The Influence of the Type of Implanted Ions on Wear Kinetics of α-Iron and Steel 45

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Abstract – The influence of a high-dose ion implantation on the deformation processes occurring in subsurface areas of α-iron and steel 45 at friction is investigated. The ion implantation is found to decrease wear by a factor of tens in the first stage. The experiment also shows that varying the conditions of propagation of acoustic waves generated by a tribological pair at friction results in reducing fracture processes in the samples. A scheme of deformation evolution under friction conditions is proposed. This takes into account the effect of the acoustic waves generated by a tribological device. The scheme allows us to account for wear kinetics in various materials including those subjected to ion implantation.

Ion beams are a good tool for purposeful changing surface properties of materials [1–5]. Using ion beams for improving wear resistance of tribological pair leads to a twofold-fivefold increase in their lifetime. This implies that the application of ion beams is a promising direction of strengthening technologies. In order to improve technological regimes of strengthening, it is necessary to know the mechanisms increasing wear resistance.

Alloying by the elements forming carbides, nitrides, oxides etc. is generally considered to results in hardening. At a high-dose implantation, there occur structural changes in subsurface layers. Granular structures are observed to transform into finer nanostructural and amorphous states which also results in hardening [6]. Indeed, ion alloying and structural changes should result in hardening the subsurface layers. However, the problem is that the thickness of an alloyed layer under a conventional high-dose ion implantation, where the energy of ions 100÷200 KeV, is about 0.1 μm, wear resistance increases at the first stage of the wear process by a factor of tens [6]. This brings about a question as to how such a small thickness of a strengthened material which should be quickly carried away at friction, may slow down the wear processes so effectively. On the other hand, acoustic waves (AW) are known to be generated [7–8]. In the case of occurrence of a resonance in a sample, these can cause destruction of the material of tribological pairs [9]. Therefore, it is interesting for examine how the AWs generated in the tribosystem affect its wear in the case of implanted and its wear in the case of implanted and unimplanted samples.

To study the mechanism of increasing wear resistance of tribologic pairs upon their processing with a high-doze ion implantation, the wear kinetics has been investigated for α-iron and steel 45 implanted by Fe, Pb, Mo, and Si ions. The samples were tested using the scheme “pin-on-disk” by the method of boundary lubrication. As a lubricant, an industrial oil I – 20 was applied. A counter-body was made of steel ShH 15. The sample-weight loss during the wear tests was measured by weighing on the analytical weights. The tests were carried out by means of a specially designed friction machine allowing the characteristics of acoustic waves generated during friction to be changed. The test pressure was 3 MPa for α-iron and 1 MPa for steel 45 and speed was 1 m/s.

The deformation processes in the subsurface layers at friction were investigated on the friction surface and on metallographic sections whose planes were perpendicular to the surface of friction, parallel to the direction of motion, and passed through a contact spot. This scheme allowed us to observe changes in the microstructure in the bulk material. The AW level was changed using a lead damper fixed on the samples or on the counter-body [10]. The samples were implanted by means of a DIANA-2 ion accelerator operating in a pulse-frequency mode at an accelerating voltage of 60 kV. The pulse duration was 200 microseconds and ion fluency for all implanted samples was 1017 ion/cm^2. Steel 45 was preliminary tempered in argon during 3 h at 850 °C followed by cooling in the furnace. After such thermal treatment the microstructure represented a mixture of ferrite and perlite approximately in equal volumes, the size of grains after tempering being ~20 μm.

The kinetic curves of weight losses in the samples of steel 45 in the initial condition at friction (Fig. 1, curve *1*) exhibit a common form of wear in the above conditions: there is an initial stage of wear with a high speed of wear which passes into a stage of steady wear. At the second stage, the rate of wear is drastically slowed down. In the same figure, the wear curve of the sample is given for the case where the AWs were suppressed both in the sample and counter-body. It is seen from the figure that the suppression of AWs results in an approximately twofold decrease of wear of steel 45.

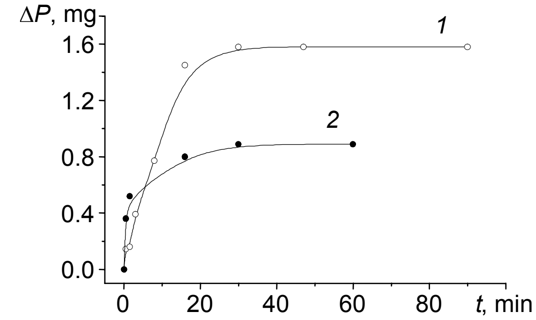

Fig. 1. Kinetic dependences of loss of weight of initial samples of steel 45 at the tests for wear: *1* – usual tests, *2* – with suppression of acoustic wave

Similar curves were also observed for α-iron. The wear of the α-iron samples at suppression of AWs has decreased fourfold.

Figure 2 shows the wear kinetics of steel 45 samples implanted by molybdenum. The kinetic dependences are similar to those observed for unimplanted samples. Note that the wear of the implanted samples is also decreased twice.

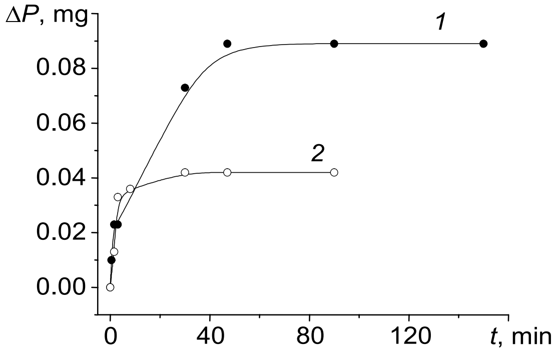

Fig. 2. Kinetic dependences of weight loss of steel 45 samples implanted by Mo using "pin-on disk" scheme: *1* – conventional tests, *2* – suppression of acoustic wave

Figure 3 shows the wear curves of steel 45 samples implanted by various ions. It follows from Figure 3 that the ion implantation affects wear resistance at the initial stage most significantly, different implanted elements influencing the extent of wear with different efficiency. The greatest increase in wear resistance is observed under implantation of silicon ions, then molybdenum, lead and iron ions.

In the case of α-iron, the implantation of iron ions reduced the wear of samples fourfold at the first stage and the implantation of silicon ions – twofold.

Metallographic research into steel 45 gives the following results. On the initial samples, after tests on friction without using dampers, a layer with a characteristic light contrast separated by a clear boundary from the underlying material is observed on the friction surface. The layer is broken to mesofragments by transverse strips with a period of 3...4 micrometers. Under the surface layer, the grains have a form extended along the direction of motion of the sample along the counter-body. This testifies to a significant plastic deformation in the subsurface layer during friction down to a depth of 50 micrometers.

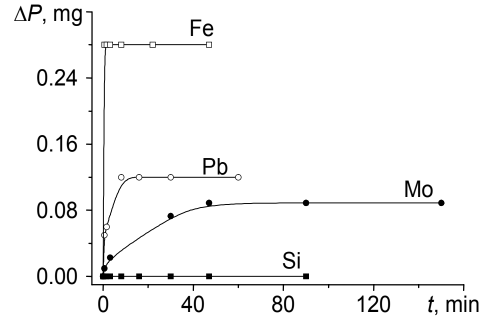

Fig. 3. Kinetic dependences of weight loss of steel 45 samples implanted by various elements at wear tests

A lateral surface of the steel 45 sample implanted by Fe after tests with suppression of acoustic waves is presented in Fig. 4.

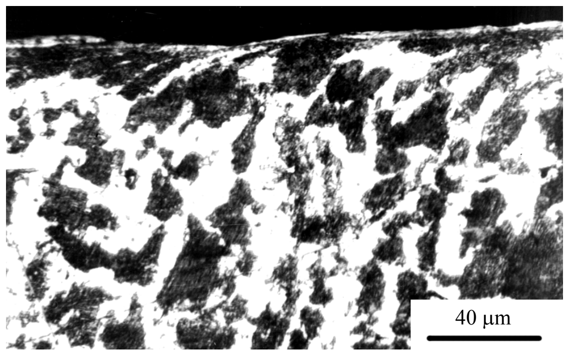

Fig. 4. Micropictures of a sample section of steel 45 implanted by Fe ions after friction tests with dampers

Similar microstructures with a thin modified subsurface layer and traces of plastic deformation were observed in other samples in the initial states implanted by iron ions in the wear tests with and without dampers. No layers with a characteristic light contrast and areas with the extended grains at the surface were found on the samples implanted by molybdenum and silicon ions.

Metallographic research into the α-iron samples after tests has revealed no appreciable deformation of the subsurface layers. It is possible that in the case of α-iron, the deformation processes develop in thinner layers (Fig. 5).

The results obtained in the work and the literature data available show that the AWs generated in the tribological system make a great contribution to the destruction of tested samples at friction.

Taking into account the influence of AWs on wear of tribosystem materials, we can explain the kinetic dependences of wear processes as follows.

Unimplanted samples. From the first moments of friction both volumetric and surface waves of various types occur in unimplanted samples. The amplitude of waves in a sample may essentially grow with the occurrence of resonant phenomena when the frequency of driving force coincides with the eigen frequencies of samples for any types of waves.

The formation of standing waves can be also assumed as it was observed in [8]. These waves promote more intensive development of deformation processes and surface-layer fracture of a material.

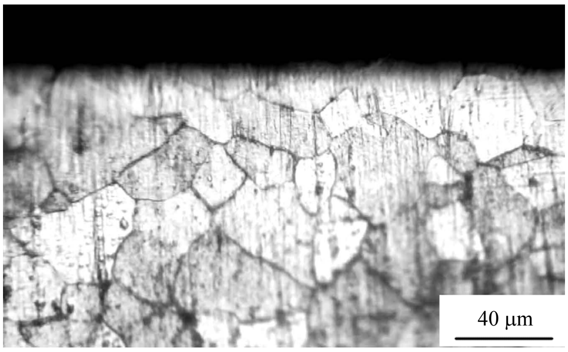

Fig. 5. Micropictures of an unimplanted α-Fe sample section after friction tests with dampers

As a result of deformation processes during friction, a gradient subsurface layer is formed at the run-in stage [6, 11]. This gradually reduces the effect of AWs on wear (Fig. 1). This assumption is supported by the results of work [7] which shows that the signal amplitude of acoustic emission at friction tests decreases with time during the initial stage and reaches a minimal value at the end of the stage. At the steady-wear stage, the amplitude of acoustic emission and wear intensity do not change with time.

Ion-implanted samples. Under ion implantation. a modified layer is formed whose physical mechanical properties greatly differ from the bulk material. In the implantation regimes used, its thickness is usually in no excess of 1 micron. This layer appears to largely affect the propagation of surface acoustic waves. The surface waves such as the Rayleigh or Layva waves in solids are known to be located in a layer of a wavelength thickness [12]. Thus, there is a good reason to assume that the presence of even such a thin modified layer may essentially change the level of AWs, thereby influencing wear resistance in materials.

The acoustic waves generated in a tribosystem were proved to affect the materials fracture, hence the investigation of acoustic waves occurring at friction and their influence on the fracture of materials is the task of great importance in tribology.

It is necessary to take into account that the initial wear changes the geometry of contacting bodies. It causes quicker wear of cutting tools, dies, bushes, etc., at the steady-wear stage.

The main attention, in our opinion, should be paid to the mechanisms of acoustic-wave generation in tribosystems, their development in the inhomogeneous near-surface and subsurface layers of contacting materials, and their influence on deformation processes in materials.

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