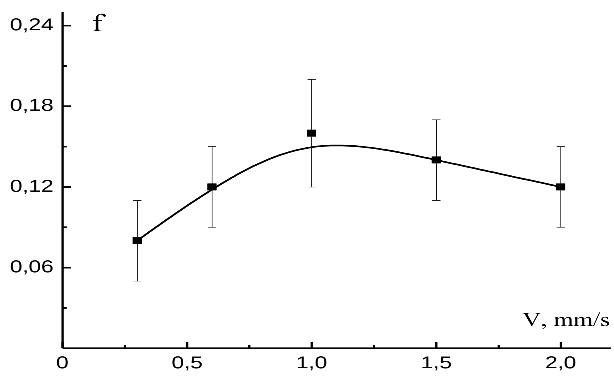


Fig. 4. The change in the friction coefficient of the treated surfaces (counter-body – hardened steel) depending on the conditions of obtaining of the coatings (V = 0.3–1 mm/s, mode I; V = 1.5–2 mm/s, mode II).

Transition from mode I of the treatment to mode II changes the dependence of the friction coefficient in the testing experiments on the conditions of manufacturing the coatings (Fig. 4). During manufacturing the coatings in mode I, the friction coefficient increases relatively to an increase of V, and it decreases for the coatings obtained in mode II (Fig. 4).

Test experiments were performed in two stages [2, 3]. At the first stage, grinding-in of the counterbody and the tested surface was performed. It was carried out during ten hours of testing with a load changing from 2 to 9 kG (a contact area of the tested surface with the counterbody was 9 mm^2, and the overall area of the treated surface, against which the counterbody was performing a reciprocal movements was 165 mm^2). The grinding-in at the initial and final loads was done during two hours and at the intermediate loads during one hour. At the second stage, the main test experiments were performed at 9 kG load during 20 h. Before and after every tests the surface roughness (Ra parameter) was measured. These values for the different conditions of coating deposition are shown in Fig.3 (curve 1).

As well as the measurements of roughness, the measurements of the specimen and counterbody weights were carried out both during the first stage of the tests (at a less load) and after the termination of the tests (Fig. 3 (curve 2)).

For the estimation of wear resistance of the coatings the ratio *K* of the weight loss of the counterbody ΔU^{cb} to the weight loss of the specimen ΔU ($K = \Delta U^{cb}/\Delta U$) was used (similarly to [2, 3]). The value of *K* was determined both after the grinding-in and after the full termination of the tests.

Earlier it was shown that the observed effect of abnormal wear of the counterbody made of hardened steel that worked in the friction couple with the coatings under study (but manufactured in the manual mode), increases with the increase of the surface roughness [2, 3]. Since, depending on the TE feed rate, roughness changed (Fig. 3). The results of this investigation could answer the question if the fact of high Ra values that are reached under the ESA is a necessary condition for the observed effects.

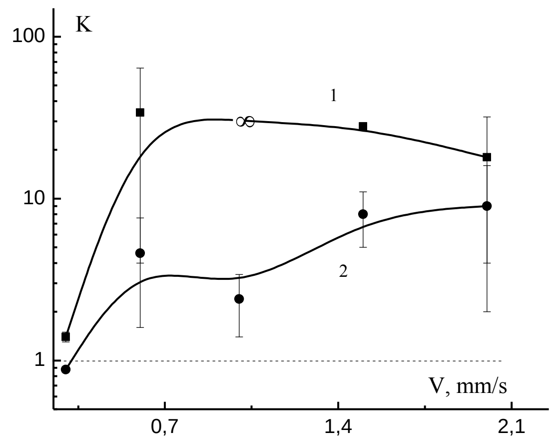


Fig. 5 The effect of the TE feed rate against the surface treated on the value of a counterbody relative wear at lubricated friction with the ESA treated surfaces after the grinding-in (1) and after two stages of testing (2).

The results presented in Fig. 5 allow us to infer: a) under the automatic deposition of the electrospark coatings (electrospark surface modification) the effect of the abnormal wear of the hardened steel counterbody is also observed (Fig. 5); b) the ESA surface roughness is insignificant for the effect of the abnormally high counterbody wear, c) this effect does not depend on whether the deposition of the layer occurs (i.e., the ESA itself, mode I) or the treatment leads tothe weight lost of the treated surface (at the "sparkling" mode used).

Indeed, during testing of the coatings with a maximum roughness (when feed rate V = 0.3 mm/s) the wear resistance of the counterbody is close to the value of the wear of the coating, whereas for the coatings manufactured at higher TE feed rates, the counterbody wear exceeds the coating wear by an order of magnitude and above that (Fig. 5). In some cases, in the process of testing the specimen weight loss was not specified, but the fact of their weight enlargement was found, i.e., the material of the counterbody turned out to be spread on the surface obtained after the ESA. In such cases, the value of K was designated as ∞ in Fig. 5.

It is noteworthy that during the transition of the first stage of testing – grinding-in – to the second one, the K values decrease, however, the effect itself was observed independently of test conditions (enhancing of loads, transition to deeper layers of the surface treated) (Fig. 5).

III. CONCLUSIONS

Surface nunostructuring as the result of the ESA with TE made of the alloy containing the infusible matrix with an easily fusible component as a mechanical mixture, depends on the TE feed rate against the surface treated, which is evidently the consequence of conditions of its crystallizing, that are modified with the change of the TE movement. It is shown that the conditions of coating manufacturing that are determined by the TE feed rate against the surface treated, define its tribological properties. The surface high roughness does not play a determining role for reaching the effect of the abnormal wear of the counterbody made of the hardened steel that works in the friction couple with such surfaces.

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