



Wear resistance of composite electrolytic coatings

M.Ye. Skyba, M.S. Stechyshyn, V.P. Oleksandrenko, N.S. Mashovets*, Y.M. Bilyk

Khmelnytsky National University, Ukraine

**E-mail: mashovetsns@ukr.net*

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Abstract

The article analyzes the influence of composite electrolytic coatings (CEC) on the wear resistance of structural steels. The issues of matrix selection and various combinations in composite coatings of different chemical elements and compounds are considered. Coatings based on chromium, nickel, iron, copper, cobalt and others are widely used in industry, but nickel-based composite coatings are the most widely used. Nickel is widely used as a matrix for CEC, because it has an affinity for most particles used as the second phase and easily forms a coating with them. These coatings are used for corrosion protection, increase of physical and mechanical and chemical parameters, increase of hardness and wear resistance, restoration of the sizes, giving to a surface of self-lubricating properties.

Nickel-based coatings with SiC filler of various fractions from size 100/80 μm to nanoparticles smaller than 50 nm were investigated on the basis of the established installation for CEC application. Thus, SiC powders with the following sizes were used in the works: less than 50 nm - nanoparticles; M5; 28/20; 50/40; 100/80 μm .

In the studies performed, 0.01... 0.02 g/l sodium lauryl sulfate was additionally introduced into the electrolyte, which promotes the incorporation of SiC particles into the coating and improves the conditions for building the Nickel matrix.

Amorphous boron powders of about 1 μm size were also added to the silicon carbides as a filler, which is explained by the possibility of boron and nickel interaction during the subsequent heat treatment of the coating and obtaining new structures (solid solutions, eutectic, dispersion-hard alloys).

It is of practical interest to study the possibility of improving the physical and mechanical properties of nickel-based CEC by introducing metals capable of heat treatment, interact with the metal matrix to form solid substitution solutions and chemical compounds (solid phases of implementation) and determine tribotechnical characteristics of these coatings.

Keywords: composite electrolytic coatings (CEC), wear resistance.

Introduction

A significant contribution to the theory and practice of electrodeposition of composite electrolytic coatings (CEC) is the work of R.S. Saifulina, Sh.Kh. Yar-Mukhamedova, V.F. Molchanova, G.V. Guryanova, D.K. Romanuskene, G. Brown, N. Guglielmi, I.Z. Pribish, I.G. Khabibulina, R.S. Kuramshina, V. Metzegra, L.I. Lozytskoho, Yu.O. Gusliencko, MV Luchki and others. Various combinations of different chemical elements and compounds in composite coatings have been studied, but the main attention is paid to the technology of application, the study of structures and the formation of various complexes of physical and mechanical properties. Studies of CEC from the standpoint of tribotechnics are very few, or they are presented in the form of single results, which can not give a general picture of the possible prospects for the use of CEC to increase the wear resistance of machine parts.

The industry widely uses coatings in which the metal base is chromium, nickel, iron, copper, cobalt and others. But the most widely used are composite coatings based on nickel. Nickel is widely used as a matrix for CEC, because it has an affinity for most particles used as the second phase and easily forms a coating with them. In addition, electrolytic nickel has sufficient mechanical properties, high corrosion resistance, ductility [1, 2].



Nickel-based CEC is used in ship, automobile, tractor, aircraft, rocket, mechanical engineering, chemical industry, for parts and assemblies operating in particularly severe friction conditions, elevated temperatures, in conditions of friction without lubrication, heavy loads. These coatings are used for corrosion protection, increase of physical and mechanical and chemical parameters, increase of hardness and wear resistance, restoration of the sizes, giving to a surface of self-lubricating properties.

CEC application technologies

In comparison with other methods of obtaining protective coatings, the technology of applying CEC is relatively simple and is reduced to the introduction into the known electrolytes of dispersed particles of chemical compounds maintained in suspended state by periodic or continuous stirring of the electrolyte suspension. Being in static or dynamic contact with the cathode surface during electrolysis, the filler particles are overgrown with the base metal. A number of works are devoted to the development of the technology of obtaining composite electrolytic coatings (CEC) [1, 3, 4, 5]. In these works the theoretical bases of joint deposition of metal and dispersed particles are stated, a large number of CEC of various properties and appointments is offered.

The type of dispersed materials for obtaining CEC is selected depending on the operating conditions of the part, physico-mechanical and chemical properties of the filler and the main effect it has on the composition.

As a filler in the creation of CEC, use dispersed particles of the following materials: diamond, amorphous carbon, boron, graphite, silicon, solid refractory compounds: oxides (Al_2O_3 , SiO_2 , TiO_2 , ZrO_2 , CrO_2 , MoO_2 , BeO_2), carbides (SiC , B_4C , TiC , ZrC , HfC , TaC , VC , WC), borides (TiB_2 , ZrB_2 , VB_2 , CrB_2), nitrides (TiN , BN , AlN , Si_3N_4), silicides (MoSi_2 , NbSi_2 , TaSi_2 , HfSi_2 , WSi_2), powders various metals (Ti , Mo , W), low-melting powders (Sn , In , Pb) and other particles [1-5].

The properties of CEC with different types of filler are mostly determined by the physical and mechanical properties of the inclusions. Thus, borides have high heat resistance, hardness and pronounced metallic properties, however, they can interact with electrolytes, and are not sufficiently stable in acids; carbides of many metals have high hardness, heat resistance and chemical resistance; nitrides, in contrast to borides and carbides, have lower hardness, greater plasticity, sufficiently heat-resistant; oxides are more resistant to aggressive environments, heat resistant; silicides are promising as heat-resistant compounds, have magnetic properties and conductivity. Substances with a layered crystalline structure are of special interest for obtaining CEC. Such materials are the basis for self-lubricating coatings and coatings with improved antifriction properties.

The volume content of particles that can be introduced into the electrolyte depends on their shape, nature, dispersion, electrolyte acidity, cathodic current density, location of the cathode surface (horizontal or vertical), mixing conditions. Theoretically, when modeling the dense packaging of the dispersed phase in the form of powders of the same size, the maximum filling of the space, provided that the spherical particles touch, is 74%. The data presented in the monograph [65] indicate the possibility of obtaining a volume fraction of the dispersed phase in the CEC up to 50%. Theoretical calculations and experimental data show that when real dispersed powder particles have different shapes and sizes, when smaller particles can be located between large ones, then the maximum volume content in the coating can reach 60%. However, in the absence of contact between the filler particles, when a solid or frame structure of the matrix is formed, their volume fraction in the coating reaches only 30% [6]. Therefore, this volume content of the dispersed phase can be considered the limit, at which the particles are completely cemented by a metal matrix. The use of CEC filler powders of various nature and dispersion can have an effect on their volume content in the coating, but usually in the direction of its reduction.

It is established [1,3] that when using electrically conductive particles in the process of forming CEC, their volume content in the coating is always greater than those that do not conduct current. This allows a lower content of particles in the electrolyte-suspension to obtain a higher content in the coating compared to the use of non-conductive powders.

Of practical and theoretical interest is the method of calculating the maximum possible production of the dispersed phase in the CEC depending on the bulk density of the powder fraction and the deposition parameters, which is presented in [4].

As for the dispersion of particles, many researchers believe that the optimal fraction $-2 + 0.1 \mu\text{m}$, which provides the maximum number of particles in the coating when deposited in continuous stirring on a vertical cathode and a fraction of $-50 + 40 \mu\text{m}$ and above when deposited on a horizontal cathode [3,5,7].

The volume content of particles in the CEC during its production is significantly influenced by the nature of the electrolyte, the presence of a sufficient number of particles, the cathode current density, the process temperature and so on. The ionic composition of the electrolyte, its electrical conductivity, density, acidity, deposition modes in different ways can affect the quality of CEC. The complexity of the deposition process, the large number of factors that affect it, does not allow to accurately predict the optimal modes of formation of CEC [1, 3, 4].

The basis for the installation for the formation of CEC, created at the Khmelnytsky National University (KhNU), the task of control and regulation of the rate of deposition of electrically conductive and sedimentation

of non-conductive particles of filler powders. This task is achieved due to the fact that in the process of electrolysis the delivery rate of the filler particles is controlled and regulated by changing the electric field strength using a potentiostat. [8].

Influence of filler content and electrolyte composition

The greatest influence on the content of inclusions in the coating, and, accordingly, on the physical and mechanical properties of the coating, has the number of powder particles in the electrolyte. From the literature data it follows [3] that with increasing concentration of both large and small particles in the electrolyte, the number of inclusions in the coating increases. The number of particles in the CEC increases both with increasing size of the fractions of the powders used and with increasing their concentration in the electrolyte. Moreover, with increasing the concentration of particles to 50 kg/m³ there is a significant increase in their content in the coating. The maximum mass fraction of inclusions in the CEC is achieved at a concentration of particles in the electrolyte of 100 kg/m³, so it can be considered optimal for all fractions of powders used.

The composition and parameters of the electrolyte affect the filler content in the coating in different ways. Thus, it was found that the formation of particles and their overgrowth with metal easily proceeds from the nickel electrolyte [3,5], and most difficult from the chromium electrolytes. The acidity of the electrolyte is a determining factor in the formation of CEC, for example, on the basis of chromium and does not have a significant effect on the production of CEC on Nickel basis. Thus, during the deposition of CEC based on Nickel using particles up to 10 µm, the change in electrolyte acidity in the range from 2 to 5 pH units does not affect the deposition of particles, including pH = 4-5 if the particles are larger than 20 µm [1].

Cathodic current density and electrolyte temperature

Increasing the cathode current density has a positive effect on the overgrowth of particles. In most cases, increasing the cathode current density leads to an increase in particle content and increase the thickness of the coating, but there is a critical value of the cathode current density exceeding which disrupts the electrolysis process and leads to deterioration of CEC [1,5].

The current density determines the rate of increase of the galvanic coating, but at a density of more than 2 kA/m² the surface of the coating has many defects, poor quality overgrown particles of silicon carbide of large fractions. In addition, the possible release of hydrogen ions and the coating is then loose, spongy and with a dendrotic structure. At a density of more than 1 kA/m² the surface has an uneven relief and high roughness. Studies have also shown that increasing the current density for non-conductive particles of boron and silicon carbide has virtually no effect on the bulk filling of the Nickel matrix with filler. Therefore, in our work, electrolysis was performed at a current density in the range of 0.4... 1 kA/m² [8].

It is noted [1] that the temperature regime of electrolytes in obtaining CEC has a certain effect on the deposition rate. This effect is especially noticeable when obtaining CEC based on metals of the iron family, although a certain pattern of the effect of temperature on the retention of particles in the coating is not observed.

The presence of two cooling circuits on the installation developed at KhNU allows to stabilize the electrolysis temperature in the cathode zone within ± 2 °C, which also helps to stabilize the electrolysis process in the formation of the metal matrix and in the formation of coatings with filler particles. It also allows to obtain a coating of uniform thickness and with a lower surface roughness [8].

Electrolyte mixing rate

The mixing rate of the electrolyte-suspension has a particularly large influence on the formation of CEC [1, 4]. Stirring of the electrolyte in the electrolysis process accelerates the process of electrochemical deposition of metals. Stirring is also necessary to ensure that the particles of the dispersed phase (even less than 1 µm), which are in the electrolyte, are always suspended. This is especially important when using particles larger than 5 microns. It is difficult to establish the explicit regularity of the influence of the stirring speed on the production of particles in the CEC, because it is not possible to accurately determine the rate of exit of particles in the current. In the general case, with increasing speed of rotation of the stirrer, the content of particles in the coating first increases, and then, when a certain limit is reached, decreases. The fraction of the filler powder has a determining influence [1, 5].

Influence of filler type for formation of nickel CEC

The study of the influence of dispersed filler particles of various natures introduced into the electrolyte on the process of formation of nickel CECs and their properties is devoted to works [1, 3, 4,5]. They present data on the effect of different filler particles on the microhardness, wear resistance and internal stresses of the CEC, determine their optimal concentrations in the electrolyte - suspension. Composite electrolytic coatings with

inclusions of titanium, tungsten and silicon carbides have the greatest wear resistance. Zirconium and aluminum oxides increase wear resistance to a lesser extent. In addition, carbides significantly (5-8 times) reduce the internal stresses of CEC [2].

In [6] the influence of electrical conductivity of dispersed particles on their distribution in the nickel matrix, structure and quality of precipitation was studied. For non-conductive particles (silicon carbide), their uniform distribution in the matrix is characteristic, while for electrically conductive materials (chromium carbide), this was not observed. The roughness of coatings filled with chromium carbide particles is higher than in CEC Nickel-silicon carbide. The wear resistance of CEC increases with increasing number of particles in the matrix [8].

Silicon carbide is recommended for the creation of compositions to increase hardness and wear resistance under friction without lubrication and at elevated temperatures [10, 11], corrosion resistance [8]. Silicon carbide in the nickel matrix improves the properties of the coating: microhardness increases by 1... 2.5 GPa, internal stresses decrease by 3... 8 times, and corrosion resistance increases by 4... 50 times [6]. Silicon carbide coatings have the best adhesion to steel compared to other fillers. The strength of adhesion to the base has the following range, kg/cm²: 487-SiC; 213-TiC; 216-Cr₇C₃ [5].

In addition, silicon carbide has high mechanical properties: microhardness 29... 35 GPa, modulus of elasticity $E = 394$ GPa, tensile strength -180 MPa, flexural strength -173... 225 MPa, compressive strength -800 MPa [8, 12].

Silicon carbide has a low cost and is produced in large quantities in the form of powders packaged in fractions. Based on the above, in our work we investigated the CEC on a nickel basis with SiC filler of different fractions from 100/80 μm to nanoparticles smaller than 50 nm. Thus, SiC powders with the following sizes were used in the works: less than 50 nm - nanoparticles; M5; 28/20; 50/40; 100/80 μm . According to the sizes of SiC particles the following designations are accepted: Ni-SiC_{nano}; Ni-SiC₅; Ni-SiC₂₈; Ni-SiC₅₀; Ni-SiC₁₀₀.

Additives of surfactants

To intensify the process of deposition of CEC and improve the quality of sediments in the electrolyte is introduced various organic and inorganic additives and surfactants (surfactants), which contribute to the receipt of uniform and dense sediments with fine crystalline structure. It is known that the addition of soluble organic and some inorganic substances changes the cathodic polarization and the equalizing ability of the electrolyte [9]. It can be assumed that these substances will significantly affect the process of formation of CEC. Thus, when studying the effect of surfactants on the coprecipitation of Nickel with silicon carbide particles, it was found that the introduction of cationic surfactants reduces the rate of SiC at low concentrations of substances in the electrolyte and increases sharply at high, and the introduction of anionic surfactants at a certain concentration completely stops particle deposition. The effect of anionic surfactants is associated with the agglomeration of particles as the concentration increases and their deposition in the electrolyte; influence of cationic surfactants - with positive charging of particles and their sedimentation with the formation of a dense layer at the cathode.

In our studies, the electrolyte was additionally injected with sodium surfactant in the amount of 0.01... 0.02 g/l, which according to [12] promotes the inclusion of SiC particles in the coating and improves the conditions for building a nickel matrix.

Amorphous boron powders with a size of about 1 μm were also added to the silicon carbides as a filler, which is explained by the possibility of boron and nickel interaction during the subsequent heat treatment of the coating and obtaining new structures (solid solutions, eutectic, dispersion-hard alloys).

Intensification of CEC formation processes

Among the modern innovations in the technology of electrolytic coatings are the use of non-stationary electrical modes (reversible or pulsed currents, the application of alternating current to direct current) [11] and the application of ultrasound in the application of electrolytic coatings [10, 11]. The use of reverse current (current with periodic change of polarity) has a positive effect on electrode processes and increases the productivity of electrolysis. During the anode period, the microprojections on the cathode dissolve and as a result the unevenness of the coating and its porosity decreases. Also, the use of such modes allows to obtain a more dispersed structure of the sludge with lower internal stresses. The use of pulsed current (current pulses with a very short duration (<1 ms) and an amplitude that is an order of magnitude higher than the limiting current of the process) allows to increase the deposition rate to obtain more uniform and fine crystalline sediments, but slightly reduced (5-10%) cathode current output. The application of ultrasonic waves allows to precipitate metal at high current densities with high current output, electrodeposition of pure metals in the presence of impurities in the electrolyte, precipitate smooth, compact, fine with high corrosion resistance and lower internal coating stresses. Thus, these methods can improve the structure of the coating, increase microhardness, increase wear resistance and anti-corrosion properties.

Combined CEC

Analysis of the results of [1-5] shows that combined electrolytic coatings based on Nickel with inclusions of dispersed particles have a significantly higher wear resistance than coatings without particles. In the general case, the increase in wear resistance of CEC in comparison with pure galvanic coatings is 2.5-5.0 times [2]. Comparative tests for friction and wear show a clear advantage of nickel-based CEC with inclusions of oxides, borides, carbides, in comparison with hardened steels 45, 40X, 30HGT. It is noted that the inclusion of carbides in nickel CEC more significantly increases the wear resistance than the inclusion of oxides, and the lowest wear was observed for coatings containing particles of TiC, WC, Cr₃C₂ [3]. The authors explain the increase in wear resistance of Nickel coatings when particles are introduced into them by the fact that solid particles carry the main load and contribute to better distribution of lubricants. Coatings with inclusions of WC particles have a high microhardness (up to 500 kg/cm²) and, accordingly, less wear than Nickel. The wear resistance of combined layers with SiC is almost 70% higher than for nickel without carbide. Data on the wear rate of composite coatings after heat treatment with nickel borides and chrome coatings are also given. It is noted that CEM with borides have the same wear resistance as chrome coatings, and sometimes exceed it.

In the absence of lubricant, galvanic coatings effectively reduce the coefficient of friction only when applied to a solid substrate. Coating steel with copper, zinc, tin, nickel, lead can reduce the coefficient of friction. Applying such coatings on a soft base is not acceptable for friction joints [3].

Wear and degree of destruction of CEC depend on friction conditions. At high specific loads (200 N/cm²) plastic deformation precedes the formation of microcracks, which due to insufficient strength of adhesion of the coating to the matrix develops mainly at the interface. For reliable operation of the friction unit, the mechanical properties of the CEC matrix must be consistent with the external operating conditions.

The mechanical and antifriction properties of CEC have a significant effect on the crystal structure of the particles. Borides and carbides increase the hardness of CEC most effectively. Particles with a cubic crystal structure significantly increase the hardness of nickel coatings. This is due to a more even distribution of local stresses in the volume of coverage and a significant improvement in the elastic properties of the matrix.

In [2,3,4,12] the hardness, wear resistance and structure of CEC on a nickel basis with microparticles of boron carbide, chromium, silicon, titanium, industrial micropowders of carborundum and electrocorundum, synthetic diamonds when reaching their maximum content in coverage. Increasing the concentration of micropowder M1 from 50 to 300 g/l leads to an increase in the number of inclusions from 4 to 10% and microhardness from 3.25 to 4.5 GPa. Increasing the volume fraction of silicon carbide particles from 3.8 to 18.9% increases the microhardness from 2.9 to 5.5 GPa and, accordingly, increases the wear resistance by 3 times [12,13].

According to the authors of [6], the increase in the microhardness of coatings during the introduction of dispersed particles is associated with a change in the substructure of the deposited metals (reducing the size of crystal blocks and increasing the density of dislocations). Thus, the existence of optimal concentrations of particles of titanium carbide, zirconium dioxide and kaolin (30-50 g/l) in the nickel electrolyte, which correspond to the minimum block size and maximum micro-distortion size and dislocation density. The change in the size of the blocks in Nickel coatings is due to the different effects of particles introduced into the electrolyte on the ratio of growth rates and passivation of crystals. According to the author, the grinding of the blocks is facilitated by submicroscopic particles that are included in the sediment and prevent the growth of crystals by shielding their surface. The content of particles in the electrolyte has only an indirect effect on the substructure of the matrix. The decrease in mosaic blocks with increasing concentration of particles in the suspension can be explained by the depressant effect of not all particles in the electrolyte, but only by the action of particles deposited on the growth front of the matrix.

Self-lubricating CEC

Self-lubricating coatings are also used to reduce friction steam wear [2,5]. These are CECs, which contain solid lubricant particles and have a better ability to run and reduced friction. As the second phase in such coatings are particles of molybdenum disulfide, graphite, boron nitride and other substances. The introduction of such particles into the matrix usually increases its plasticity and the tendency of coatings to deformation hardening. Coatings with solid lubricants are suitable for use in vacuum conditions, and their use for air friction units is limited by the temperature regime and the tendency to oxidation of particles and as a result the coefficient of friction increases sharply. However, at moderate loads and sliding speeds, solid lubricants significantly reduced the wear of CEC [14].

Thus, the dispersed particles to obtain CEC must be selected taking into account their properties, nature and crystal structure, properties of the matrix, its crystal structure and friction conditions.

Heat treatment of CEC

The analysis of CEC on a nickel basis testifies to wide technological possibilities of their reception and a variety of the received structures and their properties. Electrochemically deposited metals in most cases do not require further heat treatment and are in a state typical of metals that are subjected to low-temperature hardening. However, due to the lack of coherent connection of particles with the matrix, it is possible to chip particles in the process. At the same time, the level of wear resistance of CEC is low in comparison with hard chrome coverings. In addition, electrolytic coatings, including CEC, in comparison with others have a number of disadvantages, namely: low adhesion to the substrate, the presence of pores and microdefects, internal stresses, sludge flooding. Therefore, many researchers [3, 4, 8,9] have studied the effect of annealing on the hardness and wear resistance of CEC, in order to improve the strength of adhesion to the metal substrate, increase the density of sediments by overgrowing pores, cracks and other defects inherent in electrolytic coatings. Thus, in the process of heat treatment there is a recrystallization of the metal and a change in properties, namely the improvement of ductility and wear resistance. In [9] studies on the effect of annealing modes on the bond strength of CEC Nickel-silicon carbide, Nickel-carborundum with aluminum alloys AK-18, AL-7, AD-25. The maximum bond strength of these coatings with the substrate was achieved after annealing at a temperature of 200 ° C for 2 hours. Studies [3,16,17] aimed at increasing the hardness of nickel-based CEC with the inclusion of oxides of chromium, titanium, thorium, aluminum, as well as chromium and silicon carbides due to their annealing did not give positive results. Annealing carried out in the temperature range from 200 to 700°C, led to a loss of hardness, apparently due to the removal of internal stresses and weakening of the Nickel matrix. The microhardness of coatings with increasing annealing temperature decreased from 3.2-4.8 GPa to 2.0-3.2 GPa.

In some cases, combined electrolytic coatings are subjected to heat treatment to improve mechanical properties (high temperature resistance) or to detect the tendency to oxidation at high temperatures. For example, coatings of Ni + Al₂O₃, Ni + Ti and others. show increased durability at high temperatures. This type of heat treatment does not lead to the creation of qualitatively new structures and does not change the phase composition of the coatings.

It is possible to significantly increase the operational properties of CEC by heat treatment by conducting filler particles in them, which tend to interact with the metal matrix and form solid solutions and chemical compounds with high hardness and wear resistance. Thus, in [3, 4] data on heat treatment of combined electrolytic coatings based on Nickel, which aims to qualitatively change the phase composition and structure of the coating. The authors of these works received coatings containing powders of tungsten and molybdenum, which were subjected to subsequent annealing. Annealing of other electrolytic compositions, such as Ni+Cr (powder) and Fe+Cr (powder), leads to coatings such as stainless steel [5]. The process of heat treatment of composite coatings can be considered as a kind of chemical-heat treatment, in which the diffusion element is inside the metal matrix. In addition, the heat treatment of CEC can be carried out using concentrated energy sources such as lasers, high frequency currents, solar energy. The main advantages of such processing are locality, possibility of receiving high temperatures at insignificant duration of processing, high speeds of heating and cooling. The prospects for the use of these energy sources in heat treatment are noted in [3, 17, 18]. But in them the main attention is paid to studying of the structures formed at such processing. Based on this, it is of practical interest to study the possibility of improving the physical and mechanical properties of nickel-based CEC by introducing into their composition metals capable of heat treatment, interact with the metal matrix to form solid substitution solutions and chemical compounds (solid implementation phases) and determine tribotechnical characteristics of these coatings [8, 19].

Based on the analysis, thermal annealing in a muffle furnace was performed at a temperature of 400°C for 1... 2 h, which increased the cavitation-erosion resistance of the Ni-SiC_{nano} composition by approximately 20% in hard water and about 30% in 3% NaCl solution [8]. The latter is due to the reduction and equalization of internal stresses in the coating, reducing the heterogeneity of the structure. The annealing temperature was chosen on the grounds that irreversible transformations and eutectic formations take place in the temperature range 120... 220; 300... 350 and 370... 450°C.

Vacuum annealing with melting of the coating surface was performed on the installation OKB 8086 at temperatures of 1085... 1090°C. After holding in the furnace, the samples were cooled together with the furnace. After heat treatment, the microstructure forms a framework consisting of Ni-Ni₃B eutectic and Ni₃B borides with hardness H_μ = 6.6 ... 7.4 GPa. Cavitation-erosion tests of Ni-SiC₂₈-B CEC after vacuum annealing in hard water showed that the wear resistance in 2 hours of testing increases, compared to CEC without vacuum annealing, 2 times.

Therefore, vacuum annealing at the temperature of eutectic formation allows to obtain dense, smooth coatings with high cavitation and erosion wear resistance.

Conclusions

1. When forming CEC, depending on the physical and mechanical requirements for the surface of the part, it is necessary to choose the type of matrix, the nature of the particles and their fractionality, to find the optimal technological modes of electrolysis and so on.

2. CEC based on nickel matrix filled with silicon carbide (SiC) particles are promising coatings to improve the tribological characteristics of structural steels.

3. In order to improve the physico-chemical characteristics of the nickel-based CEC, it is necessary to introduce chemical compounds into the electrolyte, which as a result of heat treatment form solid substitution solutions and solid phases of introduction.

References

1. Antropov L.I., Lebedinsky Yu.N. Composite electrochemical coatings and materials. - K.: Technique, 1986. - 200 p.
2. Borodin I.N. Powder electroplating - M.: Mashinostroenie, 1990. - 240 p.
3. Guslienko Yu.A. Research on the processes of obtaining wear-resistant composite coatings based on nickel and iron and the study of their properties: Dis. ...cand. tech. Sciences: 05.16.01. - K., 1975. - 155p.
4. Luchka M.V., Kindrachuk M.V., Melnik P.I. Wear-resistant diffusion-alloyed composite coatings. - K.: Technique, 1993. - 143 p.
5. Saifullin R.S. Composite coatings and materials. - M. Chemistry, 1977. - 272 p.
6. Samsonov G.V., Zhunkovsky G.L., Luchka M.V. Study of the process of formation of composite coatings based on titanium carbide // Powder metallurgy. - 1976. - No. 7. - P.53-56.
7. Kovalenko V.S., Golovko L.F., Chernenko V.S. Hardening and alloying of machine parts with a laser beam. - K.: Technika, 1990. - 192 p.
8. Bilyk Yu.M. Increasing cavitation-erosion wear resistance of carbon structural steels by composite electrolytic coatings Dis. Cand. tech. Science: 05.02.04. - Khmelnytsky., 2014. - 169 p.
9. Frolova F.P., Zhitkevich I.I., Mikhailenets E.S. Causes of adhesion of nickel-silicon carbide coatings to aluminum alloy. AN Lit.SSR, 1975. - No. 5 (114). - P.21-28.
10. Yavorsky V.T., Kuntiy O.I., Khoma M.S. Electrochemical application of metal, conversion and composite coatings / Lviv Polytechnic State University. - L., 2000. - 216 p.
11. Kuntiy O.I. Electroplating: Textbook for students majoring in 7.091603 "Technical Electrochemistry" / National University "Lviv Polytechnic". - L.: Lviv Polytechnic Publishing House, 2004. - 236 p.
12. Perene N.S., Taitas L.I. Wear resistance of composite coatings // Tr.ANLit.SSR. - 1977. - No. 1 (98). - P.27-31.
13. Bykova M.I., Antropov L.I. Combined nickel coatings with increased hardness and wear resistance // Obtaining hard wear-resistant galvanic coatings. - M.: MDNTP, 1970. - P. 106-110.
14. Molchanov V.F., Ayupov F.A., Vandyshv V.A. Combined electrolytic coatings. - K.: Tehnika, 1976 - 176p.
15. Borodin I.N. Powder electroplating - M.: Mashinostroenie, 1990. - 240 p.
16. Pletnev D.V., Brusentsova V.N. Fundamentals of technology of wear-resistant and anti-friction coatings. - M.: Mashinostroenie, 1968. - 272 p.
17. Wagner E., Broszeit E. An electrochemical investigation of corrosive wear of as-plated and heat-treated Ni and Ni-SiC coatings // Wear. - 1979. - Vol. 55, No. 2. - P. 235-244.
18. Tikhonovich T.N. Structure formation, properties and technology for obtaining protective composite electrolytic boride coatings based on metals of the iron family: dissertation cand. tech. Sciences: 05.16.01. - K., 1989. - 145p.
19. Obtaining composite boride coatings by surface heating with concentrated energy sources // Yu.A. Guslienko, T.N. Tikhonovich, V.P. Stetsenko, V.S. Dvernyakov // Protective coatings on metals. - 1993. - Issue. 27. - P. 35-39.

Скиба М.Є., Стечишин М.С., Олександренко В.П., Машовець Н.С., Білик Ю.М.
Зносостійкість композиційних електролітичних покриттів

У статті проведено аналіз впливу композиційних електролітичних покриттів (КЕП) на зносостійкість конструкційних сталей. Розглянуті питання вибору матриці і різноманітні поєднання у композиційних покриттях різних хімічних елементів та сполук. У промисловості широко використовують покриття, в яких металевою основою є хром, нікель, залізо, мідь, кобальт та інші, але найбільш широке застосування мають композиційні покриття на основі нікелю. Нікель широко використовується в якості матриці для КЕП, тому що він має спорідненість до більшості частинок, що застосовуються як друга фаза і легко утворює з ними покриття. Дані покриття використовують з метою корозійного захисту, підвищення фізико-механічних та хімічних показників, підвищення твердості та зносостійкості, відновлення розмірів, надання поверхні самозмашувальних властивостей.

На базі створеної установки для нанесення КЕП досліджувалися покриття на нікелевій основі з наповнювачем SiC різних фракцій від розміру 100/80 мкм до наночастинок розміром менше 50 нм. Таким чином, в роботах використано порошки SiC₃ розмірами: менше 50 нм- наночастинки; M5; 28/20; 50/40; 100/80 мкм.

В проведених дослідженнях в електроліт додатково вводили ПАР-лаурилсульфат натрію в кількості 0,01...0,02 г/л, який сприяє включенню частинок SiC₃ покриття та покращує умови нарощування нікелевої матриці.

До карбідів кремнію в якості наповнювача додавали також порошки аморфного бору розміром біля 1 мкм, що пояснюється можливістю взаємодії бору та нікелю при наступній термічній обробці покриття і отримання нових його структур (тверді розчини, евтектика, дисперсійно-тверді сплави).

Практичний інтерес становить вивчення можливості підвищення фізико-механічних властивостей КЕП на нікелевій основі введенням у їх склад металів, спроможних у процесі термічної обробки, взаємодіяти з металевою матрицею з утворенням твердих розчинів заміщення і хімічних сполук (твердих фаз впровадження) та визначення триботехнічних характеристик цих покриттів.

Ключові слова: композиційні електролітичні покриття (КЕП), зносостійкість