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Study on Mechanical Properties and Structure of Silumin after Its Surface Modification with Yttrium Oxide

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Abstract. This paper reports on the atomic-force microscopy research of the silumin AK10M2N structure subjected to electroexplosive doping with the yttrium oxide Y_2O_3 powder. The conditions providing the maximum microhardness in the processed layer of silumin specimens are compared with other parameters of the processing. A uniform coating on the surface of a specimen is formed owing to electroexplosive doping with the yttrium oxide powder in the appropriate conditions. The procedure of electroexplosive doping is considered, and atomic-force microscopy images of the processed silumin layer are obtained. Structural patterns of the formed coating are identified. The paper informs about changed microhardness of the specimen after its surface modification. It is experimentally revealed that the microhardness of the modified layer decreases, giving account of a high porosity in the sprayed coating.

INTRODUCTION

To date, diverse procedures of processing of the material surface by external energies are used, e.g. plasma, laser, electron-beam treatment, etc. [1–8]. Pulsed surface melting and saturation of the surface layer with doping elements proceeded by self-tempering and formation of reinforcing phases produced by plasma, which is formed at electric explosion of the conductive (electroexplosive doping), is one of the up-to-date promising procedures to treat the surface of metals and alloys. Electroexplosive doping makes it possible, as previously stated [9–15], to form a multiphase submicro- and nanoscale structure in the surface layer of the material in question with a considerably improved strength, durometric and tribological properties.

Rapidly evolving technologies of material reinforcement with external energy require an approach of the time to choose a method of research into its impact on materials. One of the efficient high space resolution methods available nowadays for the analysis of morphology and local properties of a solid is scanning probe microscopy [16] with atomic force microscopy as one of the often used variants [16–25].

This study aims at atomic-force microscopy (AFM) investigation into the structure of a sprayed silumin layer and microhardness altering throughout the specimen depth subjected to electroexplosive doping with the yttrium oxide powder.

MATERIALS AND METHODS

The object of research in this study is silumin AK10M2N of the following composition: 12.49% Si, 2.36% Mg, 0.6% Cu, 0.35% Ni, 0.3% Fe, balance Al (at %), on which the yttrium oxide Y_2O_3 powder was deposited via electroexplosive doping. A specimen is cut out of the unbroken bar and shaped to a parallelepiped with the

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dimensions $20 \times 20 \times 10$ mm^3. The substrate material was selected as it is widely used in aircraft- and machine building but its wear resistance and microhardness are insufficient. The treatment of this material with the yttrium oxide powder furthers the formation of a fine structure layer on the metallic substrate surface and improves its tribological and strength parameters as well as the heat resistance.

Electroexplosive doping of the silumin surface was carried out using the EVU 60/10 machine (Siberian Industrial University, Novokuznetsk). An end scheme of explosion was used [9] to intensify the thermal impact on the material surface before its melting, thus providing conditions for doping. The aluminum foil is held between co-axial electrodes supplied with adjustable voltage through a vacuum discharger. When a capacitive storing device discharges, circumferential zones of the foil near the outer electrode-nozzle is a source of the condensed phase of the explosion product, and the foil over the central electrode, where the yttrium powder is poured, is a source of ionized vapor [13].

The doping mode of plasma formed at the electric explosion of an aluminum foil with the yttrium oxide powder is used: the time of the plasma impact 100 µs, absorbed density of power on the jet axis ~8.2 GW/m^2, pressure in the shock-compressed layer near the surface ~18.8 MPa; aluminum foil mass ~60 mg, yttrium oxide powder mass ~30 mg, and charging voltage of the accelerator energy storing device 2.6 kW [9].

Specimens were prepared for AFM testing using the FORCIPOL-2 grinding and polishing machine. A specimen was grinded with abrasive paper; the abrasive grain size decreased with further thick felt and SOI-paste processing. Chemical etching of the profile was carried out to identify the structure.

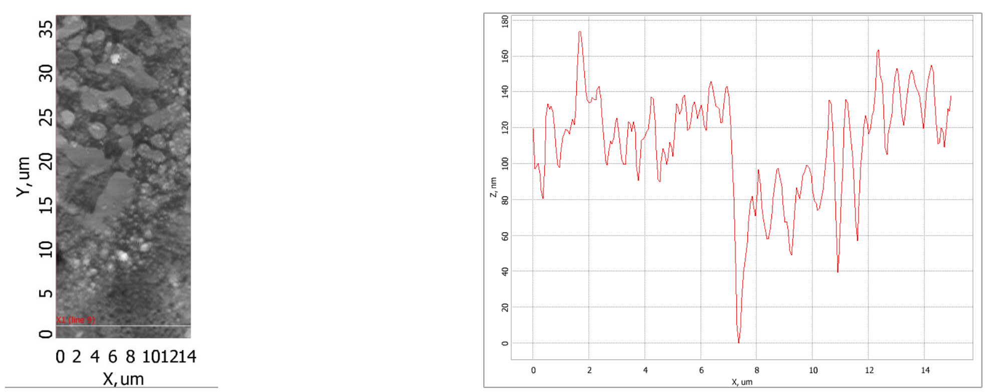
Topographical images of the interface between the sprayed layer and the substrate were made using AFM (Next Solver, NT-MDT, Zelenograd). The microscopic investigation was carried out in the Semi-Contact Topo mode. AFM images were processed in the Image Analysis 3.5 software.

Microhardness was measured on the specimen crosscut using the HVS-1000 microhardness measuring device according to the micro-Vickers method and with regard to the distance up to the surface. 15 to 20 measurements were made at each distance (30, 50, 70, 90, and 520 µm).

RESULTS AND DISCUSSION

The AFM investigations demonstrate that a multilayered structure is formed as a result of electroexplosive doping; this structure consists of a highly porous coating, a liquid-phase doping layer, and a layer of thermal impact.

Figure 1 shows a 2D-image of the interface between the substrate material and sprayed layer. As seen, particles of the coating penetrate into the grain structure of silumin. The structure of silumin (Fig. 1a, from $Y = 15$ to 35 µm) comprises grains with the size varying from 1 to 7 µm and eutectic. Electroexplosive doping with yttrium oxide forms a coating with a fine grain structure on the silumin surface; the size of its elements is tenths of a micrometer. The profilogram of the coating points to its high porosity (Fig. 2). The depth of some pores in the coating is up to 100 nm.



(a) (b)

FIGURE 1. Two-dimensional (a) cross cut images of silumin modified via electro-explosive doping with the yttrium dioxide powder: $Y = 0$ to 10 µm—highly porous coating, $Y = 10$ to 15 µm—liquid phase doping phase, $Y = 15$ to 35 µm—thermal impact layer; (b) profilogram of the zone 14×35 µm. Atomic force microscopy

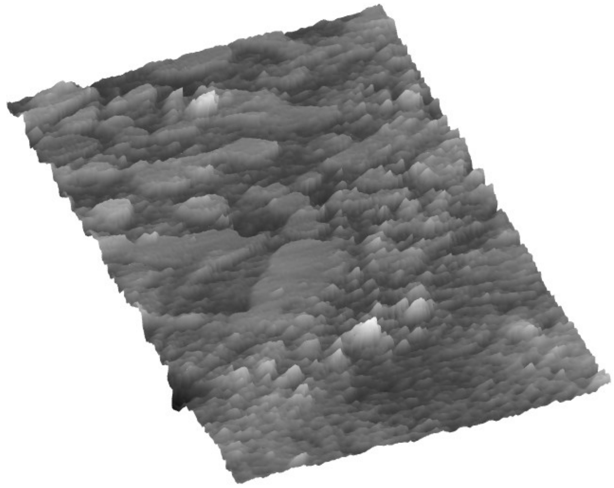


FIGURE 2. Three-dimensional cross cut images of silumin modified via electro-explosive doping with the yttrium dioxide powder: Y = 0 to 10 μm—highly porous coating, Y = 10 to 15 μm—liquid phase doping phase, Y = 15 to 35 μm—thermal impact layer. Atomic force microscopy

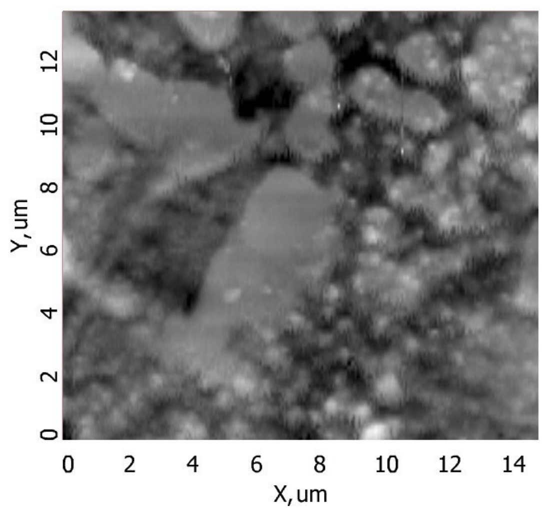


FIGURE 3. Two-dimensional topographic image of liquid phase doping layer between the silumin matrix and yttrium oxide coating

Yttrium oxide particles (white points in Fig. 3) have different sizes from 0.3 to 1 μm, thus indicating that a coating has a submicro- and nanosized structure.

The measurement results of microhardness versus distance to the modified surface are presented in Table 1. As seen from Table 1, the microhardness drops in the modified layer that confirms the AFM data of the surface profile (high porosity).

TABLE 1. Changing microhardness versus distance to the surface

***L*, μm**	30	50	70	90	520
HV	57.12	61.64	57.53	58.55	58.67
ΔHV	3.14	2.26	1.64	1.45	1.25

CONCLUSION

The studies on the layer structure sprayed on silumin AK10M2N produced by electroexplosive doping with the yttrium oxide Y_2O_3 powder are reported. 2D and 3D images of the structure as well as the crosscut profilogram of the silumin specimen modified via electroexplosive doping are presented. In the process of AFM investigation, it was revealed that the surface layer has a submicro- and nanoscale structure; its particle size varies from ~0.3 to 1 µm. It is identified that electroexplosive doping results in the formation of a multilayered structure, which consists of a highly porous coating, liquid phase doping layer, and thermal impact layer. It is experimentally revealed that the microhardness of the modified layer decreases, giving account of a high porosity in the sprayed coating.

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