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Effect of the Cathode Spots of a Vacuum Arc on the Properties of the Surface Layer of Structural Materials

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Abstract—The application of vacuum-arc discharge provides great opportunities for metallic-surface cleaning and the development of products with the required functional surface properties. The effect of vacuum-arc treatment on the roughness of the surface, its mechanical properties, and the structure and composition of the surface layer is studied. The processing and cleaning of the surface of steel samples by cathode spots of a vacuum-arc discharge form a structurally changed layer with a thickness of up to 10 μm and a microhardness exceeding the initial one by 1.4–1.5 times. The deposition of 20% solution of KOH and NaOH alkalis (substances which reduce the electronic work function of the scale surface) on the processed steel surface reduces the specific power inputs of vacuum-arc cleaning by a factor of 1.5–2.4. The depletion of the surface layer of low-grade steels by impurity elements enhances its anticorrosion properties.

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INTRODUCTION

The technologies of vacuum-arc cleaning of a metal surface, which is a new area in metal processing, are finding wider application and are needed for the cleaning of rolled and piece goods: spindles, disks, turbine blades, etc. The issues of optimization of the vacuum-arc discharge parameters in cleaning various products that are related to their geometry, surface-layer composition, and the very metal-roll material base itself require further study. A reduction in the energy consumption during processing and a change in the surface properties of the base is of special significance. The process complex occurs in the cathode spot at a temperature of 4000–5000 K for an existence time of 10^{-4} s which is accompanied by the intense effect of particles and formations taking part in this process on the surface cathode layers [1, 2]. The control of quickly moving (10^4 m/s) cathode spots which arise preliminary on areas with different formations on the cathode-product surface makes it possible to form the technological effect of the vacuum-arc discharge—cleaning and processing of the metallic surface and provides great opportunities for the development of products with programmable functional surface properties. Therefore, there is a need to study the effect of vacuum-arc treatment on the roughness of the surface, its mechanical properties, and the structure and composition of the surface layer that is the aim of the present paper.

EXPERIMENTAL

The vacuum-arc discharge effect on the surface of rolled products was studied in the vacuum assembly represented in Fig. 1. The base of the assembly is a vacuum cylindrical stainless steel chamber 620 mm in diameter and 2400 mm in length, which makes it possible to process samples up to 800 mm in length and up to 200 mm in width. Figure 2 represents an electrode cleaning system for sample bands, which is composed of a carriage onto which the sample of the band (a cathode and anode unit) cleaned is placed. Movement of the carriage is implemented by an electomechanical drive with controlled speed. The carriage with the test band, the processing side of which is directed to the anode unit, is mounted into the vacuum chamber. Cleaning of the steel product by vacuum-arc discharge is performed at a residual pressure in the vacuum chamber of no more than 6–7 Pa. Voltage was supplied from a VDU-504 power supply (Rus-

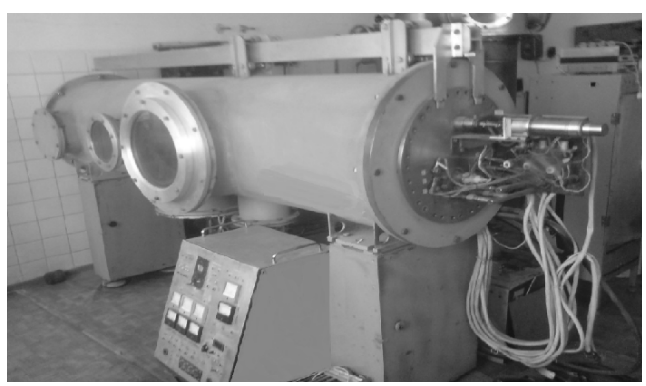

Fig. 1. Laboratory assembly for vacuum-arc cleaning.

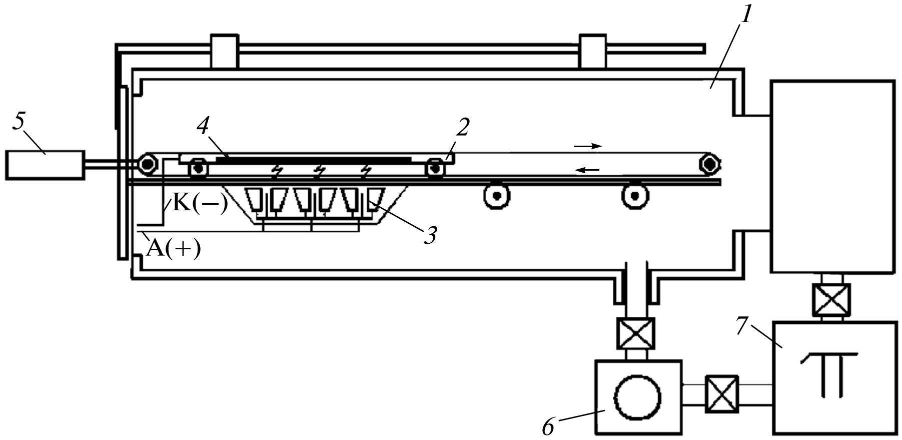

Fig. 2. Flowchart of the vacuum assembly for arc cleaning strip steel in vacuum: (*1*) vacuum chamber; (*2*) carriage; (*3*) anode; (*4*) cathode; (*5*) electric motor; (*6*) mechanical pump for low vacuum; and (*7*) oil-vapor pump.

sia) to the electrodes. The actuator is turned on and drives the carriage with the sample via a screw mechanism. The system of igniting electrodes is actuated and initiates the arc discharge. Upon movement of the sample over the anode unit during the vacuum-arc discharge the cathode spots which move along the sample-cathode surface perform its cleaning. To study the vacuum-arc treatment of steel strip and rolled products with cylindrical shape—bar and wire, we developed an electrode system of based on a cylindrical coaxial electrode system including a tubular screen with a coaxial-placed anode unit and the system with the sample. The steel product-cathode to be processed travels through the treatment zone formed by the anode system.

The movement speed of the operating area of the steel product through the arc treatment zone, on the one hand, is determined by technical rationality and, on the other hand, determines the optimum discharge current providing complete coating of the processed product area by cathode spots of arc discharge, i.e., its cleaning. At the same time, the temperature of the processed area during the arc effect must remain within limits not exceeding some value at which the quickly moving cathode spots are generated. The discharge current determines the number of cathode spots (around 5 A current per one cathode spot) and the speed of metallic surface processing.

The produced metal-roll, strip, rod, wire, tubes, and other products have roll scale, rust, and other contaminants on the surface. Their thickness, compositions, and structure generally affect the process and energy of electric-arc cleaning in vacuum. The variety of the composition of the scale and its electrophysical characteristics lead to substantial differences in processes proceeding in the cathode spot in the area of the plasma effect with the cathode surface and, as a whole, the vacuum-arc discharge parameters. This conditions the necessity for determination of the optimum discharge parameters and in studying the character of the arc effect on the surface and a change in its properties for various rolled products and, first of all, hot-rolled and cold-rolled products (the composition of the surface layer of hot-rolled products differs from that of cold-rolled products).

The test subjects for optimization of the arc-discharge parameters during rolled-surface cleaning were hot-rolled band samples of grade II KP steel with a cross section of 4.5 × 40 mm, grade 10 steel with a cross section of 5 × 40 mm, a hot-rolled strip sample of grade Kh18N10T steel with a cross section of 0.8 × 40 mm, a cold-rolled strip sample of grade 30 steel with a cross section of 0.8 × 18 mm, and rod samples of grades 65G, 12Kh18N10T, and R6M5 steel with a diameter of 6–8 mm. The rate of sample-surface cleaning was determined as the ratio of the cleaned surface area to the cleaning time. The choice of the mentioned samples for investigation is due to the wide range of application of these materials in the engineering industry and other trades and the necessity of presale surface cleaning of rust, oxides, lubricant, and other contaminants on their surface. The quality of surface cleaning (scale removal) was estimated visually. The vacuum-arc cleaning of the surface of rolled products was studied in a discharge current range of 100–500 A. The scale thickness was determined as a result of directly measuring the sample thickness using a micrometer. A number of experiments were carried out with preliminary mechanical loosening (cracking) of the scale. To study the effect of the character of the cathode spot on a metallic surface in the case of the presence of substances promoting more effective plasma generation in the cathode spot, we chose KOH and NaOH which are characterized by a low metal work function (2.22 and 2.35 eV) with close values of the evaporation energy (1.4 and 1.48 eV) and boiling temperature (1570 and 1660 K, respectively). An aqueous solution of these substances was applied preliminarily onto the processed sample surface. The sample surface roughness was measured using a Mitutoyo Surftest 401 profilometer (Japan) in the direction of the normal section of the profile at a base length of 0.8 mm. The microhardness was measured by a PMT-3 microhardness testing instrument (Russia) at a total microscope magnification of 487× with a standard load of 1.96 N using a tetrahedral pyramid with a vertex angle of 136° and, if required, with a load of 0.049, 0.098, 0.196, 0.49, and 0.98 N. The elemental composition of the surface layer of samples was determined by Auger spectrometry. The sensitivity of the detection of sample impurity atoms by the given spectrometer is ~0.03 at %. The electron-beam energy varied from 1.3 to 30 atomic layers.

OPTIMIZATION OF THE VACUUM-ARC CLEANING MODE AND POWER CONSUMPTION

The surface cleaning of conductive materials is implemented by vacuum-arc discharge with rapidly moving cathode spots. Figure 3 shows a photograph of the surface area of a cleaned hot-rolled strip sample with a width of 50 mm of grade Kh18N10T steel (area *1* is the original surface of the cleaned sample). The surface subjected to the arc discharge effect (area *2*) has no scale traces at all. The front of the arc effect (area *3* is the cleaning area) shows traces of cathode spot movement in the direction of the area not cleaned of scale. The cathode spots of the vacuum arc appear mainly at scale and other surface formations and remain there up to complete removal. Optimization of the energy parameters of the arc discharge is the basis of the formation of the technological effect of cleaning.

As samples subjected to cleaning, we used hot-rolled bands of grade II KP steel with a cross section of 4.5 × 40 mm and grade 10 steel with a cross section of 5 × 40 mm, a hot-rolled strip of grade Kh18N10T steel with a cross section of 0.8 × 40 mm, a cold-rolled strip of grade 30 steel with a cross section of 0.8 × 18 mm, and a 6–8 mm rod of grades 65G, 12Kh18N10T, and R6M5 steels. The sample length was up to 800 mm. Cleaning was performed at a residual pressure in the chamber of 6.7 Pa at a rate of 0.025 m/s. The product subjected to cleaning was a cathode; an electrode formed in the shape of a ring 35 mm in diameter served as the anode. The optimum discharge currents during sample-surface cleaning were in the following arc-current ranges of 250–430 A for the hot-rolled loosened band of grade II KP steel, 400–500 A for the hot-rolled band of grade 10 steel and the hot-rolled strip of grade Kh18N10T steel, 150–260 A for the cold-rolled strip of grade 30 steel, 150–300 A for the normal rod of grade 65G steel, 40–110 A for the loosened rod of grade 65G steel, 160–240 A for the rod of grade 12Kh18N10T steel, 80–170 A for the normal rod of grade R65M steel, and 80–120 A for the loosened rod of grade R65M steel.

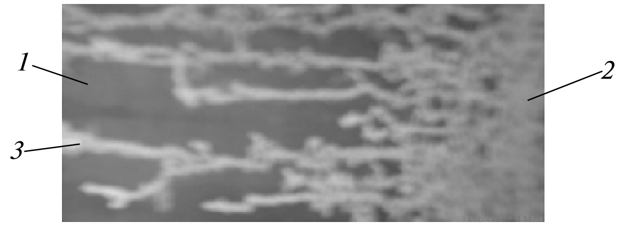

Fig. 3. Photograph of the front surface part of the cleaned hot-rolled grade Kh18N10T steel roll with a width of 50 mm: (*1*) initial surface of the cleaned sample; (*2*) surface subjected to the arc discharge effect; and (*3*) traces of cathode spots travelling in the direction of the part uncleaned from scale.

The following criteria found determination of the optimum arc discharge current for each sample. On the one hand, the discharge current must provide stable charge ignition during sample surface cleaning in the mentioned electrode system; and, on the other hand, must implement complete coverage of the processed surface by cathode spots and provide its cleaning at the given speed of sample transport through the operating area formed by the cathode–anode system.

The performed investigations showed that the mentioned cleaning parameters are attained at the following optimum arc-discharge currents: 10–430 A for the band of grade 10 steel, 490–500 A for the hot-rolled strip of grade 12Kh18N10T steel, 185–190 A for the cold-rolled strip of grade 30 steel, 650–700 A for the normal rod of grade 65G steel, 195–200 A for the rod of grade 12Kh18N10T steel, and 145–150 A for the normal rod of grade R6M5 steel. Data on determination of power consumption are listed in Table 1.

From the table it is evident that the power consumption during sample cleaning for the same steel grade are proportional to the scale thickness. In addition, the preliminary cracking of the scale of the hot-rolled metal by a scalebreaker significantly decreases the specific power consumption for cleaning one square meter and may serve as a significant reserve for enhancing the performance of vacuum-arc cleaning. It is found that the discharge parameters during cleaning and the specific power consumption substantially affect the roughness class of the treated surface. Figure 4 represents the roughness class as a function of the specific charge.

The surface roughness varies insignificantly at a low density of released energy (specific charge of 8–10 C/cm^2) and is practically within limits characteristic for the initial roughness class. The roughness increases at an energy density of 10–15 C/cm^2, and the roughness reduces to the sixth class. The roughness class substantially decreases at an energy density of more than 18 C/cm^2 (investigations were carried out up to a density of 26 C/cm^2). Thus, we observe the dependence between the arc-discharge parameters

Table 1. Energy consumption upon steel cleaning by arc discharge

Name of rolled product	Scale thickness, μm	Energy inputs, kW/h
Hot-rolled strip of grade 12Kh1810T steel	2	0.67
Cold-rolled strip of grade 30 steel	1	0.50
Rod of grade 65G steel	40	7.70
Rod of grade 65G steel	2	0.47
Rod of grade 65G and 12Kh1810T steel	6	1.90
Rod of grade R65M5 steel	10	1.30
Rod of grade R6M5 steel	5	0.85

Table 2. Chemical composition of steels, %

Material	C	Si	Mn	Ni	S	P	Cr	Ti	Cu
08X18H10	to 0.8	to 0.8	to 0.2	9–11	to 0.02	to 0.035	17–19	to 0.5	to 0.3
X8Cr17	0.12	0.75	1.00	0.04	0.03	0.50	16–18	–	–

during cleaning and, as a result, the specific power consumption for surface treatment.

Investigation of the surface roughness and the cleaning rate as a function of the KOH and NaOH concentration on a metallic surface showed that the arc discharge was more stable because the ionization of impurity particles evaporating from the cleaned product surface depended exponentially on the electron work function and the atomic ionization potential. Correspondingly, it is mainly these elements that take part in plasma formation in the cathode spots. Movement of the cathode spots along uncleaned surface areas (the probability of their location on a cleaned surface is significantly less than on a contaminated one in which atoms and alkali metals are incorporated) promotes a reduce in the integrated temperature of the part cleaned and a decrease in the surface roughness and its erosion because the main role in the formation of the plasma-forming medium is played by alkali metals and their compounds.

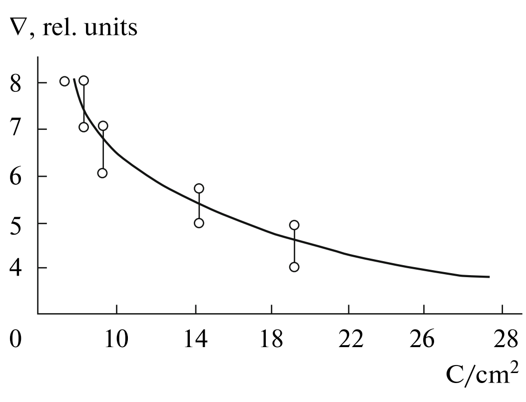

Fig. 4. Roughness class as a function of the specific charge of the strip of grade 08KP steel.

The sample roughness was measured after scale removal by the Mitutoyo Surftest 401 profilometer. The roughness abruptly decreases with increasing concentration, attaining at the minimum (10–15%) a value approximately less by a factor of 2.5 in comparison with the zero concentration. The roughness weakly increases with a further increase in the concentration. The cleaning-rate maximum is more clearly expressed at 10% concentration of alkali solution, which is approximately 1.8 times higher than the corresponding value beyond it. The voltage at the discharge gap is 1.5–2.0 V lower upon the presence of KOH and has a minimum at 10% KOH.

MICROHARDNESS CHANGE AFTER VACUUM-ARC TREATMENT

The effect of vacuum-arc treatment on the microhardness of the treated surface was studied on samples of grade 08Kh18N10 and Kh8Cr17 steels. The chemical composition of grade 08Kh18N10 and Kh8Cr17 steels are listed in Table 2.

The microhardness of the initial samples with scale was measured preliminarily and then after cleaning by vacuum-arc discharge. The surface microhardness of the mentioned steels increases by 20–30% after vacuum-arc cleaning. The microhardness of the samples of grade 08KP steel was measured under loads of 0.049, 0.098, 0.196, 0.49, and 0.98 N (5, 10, 20, 50, and 100 g). The microhardness dependence of the sample surface on the load before the vacuum-arc discharge effect and being cleaned at various modes of arc discharge is presented in Fig. 5.

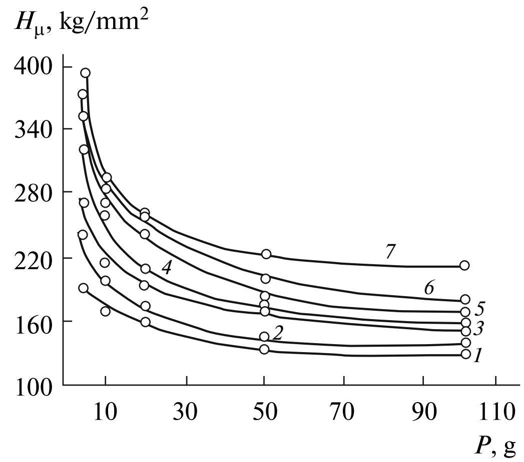

Fig. 5. Microhardness as a function of the load of the initial sample (P is the load on the indenter, g) and after cleaning in various processing modes; the cleaning parameter is the specific charge: (*1*) initial sample; (*2*) 7; (*3*) 12.3; (*4*) 14.0; (*5*) 15.8; (*6*) 19.8; and (*7*) 2/cm^2.

It follows from the figure that the initial sample-surface microhardness (curve *1*) changes from 192 kg/mm^2 at a load of 5 g up to 131 kg/mm^2 at a load of 100 g. Significant strengthening of the sample surface occurs as a result of vacuum-arc cleaning (Fig. 5). For example, the microhardness increases already at a load of 100 g from 131 (initial sample microhardness) to 215 kg/mm^2 (microhardness of samples cleaned by vacuum-arc discharge in the "hard" mode (specific charge of 25 C/cm^2, curve *7*)), i.e., by 65%, and by double at a load of 5 g. An increase in the microhardness corresponds to 8–17% at a load of 100 g and 25–41% at a load of 5 g in the "soft" mode (specific charge of 8–10 C/cm^2, curves *2* and *3*)). The energy release decreases during product surface cleaning in the "soft" ignition mode of vacuum arc, and, as a result, the increase in microhardness turns out to be less.

INVESTIGATION OF THE COMPOSITION OF THE SURFACE LAYER

The investigation of the vacuum-arc discharge effect on the physical-mechanical properties of the surface layer was carried out on samples of grade 65G steel. Their elemental composition was compared before and after treatment by arc discharge in vacuum. The sample surface underwent preliminary mechanical processing.

Figure 6 represents the energy spectrum of Auger electrons emitted by a steel target, whose surface was polished preliminary. Auger spectrograms of the polished surface showed the presence of peaks of Fe, Mn, C, Ni, Cr, Ti, Zn, P, and S in the energy spectrum and Cl, K, Ca, O, and Na, which indicates its significant contamination. To study the effect of temperature annealing of the sample on its surface cleaning of impurity elements, polished steel samples were heated to a temperature of 1500 K for 30 min at a residual pressure in the vacuum chamber of $\approx 1.33 \times 10^{-3}$ Pa. Figure 7 represents the Auger electron spectrum at an initial electron energy of $E_0 = 2.4$ keV. From comparison of Figs. 6 and 7, it is evident that heat treatment causes some cleaning of the surface of elements like P, Cl, S, K, and Ca (the intensity of the Auger peaks of these elements decreases) and enrichment with elements like Fe, Mn, Cr, Ni, and Ti. The intensity of Auger peaks of oxygen after heat treatment changes little which indicates the constancy of the oxygen concentration on the sample surface after heat treatment. The effect of vacuum-arc plasma treatment on the elemental composition of the sample surface was studied on steel samples which underwent preliminary mechanical and thermal processing. The part of the samples treated by vacuum-arc discharge was subsequently subjected to additional heat treatment in vacuum at a temperature of 1200 K for 15 min. Figures 8 and 9 represent the energy spectra of Auger electrons emitted by a steel surface after sample treatment by arc

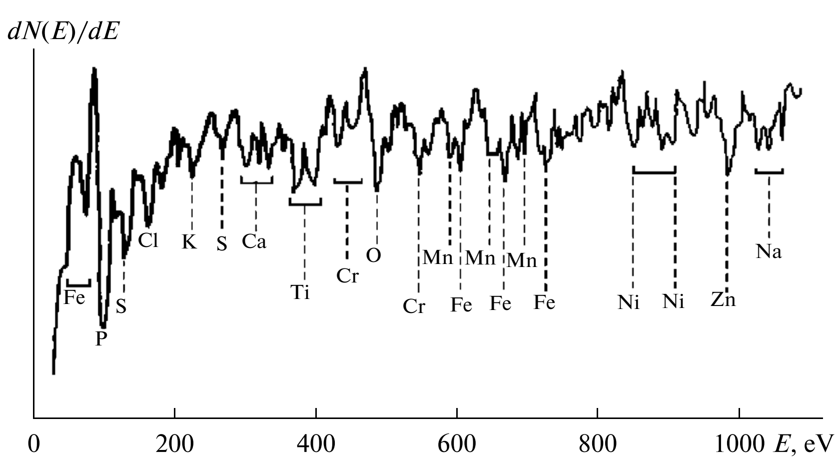

Fig. 6. Energy spectrum of Auger electrons from a polished target surface of grade 65G steel.

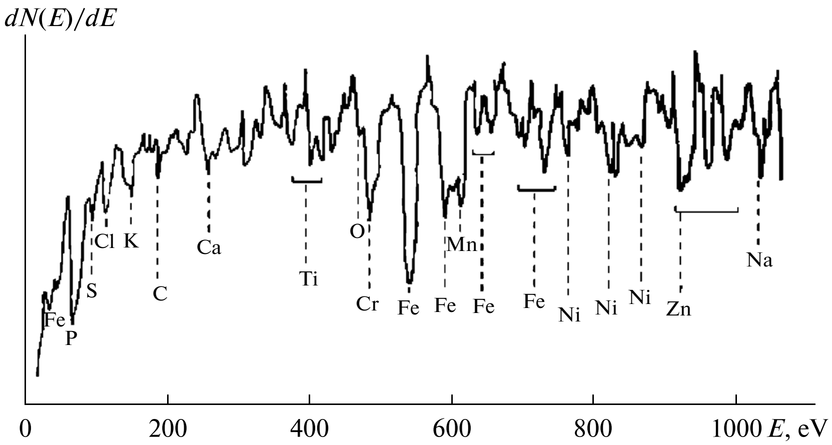

Fig. 7. Energy spectrum of Auger electrons after heat treatment of the product.

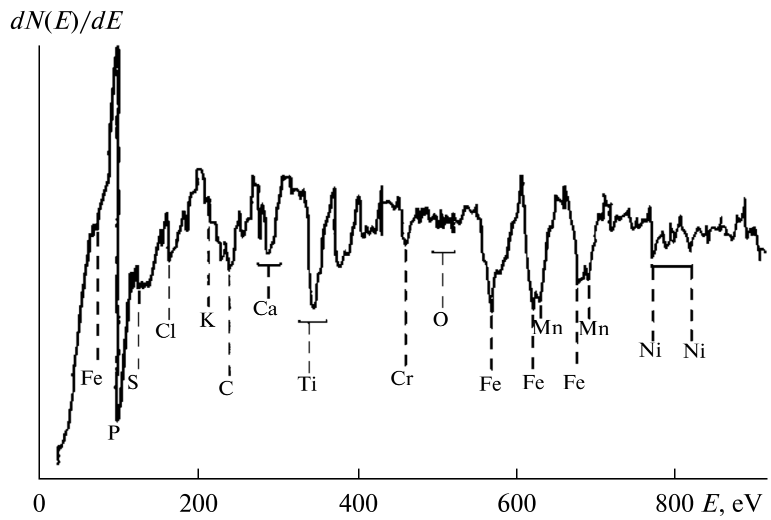

Fig. 8. Energy spectrum of Auger electrons after vacuum-arc discharge treatment at an initial electron energy of $E_0 = 2.5$ keV.

discharge in vacuum at an initial electron energy of $E_0 = 2.5$ keV. From comparison of the curves, it follows that thermal heating of the sample treated by arc discharge in vacuum practically has no effect on the Auger spectra. Comparing the Auger spectrum of those samples not treated (Figs. 6 and 7) and treated by arc discharge in vacuum (Figs. 8 and 9) one can see that the surface of the 65G steel sample subjected to the vacuum-arc discharge effect becomes significantly clearer. This is evidenced by a decrease in the intensity of the Auger peaks of electrons of Fe, S, Cl, K, Ca, and other materials and by an increase in the intensity of the Auger peaks of Fe, Mn, Cr, Ni, and Ti. An increase in the intensity of the Auger peak of carbon electrons and its form indicate that carbon is in the bound state in the carbide form. The thin structure of the peaks of Fe, Mn, Cr, Ni, and Ti testifies their chemical binding with other elements, partially, with carbon. As for oxygen, it was not revealed within detection limits after the sample surface treatment by vacuum-arc discharge.

DISCUSSION

The microhardness of the surface cleaned by vacuum-arc discharge increases by 20–30% in comparison with the microhardness of the original sample untreated by discharge. An increase in the microhardness of the processed surface occurs, first of all, because of inheritance of the defect structure from martensite, increase in the defect density, and recrystallization [3]. In addition, the growth rate of the surface temperature in the effect area of the cathode spot of the vacuum arc results in the displacement of the main phase transitions in the high-temperature region and forms special conditions for diffusion saturation of the surface layer [4]. The microhardness of the sur-

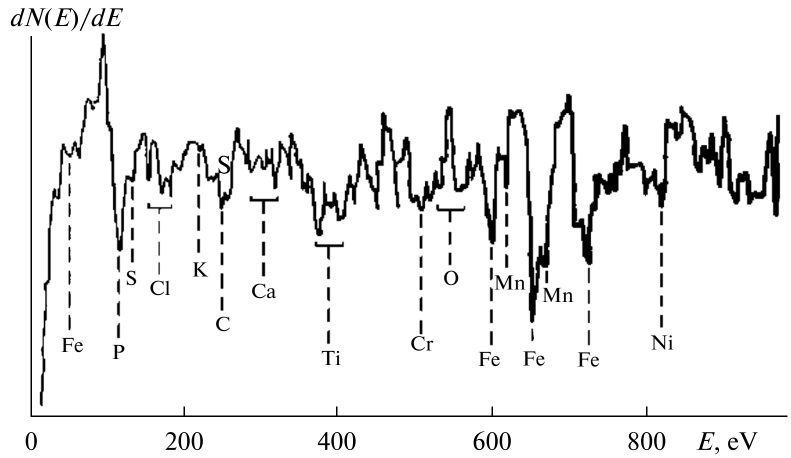

Fig. 9. Energy spectrum of Auger electrons after arc discharge and additional heat treatment of the target.

face layer increases upon combination of this process with austenite nucleation.

Coating with a substance or a mixture of substances, which decreases the electron work function of the scale surface before vacuum-arc treatment, increases the flow of neutral particles evaporated from the surface and the ionization rate in the cathode spot, which decreases the specific power consumption for cleaning [5]. For example, the application of a coating of the 20% solution of KOH and NaOH alkalis to the processed steel surface results in a reduction in power consumption for surface cleaning from scale by a factor of 1.5–2.4. Thus, the application of substances with a low work function and evaporation heat on a processed metallic surface increases the probability of cathode-spot formation and the cleaning rate and decreases the surface roughness. The probability of cathode-spot formation is undoubtedly directly associated with the mechanism of the interaction of discharge with the surface. The obtained results showed that the cathode spot with a low threshold concentration of surface plasma increases the plasma stream, which well agrees with the dependence of the discharge voltage on the concentration of the KOH aqueous solution. For example, the stability of the vacuum-arc discharge is maintained by the negative feedback between current and discharge voltage. An increase in the discharge current is provided by an increase in the frequency of cathode-spot formation and a decrease in voltage. That is, the greater the probability of cathode-spot formation, the lower the discharge-gap voltage. An increase in the lifetime of the cathode spot as the kinetic constant of its disappearance leads to the same effect as an increase in the frequency of its formation. The most favorable result of a decrease in the surface roughness and an increase in the cleaning rate was obtained with the use of KOH and NaOH which is apparently associated with a change in mechanisms within the cathode connection because of a change in the probability of cathode-spot formation.

Experimental determination of the effect of impurity redistribution as for the case of surface cleaning by vacuum-arc discharge showed that the near-surface layer is depleted by P, Cl, S, K, and Ca and saturated by Fe, Mn, Cr, Ni, and Ti. Analysis of the alloying-element concentration over depth by Auger spectroscopy [6] showed that pulsed laser processing results in the redistribution of alloying elements in the thin surface oxide layer; and, at the same time, enrichment by chromium and other elements was observed. This circumstance is very significant because prediction of the effect direction is not possible. Along with this, stainless steels contain special alloying impurities which enhance the corrosion resistance of the material. One can assume that the depletion of surface layers by alloying impurities occurs. It is different with low-grade steels. Their impurities are the result of incomplete cleaning of the metal during production. Many of these impurities decrease the corrosion resistance of the material, and the depletion of surface layers by them becomes a positive factor enhancing its anticorrosion properties. The oxygen content is extremely small on a surface subjected to high-rate heat treatment by the plasma of a cathode spot of vacuum-arc discharge. This explains the corrosion resistance of such a surface and the increased adhesion of coatings applied onto this surface. An increase in the intensity of the carbon Auger peak evidences some carbonization of the surface during its treatment by arc discharge in vacuum, which probably occurs because of saturation of these layers in the melt state by carbon-containing vapors (during pumping by an oil-vapor pump). An increase in the intensity of the carbon Auger peak and the presence of doublets indicate that carbon is in the bound state in the carbide form, and the thin structure of the peaks of Fe, Mn, Cr, Ni, and Ti testifies their chemical binding with other elements, particularly, with carbon. In essence, under the given conditions, the vacuum-arc treatment of the surface, apart from the removal of surface contaminants, changes the microstructure of the surface layers, decreases grain sizes, and forms metastable phases because of saturation of the melt in the cathode-spot area by elements of the residual atmosphere which return to the cathode. The effect of high-temperature pulsed plasma streams on metallic materials [6, 7] leads to the formation of nonequilibrium structural-phase states characterized by high microhardness, wear resistance, corrosion resistance, and other properties. It is significant that the mentioned interactions and compounds under regular conditions cannot be formed. Thus, on the one hand, there is carbonization of the surface layer; and, on the other hand, temperature quenching which changes the grain size in the surface layer and thinning of microstructure. In addition, oxidation of the surface layers is excluded in the area of the effect on the surface by cathode spots of vacuum-arc discharge. It is quite natural that these processes are damped in subsequent surface layers. The mentioned complex of processes in the zone of the cathode spot of the vacuum arc results in an increase in the microhardness and promotes the formation of anticorrosion properties and an increase in adhesion.

CONCLUSIONS

The processing and cleaning of the surface of steel samples by cathode spots of vacuum-arc discharge, which form both ion-plasma and point high-temperature effects on the sample surface, result in a change in the properties of the surface layer. A layer forms with an altered structure 10 μm in thickness and with a microhardness exceeding the initial value by a factor 1.4–1.5. The appearance of carbon in the surface layers of steel after its treatment by arc discharge in vacuum promotes strengthening of the surface. The energy consumption for cleaning a steel surface scale are proportional to its thickness and, as a whole, are from 0.13 kW/h per 1 μm of its thickness to 0.5 kW/h. The preliminary cracking of the scale of hot-rolled metal significantly decreases the specific energy consumption for vacuum-arc cleaning. The specific energy consumption for vacuum-arc cleaning decreases by a factor of 1.5–2.4 with the application of a coating of 20% solution of KOH and NaOH alkalis (substances reducing the electron work function of the scale surface) onto the processing steel surface. The most favorable results of a decrease in the surface roughness and an increase in the cleaning rate were attained for KOH and NaOH. The surface roughness is by a factor of 2.5 less at 10% concentration of the alkali solution than without it. The cleaning rate as a function of the concentration of the alkali solution has a maximum exceeding (by a factor of 1.8) the corresponding value beyond it. The clear correlation between the positions of the extremum of the alkali-solution concentration dependence of the probability of the formation of the elementary cathode spot, discharge voltage, surface roughness, and cleaning rate is revealed. It allows us to conclude that the primary cause of all changes on the surface in the presence of alkali metal compounds is in the change in the probability of the formation of cathode spots.

Depletion of the surface layer of low-grade steels by impurity elements enhances its anticorrosion properties. The experimental determination of the effect of impurity redistribution is of very importance because predicting the effect direction is impossible. It is shown that surface cleaning by vacuum-arc discharge and subsequent heat treatment cause depletion by P, Cl, S, K, and Ca and saturation with Fe, Mn, Cr, Ni, and Ti. It is probable that the corrosion resistance of the surface subjected to high-rate heat treatment and the increased adhesion of coatings applied to this surface are explained by the small oxygen content on this surface.

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