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Satbayev University

ХАБАРЛАРЫ

ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ НАУК
РЕСПУБЛИКИ КАЗАХСТАН
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Қазақстан Республикасы Ұлттық ғылым академиясы «ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы» ғылыми журналының Web of Science-тің жаңаланған нұсқасы Emerging Sources Citation Index-те индекстелуге қабылданғанын хабарлайды. Бұл индекстелу барысында Clarivate Analytics компаниясы журналды одан әрі the Science Citation Index Expanded, the Social Sciences Citation Index және the Arts & Humanities Citation Index-ке қабылдау мәселесін қарастыруда. Webof Science зерттеушілер, авторлар, баспашылар мен мекемелерге контент тереңдігі мен сапасын ұсынады. ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы Emerging Sources Citation Index-ке енуі біздің қоғамдастық үшін ең өзекті және беделді геология және техникалық ғылымдар бойынша контентке адалдығымызды білдіреді.

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CHANGES IN STRUCTURE AND PROPERTIES OF STRUCTURAL CHROMONICKEL STEELS AFTER PLASMA ELECTROLYTE HARDENING

Abstract: this work presents the research results of the impact of plasma electrolyte hardening (PEH) on the structure and properties of structural 40HN and 20H2N4A steels. Thermal surface hardening of steel parts is one of the most effective and efficient ways to increase the service life of loaded elements of machines and mechanisms, also to reduce their material consumption. In this case, only the most loaded working surface of the part is strengthened, leaving the core intact. The PEH process was carried out in an electrolyte from an aqueous solution containing 20% sodium carbonate and 10% urea. It has been established that a modified layer after PEH is formed with a thickness of 0.5-0.7 mm which consist of a hardened layer of fine-grained martensite and an intermediate layer of perlite and martensite. Microhardness increases by 2 times, wear resistance increases by 3 times after PEH. The conducted research showed the promise and feasibility of using the developed method to improve the operational properties of parts operating under friction and wear. This method, which consists in heating the part for 2 s, is recommended for hardening gears made of 40HN and 20H2N4A steels without additional heat treatment. PEH ensures the achievement of a technical and economic effect due to the use of simple equipment, not expensive aqueous solutions, reduction of processing time, and also as a result of increased wear resistance and microhardness of steels.

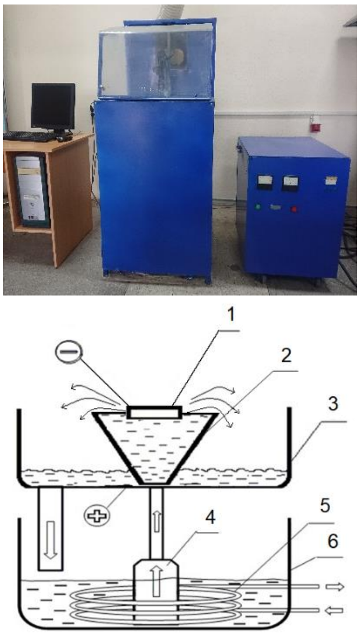
Key words: electrolyte-plasma hardening, 40HN steel, 20H2N4A steel, wear resistance, microhardness.

Introduction. It is necessary to create a property gradient in the hardened section of the part, providing for a solid and wear-resistant surface, a viscous but strong core and compressive stresses in the surface layer in order to ensure high cyclic durability, high wear resistance, and reduce sensitivity to stress concentrators [1,2]. The implementation of such a set of properties is possible when applying the method of surface heat treatment. Surface thermal hardening of steel parts is one of the most effective and efficient ways to increase the service life of loaded elements of machines and mechanisms, as well as reduce their material consumption. In this case, only the most loaded working surface of the part is strengthened, leaving the core intact. At that the progress in improving the quality of heat treatment (hardening) of the working surfaces of parts is associated with the use of concentrated energy sources: electron and laser beam, plasma jet. Such methods allow to achieve higher performance and hardening quality. Currently, high-frequency, gas-flame, plasma, electron-beam, and laser processing are widely used for surface thermal hardening of steel parts in industry [3]. Moreover, plasma surface hardening is recommended for all existing methods of hardening in its technical and economic indicators and the results of a comparative analysis. The main distinguishing feature of the plasma surface hardening method is the possibility of obtaining heating and cooling rates of materials that are several orders of magnitude higher than those typical of traditional hardening methods (furnace hardening, hardening, high-temperature hardening, gas-flame hardening, etc.), which helps to obtain hardened layers with previously unattainable levels operational properties [4,5]. The quenched-type structures formed in this case have high hardness, wear resistance, and fracture resistance.

In connection with above, the aim of this work is to study the impact of electrolyte-plasma hardening on the structure and properties of structural steels.

Research method. In accordance with the stated goal, 40HN and 20H2N4A steels were chosen as the object of research. The choice of research materials is justified by the fact that these steels are widely used for the manufacture of heavily loaded gears. The chemical composition of steels 40HN and 20H2N4A (in %): 40HN – C:0.36-0.44; Si:0.17-0.37; Mn: 0.5-0.8; Ni:1-1.4; S: up to 0.035; P: up to 0.035; Cr: 0.45-0.75; Cu: up to 0.3; 20H2N4A – C: 0.16-0.22; Si:0.17-0.37; Mn: 0.3-0.6; Ni:3.25-3.65; S: up to 0.035; P: up to 0.035; Cr:1.25-1.65; Cu: up to 0.3.

Electrolyte-plasma surface hardening of steel samples was carried out on the installation, which structurally consists of a power source, an electrolyte-plasma processing chamber and a personal computer [6-9]. General view and installation diagram of electrolyte-plasma processing is shown in Figure 1.



1 - processed sample (cathode), 2 - anode from stainless steel, 3 - pan, 4 - pump, 5 - heat exchanger, 6 - bath with electrolyte

Figure 1 – General view and scheme of electrolyte-plasma treatment installation

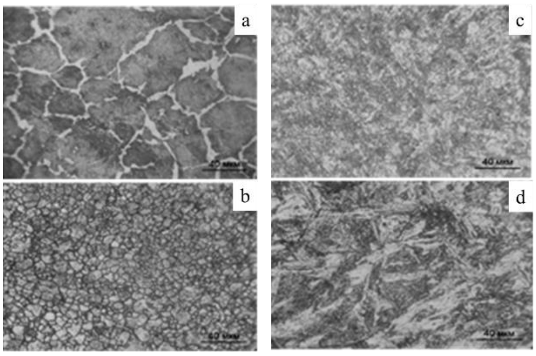
PEH steel samples are carried out as follows: the working bath is filled with electrolyte before starting work, then, the electrolyte using a pump mounted on the bottom of the working bath are entered in the electrolytic cell. In this case, the electrolyte exits through the hole of the conical septum in the form of a jet and fills the electrolytic cell and then the electrolyte is drained over the edge of the electrolytic cell into a tray, and back into the working bath. Thus, the electrolyte is in a circulating mode. The feed rate of the electrolyte (flow rate) is 4-7 l min. The flow rate of cooling running water into the heat exchanger is 3-6 l/min. The adopted parameters of electrolyte cooling allow maintaining the temperature in the range of 40-70°C when heating the samples to a temperature of 800-900°C.

The processed product is immersed in the electrolyte so that the processed zone of the products is 2-3 mm from the opening of the conical partition by using the device for fastening the processed products. At the same time, an electrolyte stream gives in to the treated zone through the hole of the cone-shaped septum, which is 10-15 mm lower than the height of the electrolytic cell. Then the anode is connected to the positive pole of the power source, and the workpiece - the cathode to its negative pole. A voltage of 320 V is supplied between the electrodes and the current density is 25-30 A/cm^2 for heating to the quenching temperature. An intensely luminous plasma layer is formed in the cathode region and the product heats up at a speed of 300-400 °C/s at such voltages. In this case, an abnormal arc discharge is formed between the electrodes, due to which the workpiece is quickly heated [10-13].

An NEOPHOT-21 optical microscope was used to study the general nature of the structure. The preparation of metallographic thin sections of steel samples was carried out according to the methods described in [16]. It should be noted that, for metallographic microanalysis, the polished sections, after polishing using a paste of chromium dioxide, were etched with a 4% alcohol solution of nitric acid. The morphology and elemental composition of the sample processed in electrolyte plasma was studied in the engineering laboratory on a JSM-6390LV scanning electron microscope - JEOL company (Japan), with the addition of an energy dispersive microanalysis INCA Energy of "OXFORD Instruments" company. X-ray diffraction studies of the samples were carried out by the well-known methods of X-ray diffraction analysis on X' PertPRO diffractometers.

The diffraction patterns were recorded using CuK_α-radiation ($\lambda = 2.2897$ A^0) at a voltage of 40 kV. The interpretation of the diffraction patterns was carried out manually using standard techniques and the PDF-4 database, and quantitative analysis was performed using the Powder Cell program [14]. The microhardness of steel samples was measured on the PMT-3 device in accordance with GOST 9450–76, with indenter loads P = 1 N and holding time at this load of 10 sec [15]. Tribological sliding friction tests were carried out on a tribometer in the laboratory of the TMSCCU of TSU using the standard “ball-disk” method according to the international standard ASTM G 133-95 and ASTM G 99. A ball with a diameter of 6.0 mm was used as a counterbody from a certified material - Al_2O_3. The experiments were carried out at a load of 1 N and a linear velocity of 2 cm/sec, a wear radius of 6 mm, the friction path was 25 m. The tribological characteristics of the modified layer were characterized by wear rate and friction coefficient [16].

Research results and discussion. The structural phase states of hardened surface layers of 20H2N4A and 40HN steels were researched. Metallographic analysis showed that in the initial state the structure of steel 20H2N4A consists of ferrite. Steel 40HN consists of ferrite and perlite. A cementite net is formed along the grain boundaries. It can be seen that the number of ferrite grains decreases, and the amount of perlite increases depending on the carbon concentration in these steels from the obtained data on the structure of steels in the initial state. The formation of a martensitic structure is observed in all steels after PEH (Figure 2).



a – 40HN initial state, b – 40HN after PEH of 2s,
c – 20H2N4A initial state,
d – 20H2N4A after PEH of 2s

Figure 2 – The microstructure of the surface of 20H2N4A and 40HN steels before and after PEH

The microstructure of the cross section of 40HN steel after plasma electrolyte hardening is shown in Figure 3. Figure 4 shows that the structure of the cross section of the steel is conventionally divided into 3 zones: zone 1 is observed on the surface – a hardened layer; zone 2 - a layer of thermal influence; zone 3 - matrix. The hardened layer is a homogeneous fine-grained martensitic structure. The formation of an inhomogeneous structure is observed with increasing depth - a zone of thermal influence, which is martensite and perlite. Then this zone passes to the ferrite-pearlite structure, i.e. to the matrix structure. The thickness of the modified layer is 1-1.2 mm.

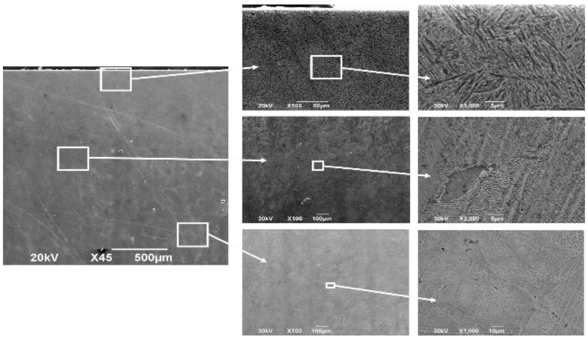


Figure 3 – The microstructure of the cross section of 40HN steel after PEH

Figure 4 shows the X-ray diffraction patterns of 40HN and $20H_2N_4A$ steels before and after PEH. X-ray diffraction analysis showed that in the initial state, that means only the α phase is present in the structure of 40HN steel after standard heat treatment. The diffraction patterns show a broadening of interference lines from the crystallographic plane after PEH (110). The broadening of the (110) interference line is associated with an increase in the dislocation density and the formation of martensite and is mainly determined by the tetragonality of martensite [17-19]. Small peaks of austenite steel are observed in the diffraction patterns of 20H2N4A. The formation of a surface layer of austenite in tone during surface hardening is quite natural. In addition, this will positively affect the wear resistance of these steels.

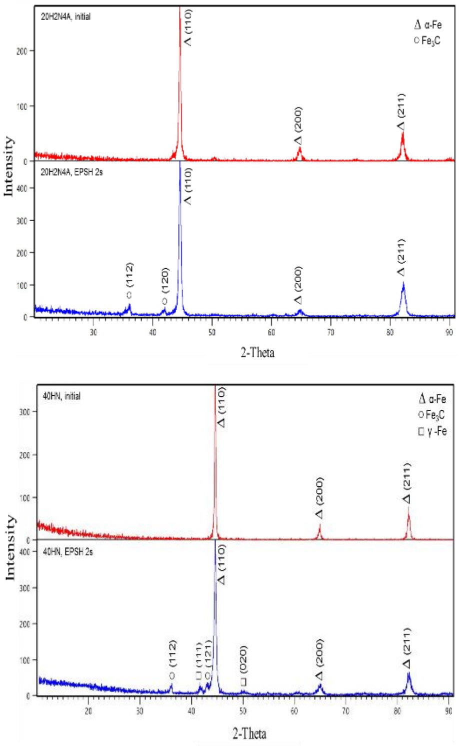


Figure 4 – Diffraction patterns samples of 20H2N4A and 40HN steels

Thus, the main advantage of PEH is the possibility of obtaining the surface of steels of the modified martensite layer. In this case, the basis of the material does not change, i.e. the part retains its viscous core. The formation of a modified layer of fine-grained martensite with residual austenite in the surface layers will positively affect on the operational properties of the parts.

The mechanism of parts wear during operation is complex and includes abrasive, adhesive and diffusion wear. In this regard, in this work wear resistance tests were carried out according to the "ball - disk" scheme. The tribological properties of the samples before and after PEH were investigated. Studies have shown that all processed samples show a significant reduction in the wear rate compared to the original sample, which indicates a significant increase in the steels wear resistance. The wear volume of the 40HN and 20H2N4A steel samples also decreased significantly, which indicates an increase in the wear resistance of 40HN and 20H2N4A steels after hardening.

The experimental curves of the dependence of the friction coefficient on the friction time of the initial and processed samples of 40HN steel are shown in Figure 5. The experiments were carried out according to the "ball-disk" scheme, the path length was 35 m, the speed was 2 cm/s, and the load was 5 N. Figure 6c shows that the coefficient of friction of steel samples 40HN before and after PEH with a heating duration of 1 and 2 seconds has approximately the same values. In this case, the coefficient of friction increases to 4.5-5.5 at the initial stage of friction, then decreases to 0.3-0.32 and remains at this level until the end of the friction. This is due to surface roughness. And the curve of the dependence of the coefficient of friction on the mean free path of samples treated by PEH with a heating duration of 3 sec has a different shape. It can be seen that the coefficient of friction gradually increases from 0.5 to 4. This is due to the unevenness of the surface layer in depth, i.e. the fine-grained martensitic structure smoothly transforms into a ferrite-pearlite structure.

Snapshots were taken of the contact zone of steel samples 20H2N4A by using a profilometer (Figure 6). We can say that the depth of the track of the specimen after PEH is much less compared to the untreated specimen by estimating the wear resistance of the samples based on the geometric parameters of the wear paths. The shape of the irregularities in general terms once again proves the improvement of the tribological characteristics of the test sample. It was found that PEH reduces the surface roughness despite of increasing the hardness of the surface layer, which leads to a decrease in the friction forces during operation, and hence to an increase in its durability.

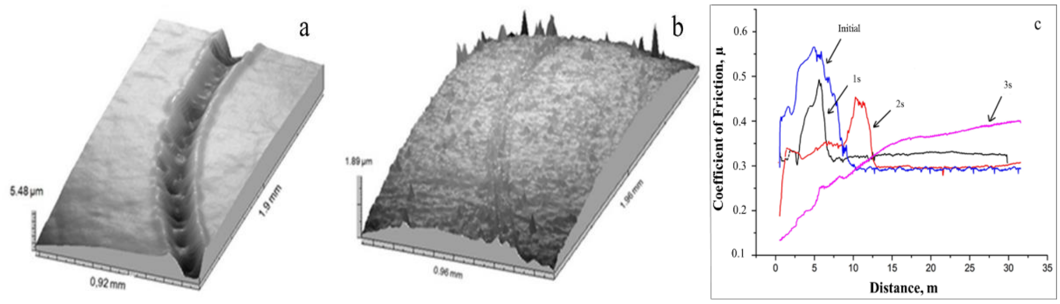


Figure 5 – Image of the wear track fragment of the initial (a), treated (b) sample and a graph of the change in the friction coefficient of 40HN steel (c)

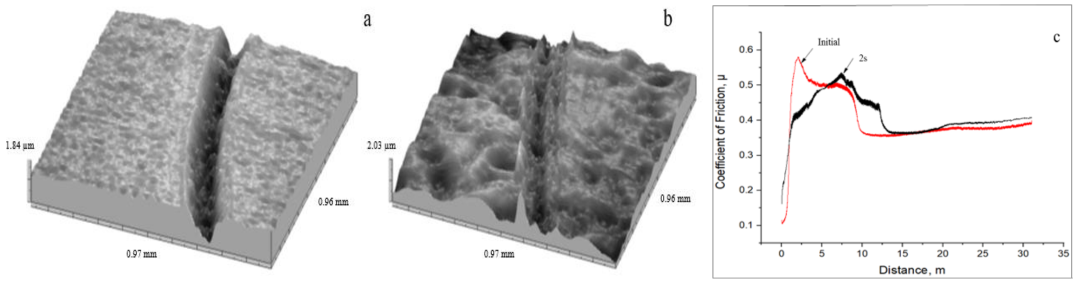


Figure 6 – Image of the wear track fragment of the initial (a), treated (b) sample and a graph of the change in the friction coefficient of 20H2N4A steel samples (c)

Changes in the microhardness of the surface layer of 40HN and 20H2N4A steels after PEH were studied. Studies have shown that the depending on the initial state microhardness of 40HN and 20H2N4A steels 2 times increases after PEH.

The research results of the mechanical and tribological characteristics of 40HN and 20H2N4A steels showed that the greatest increase in wear resistance and hardness compared to the initial ones is observed in 40HN steel. Perhaps this is due to the relatively high carbon content of this steel. And the smallest effect is observed in 20H2N4A steel.

Thus, the research results showed that the steels 20H2N4A and 40HN after PEH have high wear resistance, microhardness, and strength characteristics. A correct understanding of the hardening mechanisms of the surface layer of steels during PEH allows us to assume the structure of the layer and to predict the changes that can occur with it depending on the nature of alloying. In this regard, it is necessary to find out the basic mechanisms that provide high wear resistance of the surface layer of steels treated with PEH. In addition, the properties are determined by the nature of the structure formed in the process of PEH. In this regard, we conducted a systematic study of changes in the tribological and mechanical characteristics (wear rate, friction coefficient, microhardness and strength characteristics) of the surface layer of steels during PEH. In the previous sections we studied the structure, phase and elemental composition of steels before and after PEH to clarify the structural features that affect the microhardness and wear resistance of steels.

Table 1 shows data on the structure and tribomechanical characteristics of steels after PEH. The experimental data clearly illustrate the correlation between the structural and tribological characteristics of hardened samples.

Table 1 – Experimental data on the structure and tribomechanical characteristics of 20H2N4A and 40HN steels

Material	Characteristics				
	Phase composition	H_μ, MPa	f	j, 10^{-4} mm^3/Nm	V, μm^3
40HN initial	α- phase	2030	0.36	2.9	11.03
40HN after PEH, 3s	α'- phase, γ- phase, M_3C	4407	0.35	0.28	0.07
20H2N4A initial	α- phase	2460	0.4	2.39	3.4
20H2N4A after PEH, 2s	α'- phase, γ- phase	5420	0.4	1.17	0.21
Note: Hμ - microhardness; f - coefficient of friction; j - wear rate; V (μm^3) - the amount of wear during tests according to the ball-disk scheme					

The dependence of the tribological properties of the modified layers on the structural-phase states is clearly traced from the generalized data given in the table. The wear of the modified layer consisting of the α'-phase (martensite), the γ'-phase and Fe_3C carbide obtained after PEH is significantly lower than the layer consisting only of the α'-phase with excess particles of the γ 'phase obtained after PEH. Also, this layer, consisting of the α'-phase (martensite), the γ'-phase and Fe_3C carbide, showed the increasing the microhardness compared to the initial one. A special role is given to finely dispersed particles of the secondary carbide phases. It is known from [20-22] that the effects of increasing hardness and wear resistance are directly related to the size and number of dispersed inclusions that are formed during the PEH process. A special role is given to finely dispersed particles of the secondary carbide phases.

Thus, it was found that the surface layer of 40HN and 20H2N4A steels has a higher microhardness and wear resistance as a result of PEH. The increase in microhardness and wear resistance of steels 40HN and 20H2N4A after PEH with a heating duration of 2 is in particular associated with the formation of martensite, as well as the formation of a defective substructure. The resulting defectiveness is approached to the defectiveness of the grain boundaries. Since, plasma electrolyte hardening is carried out under conditions of excessive excitation of the metal surface and subsurface layers.

Conclusion.

- It has been established that a modified layer with a thickness of 0.5-0.7 mm with high hardness and wear resistance, consisting of a hardened layer of fine-grained martensite, an intermediate layer of perlite and martensite is formed after PEH .

- It has been established that microhardness and wear resistance of steels 40HN and 20H2N4A increase after PEH. Microhardness increases by 2 times, wear resistance increases by 3 times after PEH. The high wear resistance of steels after PEH is possibly associated with the formation of fragmented martensite with residual austenite.

- It has been determined that a modified martensite layer with residual austenite is formed in low-carbon steels, and martensite with residual austenite and cementite are formed in medium-carbon steels after PEH. In this case, the basis of the material, consisting of a ferrite or ferrite-pearlite structure, does not change, i.e. the part retains its viscous core. The presence of residual austenite and cementite in the surface layers positively affects the operational properties of the parts.

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ЭЛЕКТРОЛИТТІК-ПЛАЗМАЛЫҚ БЕРІКТЕНДІРУДЕН КЕЙІНГІ КОНСТРУКЦИЯЛЫҚ ХРОМОНИКЕЛЬДІ БОЛАТТАРДЫҢ ҚҰРЫЛЫМЫ МЕН ҚАСИЕТТЕРІНІҢ ӨЗГЕРУІ

Аннотация: бұл жұмыста 40ХН және 20Х2Н4А конструкциялық болаттардың құрылымы мен қасиеттеріне электролитті-плазмалық беріктендірудің (ЭПБ) әсерін зерттеу нәтижелері ұсынылған. Болат бөлшектерді беттік термиялық беріктендіру машиналар мен механизмдердің жүктелген элементтерінің жұмыс ресурсын ұлғайтудың, сондай-ақ олардың материал сыйымдылығын төмендетудің ең тиімді және ұтымды тәсілдерінің бірі болып табылады. Сонымен қатар, бөліктің ең көп жүктелген жұмыс беті ғана күшейтіліп, өзегі өзгеріссіз қалады. ЭПБ процесі 20% натрий карбонаты мен 10% карбамиді бар сулы ерітіндідегі электролитте жүргізілді. ЭПБ-ден кейін қалыңдығы 0,5-0,7 мм модификацияланған қабат пайда болды, ол ұсақ түйіршікті мартенситтің қатайтылған қабатынан және перлит пен мартенситтің аралық қабатынан тұратындығы анықталды. ЭПБ-дан кейін микроқаттылық 2 есе артады, тозуға төзімділік 3 есе артады. Жүргізілген зерттеулер үйкеліс пен тозу жағдайында жұмыс істейтін бөлшектердің пайдалану қасиеттерін жақсарту үшін әзірленген әдісті қолданудың болашағы мен орындылығын көрсетті. Бөлікті 2 с ішінде қыздырудан тұратын бұл әдіс, қосымша термиялық өңдеусіз 40ХН және 20Х2Н4А болаттан жасалған тісті доңғалақтар берілістерді қатайту үшін ұсынылады. ЭПБ қарапайым жабдықты, арзан су ерітінділерін пайдалану, өңдеу уақытын қысқарту есебінен, сондай-ақ болаттардың тозуға төзімділігін және микроқаттылығын арттыру есебінен техникалық-экономикалық тиімділікке қол жеткізуді қамтамасыз етеді.

Түйін сөздер: электролиттік-плазмалық беріктендіру, болат 40ХН, болат 20Х2Н4А, тозуға төзімділік, микроқақтылық.

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ИЗМЕНЕНИЕ СТРУКТУРЫ И СВОЙСТВ КОНСТРУКЦИОННЫХ ХРОМО-НИКЕЛЕВЫХ СТАЛЕЙ ПОСЛЕ ЭЛЕКТРОЛИТНО-ПЛАЗМЕННОГО УПРОЧНЕНИЯ

Аннотация: в данной работе представлены результаты исследования влияния электролитно-плазменного упрочнения (ЭПУ) на структуру и свойства конструкционных сталей 40ХН и 20Х2Н4А. Поверхностное термическое упрочнение стальных деталей является одним из наиболее эффективных и действенных способов увеличения ресурса работы нагруженных элементов машин и механизмов, а также снижения их материалоемкости. При этом упрочняют только наиболее нагруженную рабочую поверхность детали, оставляя нетронутой сердцевину. Процесс ЭПУ проводили в электролите из водного раствора, содержащего 20% карбоната натрия и 10% карбамида. Установлено, что после ЭПУ формируется модифицированный слой толщиной 0,5-0,7 мм, состоящий из упрочненного слоя мелкозернистого мартенсита и промежуточного слоя перлита и мартенсита. После ЭПУ микротвердость увеличивается в 2 раза, износостойкость увеличивается в 3 раза. Проведенные исследования показали перспективность и целесообразность использования разработанного метода для улучшения эксплуатационных свойств деталей, работающих в условиях трения и износа. Этот метод, заключающийся в нагреве детали в течение 2 с, рекомендуется для закалки зубчатых колес из сталей 40ХН и 20Х2Н4А без дополнительной термической обработки. ЭПУ обеспечивает достижение технико-экономического эффекта за счет использования простого оборудования, недорогих водных растворов, сокращения времени обработки, а также за счет повышения износостойкости и микротвердости сталей.

Ключевые слова: электролитно-плазменное упрочнение, сталь 40ХН, сталь 20Х2Н4А, износостойкость, микротвердость.

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