Electron beam modification of the Grade 2 titanium surface after ion-plasma nitriding

Andrey N. Drobov, Siarhei V. Yurevich, Igar L. Pobol

The change of structure of Grade 2 titanium subjected to ion-plasma nitriding at 850 °C for 5 hours in a gas atmosphere consisting of pure argon at the heating stage, and Ar + N_2 in the soaking stage, after electron-beam exposure are investigated.

Keywords – Electron beam modification, titanium Grade 2 alloy, ion-plasma nitriding microhardness.

Introduction

Among materials of modern technology, titanium alloys occupy an important place due to their unique combination of physical, chemical and mechanical properties. However, for all the complex outstanding properties of titanium alloys, they have rather low hardness and wear resistance. Titanium alloys have a high coefficient of friction, especially in the titanium-titanium pairing. To some extent, these shortcomings make it possible to eliminate surface chemical-thermal treatment when titanium alloys are subjected to chromium plating, oxidation and application of protective coatings [1].

The most technologically and profitable form of obtaining the necessary properties and material costs is the method of vacuum ion-plasma nitriding. The technology of ion nitriding has found wide application [2, 3] for surface hardening of titanium alloys for various purposes. This method is optimal from the point of view of reproducibility of results, provides a high saturation rate, makes it possible to control the structure of the diffusion layer. In addition to this, ion nitriding is the most environmentally friendly method of chemical-thermal treatment, since there are no harmful effects on personnel and harmful emissions of industrial premises in the operation of the equipment.

However, in conditions of using titanium alloys, the presence of an extremely high hardness on the surface of the nitride zone is not always required. In some cases, it is preferable to obtain only the diffusion hardened layer. This is due to the high hardness of the nitride layer (1000 – 1400 HV), which in the process of operation can be broken into fragments of titanium nitride, when these fragments gets into the friction zone, it causes an increase in wear of components and lead to failure of the entire pair of friction. It is quite difficult to obtain a diffusion layer without the presence of a nitride zone on the surface however, it is possible to obtain this layer with extremely slow heating and strictly defined dosing of the nitrogen-containing atmosphere into the vacuum chamber to ensure chemical discharge activity, at which the nitride zone does not yet form on the surface. All these measures require the use of extremely pure gases and an increase in the duration of the process, which negatively affects the cost of processing and leads to the failure of the entire pair of friction.

One of the ways to solve this problem can be a combined treatment, including the impact on the nitrided layer by an electron beam [4, 5].

Electron beam machine and samples preparation

The chemical specification of the Grade 2 titanium is shown in Table 1. Ion nitriding was carried out at Physical-technical institute of the National academy of sciences of Belarus at 850 °C for 5 hours. After nitriding, the samples were subjected to electron beam exposure at a facility developed on the basis of ELA-15 power unit.

Table 1

Chemical specification of the Grade 2 titanium

Component	Wt. %
C	Max 0.1
Fe	Max 0.3
H	Max 0.015
N	Max 0.03
O	Max 0.25
Ti	99.2

Parameters of the electron-beam treatment: accelerating voltage - 60 kV, beam current – 15, 25, 35, 45 mA, spot diameter of heating - 8 mm (defocused beam with normal distribution of energy density in the heating spot), speed of heat spot displacement - 11.5 mm / s, the residual pressure in the vacuum chamber is $5 \cdot 10^{-3}$ Pa.

Samples preparation was carried out with the equipment manufactured by Metcon. The samples were cut off on a precision cutting machine Micracut 151. Hot pressing of the samples was carried out in epoxy powder on the Ecopress 100 programmable automatic press. The final grinding and polishing was carried out on the Digiprep 251 programmable grinding and polishing machine.

The microhardness was measured using a DM8 manufactured by AFFRI, at a load of 10 N. Photomicrographs of the samples were obtained with the MI-1 Planar microscope, an etchant solution of HNO3 and HF in water was used to identify the structure.

Ion Plasma Nitriding

Fig. 1 shows the microstructure of the titanium Grade 2 alloy after ion nitriding. At the surface, one can observe a nitride layer of 50 – 60 μm thick with hardness of HV 800 – 1100. In this case, the structure of the base metal remains sufficiently fine-grained, since the nitriding process is carried out below the transition temperature.

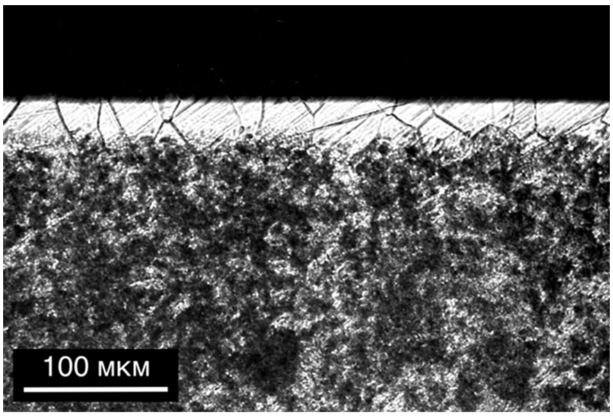

Fig. 1. Microstructure of the sample Grade 2 alloy after ion nitriding.

Electron-beam treatment

Fig. 2 shows the microstructure of a sample from a nitrated titanium Grade 2 alloy after an electron beam exposure at a current of 15 mA. It can be seen that this treatment leads to the disintegration of the nitride layer on the surface. The microhardness distribution in depth is shown in Fig. 3.

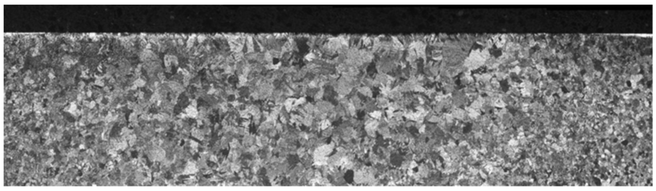

Fig. 2. Microstructure of nitrided sample Grade 2 alloy after electron-beam treatment at a current of 15 mA.

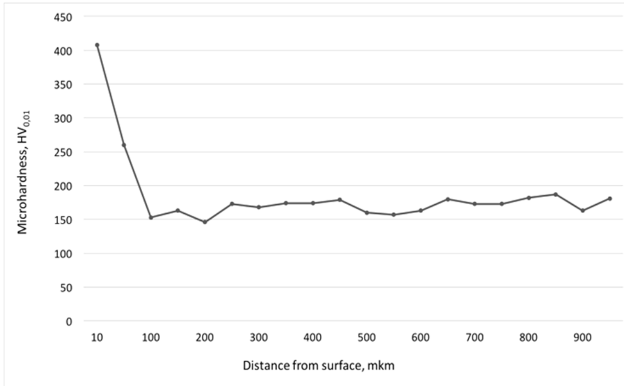

Fig. 3. The microhardness distribution in depth after electron-beam treatment at a current of 15 mA.

Fig. 4 shows the microstructure of a sample from a nitrated titanium Grade 2 alloy after an electron beam exposure at a current of 25 mA. The microhardness distribution in depth is shown in Fig. 5.

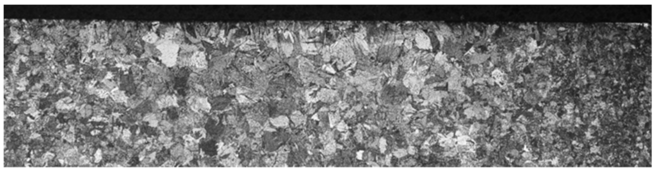

Fig. 4. Microstructure of nitrided sample Grade 2 alloy after electron-beam treatment at a current of 25 mA.

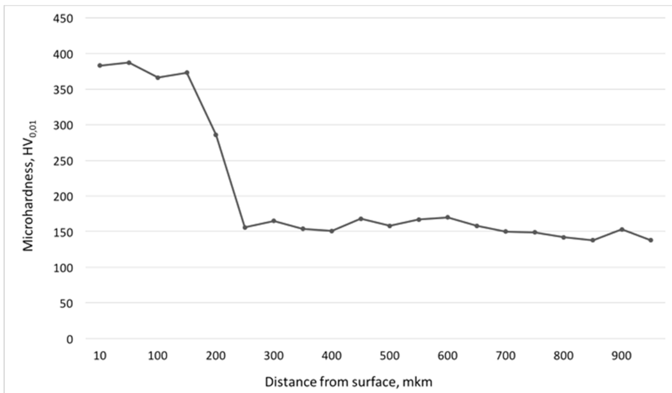

Fig. 5. The microhardness distribution in depth after electron-beam treatment at a current of 25 mA.

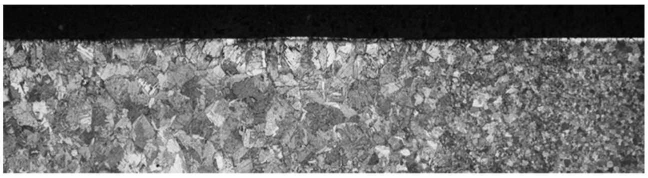

Fig. 6. Microstructure of nitrided sample Grade 2 alloy after electron-beam treatment at a current of 35 mA.

In Fig. 6 and Fig. 7 the microstructures of Grade 2 alloy after electron beam treatment with currents of 35 and 45 mA respectively is shown. Also, in Fig. 8 and Fig. 9 microhardness distributions in depth after electron-beam treatment with currents of 35 and 45 mA was also shown. In Fig. 9, one can see a small increase in hardness at a distance of 1 mm from the surface. This is due to the dissolution of nitrogen in the bulk of the molten metal from the nitride layer.

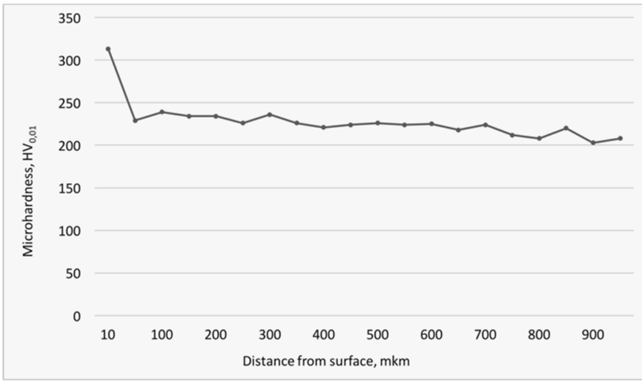

Fig. 7. The microhardness distribution in depth after electron-beam treatment at a current of 35 mA.

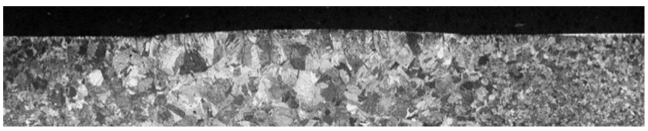

Fig. 8. Microstructure of nitrided sample Grade 2 alloy after electron-beam treatment at a current of 45 mA.

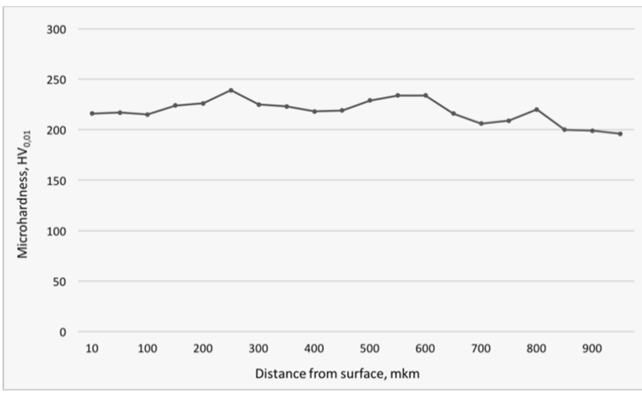

Fig. 9. The microhardness distribution in depth after electron-beam treatment at a current of 45 mA.

Conclusions

Combined treatments of titanium alloys, including exposure to the previously nitrided layer with an electron beam, makes it possible to form a diffusion zone on the surface with increased hardness. Electron-beam processing can lead to a surface decay on the nitrided layer of titanium nitride. Reduction of the hardness of the material can be explained by the decomposition of the nitride layer, some of the released nitrogen passes into the crystal lattice of titanium, forming a solid solution. Under non-optimal processing conditions, most of the nitrogen from the material evaporates. The formation of an extended modified zone with increased microhardness with such short-term exposure can be explained by the fact that the diffusion coefficient of nitrogen in the β-state is higher than in the α-phase.

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