OXIDATION RESISTANCE OF THE SURFACE LAYERS IN THE Nb/Ti SYSTEM TREATED BY COMPRESSION PLASMA FLOWS

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Introduction. Compression plasma flows (CPF) are strongly directed flows of dense plasma (charge particles concentration up to 10^{17}-10^{18} cm^{-3}) compressed by the own magnetic field moving with a large velocity /1/. The CPF is a promising tool for structure and property modifications of surface layers of materials /2/. One of CPF peculiarities is a relatively high duration of the flow stable form that achieves up to 100 μs. When the CPF influencing to different materials at absorbed energy density in the range of 13 – 35 J/cm^2, the surface layer of the material is melted and the life-time of the melted state is comparable with the pulse duration. In this case the role of the liquid phase processes increases. In /3/ the possibility of alloying of the surface layers of the materials with other metals by means of CPF impact was shown. In this paper we proposed to use CPF to create a modified surface layer in titanium alloyed with niobium atoms and which has a higher oxidation resistance.

Experimental. Commercially pure titanium alloy was chosen as a material for the experiments. The samples (10×10 mm, thickness 2 mm) were mechanically polished before the treatment. The niobium coating was deposited using the PVD method (vacuum arc vapor deposition) with the following operating parameters: arc current 190 A, negative bias voltage on the titanium substrates of – 120 V, deposition temperature of 400 ºC, deposition time of 10 minutes. Thickness of the formed Nb coating was 2.5 μm.

The obtained “Nb coating/Ti substrate” system was subjected to the CPF generated in magneto-plasma compressor of compact geometry. The discharge device of the MPC was made as a system of two coaxial electrodes, the central electrode serving as a cathode and six surrounding electrodes performing a function of an anode. Capacitive storage of 1200 mF operated at the initial voltage of 4 kV. The experiments were performed in a “residual gas” mode by which the vacuum chamber was filled with nitrogen gas at the pressure of 400 Pa. Plasma flow parameters were the following: pulse duration 100 μs, plasma velocity (5 – 6)×10^6 cm/s, electron concentration (4 – 7)×10^{17} cm^{-3}, plasma temperature 2 – 3 eV. The distance between the electrodes and the treated surface of the samples was 12 cm that corresponds to the energy density of heat flux absorbed by the sample 13 J/cm^2 (registered by calorimetric measurements). The treatment was carried out as a series of three pulses at intervals ~ 5 s.

The treated samples were annealed in air at the temperatures 300 – 600 ºC during 1 hour.

The elemental composition of the surface layer in the treated samples was investigated by means of energy-dispersion X-ray microanalysis (EDX). Phase composition of the modified layers of titanium was investigated by means of X-ray diffraction method with Ultima IV RIGAKU diffractometer in Bragg-Brentano geometry with parallel beams in Cu Kα radiation (λ=0.15406 nm).

Results and Discussion. The surface layer of titanium is saturated by oxygen atoms during air annealing. XRD results (Fig. 1) showed the formation of the titanium oxide TiO_2 (anatase) with a tetragonal crystal lattice (space group *I41/amd*) at the temperatures in the range of 300 – 500 ºC. The corresponding diffraction line is found at 24.85 degree on the XRD pattern. The increase of the temperature of the annealing up to 600 ºC results in formation of titanium oxide TiO_2 (rutile) with a tetragonal crystal lattice (space group *P42/mnm*). Moreover, the diffusion mechanism of the oxygen transport inside the titanium provides the formation of the underneath layer with the oxygen concentration not enough for the oxides growth. So, in this area the oxygen atoms are dissolved in the crystal lattice of hcp α-phase of titanium. It is confirmed by small shoulders near the diffraction peaks (002), (102) and (103), the intensity of the shoulders increasing with rising of the temperature.

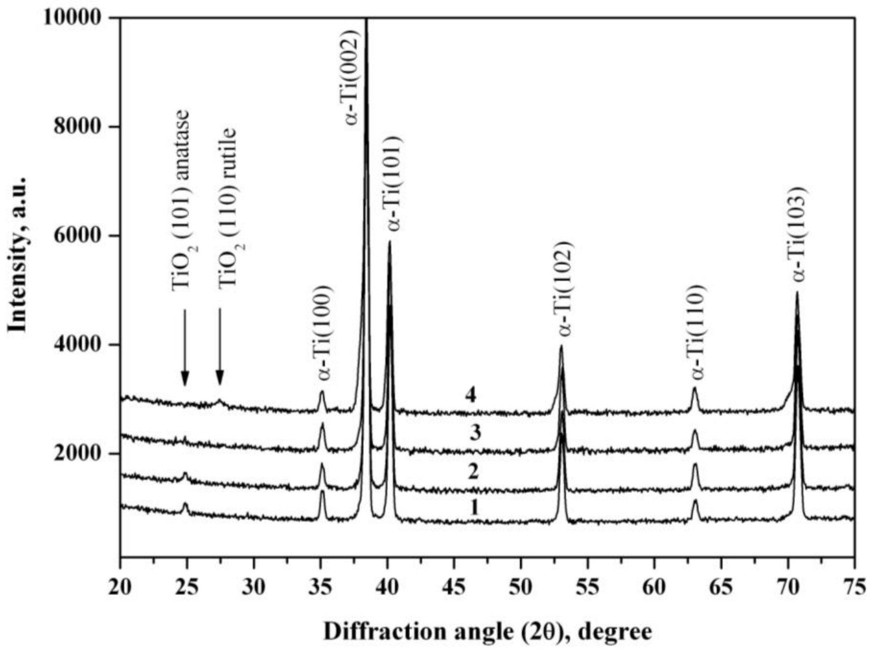

Fig. 1. XRD patterns of the titanium after air annealing at 300 ºC (1), 400 ºC (2), 500 ºC (3) and 600 ºC (4) during 1 hour

In the case of air annealing of the titanium samples previously treated be the CPF, diffraction lines corresponding to the oxide phases were not found (Fig. 2). The formation on the surface of the samples a thin layer of titanium nitride /4/ during CPF treatment can be a main reason of absence of the oxides. The solid solution of the oxygen atoms in the hcp α-Ti can be formed during the annealing. It is known that high cooling rate of the melting state after the CPF influence results in dispersed structure formation. So, the fraction of the grain boundaries increases. It allows to enhance the grain-boundary mechanism of the oxygen diffusion towards the underneath layer and, therefore, prevent from its segregation near the surface and the oxides formation.

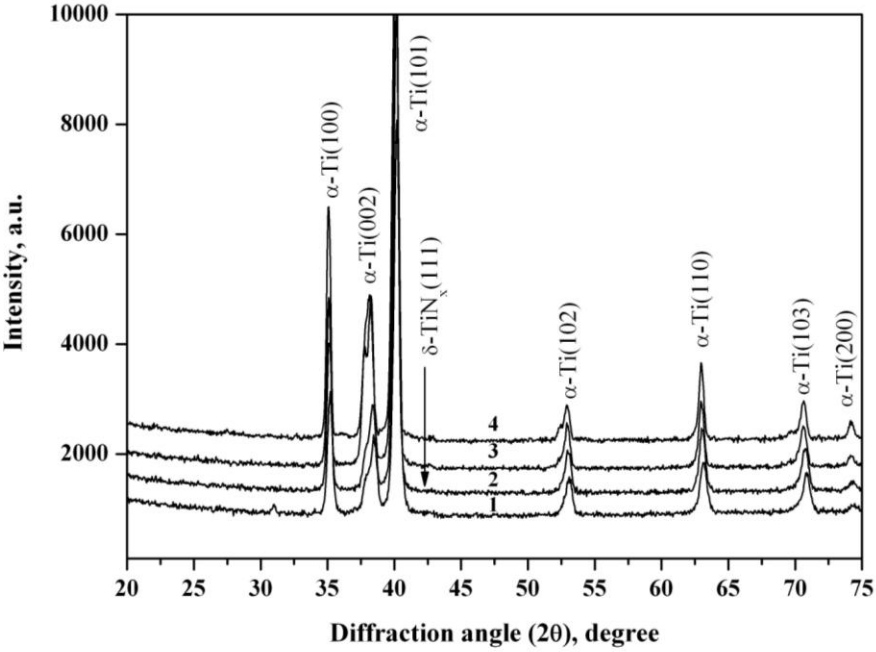

Fig. 2. XRD patterns of the titanium treated by CPF and annealed in air at 300 ºC (1), 400 ºC (2), 500 ºC (3) and 600 ºC (4) during 1 hour

The oxide phases of titanium were not found in the Nb/Ti systems treated by the CPF (Fig. 3). The grain-boundary mechanism of the oxygen diffusion takes place, too. The analysis of the elemental composition of the surface layer the Nb/Ti system after the CPF impact showed the presence of Nb atoms with the concentration of about 10 at. % in the surface layer. Nb atoms can be dissolved in both low-temperature (hcp α-Ti phase) and high-temperature (bcc β-Ti phase). It was found the shift of the diffraction lines of α-Ti phase towards the small diffraction angles that indicates the change of the crystal constant. It appears due to movement of Nb atoms and leaving the hexagonal crystal lattice with the following formation of the solid solution β-Ti(Nb) based on the high-temperature Ti phase at the temperature more than 500 ºC.

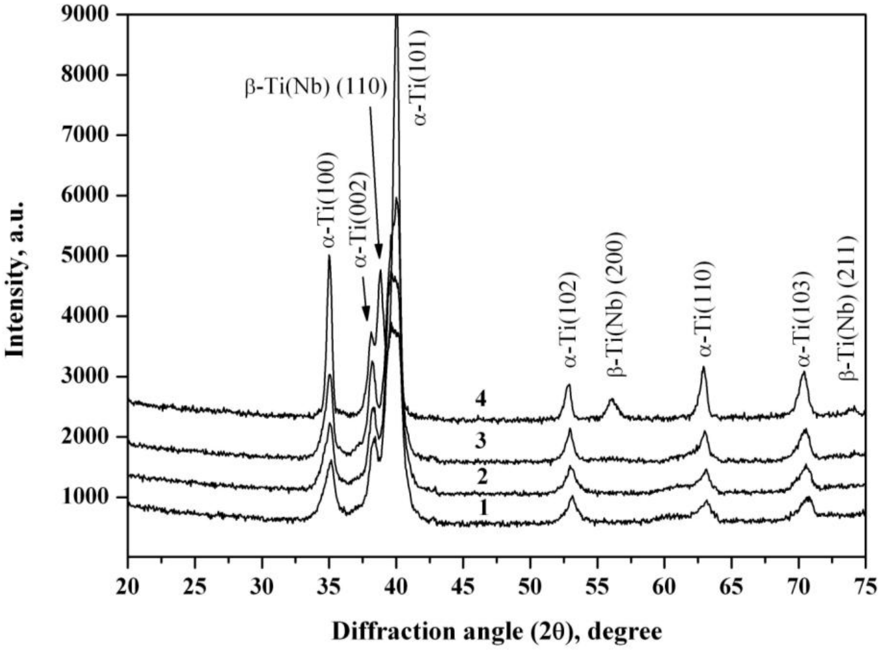

Fig. 3. XRD patterns of the Nb/Ti system treated by CPF and annealed in air at 300 ºC (1), 400 ºC (2), 500 ºC (3) and 600 ºC (4) during 1 hour

Conclusions. The influence of compression plasma flows on Ti and Nb/Ti system with the absorbed energy density 13 J/cm^2 results in formation of dispersed structure preventing the formation of the oxides on the surface due to enhancement of the grain-boundary diffusion after air annealing at the temperatures 300 – 600 ºC. The solid solution β-Ti(Nb) if formed at 500 ºC in the surface layers of the titanium alloyed with Nb atoms by means of the compression plasma flows impact.

References

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