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Thermal Stability of the Structure and Phase Composition of Titanium Treated with Compression Plasma Flows

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Abstract—The results of studying the structure and phase composition of the surface layer of commercial pure VT1-0 titanium treated with compression plasma flows in nitrogen atmosphere and annealed in the temperature range of 400–900°C for 1 h are presented. Using the X-ray diffraction method, the α-Ti(O) solid solution is found to form in the titanium surface layer at 500°C, without pretreatment with plasma, and to transform into the titanium oxide TiO_2 (rutile) phase at 600°C. Pretreatment of titanium with compression plasma flows promotes the formation of α-Ti(N) solid solution decreasing the rate of surface oxidation and increasing the initial temperature of rutile formation to 700°C, which indicates enhancement of the thermal stability of this structure.

Keywords: titanium, titanium oxide, rutile, oxidation, thermal annealing, compression plasma flows, phase composition

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INTRODUCTION

Modification of the structure and phase composition of surface layers of metals and alloys aimed at improving their physical and mechanical parameters is one of the problems considered in materials science. Ion/electron beam [1–7] and plasma [8–10] approaches to surface treatment have become the most prevalent today. In many cases, surface modification is accompanied by the production of various nonequilibrium structures, such as oversaturated solid solutions, intermetallide phase inclusions, or nanocrystalline structures. However, there is the problem of the thermal stability of these structures, which is quite important in view of the frequent practical use of parts, including with modified surfaces, under outdoor conditions at high temperatures. In this paper, we consider the formation of oxygen-based compounds on the surface, which can diminish the positive effect achieved upon preliminary modification of the surface.

Earlier studies [11–13] showed the unique possibility of using compression plasma flows generated by quasi-stationary plasma accelerators to modify the surface layers of metals and alloys. These experiments show that the use of such flows, unlike conventional approaches involving intensive electromagnetic (laser) radiation and beams of charged particles (ions and electrons) to treat materials, promotes a considerable increase in the depth of the modified layer reaching tens of micrometers. This is due to a combination of a high density of the absorbed energy measured at tens of J/cm^2, and rather long lifetime of the plasma flow (100 μs), which results in melting of the surface layer and, due to hydrodynamic intermixing of the melt, promotes an increase in its thickness due to the convective mechanism of heat transfer. The direct treatment of materials with compression plasma flows produces small-crystalline, including nanocrystalline, structures, metastable solid solutions, and intermetallide phases, while a thin surface layer becomes enriched with atoms of the plasma gas (nitrogen). All this promotes, first of all, improvement of the mechanical characteristics of the modified layer (microhardness and wear resistance) [14, 15].

Because of the widespread application of titanium and its alloys, compression plasma treatment is aimed at both improvement in their tribological characteristics [16] and minimization of the toxic impurity concentration in the surface layer of titanium alloys used for medical purposes [17]. However, no studies of the thermal stability of the structures by their heating in air have been carried out. In this paper, the results of studying the thermal resistance of titanium modified by compression plasma flows in the temperature range of 400–900°C are presented.