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Surface modification of steel mark 2 electrolytic-plasma exposure

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This work is devoted to the research of the influence of the technological parameters of electrolytic-plasma surface hardening on the structure and tribological properties of the surface of samples of the retaining steel mark 2. In the electrolytic-plasma surface hardening was carried out in an electrolyte from an aqueous solution of 20% urea and 20% sodium carbonate. According to the result of metallographic and X-ray diffraction analysis, it was determined that the phase composition of steel mark 2 after processing varies, and fine martensite with a small amount of troostite and iron oxide is formed on the surface of the samples. Tribological experiments of samples without lubrication were carried out. These experiments have shown that all the studied samples have an increased wear resistance, which may be associated with the formation of a fine-grained martensitic structure. It was shown that from the point of view of the complex of the properties obtained, the most promising is electrolytic-plasma action with a treatment time of 2 s.

Keywords: electrolytic-plasma surface hardening, bandage steel, wear resistance, microstructure, microhardness.

Introduction

The problem of wear of the crests of tires of locomotive wheelsets has been repeatedly highlighted by many scientists as the most significant reason for the inability to increase the overhaul run of locomotives, which significantly increases maintenance costs and simple locomotives in repair depots [1]. It is known that over the past 20 years there has been a gradual increase in the wear rate of the wheelset of locomotives on Kazakhstan Railways. This is due to the increase in distillation speeds of trains and axial loads, as well as the transition to reinforced concrete sleepers. At the same time, steel for the manufacture of bandages has not changed. For the manufacture of bandages in Kazakhstan, mainly used steel mark 2. The bandage is a replaceable element of a wheel pair. The bandage directly interacts with the rail and due to the large static and dynamic loads, is subjected to the greatest wear. The strength characteristics of the bandage steel mark 2 according to GOST 398-2010 is insufficient and does not correspond to the more stringent conditions of loading of the bandage in operation, associated with the increased power of the locomotive and the implementation of the increased coefficient of adhesion of the bandage with the rail [2, 3].

Currently, there are several methods for increasing the service life of wheelset bands. The most effective of these is plasma hardening of the crests of the tire trunking of wheel sets and the lateral surface of the rails. Currently, in practice, various methods of plasma hardening (quenching) are used using a compressed arc of direct or indirect action generated by a special plasma torch [4]. However, many technologies have several disadvantages associated with the processes of decarburization, oxidation and insufficient cooling rate. To eliminate these drawbacks, electrolytic-plasma technology can be used for surface heat treatment. Electrolyte-plasma surface hardening (EPSH) is one of the methods of high-speed heating, in which the workpiece is a cathode or anode relative to an aqueous electrolyte [5, 6]. Depending on the heating mode, electrolyte composition, design parameters of the equipment, it is possible to produce hardening, chemical-thermal and thermal-cyclic processing of materials. At the same time EPSH is the most economical and productive method. It is characterized by less energy consumption, simplicity of technological equipment and large size of the hardened zone. The advantages of the method are a sufficiently large process performance and the ability to strengthen the details of a large mass and a complex profile, and the degree of hardening is comparable to plasma quenching [7].

In connection with above, the aim of this work is to study the effect of EPSH on the structure and surface properties of specimens of the mark 2 retaining steel.

Experimental procedure

In this work EPSH was subjected to samples of steel mark 2, used for the manufacture of locomotive wheel sets in accordance with the requirements of GOST 398 - 96. The chemical composition of steel: 0.55 - 0.65% C; 0.5 - 0.9% Mn; 0.22 - 0.45% Si; No more 0.1% V; No more 0.03% S; No more 0.035% P; the rest of Fe, also the permissible mass fraction (%): Ni $\leq$ 0.25, Cr = 0.20, Cu = 0.30 to GOST 398 - 96.

Blanks of steel samples of mark 2 for study were cut out of a bandage in the form of a parallelepiped measuring $15 \times 15 \times 10$ mm^3. The technology of preliminary heat treatment of steel wheels provides for their hardening and subsequent tempering. In this work, in its initial state, steel mark 2 was heat-treated by quenching at 890-920 $^\circ$C (exposure 2 h) with subsequent tempering at 580 - 620 $^\circ$C (exposure 2.5 h, cooling in warm water at 30 - 60 $^\circ$C) [8]. EPSH was carried out at the electrolyte-plasma treatment facility developed by the authors of work [9]. A schematic diagram of the installation for the EPSH is shown in (Figure 1). The power source was a powerful rectifier, giving a maximum 360V/60A output in the form of direct current. Samples were processed by rapid heating for 2 - 4 s and then cooling in a flow-through electrolyte. A water solution of urea and sodium carbonate was chosen as the electrolyte. The process was carried out under the following parameters: Electrolyte composition (% mass) is 20% carbamide $(NH_2)_2CO$ + 20% sodium carbonate Na_2CO_3 + 60% water; processing time - 1 s, 2 s, 3 s, 4 s; T_{max} = 850 - 900 °C; U =320 V; I = 40 A.

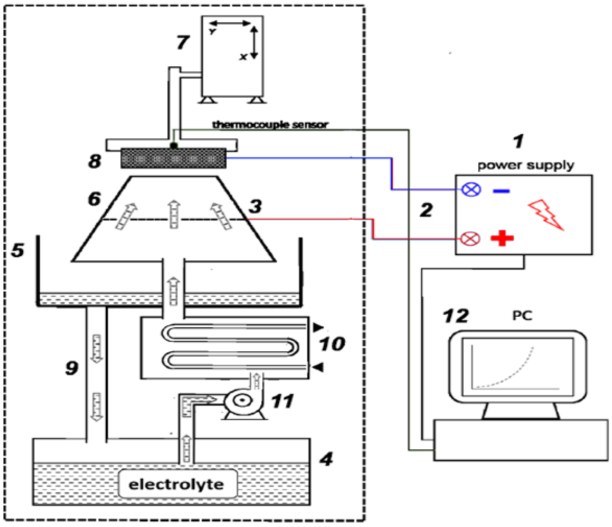

Figure 1. Functional diagram of the installation for electrolyte-plasma processing of materials. 1 – power supply; 2 – current lead; 3 – anode (plate); 4 – main tank for electrolyte; 5 – intermediate capacity; 6 – electrolytic cell; 7 – coordinate device; 8 – workpiece; 9 – branch pipes; 10 – heat exchanger; 11 – pump; 12 – control computer.

The microstructure of the surface was studied on an optical microscope "ALTAMI-MET-1M". The microhardness of the surface layers of the samples before and after processing was measured by the method of pressing the diamond indenter using a PMT-3M instrument at a load of 1 N and a holding time at this load of 10 s. Tribological characteristics were studied on the THT-S-BE-0000 tribometer. The wear tracks were investigated using the MICROMEASURE 3D station contactless 3D profilometer. The phase composition of the samples was studied by X-ray diffraction analysis on an X'PertPro diffractometer using CuKα radiation. Test samples for abrasive wear was performed on an experimental setup for testing for abrasive wear according to the scheme "rotating roller - flat surface" in accordance with GOST 23.208 - 79. The durability of the treated sample was evaluated by comparing its wear with the wear of the reference sample (not the treated sample). Wear was measured by the gravimetric method on an analytical balance with an accuracy of up to 0.0001 g. The wear resistance of the test material was estimated by the weight loss of the samples during the test according to GOST 23.208 - 79 which coincides with the American standard ASTM C 6568 [10].

Results and Discussion

The conducted metallographic studies have shown that the structure of the bandage steel mark 2 in the initial state, i.e. after standard heat treatment, it is a ferritic-pearlite structure. As can be seen from (Figure 2a), the pearlite and ferrite grains are randomly located relative to each other. Approximately 60% of the bulk of the investigated steel is occupied by ferrite grains.

Under the research of the microstructure of the surface layers of samples of steel mark 2 subjected to EPSH, structural changes were found. Figure 2 shows the microstructure of the surface layer of steel before and after treatment in the electrolyte containing an aqueous solution of 20% urea $(NH_2)_2CO$ and 20% sodium carbonate Na_2CO_3 with a treatment time of 1 - 4 s.

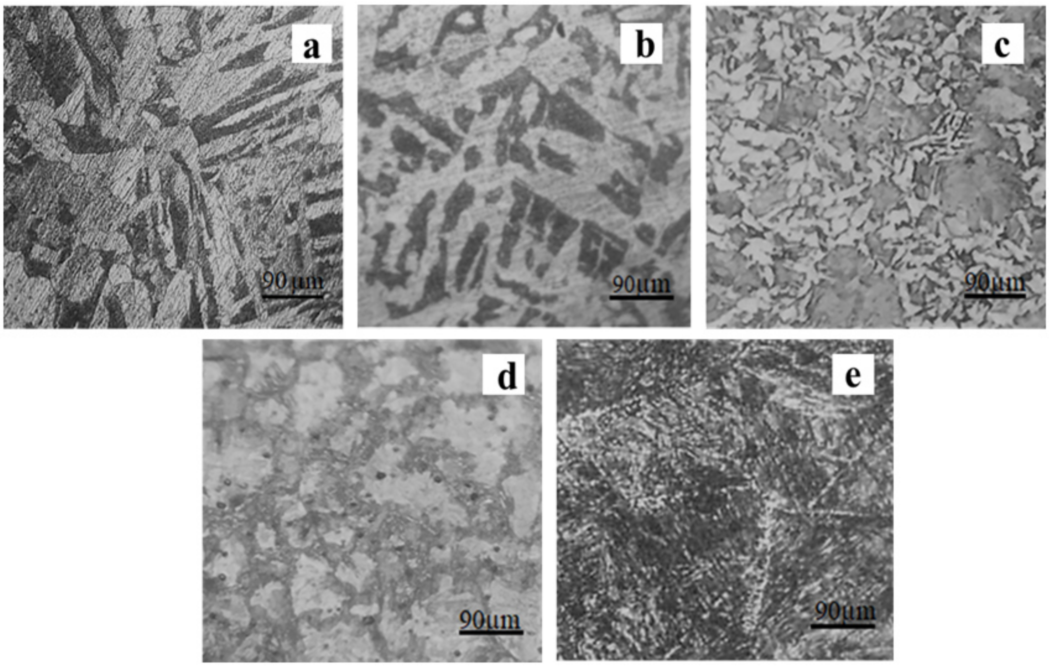

Figure 2. Microstructure of the bandage steel mark 2 before and after the EPSH. a) in the initial state; after EPSH: b) 1 s; c) 2 s; d) 3 s; e) 4 s.

Figure 3a shows a fragment of the X-ray diffraction pattern, where the diffraction peaks correspond to the α-Fe phase. After EPSH, the formation of a structure from fine martensite and troostite (highly dispersed perlite) is observed. According to the results of X-ray phase analysis, cementite and iron oxide FeO were found together with martensite (Figure 3c). The observed cementite lines on the diffractogram confirm the formation of troostite. Thus, the microstructure of the surface of a hardened sample of steel mark 2 is a fine-grained martensitic structure with a small amount of troostite and iron oxide.

Considering the actual of the problem of increasing the performance characteristics of the retaining steel of mark 2, one of the most important properties of the surface layer, which greatly affects wear resistance, is hardness, in this work, changes in the microhardness of the surface layer of steel mark 2 after EPSH are studied. Figure 4 shows a diagram of the dependence of the microhardness value of steel mark 2 on the duration of exposure to electrolytic plasma. The microhardness

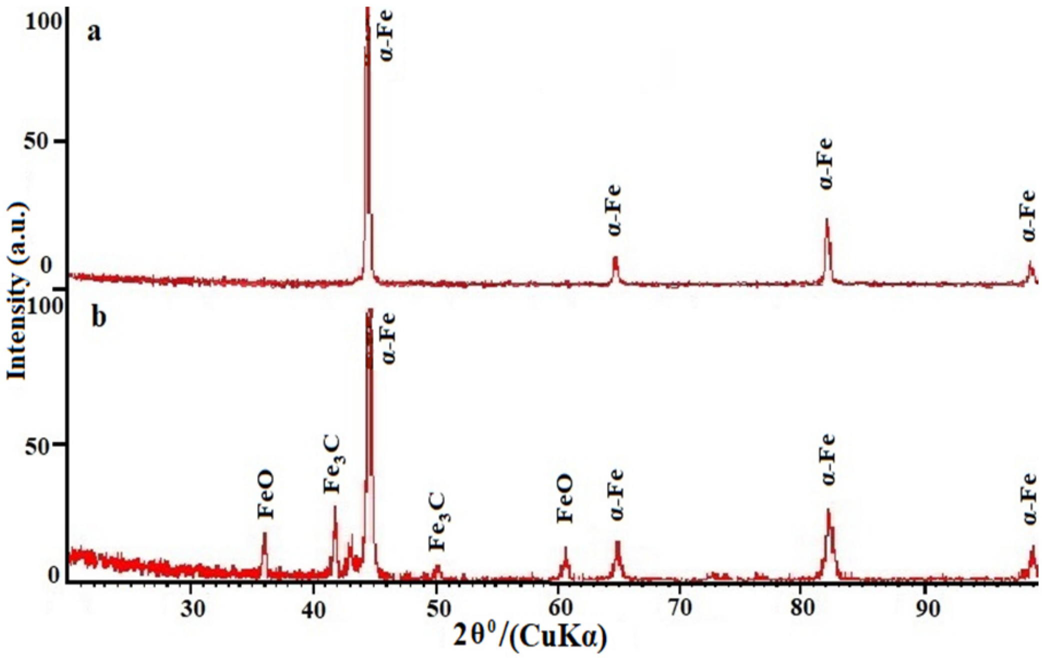

Figure 3. X-ray phase analysis of steel mark 2 before (a) and after the EPSH (b).

of steel mark 2 in the initial state is 1448 MPa, and after quenching with a duration of 1 - 4 s: 1757 MPa, 3486 MPa, 2911 MPa and 3523 MPa, respectively, which is 2.4 times increased compared to the microhardness in the initial state. According to the microhardness data obtained for the retaining steel mark 2, it is considered the optimal mode for EPSH: treatment at a temperature of 860 °C with the electrolyte composition of an aqueous solution of 20% urea $(NH_2)_2CO$ and 20% sodium carbonate Na_2CO_3 with a processing time of 2 s.

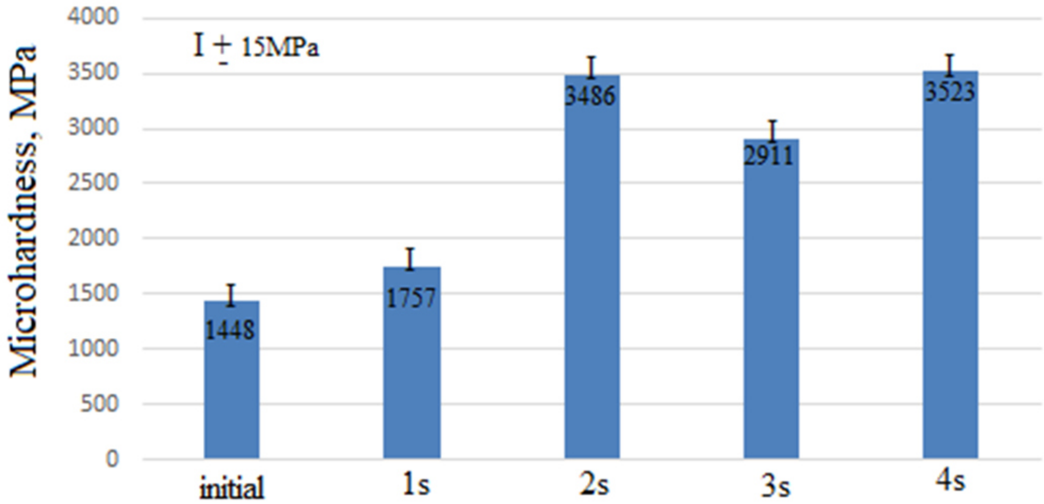

Figure 4. Diagram of the value of the surface microhardness of steel mark 2.

The tribological properties of the samples before and after the EPSH were also examined. Experimental curves of the friction coefficient versus the path length are shown in Figure 5. The test was carried out according to the ball-disk scheme, the path length was 31 m, speed 2 cm/s, load 5 N.

The results of experiments showed that there is a slight change in the coefficient of friction after the EPSH. At the same time, a relatively low coefficient of friction

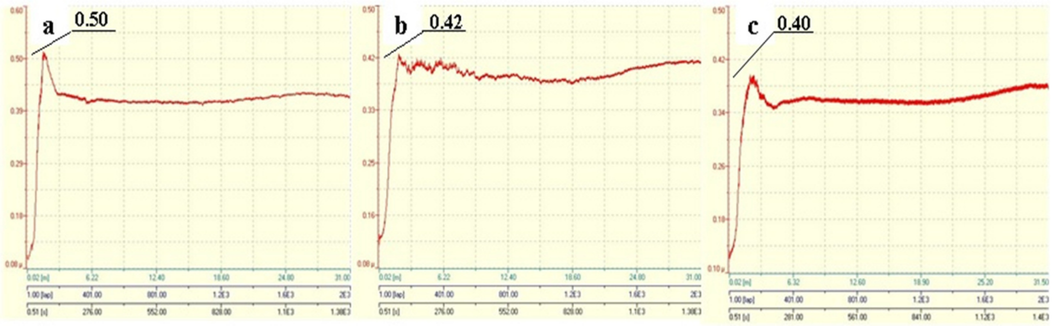

Figure 5. Friction coefficient of bandage steel mark 2 before and after EPSH. a) before EPSH; after EPSH; b) 2 s; c) 4 s.

is observed in samples treated with EPSH for 2 s.

We took pictures of the sample wear track before and after the EPSH with different processing times using a 3D profilometer, (Figure 6). Assessing the wear resistance of the samples based on the geometrical parameters of the wear tracks, it can be said that the depth of the sample track after the EPSH is significantly lower compared to the untreated sample.

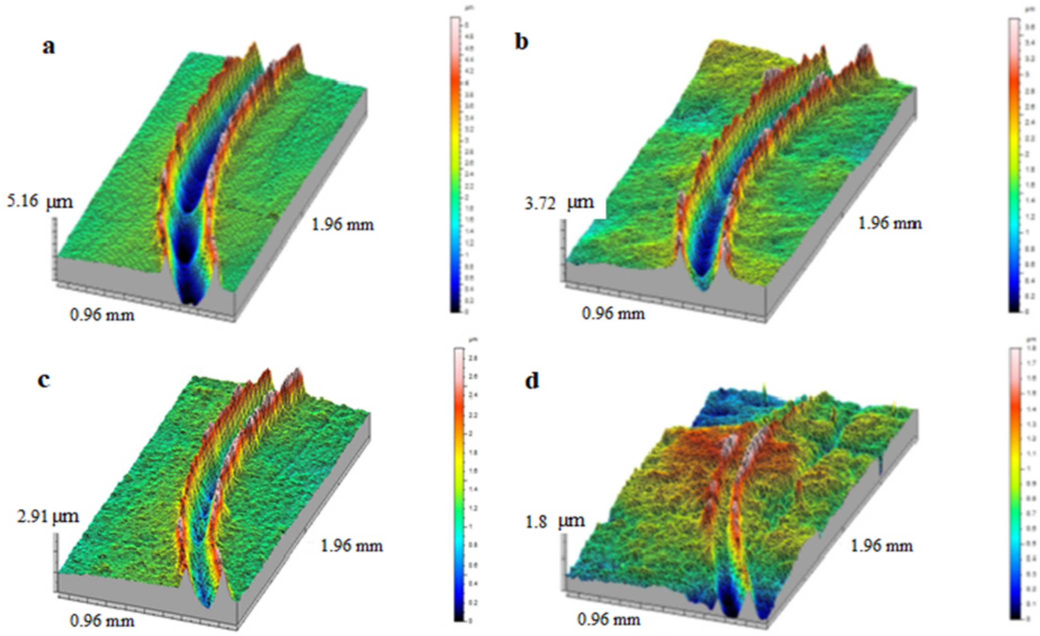

Figure 6. Wear tracks after tribological testing of samples in the initial state (a) and after an EPSH with a treatment time of 2s (b), 3s (c), 4s (d).

The results of the abrasive wear test were characterized by the weight loss of the samples after the test. Figure 7 shows the mass loss values of samples of steel mark 2 before and after the EPSH. A significant increase in wear resistance is observed on all samples subjected to EPSH.

It is seen that the loss of mass after the EPSH is less than the original samples, which indicates an increase in the resistance to abrasive wear of steel mark 2 after the EPSH. According to the mass loss data, the relative wear resistance of steel mark 2 was determined. After the EPSH, the resistance to abrasive wear increased by 2.5 - 3 times.

It is seen that the loss of mass after the EPSH is less than the original samples, which indicates an increase in the resistance to abrasive wear of steel mark 2 after

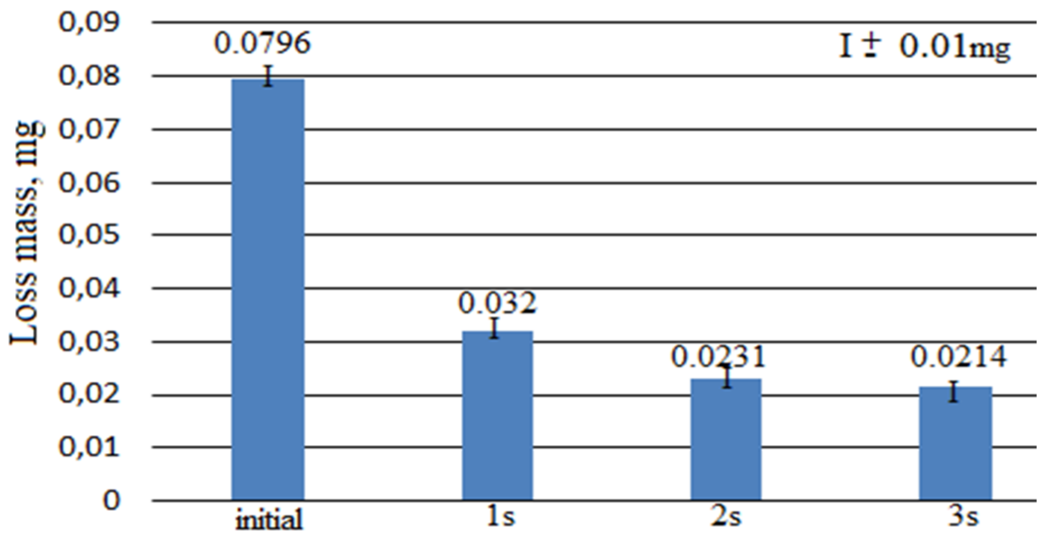

Figure 7. Resistance to abrasive wear of samples of steel mark 2.

the EPSH. According to the mass loss data, the relative wear resistance of steel mark 2 was determined. After the EPSH, the resistance to abrasive wear increased by 2.5 - 3 times.

Conclusion

Analyzing the results obtained in the work, we can draw the following main conclusions:

– the use of EPSH allows to obtain a fine-grained martensitic surface structure, which significantly affects the mechanical and tribological properties;

– at EPSH of steel mark 2 with a processing time of 1 - 4 s at a temperature of 860 ° C in an electrolyte containing an aqueous solution of 20% urea $(NH_2)_2CO$ and 20% sodium carbonate Na_2CO_3 a surface layer is formed on the surface of the samples under study α - Fe ferrite, cementite Fe_3C and iron oxide;

– Based on the results of microindentation and abrasive wear tests, it was shown that EPSH of steel mark 2 with a heating time of 1 - 4 s leads to an increase in wear resistance 2.5 - 3 times, and microhardness 1.8 - 2.4 times.

This paper presents the results of an experimental study of the effect of the technological parameters of the EPSH on the microhardness and tribological properties of the retaining of steel mark 2. In further studies, the laws governing the improvement of the tribological properties of steel mark 2 will be studied based on the results of the study of the structural phase state and the evolution of the fine structure of sample.

Acknowledgments

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