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NEW TECHNOLOGIES FOR DESIGN AND PROCESSING OF MATERIALS

Thermal Stability of Structure and Properties of the Surface Layer of Instrumental Steel Alloyed with Zirconium and Silicon Atoms under the Action of Compression Plasma Flows

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Abstract—The phase and elemental composition and microhardness of instrumental steel U9 with zirconium and silicon coatings subjected to compression plasma flows and air thermal annealing are investigated. It is found that plasma impact leads to the formation of a surface layer with the thickness of up to ~8.5 μm alloyed with zirconium and silicon atoms and containing Fe_2Zr intermetallic. Formation on the surface of the oxide γ-ZrO_2 and carbonitride Zr(C, N) as a result of interaction with the residual atmosphere of the vacuum chamber is found. Change in the phase composition and dispersion of the structure leads to a twofold increase in microhardness. The alloyed layer retains the stability of the structure and phase composition (excluding polymorphic transition in ZrO_2) up to 400°C. Annealing at 600°C leads to the internal oxidation accompanied by formation of a surface iron oxide scale and penetration of the oxygen atoms to the whole depth. The increase in the annealing temperature leads to the decrease in microhardness throughout the alloyed layer.

Keywords: steel, compression plasma flows, phase composition, corrosion resistance, microhardness
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INTRODUCTION

In recent decades, the concentrated flows of energy have been actively used for modification of the surface layers of metal and semiconducting materials. For this purpose, the high-current electron beams, continuous and pulsed laser beams, and high-temperature pulsed plasma flows are applied [1–6]. Results of investigations [2, 4–6] showed that the high-energy treatment of materials leads to a significant change in microstructure (including its dispersion) and phase composition (formation of metastable phases, etc.) of modified layers as a result of the nonequilibrium processes at high cooling rates (10^5–10^7 K/s). The noted effects in the surface layers lead in some cases to the improvement of different service characteristics.

One of the concepts of modification of the surface layer is the liquid-phase alloying made by pre-deposition of the film or coating of one or several alloying elements on the surface of the material and the further treatment by the high-energy particle flow. The high-energy impact allowing the melting of the coating and substrate material leads to the liquid-phase mixing in the liquid alloy owing to convective mass transfer and further crystallization under superfast cooling [7]. Such an approach allows the tailor-made synthesis of compounds containing the alloying elements introduced to the surface layer.

However, the formed metastable structures may be ineffective under high-temperature functioning of the material. Moreover, the ultrarapid quenching from melt leads to the decrease in grain size and therefore to the increase in the area of grain boundaries and growth of the intensity of the grain boundary diffusion. This effect may both increase and decrease the corrosion stability of the material [8]. Thus, for example, the alloys Fe–9% Cr with nanocrystal structure possess higher résistance to atmospheric corrosion in the air at 840°C as compared with the alloys with microcrystal