

Functional Surface Layer Strengthening and Wear Resistance Increasing of a Low Carbon Steel by Electrolytic-Plasma Processing

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The modified technology for strengthening the surface layer of low-carbon steel for machine components by electroplasma processing is proposed. This technology is to be used as an alternative carburizing method with subsequent hardening. The developed technology of strengthening by the proposed method is based on the author's invention. The parameters of this process are given, resulting in a thickness of the reinforced surface layer of 1000 μm to 1700 μm . An increase in microhardness of 1.5 to 2 times (compared to the initial state) was observed. With hardening, chemical modification of the material's surface layer occurs. The microstructure of the treated surface of the steel samples is characterised by a dark modified surface layer: a fine needle-like structure of martensitic origin under the dark layer transforms into an initial pearlite-ferritic structure. The advantage of strengthening based on the electrolytic plasma processing consists of low energy consumption at high hardening speeds and the possibility of local processing of surface areas, especially large parts of complex shapes. In addition, the proposed surface treatment method using electrolytic plasma processing (EPP) not only achieves a smooth surface but also improves the service qualities of the components, specifically wear resistance.

Keywords: low-carbon compound steel, strengthening, electrolytic plasma processing

Highlights

- The author's technology of strengthening the surface layer of low-carbon compound steel for details of machines by electrolytic plasma processing is developed.
- This technology is proposed as an alternative method of carburizing with subsequent hardening; the total thickness of the strengthened surface layer is 1000 μm to 1700 μm , and the microhardness of the strengthened area of a martensitic structure is 6500 MPa to 7200 MPa.
- The microstructure of the processed surface of steel samples is characterized by a dark modified surface layer. A fine needle-like structure of martensitic origin under the dark layer changes into the initial pearlite-ferritic structure.
- It is stated that in the structure of 18CrNi3Mo-Sh steel sample after electrolytic plasma processing, particles of residual cementite Fe₃C, α -phase based on Fe, Cr0.6 Fe1.4 - phase and Fe2.7 Mo0.8 Ni0.1 - phase appear, which confirms availability of martensite hardening.
- The advantage of strengthening based on the electrolytic plasma processing consists of low energy consumption at high hardening speeds and the possibility of local processing of surface areas, especially large parts of complex shapes.

0 INTRODUCTION

Mechanical engineering development is largely related to solving the tasks of increasing machines' reliability. To increase the operational reliability of machines, it is necessary to increase the endurance and durability of their parts [1] and [2] and reduce the risk of their failures [3] and [4]. This is achieved by various methods, including strengthening the operating surfaces of component parts and creating new technological processes of highly wear-resistant materials manufacturing [5] to [7]. Toughening the requirements concerning the microstructure and properties of the surface layers of machines' component parts requires new methods for their modification and strengthening [8]. Techniques involving the influence of concentrated energy flows

on the surface of component parts appeared to be widely used [9]. The most promising technology for surface strengthening of component parts is electrolytic plasma processing (EPP) [10]. EPP is an electrochemical heat treatment process and mass transfer (coating) on a component part (product) surface using a plasma jet. A plasma jet is a partially or fully ionized gas in combination with electric discharged phenomena at the boundary of the main electrode-water electrolyte solution at high capacities up to 1000 V [11].

With a gradual increase in the applied constant voltage, salt electrolysis occurs. According to Ohm's law, the current increases (section from 0 to A, Fig. 1). This area is characterized by scaling up the current with voltage increasing. Doing this, the electrolyte temperature also increases. This is a consequence of

the current passing through the electrolyte. When a certain voltage value is reached (from 100 V to 176 V), the electrolyte starts boiling on the surface of the cathode, and an active release of bubbles near the surface occurs (bubble boiling). At bubble boiling, the temperature of the component part is close to the steam point. When bubble boiling occurs around the active electrode, large current pulsations can be observed. Their amplitude is significantly reduced when the component part is heated above 470 °C.



Fig. 1. Volt-ampere characteristic of electrolyte plasma processing

Over a further increase in rectified voltage, film boiling appears (point A, Fig. 1), which is characterized by the disappearance of bubble boiling and a sharp drop in current because the resulting gas-steam jacket has a higher electrical resistance than a liquid electrolyte (section from A to B, Fig. 1). Since the gas-steam jacket is less electrically conductive, the main voltage drop occurs precisely where more heat is generated. The low-temperature plasma of a specific blue glow around the component part is formed due to a gas-steam jacket forming an electric current passing through it. The brighter the blue colour of plasma burning, the more ions it contains, including ion modifiers. An abnormal discharge is observed when increasing the voltage [12]. The principle of the technological process of strengthening based on the method of EPP is as follows. The cathode is made of 18CrNi3Mo-Sh steel (which corresponds to the standard 18HN3MA-III TU 3-850-80) for manufacturing roller cones. It is immersed in the electrolyte (10 % water solution Na₂CO₃) to 4 mm to 6 mm depth. The anode is stainless X10 CrNiTi 18-10 (corresponding to the standard 12X18H10T GOST 5949-75 Steel). It is in the form of a disk with a diameter of 50 mm and a thickness of 2 mm; 4 mm holes are drilled in the disk. Plasma arises between the cathode and liquid electrolyte. Negative ions ease excess electrons when passing through the holes of the anode of stainless X10 CrNiTi 18-10 steel. The

cations are entrained by the hydrodynamic flow of electrolyte and recombine at the cathode (the surface of the sample material of the drill bit). The conversion of electrical energy into heat occurs mainly in the plasma layer on the heated cathode surface. When being processed, cathode surfaces are cemented with carbon ions and hardened in an electrolyte in a short time.

The modification of the surfaces of machines' component parts with the EPP method contributes to the compositional restructuring of a surface layer that increases strengthening properties and wear resistance due to physical input (ions of high-temperature plasma, electrical discharge). The EPP method is currently used when modifying the surfaces of component parts of bent shafts, iron cylinders of diesel engines, circular saws [13], and others. The main advantages of the EPP method are the following: a complex profile strengthening, internal surfaces and cavities; no need for special preparation of surfaces before strengthening; ecological safety (use of special treatment facilities is not required). Analysis of existing technologies for low-carbon compound steel products hardening suggested that electrolytic plasma strengthening could be the most appropriate technology for the thermal hardening of component parts. The aim of this research is to identify experimentally the values of parameters for the technological process of electrolyte-plasma hardening of 18CrNi3Mo-Sh steel. The article presents the research methodology description, the obtained results, their discussion, conclusions, and acknowledgements.

1 METHODS AND EXPERIMENTAL APPROACH

A multiple-factor experiment has been fully implemented to select optimal electrolyte plasma processing conditions. Experiments of this type can localize the area necessary and present all possible independent variables' values. Heating a sample of a component part in depth is associated with an inhomogeneous temperature distribution in the volume of the material of a component part [14].

A drill bit (Fig. 2) provided by JSC Vostokmashzavod (VKMZ JSC) was selected to study the effectiveness of various methods of strengthening. Contact durability, abrasive and shock-abrasive wear resistance of the drill bit's component parts are provided by gas carburizing followed by hardening. Deformation, low carbon steel cracking, and high labour and energy intensity are the disadvantages of that heat processing. In order to eliminate the

disadvantages of the above treatment method, for EPP, the following samples from drill bit's component parts were used: 18CrNi3Mo-Sh (0.16 % to 0.18 % C; 3.3 % Ni; 0.9 % Cr; 0.51 % Mo; 0.44 % Mn; 0.34 % Si; 0.05 % Al; 0.008 % S; 0.012 % P; 0.015 % N; 0.01 % O; 0.01 % H) NSS 4543-71 [13]. Low-carbon, compound, heat-resistant steel of electroslag remelting can be used at $-70\text{ }^{\circ}\text{C}$ to $+450\text{ }^{\circ}\text{C}$. Carbon, chromium, molybdenum, manganese, and silicon are alloying constituents, increasing strengthening properties. Nickel provides strength and good toughness; molybdenum provides heat resistance to steel. Samples of $10\text{ mm} \times 10\text{ mm} \times 20\text{ mm}$ were cut out of roller cones with a diamond blade with a thickness of 1 mm, which was immersed in cooling fluid. The samples were made from roller cones in the initial condition and compared after thermal processing on the JSC "VKMZ" base. Two series of samples (3 repetitions in each) hardened according to the method given by JSC "VKMZ" and processed using the EPP method were examined.

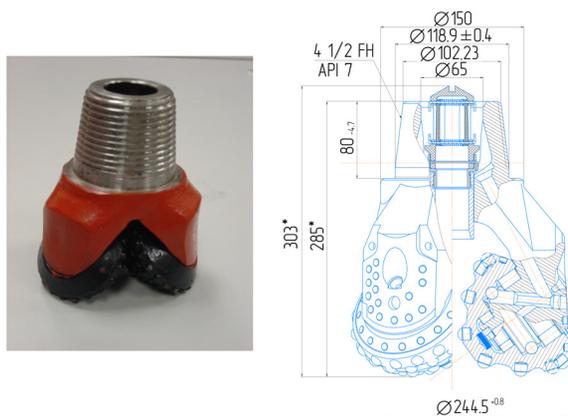


Fig. 2. Roller cone

At low cutting speeds ($n = 350\text{ rpm}$) and low load ($m = 250\text{ g}$), the sample does not experience significant deformations and thermal effects. The samples were first polished with chromium dioxide cement and then etched with 5 % alcoholic nitric acid solution to do a metallographic microanalysis.

Application investigations and mechanical testing were carried out in the Regional University Engineering Laboratory Irgetas and the research and manufacturing complex Machine industry of D. Serikbayev East Kazakhstan State Technical University [15]. Metallographic analysis was carried out using an Axioscop-2MAT microscope equipped with a Sony digital camera. Qualitative and quantitative phase analysis of the steel samples' structure was carried out using an X'Pert PRO X-ray

diffractometer of the PAN analytical firm, applying Cu-K α radiation. The electron images were made with the following equipment: a raster electron microscope JSM-6390LV "JEOL Ltd." (Japan) with an energy dispersive microanalysis system INCA Energy Penta FET X3 "OXFORD Instruments Analytical Limited". Microhardness measurements were carried out using a PMT-3 device, equipped with a diamond pyramid, with a load on the 2H indenter by 9450-76 GOST. The wear resistance of the samples was estimated by the loss of mass per unit time when the sample was being tested by attrition on the abrasive disc when sliding rubbing without lubricant [16]. To measure the mass of the samples, an electronic weighing unit of the VL-120 model with an accuracy of 0.1 mg was used.

2 RESULTS

The influence of technological and electrical parameter changes during electrolyte (10 % water solution of Na_2CO_3 calcined soda) on the strengthening quality was studied. It was experimentally proved that the considered factors of EPP modes affect the quality of the steel surface, which is strengthened. It should be noted that the main technological parameters, such as the thickness of strengthening, microhardness, and wear resistance of steel depend on the heating time, hardening time, the number of strengthening cycles by the EPP method and the electric current voltage [14]. Fig. 3 shows the initial microstructure of the material of the sample of a strengthened component part of 18CrNi3Mo-Sh steel. It is seen that a coarse-grained pearlite-ferritic microstructure characterizes the material of the sample.

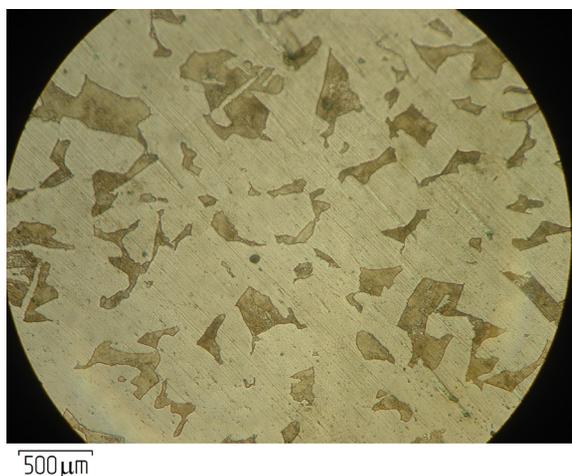


Fig. 3. The initial structure of the sample material of a component part of 18CrNi3Mo-Sh steel

In the course of the study, a series of searching experiments were carried out, involving EPP testing for sample processing to identify the logical modes of the process. The ranges of the numerical values of the parameters studied are presented in Table 1.

Table 1. Technological parameters for hardening of 18CrNi3Mo-Sh steel by the EPP method

Terms in the program of the experiment	Physical factors	Factor levels	
		min	max
X1	The heating time of a work piece from the plasma temperature [s]	1	15
X2	The hardening time in the flow of electrolyte [s]	1	10
X3	DC voltage [V]	180	260
X4	Number of cycles [-]	20	40

It was decided to switch to a three-factor experiment model and settle the number of processing cycles at 30 to conduct a comparative analysis of technological modes' influence on the material of the component part strengthening. To systematize the assessment of the EPP modes' effect on the quality indicators of steel of drill bits strengthening, depending on such main parameters as heating time $T_{heating}$ from ionized plasma and hardening time $T_{hardening}$ in the electrolyte flow, taking into account the direct current (DC) voltage U between the electrodes, we converted micrographs of material microstructure into a tabular form (Table 2). In one case, the images located along the edges lack the modes for optimal hardening of the material of a sample (left). In another case, the sample matrix burns out (right), transforming the hardening process in EPP into the process of ion transfer of metal from the anode to the strengthened cathode.

Table 2. EPP modes while steel drill bit strengthening

Parameters	Modes EPP processing		
	A	B	C
Heating time $t_{heating}$ [s]	2	4	15
Hardening time $t_{hardening}$ [s]	2	4	15
DC voltage U [V]	190	200	250

Fig. 4 shows the microsections of electrolyte-plasma processed steel to the depth of the hardened layer (cross-section). A comparison of microsections (cross-sectional cuts to the deep from left to right), presented in Fig. 4, makes it possible to note the features of the microstructure of the material obtained at different modes of EPP processing: when processing

at mode A, the influence of high-temperature plasma is observed (Fig. 4a, the dark area from left to right). The layer of coarse needle-like martensite smoothly transfers into the initial structure as it deepens into the material. When processing at mode B, there is also an area of high-temperature plasma exposure. Its depth is comparatively larger than at mode A and is approximately 200 μm deep (Fig. 4b, dark area from left to right). The availability of fine needle-like martensite with a smooth transition to the initial structure of the sample material is noted.

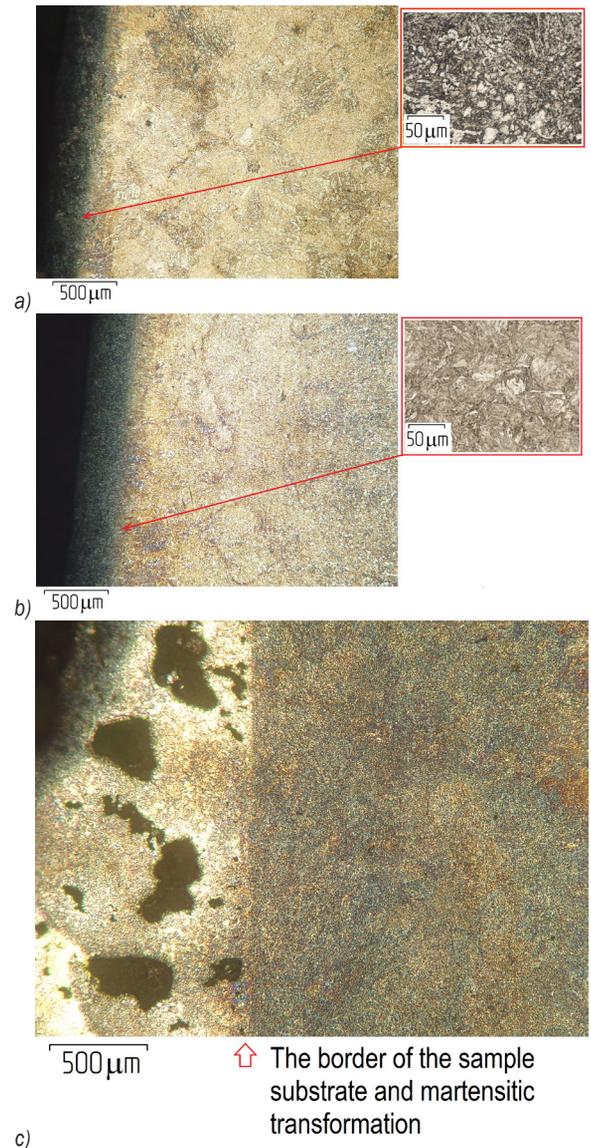


Fig. 4. Micro sections of the cross-section (to the depth of material) of electrolytic plasma processed steel

After 15 s of EPP processing (at mode C), a deposited layer of anode material (steel X10 CrNiTi

18-10) on the microsection occurs. The sample substrate's border and martensitic transformation are clearly visible (Fig. 4c, to the depth from left to right). Thus, images of microsections reveal:

- mode A lacks parameter values of EPP processing for the optimal hardening of the sample material (Fig. 4a),
- mode B burns out the material of a sample while EPP processing (Fig. 4b), transforming the hardening process into the process of ion transfer of metal from the anode to the strengthened cathode.

It is stated that electrolyte-plasma processing requires low power (within 3 kWh) when rapid motion occurs. The obtained data are used in [17].

In actual practice, a thermal exchange is a complex process. To facilitate its study and simplify the correlations obtained, the concept of elementary types of thermal exchange is introduced: experimentally determined thermocouples made by a natural thermal junction. Two thermocouples are installed in two layers of the sample workpiece at a depth of $h1$ and $h2$ from the heated surface (Fig. 5). Thermocouples are installed to control the temperature mode of the process to prevent the material's melting from being strengthened.

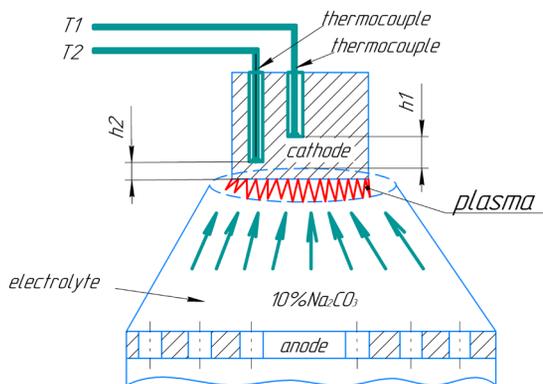


Fig. 5. The layout of thermal junctions in the surface layer of the sample when measuring the temperature in the process of electrolytic plasma heating

A 10 mm × 10 mm × 20 mm steel sample acts as a cathode. The temperature is measured by a thermocouple mounted in the cathode body. The thermocouple is a thermoelectric converter of the TXA type, conditional designation XA (K) according to GOST 3044-84. The measurement range is from minus 200 °C to plus 1000 °C. Admission class 1. The limits of permissible deviations are ±0,004× T when a measurement is in the range above plus 375 °C to plus

1350 °C. The sensitivity of the thermocouple is 40 μV/°C. The range of measured temperatures corresponds to the temperature of phase transformations from plus 840 °C to plus 860 °C.

Heating temperature is the main parameter of phase transformations for 18CrNi3Mo-Sh steel and is 860 °C [18]. At EPP, the bulk temperature increases to the hardening temperature of 860 °C, and the temperature of the ionized plasma overheats the surface. Its temperature exceeds 1100 °C. When ionized plasma is excited (plasma temperature ranging from 6000 K to 30000 K), a gas-vapor layer appears on the sample surface due to electrolyte dissociation [19]. The gas-vapor layer prevents the ingress of electrolyte on the overheated surface. It reduces the cooling rate, eliminating the formation of thermal (hardening) cracks. As a result, the operating durability of steel increases. Thus, the main factors determining the quality of steel strengthening at EPP have been experimentally stated. They are heating time, hardening time, and electric current voltage.

A mathematical model is developed to describe the change in the key parameter of the technological process of steel strengthening at the EPP method: the heating temperature T . The following regression equation expresses the logarithmic dependence of the temperature T on the main factors:

$$\ln(T) = C \cdot a \cdot \ln(t_{\text{heating}}) + D \cdot b \cdot \ln(U) + E \cdot d \cdot \ln(t_{\text{cooling}}), \quad (1)$$

where T is steel heating time [s], t_{heating} heating time [s], t_{cooling} cooling time in the electrolyte flow [s], U voltage [V], and $C = 4.5$, $D = 4.8$, $E = 18$, $a = 2$, $b = 1$, $c = 1$ the coefficients for Eq. (1) were found by using logarithm in the Deductor Studio Academic software.

Then Eq. (1), which describes the dependence of the heating temperature on the heating time, cooling time and voltage, was transformed to Eq. (2):

$$T = 4.5 \cdot t_{\text{heating}}^2 + 4.8 \cdot U - 18 \cdot t_{\text{cooling}}, \quad (2)$$

where T is steel heating time [s], t_{heating} heating time [s], t_{cooling} cooling time in the electrolyte flow [s], and U voltage [V] [20].

Experimentally determined optimal modes of steel hardening by the EPP method ($t_{\text{heating}} = 4$ s, $t_{\text{cooling}} = 4$ s, $U = 200$ V) have a good correlation with the established dependence, see Eq. (2).

A raster elemental analysis of the processed surface (Fig. 6) revealed chemical modification of the surface layer of the metal happening along with hardening during the electrolytic plasma heating of the sample [21].

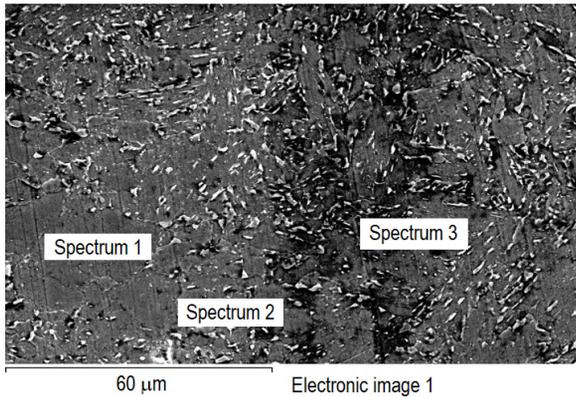


Fig. 6. Raster elemental analysis of the 18CrNi3Mo-Sh steel surface after EPP strengthening

Table 3. Qualitative and quantitative analysis of the sample processed [23]

No. of spectrum	Spectrum 1	Spectrum 2	Spectrum 3
C	0.56	0.69	0.71
Na	–	0.38	–
Si	–	–	0.31
Cr	0.66	0.66	0.54
Mn	0.48	–	0.54
Fe	95.73	95.75	95.48
Ni	2.57	2.52	2.42
Total	100.00	100.00	100.00

Temper increasing (Table 3), relative to the initial state, is because charged carbon ions [22], saturating the surface of the sample, are generated in the plasma layer of electrical gas discharge from the water solution of soda ash Na_2CO_3 when electric current flows. In water solution Na_2CO_3 , such ions as 2Na^+ , CO_3^{2-} , OH^- , H^+ occur. When passing through the holes in the anode, anions ease away excess electrons. The

Table 4. The phase composition of 18CrNi3Mo-Sh steel samples

Processing type	Phase composition	2Theta [deg]	d [Å]	h	k	l	l [%]	
After EPP	Initial	$\text{Cr}_{0.6}\text{Fe}_{1.4}$	44.677	2.0267	1	1	0	100
			65.028	1.4331	2	0	0	11.5
			82.344	1.1701	2	1	1	17.4
			63.845	1.456730	3	0	2	17
			67.048	1.3947	2	0	5	13
			61.739	1.5013	2	1	3	21
	$\text{Fe}_{2.7}\text{Mo}_{0.8}\text{Ni}_{0.1}$	96.981	1.0286	4	0	0	6	
		98.149	1.0195	4	0	1	1	
		99.472	1.0094	2	2	4	20	
		Fe_3C	44.750	2.0235	1	1	0	10.8
			65.108	1.4315	2	0	0	10
			82.444	1.1689	2	1	1	37
		99.064	1.0125	2	2	0	14	

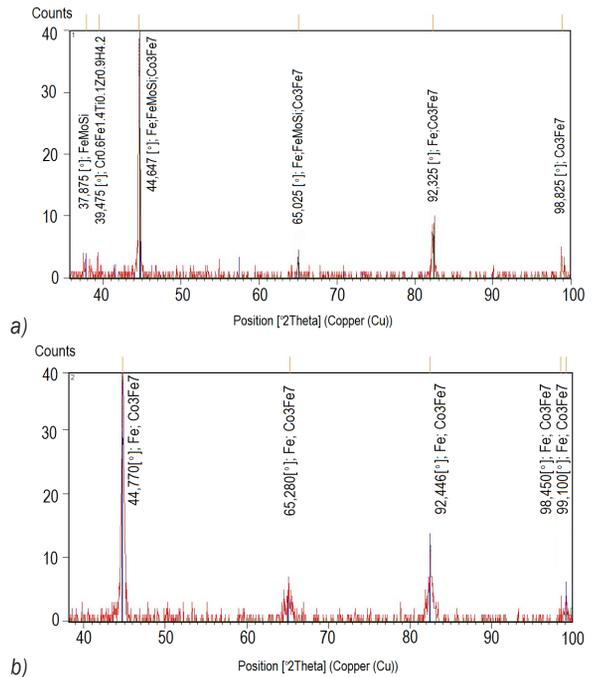


Fig. 7. X-ray diffraction pattern of 18CrNi3Mo-Sh steel; a) in the initial state, b) after EPP strengthening

cations are entrained by the hydrodynamic electrolyte flow and recombine on the cathode (the product's surface).

All the results in Table 3 are presented in weight fractions and expressed in percentage terms. X-ray structural analysis of 18CrNi3Mo-Sh steel samples in the state, as received (Fig. 7a), and after EPP strengthening according to mode B (Fig. 7b) revealed the α phase line, based on Fe, line $\text{Cr}_{0.6}\text{Fe}_{1.4}$ phase, and also the line $\text{Fe}_{2.7}\text{Mo}_{0.8}\text{Ni}_{0.1}$ phases.

3 DISCUSSION

After EPP, an expansion of intensity acceleration and diffraction lines can be observed (Fig. 7b) relative to the initial state (Fig. 7a). This indicates a stress state due to thermal exposure. The phase composition of samples of 18CrNi3Mo steel is presented in Table 4.

As is known from [24], while hardening, the martensitic (A → M) transformation is not fully completed, and the decay products are left in steel. Lines after EPP, a phase of Fe₃C residual cementite and α-phase based on Fe, line Cr_{0.6} Fe_{1.4} phase, line Fe_{2.7} Mo_{0.8} Ni_{0.1} phase indicate martensitic hardening. According to the Kurdjumow-Sachs theory [25], a martensitic crystal appears on the forming shear area. Stresses play a very important role. Sources of stress are heat gradients along the cross-section, the heterogeneity of chemical composition, structural imperfections, different spatial crystal orientations, the specific volumes of austenite and martensite, and various coefficients of phase linear extension. There is a fine-grained lamellar structure of a fine needle-like martensitic class on the cross-section cut of the electrolytic plasma-processed sample (Fig. 8). The microstructure to the processed surface (left) is characterized by a dark layer, which is the structural phase transformation formed under the influence of an ionized high plasma temperature [23]. The methods and methodology relating to Fig. 8 are mentioned in the patent specification [24].



Fig. 8. The microstructure of the cross section of 18CrNi3Mo-Sh steel after EPP strengthening (100 times increase)

It is established that electrolytic plasma processing makes it possible to obtain a strengthened layer of thickness from 1000 μm to 1700 μm (Fig. 9). Microhardness at the cross-section of the strengthened

area (martensitic structure) ranged from 6500 MPa to 7200 MPa.

The results of microhardness measurements on the surface of a heat-treated sample in a plant (VKMZ JSC) averaged 7000 MPa (Fig. 9). Microhardness decreases to the initial state and averages 3000 MPa when moving away from the processed surface [26]. The microrelief on the worn EPP surface of the steel sample after wear testing (Fig. 10a) indicates the least abrasive wear. With fine-grained martensite, a strong surface structure is formed that cannot be broken even when worn (during the experiment) by severe forms of abrasive wear, thereby preventing large areas of destruction.

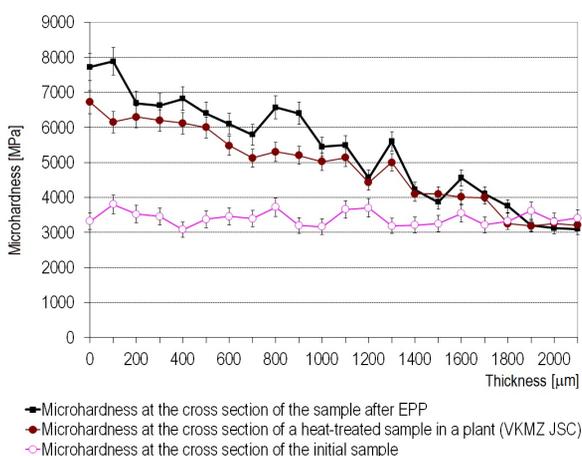


Fig. 9. The value of the microhardness of 18CrNi3Mo-Sh steel after EPP strengthening

The worst wear can be observed on the initial untreated steel sample (Fig. 10c). The pearlite-ferritic structure is easily abraded by abrasion, confirming the low wear resistance of thermally unprocessed steel. A steel sample that was thermally treated at JSC “VKMZ” wears out less than the initial sample (Fig. 10b). However, in terms of wear resistance, it is significantly inferior to the sample strengthened with the EPP method.

A sample after EPP strengthening has better wear resistance. As can be seen from Table 5, the steel resistance to abrasion increased significantly after EPP strengthening.

Table 5. Value of wear of 18CrNi3Mo-Sh steel samples

Processing type	Hv [MPa]	Wear [mg/h]
EPP strengthening	6817	54.4
Thermo processed at JSC “VKMZ”	6298	100.4
State as received	3271	150.0

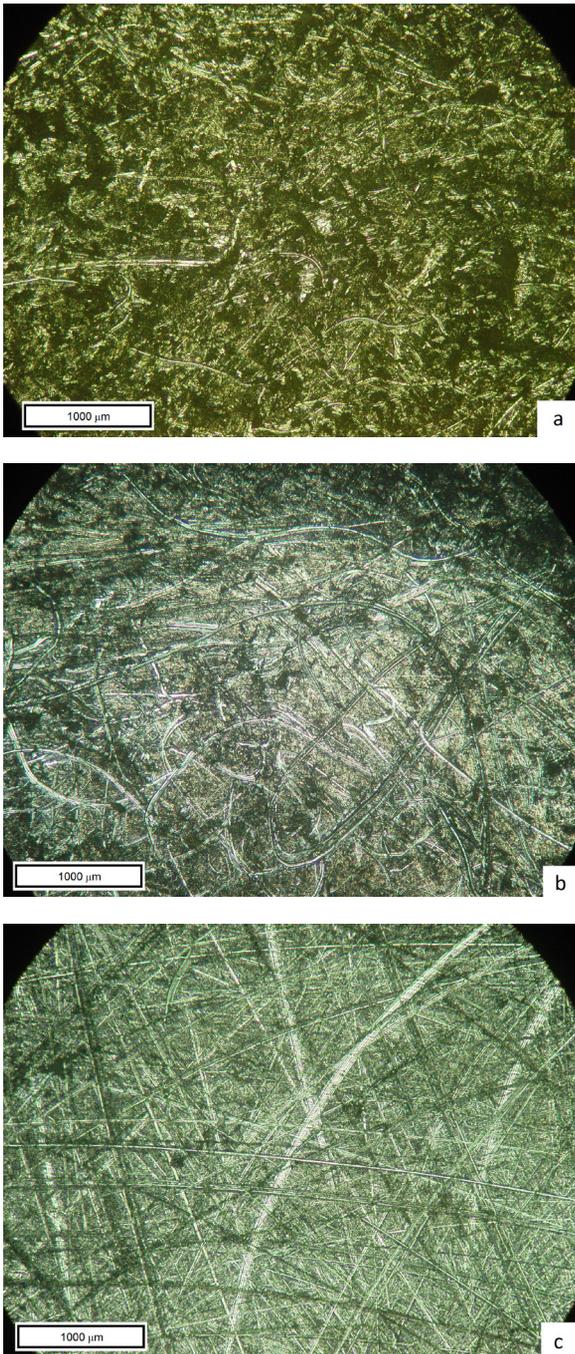


Fig. 10. Microrelief of 18CrNi3Mo-Sh steel samples after testing for abrasive wear resistance, 100 times increase; a) after EPP strengthening, b) thermo processed at VKMZ JSC, and c) initial state

Based on the data obtained, it can be concluded that electrolytic plasma processing significantly increases the wear resistance of drill bit component parts at low labour intensity, which reduces the cost of the product as a whole [27].

The practical significance of the obtained results of scientific research in the field of working surface hardening by the EPP method means that the developed technology applies to a wider range of parts. In particular, they include the vast majority of the articulated elements of machines that work as friction pairs. A special feature of the operating modes of articulated joints is the intense relative movement of the mated working surfaces, high contact load, unsatisfactory lubrication conditions of the friction surfaces due to the extrusion of the lubricant, the ingress of corrosive media into the mating zone, as well as abrasive particles. Such conditions are typical for loading and delivering vehicles when working in underground mines and open pit mining.

The experimental research was conducted to ensure the operability of parts on the example of the rotary mechanism hinge assembly of the underground loader Caterpillar R1300G confirmed the possibility of effective use of the developed technology to strengthen the surface parts based on the EPP method.

Thus, it has been stated by experiments that controlling EPP modes makes it possible to affect the quality of steel strengthening and obtain wear-resistant surfaces and significantly improve EPP productivity. This fact suggests the controllability of the EPP technological process and the possibility of practical implementation of the developed technology in the production

4 CONCLUSIONS

The effect of electrolytic plasma processing on phase transformations and structural changes and the properties of low-carbon and compound steels has been theoretically and experimentally studied. The microstructure of the processed surface of steel samples is characterized by a dark modified surface layer. A fine needle-like structure of martensitic origin under the dark layer changes into the initial pearlite-ferritic structure. The total thickness of the strengthened surface layer is 1000 μm to 1700 μm . The microhardness of the strengthened area of a martensitic structure is 6500 MPa to 7200 MPa. The structure of 18CrNi3Mo-Sh steel sample in the initial state is composed of particles of α -phase based on Fe, $\text{Cr}_{0.6}\text{Fe}_{1.4}$ phase, as well as $\text{Fe}_{2.7}\text{Mo}_{0.8}\text{Ni}_{0.1}$ phase after electrolytic plasma processing in the structure of 18CrNi3Mo-Sh steel samples there appear particles of residual cementite Fe_3C , α -phase based on Fe, $\text{Cr}_{0.6}\text{Fe}_{1.4}$ phase, $\text{Fe}_{2.7}\text{Mo}_{0.8}\text{Ni}_{0.1}$ phase, that testifies availability of martensite hardening. The most effective surface strengthening method of drill bit

parts is electrolytic plasma processing. The advantages of this method are low energy consumption at high speeds of hardening, the possibility of local surface processing of parts of complex shapes operating under conditions of intense loads and the simplicity of the process.

5 ACKNOWLEDGEMENTS

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