Influence of Si^+ and Ar^+ implantation on surface layer structure and mechanical characteristics of titanium alloy

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Introduction

The exposed and interphase surfaces in materials have been a subject of thorough investigation lately. The interphase areas are characterized by processes of formation and destruction of materials. As for the state of the surface and the environment with which the material interacts a large series of physico-chemical phenomena is associated with this. This is why today's researchers combine surface studies with the new methods of changing surface structure and composition.

Ion implantation is one of the promising techniques of material surface treatment aimed at changing the specific characteristics of materials (increase of fatigue limit, thermal stability, corrosion resistance, wear, etc.) [1].

The experimental investigation of the relationship between ion implantation by Si^+ and Ar^+ ions and the surface layer structure and physico-mechanical characteristics of titanium alloy is the purpose of the work presented.

1. Experimental

OT4 alloy (8.4 at.% Al, 1.3 at.% Mn, the rest being Ti) was taken as an investigation sample. The samples are plates 55 mm long and 9 x 2 mm^2 in cross-section cut from a sheet annealed at 700 ^oC.

To decrease the quantity of surface-stress concentrators the initial samples were polished prior to ion implantation. Part of the samples were implanted by Si^+ ions (E=40 кэВ, Ф=8000 мкКл/$см^2$, j=10 мкА/$см^2$), the rest were subjected to Ar^+ ion implantation (E=40 кэВ, Ф=8000 мкКл/$см^2$, j=10 мкА/$см^2$).

P4-SPM-MDT scanning probe microscope manufactured by the HT-MDT company (Russia) was used to study the sample surface patterns before and after ion implantation in the atomic force microscopy (AFM) regime. The measurements were performed with the help of silicon cantilever CS11 (HD-MDT) at room temperature in atmospheric conditions.

To perform these investigations a special device for the precise probe positioning was designed and fabricated [4]. The device allows repositioning to the initial area after sample modification so that the comparison of the studied objects might be possible. Besides, the device makes possible the orientation of the sample axis precisely along scanning axes, which is actual for better crack propagation monitoring. The device is currently in the state of further refinement with allowance for the sizes of the given samples.

Fatigue resistance test bench was used to damage the samples. The chemical composition of surface layers was measured by means of the secondary ion mass spectrometry (SIMS) on MS-7101M mass-spectrometer. DRON-3M apparatus was used for X-ray diffraction analysis. The structure of fractures was studied by means of the electron microscope REM-100U. To measure microhardness a microhardness meter PMT-3 was used.

2. Results

On Fig.1 given are the images of the initial sample surface after polishing, as well as of the samples after ion implantation and fatigue strength. Data on the statistical processing of images are summed up in Table 1. It has been stated that after ion implantation the increase of surface roughness takes place. Note that Si^+ implantation results in a higher roughness (40% higher) than it is observed in the case with Ar^+ ions. It is seen from the images (Fig.1b and 1c) that surface sputtering happened as a result of ion implantation (deeper scratches and nonuniformity growth are observed), which can be a possible reason for the decreased strength of samples under study. After Si^+ implantation comb structures are seen to be formed on the surface (Fig.1b) along the sample axis. Ar^+ implantation gives rise to the formation of lamella structures also with the traces of etched nonuniformities (Fig.1c).

Fatigue strength tests demonstrated the decrease in the number of cycles before damage (1000) after ion implantation in comparison with the initial samples (14000-65500) at one and the same loading (100 g). This may be due to the redistribution of alloying elements, their migration to the surface and interphase boundaries. The SIMS-data indicate the Al- and Mn-enrichment of the surface layer (after Si^+ implantation Al - as high as 46 at.%, Mn - as high as 10 at.%, Si - as high as 18 at.%; after Ar^+ implantation Al - as high as 35 at.%, Mn - as high as 10 at.%). Furthermore, the increased values of the roughness parameters of the damaged implanted samples were observed in comparison with the initial sample. Also the strengthening of the surface layer took place (microhardness is 10-20% higher in implanted samples than in the initial ones) [3]. The SEM investigation of the fracture of these samples indicated viscous damage [2] that propagates from the irradiated surface to the sample depth.

Conclusion

It has been stated in the investigation that changes arising in the physico-chemical characteristics of the studied samples are associated with the increased number of surface flaws after ion implantation, and with the redistribution of alloying elements in surface and interphase layers, with the effects more pronounced in the sample irradiated by silicon ions.

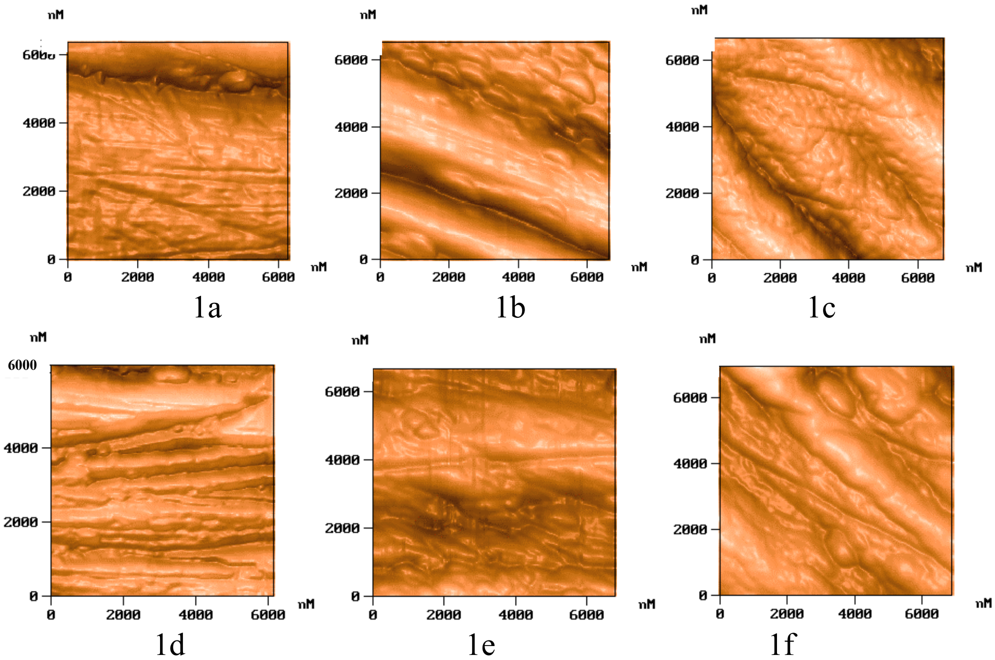

Fig.1. Surface topography images of samples under study

1a – initial sample; 1b – Si^+-implanted; 1c – Ar^+- implanted; 1d – initial damaged sample; 1e – surface of damaged sample after Si^+ implantation in the vicinity of fracture; 1f – surface of damaged sample after Ar^+ implantation in the vicinity of fracture.

Table 1.

Figure	Sample	Height difference R_{max}, nm	Mean route square roughness Rq, nm
1a	Initial	45.606	10.204
1b	Si^+ – implanted	120.846	27.066
1c	Ar^+ – implanted	109.541	16.766
1d	Initial, damaged	126.636	26.377
1e	Damaged (Si^+-implanted)	139.815	32.351
1f	Damaged (Ar^+- implanted)	198.119	34.759

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