Application of Plasma Nitriding in Medical Implants Post-Processing

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The features of titanium implants nitriding in the dense stream of nitrogen ions generated in non-self-maintained gaseous discharge with a hollow anode are investigated. We have determined that nitriding process in such type of discharge is much more intense than in the non-self-maintained discharge with a planar anode wherein there is no dense flux of ions. It has been found also that the rate of nitriding of surfaces oriented tangentially to the flux of ions exceeds the rate of nitriding of surfaces oriented perpendicular to the flux.

Keywords: medical implant, nitriding, non-self-maintained discharge, nitrided layer.

1 INTRODUCTION

A number of different materials are used for making of medical implants, including cobalt- and titanium-based alloys, plastic and ceramic. Titanium-based alloys, as a rule Ti-6Al-4V, have a good machinability, excellent mechanical properties, good bio-compatibility and enhanced corrosion resistance. Due to these properties, the alloy Ti-6Al-4V is widely used for a hip implants making, Fig.1. The hip implants are functioning together with a acetabular cup, which is usually made of polyethylene, ceramic or metal. The metal-on-metal option is the most reliable for young and active patients, because there is a risk of damaging of a ceramic cups or rapid wear of a polyethylene cups under considerable physical activity. At the same time, hip replacements among all categories of patients showed that 6.2% of metal-on-metal hip implants had failed within five years, compared to 1.7% of metal-on-plastic and 2.3% of ceramic-on-ceramic hip implants [1]. Failures may relate to release of microscopic fragments of metallic particles or metal ions from wear of the implants, causing a toxic reaction, pain and disability. In this connection authors of this work in collaboration with Sytenko Institute of Spine and joint Pathology, Academy of Medical Science, Ukraine have performed the hardening of the surface of titanium-based alloy implants by nitriding in directed ion fluxes generated in non-self-maintained gaseous discharge with hollow anode [2], [3].

Fig.1: Hip implants of titanium-based alloy.

2 EXPERIMENTAL

Non-self-maintained gaseous discharge is generated between hollow cathode (vacuum chamber 3) and hollow anodes 6, Fig. 2.

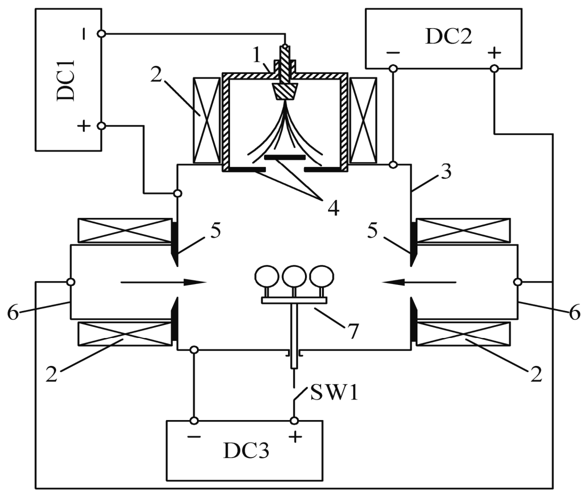

Fig.2: Scheme of experimental setup; 1 - vacuum-arc plasma gun; 2 - electromagnetic coils; 3 - vacuum chamber; 4 - screen; 5 - aperture; 6 - hollow anodes; 7 - samples; power sources DC1 and DC2 supply arc and gaseous discharges

Vacuum-arc plasma gun 1 serves as a source of supplementary charges. To prevent the penetration of the metal ions from gun 1 into gaseous stage of discharge, the aperture of anode of the plasma gun 1 is overlapped by the screen 4, which is mainly permeable to electrons. Hollow anodes 6 are surrounded by electromagnetic coils 2. Vacuum arc discharge and non-self-maintained gaseous discharge are supplied by power sources DC1 and DC2 respectively. If the switch SW1 is turned on, the positive voltage of 50 Volts is applied to implants 7 from power source DC3. As a result, the implants 7 are heated by electron current of 50÷100 A. By turning SW1 on and off one can to maintain a required temperature of implants 7. (The effectiveness of nitriding in a plasma of non-self-maintained gaseous discharge when applying a positive potential for the first time have been demonstrated by the authors of works [4], [5] with using an conventional planar anode). The ion current ejected from each hollow anode is near 3 A. The current density of nitrogen ions is in a range of 30÷40 mA/cm^2. The mean energy of ions is 25 eV. Other plasma parameters of non-self-maintained gaseous discharge with a hollow anode are presented in [2].

Investigation of nitriding process under applying of positive potential to titanium implants has been carried out on plates of Ti with dimensions of 20×10×2 mm which were attached to the walls of stainless steel tube in various ways [3]. The surface of first group of samples was oriented normal to the ion flux; the second group was oriented tangentially and the third group of samples was placed inside the tube (in center) with inner diameter of 25 mm and length of 120 mm, out of ion flux. The temperature of Ti plates and hip implants heads has been measured with pyrometer Optris P20. The processing time for all samples was 20 min. The hardness of the samples has been measured using a PMT-3 hardness tester. The hardness in a depth of Ti plates has been defined as an average of 10 measurements performed at equal distances from the surface at a microsection of the plate.

3 RESULTS

The hip implants heads (see Fig. 1), after nitriding under positive potential, have a high surface quality without symptoms of etching, as it take place in a case of heating by applying of a negative potential. The heads have a golden color indicating on the formation of titanium nitride layer. The depth hardness profiles obtained for Ti plates points out that the nitriding of surfaces oriented tangential to ion flux, Fig. 3, occurs faster than in a case of normal oriented surfaces, Fig. 4.

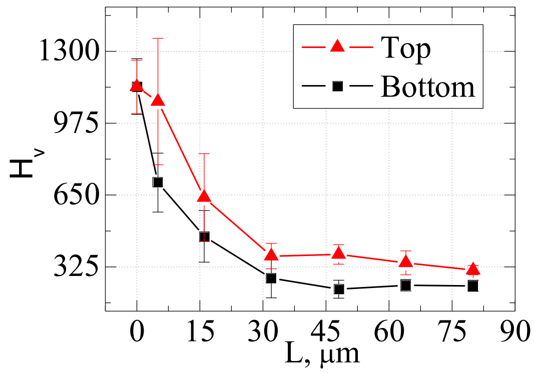

Fig.3: Microhardness distribution along a depth of Ti plate after nitriding at 750 ^{0}C in tangential to the surface ion flux; P=1·10^{-3} Torr; Top - side turned to stream of ions; Bottom - back side, adjoining to the tube wall; nitriding time is 20 min

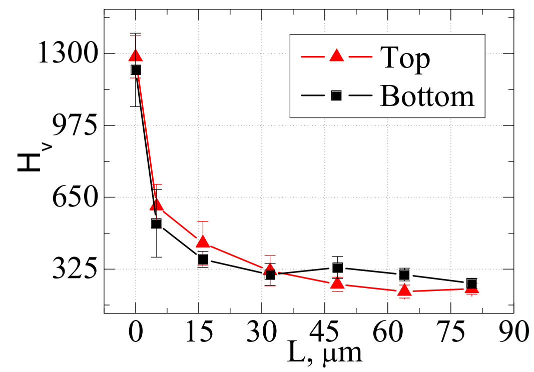

Fig.4: Microhardness distribution along a depth after nitriding at 750 ^{0}C in normal to sample surface ion flux; P=1·10^{-3} Torr; Top - side turned to stream of ions; Bottom - back side, adjoining to the tube wall; nitriding time is 20 min

This result is valid for some higher temperature and pressure (see Figs. 5 and 6). Perhaps the different rates of nitriding can be caused by more intense formation of TiN layer on a perpendicular to the ion flux surface. TiN serves as a barrier layer that inhibits a diffusion of nitrogen atoms into a sample. The back sides of samples (black line on Figs 3-7), despite the

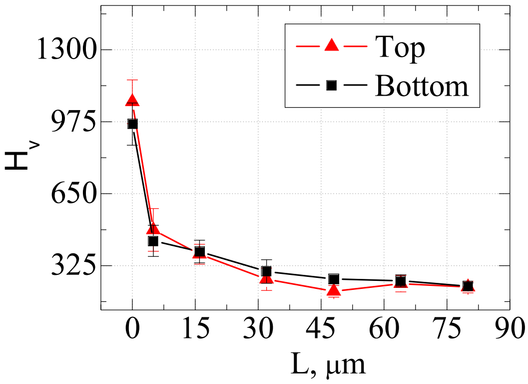

Fig.5: Microhardness distribution along a depth after nitriding at 800 ^{0}C in tangential ion flux; P=2·10^{-3} Torr; Top - side turned to stream of ions; Bottom - side, adjoining to the tube wall; t=20 min

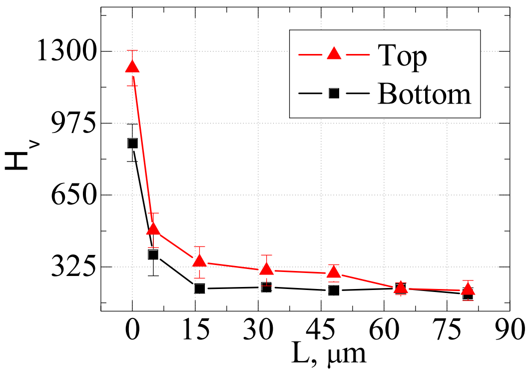

Fig.6: Microhardness distribution along a depth after nitriding at 800 ^{0}C in normal ion flux; P=2·10^{-3} Torr; Top - side turned to stream of ions; Bottom - side, adjoining to the tube wall; t=20 min

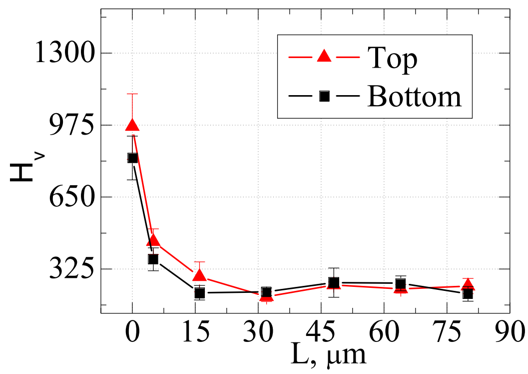

Fig.7: Microhardness distribution along a depth in Ti sample placed inside the tube with inner diameter of 25 mm and length of 120 mm after nitriding at 800 ^{0}C; P=2·10^{-3} Torr; t=20 min

gap between these sides and tube wall did not exceed 0.5 mm, are hardening almost to the same extent as the sides facing to the ion flux. Fig. 7 further shows that effective nitriding occurs even in the hollows or cavities where there no nitrogen ions and electric field. This fact confirms an opinion expressed by author [6] according to which for the successful nitriding it is enough the presence of excited nitrogen atoms and suitable temperature. The somewhat smaller nitrided layer (see Fig. 7) on samples placed inside of the tube indicates that the concentration of excited nitrogen atoms therein is less than outside of tube.

4 CONCLUSIONS

Nitriding of titanium-based alloy in a non-self-maintained gaseous discharge with hollow anodes have been investigated. It has been found that a nitrided layers grows with a rate of 0,5÷1 µm/min; furthermore, at the same rate the nitriding takes place on surfaces that have no contact with plasma i.e. in hollows or cavities. The heating of titanium samples by electrons of non-self maintained gaseous discharge avoids the ion etching and allows do not degrade the quality of treated surface.

Several surgical procedures for replacement of hip joint by nitrided prosthetic implants were performed during the last year in Sytenko Institute of Spine and joint Pathology. The conclusions about effectiveness of nitrided hip implants may be done only within a few years.

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