The Influence of High-Ion Implantation on Wear Mechanisms of Ti and VT6 Alloy in Coarse-Grained and Ultrafine Grained States

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Abstract – The influence of high dose implantation and suppression of acoustic waves generated by tribosystem itself on tribological properties of titanium and its VT6 alloy has been investigated. The samples were used in two structural states such as coarse-grained state and ultrafine grained state.

It is shown that high dose ion implantation of titanium and its VT6 alloy allows inhibiting the change from fatigue wear to adhesive-abrasive one.

Acoustic wave suppression generated in the tribosystem itself essentially influences on wear of titanium and its VT6 alloy.

1. Introduction

High strength-to-weight ratio and corrosion resistance of titanium and its alloys give great advantages in their industrial and medical application. However, wide application of titanium alloys is limited by their low tribotechnical characteristics. The reason of that is small thickness of oxide film (<1 nm) and high reaction ability of juvenile surfaces arising during friction [1].

Low wear resistance of titanium and its alloys is a serious problem. It is determined by wide range of assemblies and components made of titanium alloys working in wear conditions nowadays. Titanium and its alloys are applied in such fields as chemical industry (working impellers, rollers, valves, gate fingers, and faucets), aviation (units of turbine engines, mechanization rails for a plane wing), implantation medicine (friction assemblies of endoprosthesis, etc). Wear resistance increase of titanium alloys is an essential task that would allow us to change steel into lighter, stronger and more corrosion resistant titanium alloys. Thus, it is of great interest for investigating tribological properties of titanium and its alloys and searching the ways of increasing their wear resistance.

High dose implantation efficiency for increasing wear resistance is shown for plenty of materials. However, the information about ion implantation influence on wear processes is limited for titanium and its alloys and for ultrafine grained materials this information is missing. Works [2–3] show that wear is essentially influenced by acoustic waves (AW) generated by tribosystem itself. Vibration damping of AW can increase wear resistance of tribosystem [3, 4]. In this connection, it is interesting to investigate the influence of AW suppression on wear resistance of titanium and its alloys. In this work the investigations of the tribological properties of titanium VT1-0 and VT6 alloy have been carried out in two states such as ordinary state, coarse-grained state and ultra-fine grained state, obtained by severe plastic deformation.

2. Experimental

The samples were tested using the scheme "pin-on-disk" in the method of boundary lubrication. As a lubricant, industrial oil I–20 was applied. Parallelepiped-shaped samples had the size of 5×5×40 mm^2. A counter-body was made of steel ShH 15. The sample weight loss during the wear tests were measured by weighing on the analytical weights. The tests were carried out by a specially designed friction machine similar to UMT-1 that allowed changing the characteristics of acoustic waves arising during friction. The test pressure was 0.125–3 MPa at speed 1 m/s. The AW level was changed by using a lead damper fixed on the samples and on the counter-body [3]. The samples were implanted by means of a DIANA-2 technological ion accelerator operating in a pulse-frequency mode at an accelerating voltage of 60 kV. The pulse duration was 200 microseconds and ion fluence for all implanted samples was 10^{17} ion/cm^2.

3. Results

Wear resistance tests of VT1-0 and VT6 in both states show that sharp adhesive seizure of the samples and counter-body takes place at contour load of 3; 1; 0.5 MPa that resulted in the test ceasing in 30 seconds. During tests with contour load of 0,125 MPa the formation of titanium layer took place on the surface of the counter-body in ~30–60 seconds and then intensive wear process started. According to the wear curve and test conditions we can define the adhesive-abrasive character of the wear (Fig. 1, curve 1). The formation of a titanium layer on the surface of the counter-body in the abrasive form indicates that as well. 30–60 seconds is the time for titanium layer formation on the surface of the counter-body at the given load.

Further decrease of the load up to 0,125 MPa resulted in increasing of normal (fatigue) wear up to 16 minutes. In this connection the time of abrasive layer formation on the surface of the counter-body and change into adhesive-abrasive wear increased up to 90 minutes (Fig.1, curve 2).

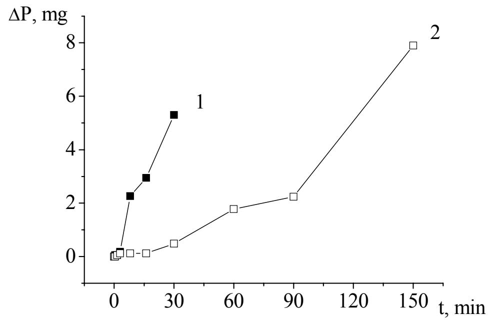

Fig. 1. Kinetic dependencies of weight loss of VT1-0 titanium samples in initial state at wear tests with contour loads: 1–load 0,25 MPa; 2– load 0,125 MPa

Silicon ion implantation of VT1-0 titanium samples with the energy of 90 keV resulted in sharp decreasing of adhesive seizure. It also led to wear resistance rate decrease in the initial stage of the tests. However, after the wear of ion-implanted layer, wear curves sharply changed the direction and the process run as it was before ion treatment and adhesive seizure was restored as well. Silicon ion implantation of VT1-0 titanium samples inhibited reaching the adhesive-abrasive wear during the tests for 60 seconds. Similar wear character was observed after carbon ion implantation with the energy of 60 keV as well, however the adhesive-abrasive wear was reached just in 9,5 hours. (Fig. 2).

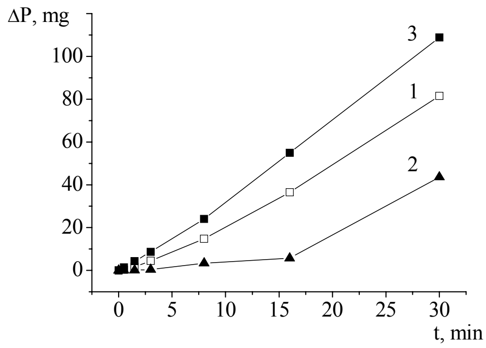

Fig. 2. Weight loss of VT1-0 titanium samples at wear tests: 1 – initial state; 2 – after Si implantation; 3 – after C implantation. Load equaled 0,25 MPa

Silicon ion implantation of VT6 titanium samples inhibited reaching the adhesive-abrasive wear during the tests for 15 minutes. After carbon ion implantation of VT6 titanium samples the wear rate increased (Fig. 3).

According to the investigation results of load influence on wear rate the load decrease of tribosystem can increase its wear resistance (Fig. 1). It is obvious that this method of wear resistance increasing in tribosystems is not possible to use in all cases of titanium practical application.

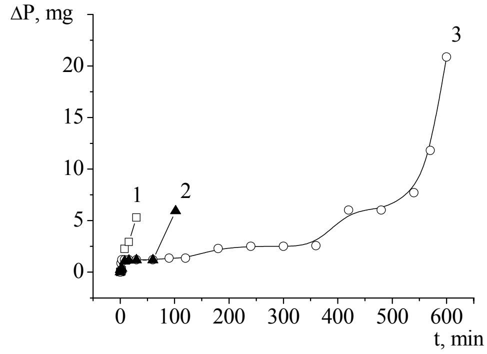

Fig. 3. Weight loss of VT6 titanium samples at wear tests: 1 – initial state; 2 – after Si implantation; 3 – after C implantation. Load equaled 0,25 MPa

Nevertheless this result is of great interest in connection with the following. Investigating the mechanisms of material failure in tribosystems of steel 45 samples it was shown that AWs arising in the tribological system itself made a great contribution to the failure of materials [2–3]. According to the results of the given works we can conclude that the effect of AW is similar to extra "effective" load [3]. On damping AWs generated in tribosystem is possible to decrease this load without decreasing contour load [3]. Moreover, in the work [2] it was assumed that high effectiveness in increasing wear resistance of tribological pairs after ion implantation can be explained by AW suppression arising during friction.

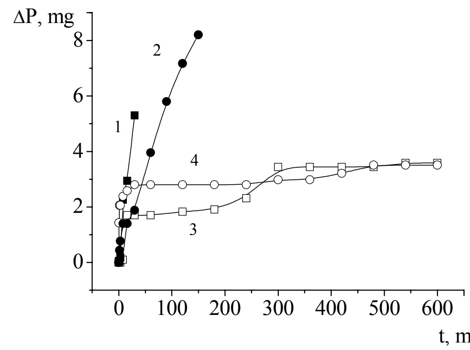

Fig. 4. Kinetic curves of weight loss at wear test of the titanium samples: 1 – VT1-0 in initial state; 2 – VT1-0 in ultrafine grained state; 3, 4 – VT1-0 in initial state and VT1-0 in ultrafine grained state respectively using dampers during tests. Load equaled 0,25 MPa

In this connection it is interesting to investigate the influence of AW damping generated at friction using titanium samples and its alloys. Test results of VT1-0 titanium samples both in initial and ultrafine grained states with and without dampers are given in Fig. 4.

Wear curves without using dampers are shown in this Figure for comparison. This Figure demonstrates that wear pattern is seriously changed at AW suppression using dampers both in samples and a counter-body. An average fatigue wear is observed having two stages: the first one is a wear-in stage and the second one is the stage of stable and significantly less intensive wear of AW [5]. The wear test mechanism hasn't been changed for 10 hours. During this test a titanium layer hasn't been formed on the surface of the counter-body. (for being precise it has been formed very slowly).

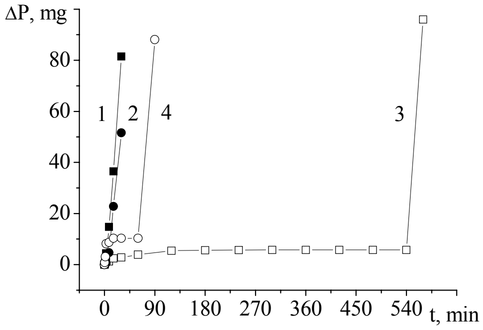

Fig. 5. Kinetic curves of weight loss at wear test of the samples: 1 – VT6 in initial state; 2 – VT6 in ultrafine grained state; 3, 4 – VT6 in initial state and VT6 in ultrafine grained state respectively using dampers during tests. Test load equaled 0,25 MPa

Similar tests with AW damping were carried out for VT6 titanium alloys. Test results are given in Fig. 5. Wear curves without using dampers are shown in this figure for comparison. During tests of VT6 in initial state for 9 hours two stages were observed: a wear-in stage and stable, non-intensive wear stage. However, adhesive seizure was observed after 9 hours of a test. Then, wear mechanism is changed from fatigue to adhesive-abrasive one and wear of samples is sharply increased (compare the curves 1 and 3, Fig. 5). A titanium layer was formed on the counter-body on the friction surface. Wear intensity became the same as at tests without dampers. It meant that despite AW damping, gradual accumulation of a titanium layer because of adhesive transfer of the material from samples to a counter-body took place. After accumulating sufficient quantity of particles on the counter-body surface wear mechanism changed.

Similar situation was observed during VT6 tests in ultrafine grained state. However, wear pattern changed after 60 minutes of a test (compare the curves 2 and 4, Fig. 5).

4. Discussion

Titanium wear at sliding on the steel includes some stages each of which is connected with definite processes. The first stage includes both wear-in and relatively steady-state stages. This stage, as a rule, is very short and it can't be revealed every time. During the first stage, a titanium layer is formed on the counter-body because of adhesive transfer of the material from the samples to a counter-body. After formation of such a layer, wear mechanism becomes adhesive-abrasive [1]. Silicon ion implantation in VT1-0 and VT6 titanium leads to decrease of adhesion and increases the period of the second stage that is relatively steady-state one. However, after wear of the implanted layer, titanium layer is formed on the counter-body and the process changed into adhesive-abrasive wear. Interesting results were obtained during carbon implantation. In the case of VT1-0 carbon implantation adhesive-abrasive wear started only after 9,5 hour test.

VT6 titanium tests show that after carbon implantation of the samples the wear becomes more intensive. Obviously, such a different behavior of the materials can be explained by the following. Carbon implantation into the VT1-0 titanium leads to titanium carbide formation that is wear resistant material decreasing adhesion. Probably aluminum forming VT6 results in formation of aluminum carbide that facilitates rapider wear process.

Titanium tests on wear in the conditions of AW suppression in comparison with test results with various loads indicates that AW effect is similar to extra "effective" load. Decreasing of this "effective" load results in adhesion decrease and wear rate respectively.

5. Conclusion

High dose ion implantation of titanium and its VT6 alloy allows inhibiting the change from fatigue wear to adhesive-abrasive one.

It is shown that acoustic wave suppression generated in the tribosystem itself is an effective method of wear decreasing.

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