Problems of Tribologyy, 24 (3/93) (2019) 51-61

Problems of Tribology
Website: http://tribology.khnu.km.ua/index.php/ProbTrib
E-mail: tribosenator@gmail.com

DOI: https://doi.org/10.31891/2079-1372-2019-93-3-51-61

Of combined electric arc coatings

M. Ageev[1*], L. Lopata[2*], T. Smirnova[3], A. Dudan[4], A. Lopata[5]

[1]*Kherson State Maritime Academy, Ship Power Plant Operation, Kherson, Ukraine,*
[2]*G S. Pisarenko. Institute for Problems of Strength of the National Academy of Sciences of Ukraine, Kiev, Ukraine,*
[3]*Central Ukrainian National Technical University National technica, Kropyvnytskyi, Ukraine,*
[4]*Polotsk State University, Novopotsk, Belarus,*
[5]*National Technical University of Ukraine "Igor Sikorsky, Polytechnic Institute", Kyiv, Ukraine*
[*]*E-mail: maxageev73-73@ukr.net*
[*]*E-mail: beryuza@ukr.net*

Abstract

The paper considers possibilities to increase the wear resistance for parts machines and mechanisms using combined electric arc coatings thanks to nitriding the coatings deposited. The possibility of controlling the properties of surfaces owing to choice with required characteristics electric arc coatings is shown. The influence of spray factors such as the flow rate and pressure of working gases, composition of combustion mixture, spraying distance, dispersion of the spray, properties of wire material, etc. on the properties of the coatings obtained has been investigated. The paper considers the use of pulse ion nitriding of arc-spray EAS (eelectric arc spraying) coatings from wire materials as one of the efficient ways to increase their performance characteristics.

Key words: combined electric arc coating, pulse ion nitriding, wear resistance, corrosion resistance, adhesion strength, eelectric arc spraying.

The state of the problem and the purpose of the research

In the world practice of hardening, recovery, and anticorrosion protection, EAS has become widespread as the most technologically advanced and productive method (productivity is 3 - 4 times that for flame spraying) [1, 2]. This is due to the simplicity of the equipment, the availability of energy source for metal melting, The quality of EAS coatings are practically the same as that of coatings produced by plasma and detonation methods, and the coating-to-base adhesion strength is greater than in the case of flame spraying. In [1-5], information is given about the advantages of EAS over surfacing in terms of labor input and consumption of electrode material: duration of surfacing is 1 h 10 min and wire consumption 1.3 kg, while for EAS these parameters are 24 min and 0.95 kg, respectively.

The successful use of EAS is provided by its advantages such as obtaining coatings with a thickness of 0.1 to 10 mm; the absence of significant thermal effects on the part; the possibility of applying coatings on parts made of various materials; obtaining coatings with desired properties, *et al.* EAS is characterized by technological flexibility concerning application to various standard sizes of parts, low recovery cost (by 1.4 - 1.8 times lower than for surfacing). The equipment on which coating is performed is relatively simple and light and can be moved fairly quickly. The part dimensions do not limit the use of EAS [9, 10]. This method is effective and economical in the manufacture and renovation of parts in the conditions of repair enterprises and small workshops with a single production [6].

The EAS process consists in heating (to melting) converging wires (electrodes) by an electric arc and spraying the molten metal with compressed air [1, 2]. Two wires move forward in two channels in the spray head, and between their tips an electric arc is excited (Fig. 1).

A jet of compressed gas (air), which sprays the molten metal wires and transports the melt in the form of particle flux to the surface being restored (or hardened), flows out of the central channel of the EAS apparatus head. For spray, a wire with a diameter of 0.8; 1.0; 1.6, and 2.0 mm is traditionally used. The use of thermoreacting cored wires is promising [7 - 9]. It should be noted that in the course of EAS, the sprayed metal in the form of droplets falls on a substrate and cool to the substrate temperature for a short time, providing the formation of quenched structures in the coating; herein the hardness of the sprayed layer exceeds that of the starting material [1, 2].

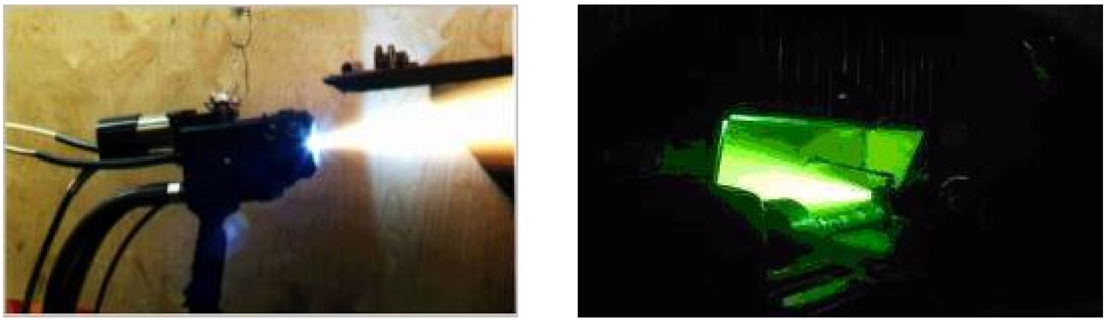


Fig. 1. Eelectric arc spraying (EAS)

The EAS technology includes three main procedures: jet-abrasive processing, deposition of a sublayer from refractory Ni-Cr alloy, and deposition of a main layer of carbon alloyed steel [1, 2]. The coating treatment after spraying (heat treatment, coating compaction, finishing) is conducted when required [10 - 12]. The coating obtained is machined with some allowance. The main types of processing sprayed coatings are cutting and grinding. For processing coatings from corrosion-resistant and carbon steels, high-speed and hard-alloy tools may be used. Pretreatment of the base surface is an important factor for providing strong adhesion of the sprayed coating to the part [1, 2, 10 - 12]. The increase in the adhesion strength is associated with an increase in the part area and preparation of a developed surface roughness on before spraying.

The main EAS process parameters are: the composition, diameter, and feed speed of wires to be sprayed; arc power; flow rate of spraying gas; spraying distance; velocity of the spray spot. Traditionally, the distance from the spraying apparatus is 100 - 200 mm [1, 2].

In addition to the positive qualities of EAS (manufacturability, simplicity, high efficiency, absence of thermal conductors, low cost, versatility, *etc.*), there are also disadvantages such as increased metal oxidation; the presence of porosity; insufficient adhesion of the coating to the base; cooling of the molten metal particles with spraying compressed air, *etc.* As a result of the latter, cracks and peels may appear due to the presence of residual internal stresses [1, 2]. Small feed speeds of the wire lead to its oxidation, and a large amount of heat generated during arc burning leads to a significant burning out of the alloying elements included in the material being sprayed (for example, the carbon content in the coating material decreases by 40-60%, and silicon and manganese by 10 - 15 %).

The microstructural analysis made it possible to establish that coatings obtained with the use of wires containing a high percent (from 0.8 to 2.3) of silicon and manganese have the most porous structure due to iron insoluble slags, and, accordingly, the lowest strength properties as compared to coatings from wires with a lower content of deoxidizers. A conclusion follows that for efficient EAS, it is advisable to use wires with as low content of manganese and silicon as possible, which allows deliverance of the coating obtained from delamination and chipping.

Low hardness of coatings, causing carbon burnout during spraying, was always considered to be a limiting factor for the use of EAS. The maximal achievable hardness of coatings from different steels is within 35-50 HRC$_E$, which markedly reduces their wear resistance. The above mentioned disadvantages of the EAS procedure limit the efficiency and narrow the area of its application to increase the service life of parts.

The wear resistance, protective and strength properties of EAS coatings are increased by means of laser [13, 14], ultrasonic [10], electron beam [15, 16], chemical thermal [17, 18], and other treatment methods [10]. Treatment of sprayed coatings is an integral and indispensable part of the coating technology. Thanks to laser treatment of sprayed coatings [13, 14], their resistance to high temperature corrosion increases with minimal thermal impact on the base, microhardness increases by 2 - 10 times and wear resistance by 1.8 times. Coatings can be melted by high-frequency currents [19, 20], fast pulsed plasma jets [10], or in vacuum furnaces [10]. The increase in microhardness and wear resistance by 5 times, adhesion strength by 2.5 - 3.5 times, the endurance limit by 60 - 80 % is provided by coatings deposited using an electron beam method [15, 16]. For treatment of coatings, it is necessary to use methods characterized by minimum necessary heating and small allowances. A significant increase in hardness and wear resistance of sprayed coatings is provided by pulse ion nitriding (PIN) [21]. Also, the use of surface plastic deformation allows one to improve the coating characteristics and activate the related processes [10].

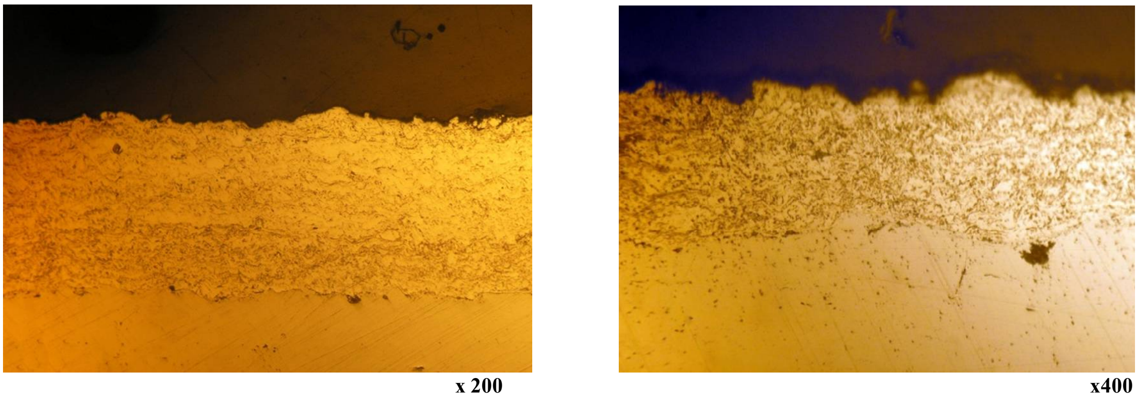
On the basis of studying the problem of hardening and restoring parts of the using EAS coatings, **the aim of the work** was set up to increase the wear resistance and service life of parts *via* combining EAS coatings characterized by high density, adhesion strength, and microhardness due to the activation of the spray process and nitriding of the coatings sprayed.

Study influence factors of the spraying process on the properties of EAS coatings

The EAS process coating is the result of the following physicochemical interactions: the air flow with the wire melt and the formation of a jet of sprayed particles; transformation of the kinetic energy of the sprayed particles into the work of deformation during their mechanical contact with the part surface, and the transfer of internal (thermal) energy from the particles to the part. On the part surface, a coating layer is formed (Fig. 2), the properties of which depend on the characteristics of physicochemical processes listed above.

The dominant influence on the density of coatings and the strength of adhesion to the base is exerted by the dynamic activation of sprayed wire particles, their temperature and size (spray dispersion).

Porosity and adhesion depend on the spraying process parameters such as the flow rate and pressure of working gases, composition of combustible mixture, amount of wire fed per unit time, spraying distance, *etc.* The main effects on them are exerted by the spraying distance, size of sprayed particles, and properties of wire material. Fig. 3 shows the dependence of the porosity of sprayed coatings from 40Kh13, 12Kh18N10T, and Kh20N80T wires on the spraying distance.



a

b

Fig. 2. Microstructure of EAS coatings from wire from (a) Kh20N80T and (b) 12Kh18N10T

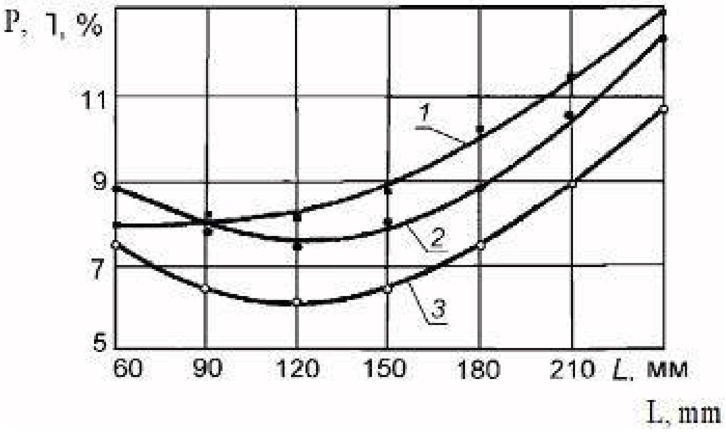
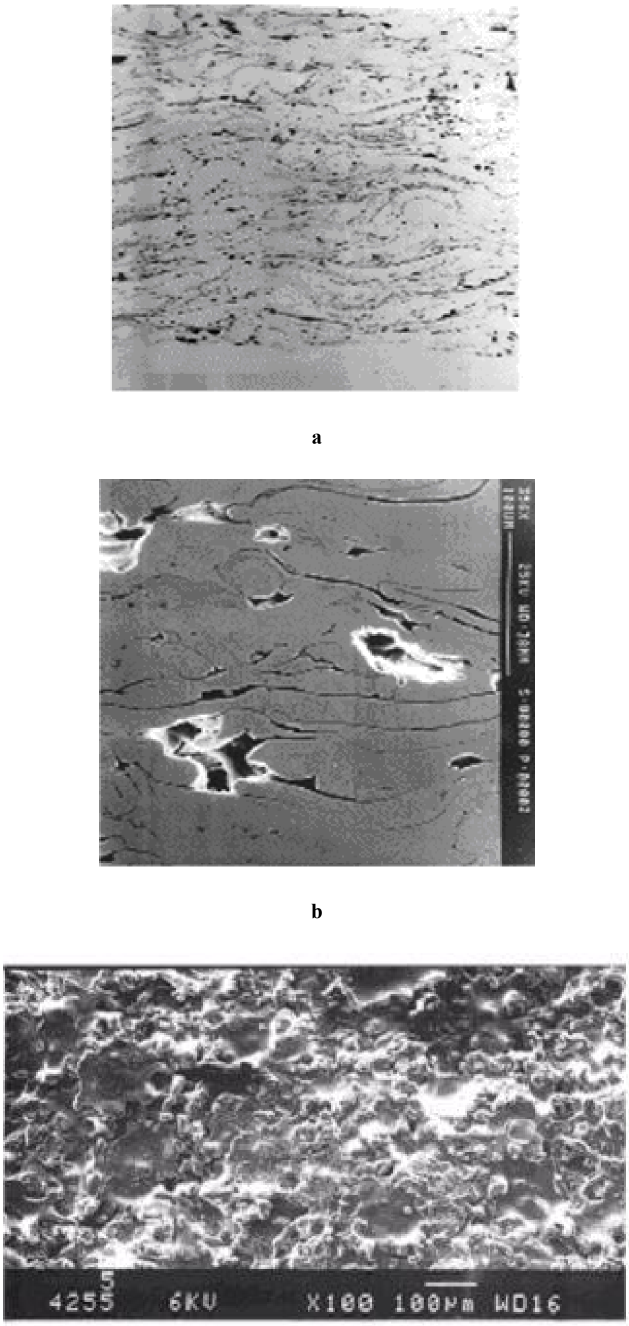


Fig. 3. Dependence of total porosity of coatings on the spraying distance:
1 – steel 20Kh13;
2 – 12Kh18N10T;
3 – nichrome

As can be seen, the highest density of coatings from these materials is achieved at a spraying distance of 110 - 140 mm. The nichrome coatings have a lower porosity due to lower melting temperature. For most sprayed coatings, adhesion strength is directly proportional to their porosity, since it is determined by the number of microcontacts between the metals.

A sprayed coating is formed *via* melting a wire and forming particles under the conditions of their intense interaction with the spray torch and subsequent laying of the molten droplets on the part surface. In the formed surface layer, processes of crystallization, deformation, and tempering take place. The structural state and properties of the coatings depend on a combination of the EAS process parameters. Spray particles are formed as a result of the air jet/liquid metal interaction. They undergo oxidation, which results in forming an oxide film on them by the moment of collision with the part surface. In the sprayed coatings, the oxygen content can be qualitatively assessed with help of microstructural studies. Oxides are visible on microsections in the form of oblong dark or gray areas, and pores are as black areas (Fig. 4).

Comparative tribological tests were conducted for coatings from steel 40Kh13. For comparison, samples from rolled steel 40Kh13, which was pre-quenched and tempered at 970 K for 5 h (H_v = 27 GPa), were tested as well. Under friction without lubrication, an adhesion interaction of the coating material with the counterbody occurs, accompanied by a tear and intense weight wear of the coupling materials (Fig. 5).



a

b

c

**Fig. 4. Microstructure (a, b)
and microtopography (c)
of the coating from steel 40Kh13**

As seen in the figure, the curve of accumulated weight wear of tempered steel has a characteristic stage of running-in and a steady wear stage with almost linear dependence of the weight wear on the friction path. For EAS coatings, the stages of steady wear periodically alternate with the relatively short-term stages of accelerated wear, i.e., wear of EAS coatings is pronouncedly cyclical (Fig. 5). The highest averaged weight wear rate was 0.41 mg/m (Table 1).

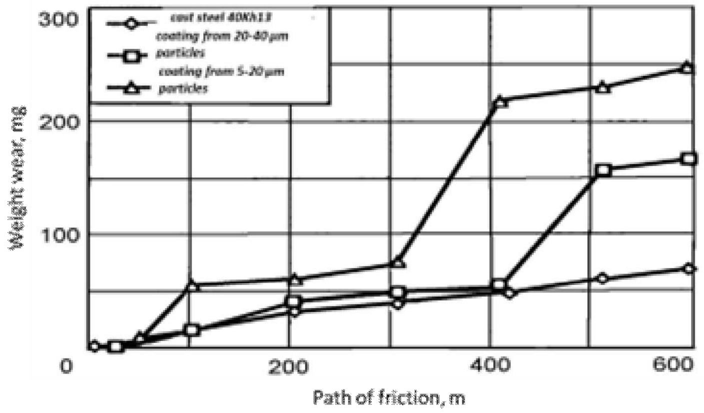


Fig. 5. Dependence of the weight wear on the friction path for EAS coatings from steel 40Kh13. (Friction without lubrication, pressure 1.5 MPa, counterbody from hardened steel 60)

Table 1

Wear rate and coefficient of dry friction for EAS coatings and tempered cast steel 40Kh13

Material	Wear rate, mg/m	Coefficient of friction
Cast steel 40Kh13	0.11	0.80 - 0.92
EAS coating	0.28	0.85 - 0.95
EAS coating	0.41	0.95 - 1.05

The observed cyclicity of the weight wear of EAS coatings is associated with the degradation of their surface layers during friction, described before in terms of physical mesomechanics of solids [22 - 14]. In accordance with the findings in those works, under friction the appearance of fragmented structures occurs with the formation of mesofragments of different scale in the 100 µm thick surface layers. The translational and rotational motion of the mesofragments leads to the occurrence of compressive and tensile stresses in the subsurface layers, the origin of microcracks at the boundaries of the mesofragments, and their separation in the form of wear particles. At the same time, the wear process can be represented as follows: at the initial stages (after the run-in stage) mesofragments of different scale are formed along with the destruction and flaking of small-sized mesofragments close to the surface. This corresponds to the stage of steady wear.

As the path of friction increases, the formation of large mesofragments, which capture the subsurface layers, proceeds. After accumulation of some critical deformation in the coating, peeling of large mesofragments occurs, accompanied with a sharp intensification of coating wear (the stage of accelerated wear). As a result of the removal of large mesofragments, non-deformed subsurface layers enter the interaction zone, and a new cycle of formation of multisized mesofragments begins followed by their subsequent exfoliation.

At the steady wear stage, the wear rate of coatings from 20 - 40 µm particles differs slightly from that of cast steel. The reason for this is the high fracture toughness of coatings containing austenite as well as hardening of the coatings due to the $\gamma - \alpha$ martensitic transformation. The layer microhardness increases to 6.5 GPa. Studies of the resistance to fatigue failure of coated samples were carried out on a magnetostriction unit designed at the Institute for Problems of Strength of NAS of Ukraine. Herein, the magnetostriction effect is realized with help of 0.1 mm thick nickel plates, assembled into a package forming a vibrator. The magnetic bias current was about 15 A at a voltage of 2 - 3 V. The operating frequency of the unit, at which it can be used for fatigue testing, is approximately within 9.8 - 10.8 kHz. The frequency is determined by the driving generator and measured by an electronic frequency meter.

Via varying the amplitude of vibrations, after a certain number of loading cycles, the stress required for fatigue failure of samples is established. The relationship between the amplitude at any point of the vibrating sample and the stresses acting in it was determined (depending on the type of vibrations and sample design) by appropriate calculations based on the theory of vibrations. The results are shown in Fig. 6.

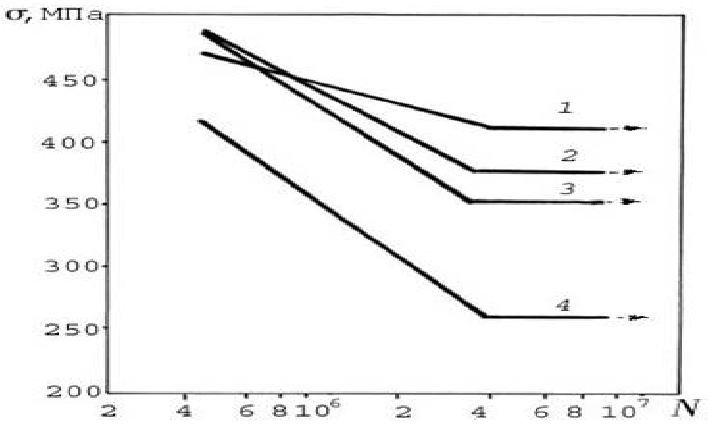


Fig. 6. Curves of fatigue for samples with:
1 – no coating;
2 – gas-flame coating;
3 – EAS coating; 4 – fused coating

As displayed, EAS coatings cause a slight decrease in the fatigue limit (by 10 - 3 %). After vibro-arc surfacing, the fatigue limit is reduced by 35 - 40 %. In the deposited layer, the reason for the decrease in fatigue resistance is the low ductility in the zone of the coating-base contact melt.Accelerated tribological tests of samples with EAS coatings from wire steel 40Kh13 were conducted on an upgraded machine of the 2070 SMT-1 type. Upon spraying, an irregular coating structure was formed *via* layered stacking of molten steel droplets (Fig. 7). Such a structure provides damping of elastic excitations caused by friction. After the tribological tests, no noticeable wear of EAS coatings was detected for 9 h.

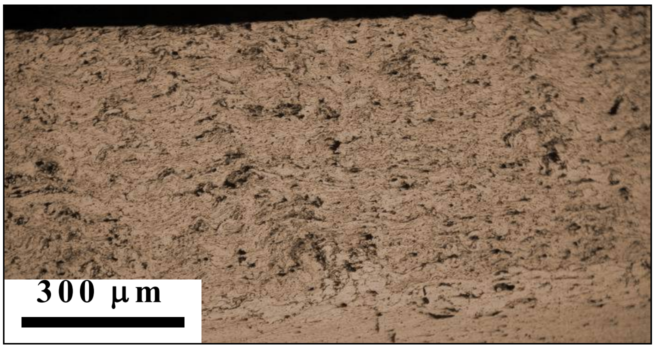


Fig. 7. Structure of EAS coating after 9 h testing

Treatment of EAS coatings with nitriding

An effective way to solve the problem of improving the operation characteristics of EAS coatings from wire materials may be the formation of high-strength surface layers on them with a multilayer structure through the use of various techniques for surface modification and chemical heat treatment. The paper presents the results of studies to improve the properties of EAS coatings by pulse ion nitriding (PIN).

Among a large number of techniques for diffusional alloying of surface layers, nitriding methods are notable for their manufacturability, environmental safety, and economic efficiency [25]. For the subsequent treatment of EAS coatings, the PIN method was chosen in [26, 27]. It was carried out in vacuum using nitrogen and an argon-hydrogen mixture as a reaction gas, which ensures the formation of a layer of nitrides (compounds with high hardness). Both a PIN process and environmentally-friendly and energy-saving equipment for it were developed at G.S. Pisarenko Institute for Problems of Strength of NAS of Ukraine. This process improves the surface properties of parts without changing their geometry. By using PIN treatment of EAS coatings, it is possible to replace expensive cored wires with cheap steel ones along with increasing microhardness. The microhardness of nitrogen-modified layers on EAS coatings ranges from 5.6 to 12.0 GPa (Table 2).

It is known [26, 27] that by changing the process temperature as well as the carbon/nitrogen potential ratio, one can control the depth of the diffusion layer and its hardness. The findings of the study for the phase composition of ion-modified (under various conditions) EAS coatings are summarized in Tables 3 - 4.

Table 2

Effect of PIN temperature on the microhardness of modified EAS coatings

Material of coating	Microhardness, GPa, at temperature of nitriding, K						
	600	620	650	670	700	720	770
Martensitic steels	8.6	11.3	12.9	14.0	15.9	12.7	11.3
Austenitic steels	5.6	6.2	8.0	8.9	11.1	12.0	11.8

Table3

Structural parameters of modified coatings from martensitic steels

Treatment conditions		Layer thickness, μm	Phase composition
AEAS	N^+ 620 K	5 - 10	α-Fe, γ-Fe, γ_N, Fe_3O_4, ε-$(Fe,Cr)_3N$
	N^+ 670 K	10 - 15	α-Fe, Fe_3O_4, ε-$(Fe,Cr)_3N$, γ'-Fe_4N
	N^+ 720 K	15 - 20	α-Fe, Fe_3O_4, ε-$(Fe,Cr)_3N$, γ'-Fe_4N, CrN
	N^+ 770 K	25 - 30	α-Fe, Fe_3O_4, γ'-Fe_4N, CrN

As the PIN temperature for EAS coatings increases, the depth of the modified layer increases to 40 μm. The microhardness of the modified layer, as a result of treatment at 670 - 720 K, increases and reaches 14.0 - 15.9 GPa. The basic phases present in the nitrogen-modified layer on the martensitic steel coatings are nitrides ε-$(Fe,Cr)_3N$ and γ'-Fe_4N. After ion treatment at 720 and 770 K, a sharp decrease in the content of high-nitrogen ε-nitride and the formation of CrN are fixed in the nitrided layers. The microhardness of the layer decreases to 11.3 - 12.7 GPa. In nitrogen-modified layers, the Fe_3O_4 oxide remains, while the FeO oxide reduces.

Ion nitriding of EAS coatings from austenitic steels leads to the formation of modified layers with a thickness of 3 - 5 to 15 - 25 μm (Table 4). The microtopography of the layer surfaces after PIN showed that porosity of the coatings adversely affects the quality of the surface treated with nitrogen ions. It was established that on prior polished layers with a porosity of more than 7 % after ion hardening, areas of coating swelling with a size of 200 - 500 μm appear.

Table 4

Structural parameters of modified coatings from austenitic steels

Treatment conditions		Layer thickness, μm	Phase composition
AEAS	N^+ 620 K	3 - 5	α-Fe, γ-Fe, Fe_3O_4, γ_N,
	N^+ 670 K	3 - 5	α-Fe, γ-Fe, Fe_3O_4, γ'_N,
	N^+ 720 K	10 - 15	α-Fe, γ-Fe, Fe_3O_4, γ'_N, γ'-Fe_4N, CrN
	N^+ 770 K	15	α-Fe, γ-Fe, Fe_3O_4, γ'-Fe_4N, CrN

After peeling, the swelling areas become caverns. It is obvious that the greater the layer porosity, the stronger the swelling effect. The studies revealed that at the layer density above 94 %, this effect does not occur. The reason for the nitrided depth limit in EAS coatings of 15 - 30 μm is the presence of a large amount of oxide films, which act as a barrier to PIN. Fig. 8 demonstrates the structure of the NiCr (Kh20N80) coating obtained by AEAS and the hardened surface before nitriding, whereas Fig. 9 presents the structure of the AEAS coating from the same steel and the hardened surface after nitriding. Coating thickness was ~ 200 μm and microhardness $HV_{0.05}$ was 2680 ± 70 MPa.

Oxides are formed during the flight of molten particles and during crystallization on the part surface. Coatings with a porosity of more than 6% are almost impossible to harden without formation of defective areas, since the walls of pores are covered with a thin layer of iron oxides. It is possible to eliminate the formation of oxide films by spraying steel wires with an inert (argon) or non-oxidizing (nitrogen) gases. In our case, we used AEAS, which allows creation of coatings with a density that approaches the density of a \\\compact material.

The study of the coating adhesion strength displayed that treatment with PIN can significantly improve adhesion. An increase in adhesion strength is characteristic for coatings having porosity in the range of 5 - 14 %, and the further increase in porosity leads to a decrease in adhesion.

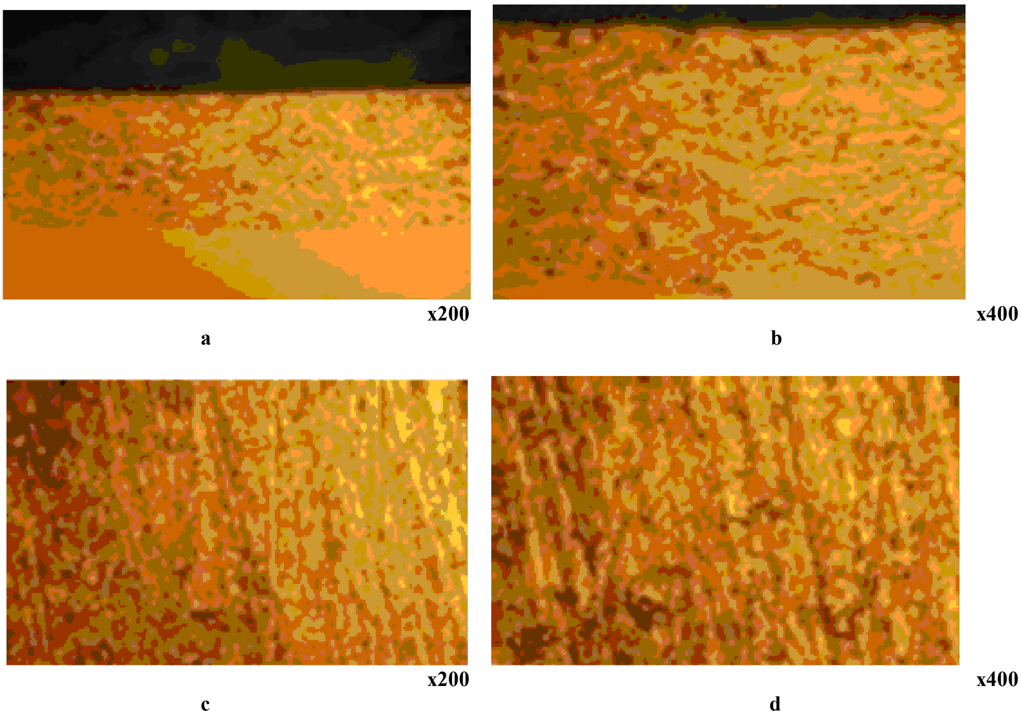


Fig. 8. The structure of coating obtained by AEAS from NiCr (Kh20N80) (a, b) and its hardened surface before nitriding (c, d)

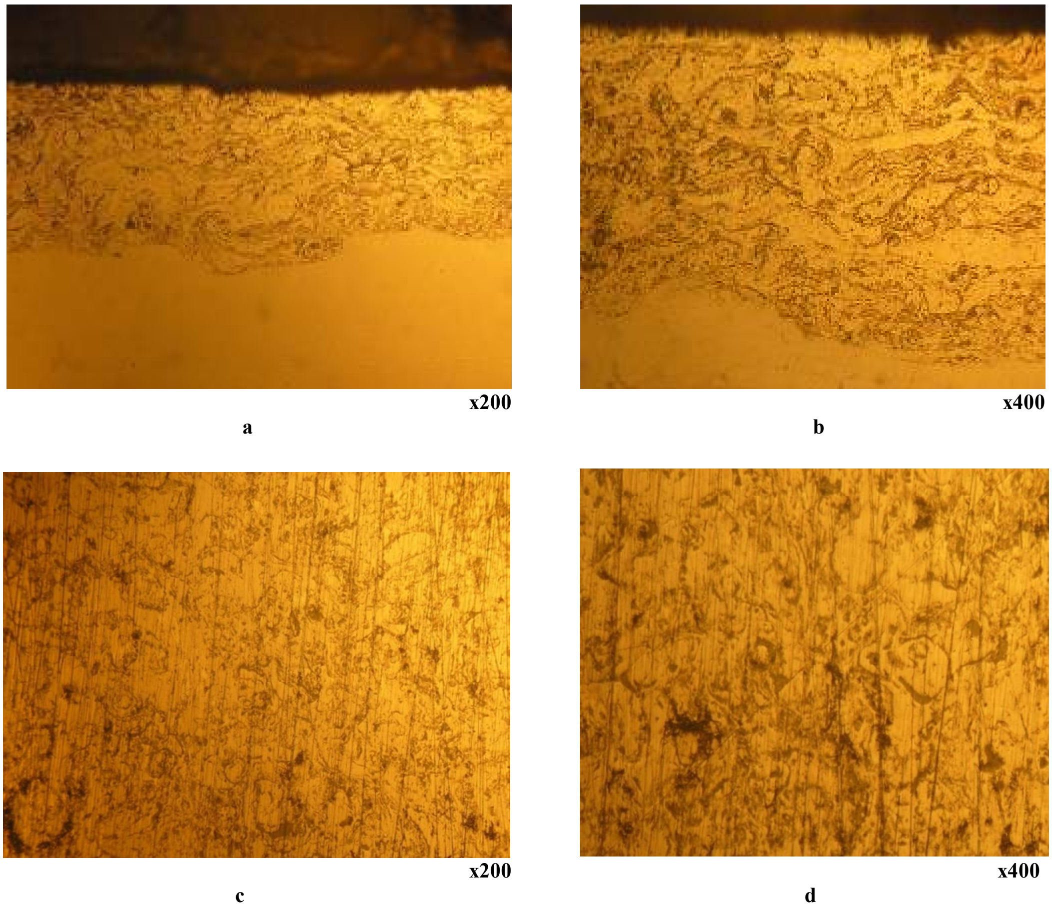


Fig. 9. The structure of coating obtained by AEAS from NiCr (Kh20N80) (a, b) and its hardened surface after nitriding (c, d). The surface microhardness after nitriding $HV_{0.05}$ = 4320±110 MPa

As a result of tribological tests (pressure 0.64 MPa, dry friction) of coatings after various nitriding conditions, it was found that an increase in the treatment temperature of coatings from steel 40Kh13 and

Kh18N10T leads to a sharp increase in their wear resistance [28, 29]. The coatings treated with nitrogen ions at 670 - 770 K exhibited the highest wear resistance. The increased wear resistance of the layer nitrated at 770 K is due to its great depth and high microhardness.

As follows, to restore and harden the surface of SMM parts, it is expedient to combine deposition of AEAS coatings from wire martensitic and austenitic steels with their subsequent treatment with PIN.

Conclusions

The present work recommends to increase the wear resistance, parts *via* hardening and renovating them using combined EAS coatings characterized by high density, adhesion strength, and microhardness due to subsequent nitriding of the coatings sprayed.

The research has revealed the influence of the spraying process factors such as the flow rate and pressure of working gases, composition of combustible mixture, spraying distance, dispersion of spray, properties of the wire material, *etc.* on the properties of EAS coatings. Furthermore, the effects of the spraying distance, the size of sprayed particles, and the properties of the wire material on the porosity and coating-to-substrate adhesion was evaluated. It was determined that in steel coatings, a decrease in tear resistance from 22 - 30 MPa to 15 - 18 MPa is observed with an increase in the average size of sprayed particles from 30 to 100 μm. When spraying nichrome, increase in the average size of particles from 15 to 100 μm makes it possible to increase the adhesion strength from 23 - 27 to 40 - 46 MPa.

As a result of experimental studies of the influence of the modifying effect of PIN on the physicomechanical properties of steel EAS coatings, it was found that in order to increase the efficiency of nitriding, it is necessary to use coatings with a porosity of no more than 6 %,

Also, it was shown that EAS of steel wires combined with subsequent PIN allows the formation of coatings with the surface layer microhardness from 6.5 to 15.0 GPa and thickness from 5 to 40 μm. As a result of nitriding EAS coatings from wire steel 40Kh13, surface layers are formed with a microhardness of 7.5 - 7.7 GPa.

The wear resistance of EAS coatings from steels 40Kh13 and Kh18N10T after PIN increases from two- to eight-fold. The amount of oxides in the coatings does not change after nitriding and favorably affects the performance of the coatings under the conditions of dry friction in air.

References

1. V.N. Boronenkov, Yu.S. Korobov Fundamentals of arc metallization. Physicochemical regulairities. USU; Yekaterinburg: Univ. Publ. house 2012, 267 p.

2. Ya.V. Zagorsky The mechanism of electric arc hardening of low- and medium-carbon steels. Congress materials. Ufa: Mir pechati, 2003, 105 p.

3(11). M.S. Ageev, B.A. Liashenko Application of hybrid technologies for renovation and resource increase of ship machinery and mechanisms. Bulletin of Brest State Technical University. Journ. “Machinostroyenie”, Brest, 4(94), 2015 – P. 18-22.

4. B. Vilage, K. Rupprecht, A. Pokhmurskaya Features of gas-thermal spraying with flux-cored wires. Automatic welding., No. 10. 2011. P. 26-30.

5. V.I. Pokhmursky, M.M. Student, V.S. Pikh. Protective and restorative electric metallization of coatings from cored wires. New processes and equipment for gas-thermal and vacuum coating: Coll. of papers “Electric welding”- Kyiv, 1990. P. 66 - 69.

6. M.M. Student Development of old and new electrometallic coatings to cover powder darts: Thesis. Lviv, 1998 - 18 p.

10. R.O. Vitiaz, P.A. Azizov., M.A. Belotserkovsky Hardening of gas-thermal coatings. - Minsk: Bestprint, 2004. - 192 p.

11. L.A. Lopata, N.A. Medvedeva, T.M. Tunik, S.G. Salii Improvement of sprayed coatings. “World of Engineering and Technologies”, 8 (54), 2005. P. 54-56.

12. E.N. Matveishin Deposition of layers with high adhesion strength by methods of arc metallization. Automatic welding. 8, 2000. P. 20-22.

13. G.V. Pokhmursk., V.M. Dovguni., M.M. Student Wear resistance of laser-modified electric arc coatings from cored wire FMI-2. FKhMM № 4. – 2003. P. 61-64.

14. I.A. Podcherniaeva Laser reflow of gas thermal coatings based on cortinite. Technol. and body. № 2. 1992. P. 42-43.

15. N.V. Prokhorenkova The structure and properties of coatings based on Ni deposited by a plasma jet and subjected to electron irradiation. International school "Physics and Chemistry of Nanomaterials", Tomsk: TSU, 2005. –P.118-120.

16. A.A .Shipko, I.G. Urban Effect of electron beam heating on the structure and properties of detonation coatings Vestnik of AS of Belarus. 4, 1992. P. 8-14.

17. P.A. Vitiaz, R.O. Azizov, M.A. Belotserkovsky, V.A. Kukareko. Improving the quality of gas-thermal coatings from wire materials by means of chemical heat treatment. Friction and wear. - Vol. 24, No. 6. 2003. - P. 666–672.

18. M.A. Belotserkovsky, V.M. Konstantinov, G.A. Tkachenko. Hardening by chemical heat treatment of coatings obtained by fast spraying steel wires. Surface Engineering, Welding: Proc. Int. Symp., Minsk, 2009. P. 178–184.

19. M.A. .Glebova, A. B. Korne., V.V. Glebov *et al*. Improving the quality of gas-thermal coatings by heat treatment with high-frequency currents and a laser beam. Welding Production № 6, 2004. P.43-46.

20. Yu.V. .Sokolov, M.A. Sadova, D.A. Popok Heat treatment of sprayed coatings / Vest. Belarus tech. inst. № 3, 2004. - P. 40-41

21. B.A. Liashenko, M.A. Belotserkovsky, V.N. Lopata., *et al*. Thermal spraying and ion nitriding as a promising combination. Proc. 14th Inter. Conf., June 2014, Svaliava - Kyiv: ATM of Ukraine, P.79-80.

22. M.A. Belotserkovsky Structural anomalies in steel gas-thermal coatings and the possibility of their use Strengthening Technologies and Coatings, 10, 2008. P. 39-44.

23. P.A. Vitiaz, M.A. Belotserkovsky, V.A. Kukareko, *et al*. Structure and properties of coatings from steel 40Kh1 produced using various methods for gas-thermal spraying. Physical mezomechanika.-, V.5, No. 1. 2002 P. 15-22.

24. B.A.. Potekhin, M.N. .Lobanov, E.M. Nasedkina Influence of unstable austenitic structure of steel 9Kh18 on cavitation and abrasive resistance. Phys.-chemical mechanics of materials, , 2. 1976. P. 116-118.

25. B.A. Liashenko, N.O. Kuzin, E.K. Solovykh Comparative analysis of the energy intensity of nitriding methods.. Proc. 14th Inter.Conf. 2014. P. 80-82.

26. V.V. Kharchenko, B.A. Liashenko, R.I. Kuriat, G.V. Isakhanov. Thermocyclic nitriding as a synthesis of developments of the NAS of Ukraine. Proc. 12th Inter. seminar, Svalyava - Kyiv: ATM of Ukraine, 2012. P. 287-290.

27. V.V. Kharchenko, B.A. Liashenko, R.I. Kuriat, A.V. Rutkovsky, Ye.V. Korbut Kharchenko V.V. Method for surface hardening of steel parts with ion-plasma pulse nitriding. Patent of Ukraine 78071 S23S 8/06 (2006.01), Publ. 03.11.2013, Bull. No. 5

28. B.A. Liashenko, A.V. Rutkovsky, O. Yu. Kumurzhi. Use of ion-plasma thermocyclic nitriding to increase wear resistance of high-alloy steel. News of Zhytomyr Technological University, №3 (74), 2015. P. 28–33.

29. O.Yu. Kumurzhi, A.V. Rutkovsky. Wear resistance of steel 40Kh13 after hardening by the method of thermocyclic ion-plasma nitriding under abrasive wear. Coll. of papers “Problems of friction and wear”- 57, 2012, P. 240-250.

Агеев М.С., Лопата Л.А., Смирнова Т.В., Лопата А.В. Комбинированные электродуговые покрытия.

В работе предложено повышать износостойкость деталей машин и механизмоа комбинированными ЭДН-покрытиями за счет азотирования напыленных покрытий. В работе исследование влияния факторов процесса элпектродугового напыления: расхода и давления рабочих газов, состава горючей смеси, дистанции напыления, дисперсности распыления, свойств материала проволоки и др. на свойства ЭДН-покрытий. В работе рассмотрен один из способов повышения эксплуатационных характеристик ЭДН-покрытий из проволочных материалов посредством использования импульсного ионного азотирования.

В работе предложено повышать износостойкостьь и срок службы деталей машин и механизмоа при их упрочнении и реновации комбинированными ЭДН-покрытиями с высокой плотностью, прочностью сцепления и микротвердостью за счет управления параметрами электродугового напыления и процесса азотирования напыленных покрытий. В работе рассмотрена возможность обеспечивать необходимые свойства поверхностей с целью повышения ресурса деталей машин путем регулирования факторами ЭДН. В частности, регулируя скорость и температуру струи транспортирующего газа и частиц можно уменьшить диаметр капель, повысить плотность и снизить окисляемость покрытий. В работе исследование влияния факторов процесса напыления: расхода и давления рабочих газов, состава горючей смеси, дистанции напыления, дисперсности распыления, свойств материала проволоки и др. на свойства ЭДН-покрытий. В работе рассмотрен один из способов повышения эксплуатационных характеристик ЭДН-покрытий из проволочных материалов посредством использования ионного азотирования.

Ключевые слова: комбинированные электродуговые покрытия, ионное азотирование, износостойкость, коррозионная стойкость, прочность сцепления, электродуговое напыление.