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MODELING AND OPTIMIZATION OF CHROMIUM ALLOYED COATINGS PRODUCTION USING CPS

Modeling and optimization of the formation of protective layers of titanium alloyed with chromium, obtained using composite powder charge (CPS) is considered. As an optimization parameter the wear resistance *index at titanium-chromium plating for Ti-Cr system is chosen. The mathematical dependences of microhardness on the thickness of the obtained titanium-chromium coatings on the composition of the powder charge, which are described by a polynomial of the fifth order, are established. The response surfaces of the obtained mathematical models are represented by three-dimensional graphical dependences.*
Keywords*: mathematical modeling, wear resistance, composite powder charge, temperature, optimization, microhardness.*

Розглянуто моделювання та оптимізація формування захисних шарів титану, легованого хромом, отриманого з використанням композиційного порохового заряду (КПЗ). Як параметр оптимізації обрано показник зносостійкості при титанохромуванні для системи Ti-Cr. Встановлено математичні залежності мікротвердості товщини отриманих титанохромових покриттів від складу порошкової шихти, які описуються поліномом п'ятого порядку. Поверхні відгуку отриманих математичних моделей представлені тривимірними графічними залежностями.
Ключові слова*: математичне моделювання, зносостійкість, композиційні порошкові середовища, температура, оптимізація, мікротвердість.*

Formulation of the problem

Modern operating conditions of parts of machines, aggregates, equipment, tools and mechanisms place increased demands on their physical and mechanical characteristics and working life. In this regard, the properties of their surface layer are of great importance, and the development of new technologies for strengthening parts from structural materials is gaining relevance.

Methods of creating various functional coatings are widely used for processing products made of carbon and alloy steels. The coating is a locally modified surface layer, characterized by a certain chemical and structural phase composition, which is qualitatively different from the base material.

In the work [1], which is devoted to refractory coatings, they are divided into four groups: diffusion, plasma, detonation, combined. In this case, the classification of coatings is given according to the technological principle. Coating methods in work are classified by the type of delivery of the coating material to the surface of the base material and are divided into two large groups: contact methods, in which the base material comes into contact with the coating elements, which are in any phase (gas, solid, liquid); non-contact or chemical methods, in which the coating material comes in bound form. The given classification is convenient for identifying the limiting process of coating formation, as well as for kinetic assessment of the concentration of the coating element in the surface layer of the substrate.

Analysis of recent research and publications

Classification of existing methods and methods of surface modification of materials are given in works [2—8]. The authors [9—11] highlighted the following methods: hot method, electrolytic method, galvanization, spray metallization, diffusion saturation, plasma and laser sputtering, chemical method, plating, electrophoretic method, vacuum metallization.

Hot dip in a melt is one of the oldest coating methods. Bath metals have a low melting point (zinc, tin, aluminum) and protect the base metal from corrosion. Spraying is carried out with small particles of material or powder through an oxygen-acetylene flame, followed by deposition on a cold base. Electric arc or plasma metallization can be used for heating. This helps to improve adhesion and reduce the porosity of the coating. Surfacing is carried out by fusing the deposited material with the surface layer of the product. All basic welding processes can be used for coating by surfacing: gas flame, electric arc, plasma, electron beam, etc. Electrochemical deposition of metals from salt solutions is usually used to obtain galvanic coatings of chromium and nickel with a thickness of 0.12—0.60 mm. Electrolytic coating of Ni – P and Ni – B alloys is carried out as a result of chemical interaction. Chemical vapor deposition, or the CVD process (chemical vapor deposition), is a process in which stable reaction products are generated and grow on a substrate in an environment with chemical reactions (dissociation, reduction, etc.). Thanks to the high temperature, very thin layers are formed on the surface. The CVD process is used to apply coatings to tools and dies. The most common method of surface strengthening is chemical-thermal treatment (CHT). CHT technology is a fairly effective method of processing aimed at obtaining coatings with high adhesive strength with the base due to significant mutual penetration of saturating elements into the base, and elements of the base into the coating, wear resistance, corrosion resistance, and provides increased static strength under the influence of alternating loads. It should also be noted that diffusion coatings, unlike coatings obtained by other methods, are characterized by the stability of properties in various operating conditions. A variety of combined processing methods can be used, for example, a combination of CHT methods with plasma processing [9].

Formulation of the purpose of the research

The purpose of the work is to search for effective powder CPS, which allows to form wear-resistant protective layers on structural materials with different carbon content using technological processes of self-propagating high-temperature synthesis. The surface hardness is used as an optimizing factor, which has a direct proportional effect on wear resistance under conditions of various types of friction. Solving this problem allows to ensure the durability of the equipment in the conditions of coke-chemical production and details of the utility company "Vodokanal".

Presenting main material

The wear characteristic ДJ is the change (decrease) in the mass of the sample made of steel 45, on which the coating was obtained at $t_п = 1050$ °C and $ф_в = 60$ minutes.

The selection of the optimal composition of the charge for carrying out SBS under conditions of thermal self-ignition is carried out on the basis of the results of studies of the thermal picture of the CPS process.

Optimization parameters:

Y1 — indicator of wear resistance for the system Ti-Cr;

The choice of the main level and the intervals of variation is based on the fact that the introduction of CS, less than 10 % by mass, leads to the breakdown of the combustion wave of thermal self-ignition. Based on the study of the change in the characteristic temperatures of the CPS process, the amount of CS is selected. It is used as a ballast admixture to obtain a one hundred percent composition of powder CPS-charges Al_2O_3.

The numerical value of the regression coefficients and their significance, determined taking into account the difference in variance for each response function, as well as the significance test according to the Student's test and the assessment of the adequacy of the model according to the Fisher test.

As a result of the regression analysis, equations are obtained that show the dependence of the wear resistance of protective coatings on the mode of thermal self-ignition and the content of alloying elements.

As a result of the calculations, the following equations are obtained:

$$Y_1 = 87{,}6 - 1{,}3X_1 - 1{,}3X_2 - 0{,}6X_3 - 1{,}5X_1^2 + 1{,}5X_2^2 + 3X_3^2 - 0{,}875X_1X_2 + 2{,}125X_1X_3 - 0{,}25X_2X_3. \quad (1)$$

Testing the adequacy of the models shows that they can be used to predict the response functions at any factor values between the upper and lower levels. For this, it is advisable to switch to natural variables using the translation formula presented in the following form:

$$X_{ij}^{k} = \frac{X_{ij}^{n} - X_{ij}^{o}}{\Delta_i}, \tag{2}$$

where X_{ij}^{k} — coded value of the *i*-th factor, which is studied in the *j*-th equation; X_{ij}^{n} — natural value of the *i*-th factor, which is studied in the *j*-th equation; X_{ij}^{o} value of the *i*-th factor, which is studied in the *j*-th equation at the basic level; Δ_i — value of the variation interval of the *i*-th factor under investigation.

Coefficients whose absolute value is equal to the confidence interval Дb or more should be considered statistically significant. Statistically insignificant coefficients can be excluded from the models.

By replacing the variables Xi in equation (1) with the right-hand side of equation (2) and the subsequent reduction of similar ones, we obtain natural equations characterizing the effects of the mode of thermal spontaneous ignition and the content of alloying elements on the wear resistance of protective coatings:

$$ДJ_1 = 140{,}35 + 1{,}39\,XC + 0{,}31Ti - 6{,}59Cr - 0{,}06\,XC^2 + 0{,}06\,Ti^2 + 0{,}12\,Cr^2 - 0{,}04\,XCTi + 0{,}09XCCr - 0{,}045TiCr. \tag{3}$$

To assess the adequacy of the equations, a calculation is made based on the obtained regression equations for the optimal mode of thermal self-ignition. Calculation results are compared with experimental data. It was established that the error between the calculated and experimental values of the response function does not exceed 1.5 %.

With the help of mathematical planning of the experiment, the number of studies required to calculate the coefficients of the regression equation and obtain an adequate model, which characterizes the influence of the elements of the CPS charge on the operational properties of steels with alloyed protective coatings, is significantly reduced. The response surfaces of the obtained mathematical models are represented by a three-dimensional graphical dependence (Fig. 1).

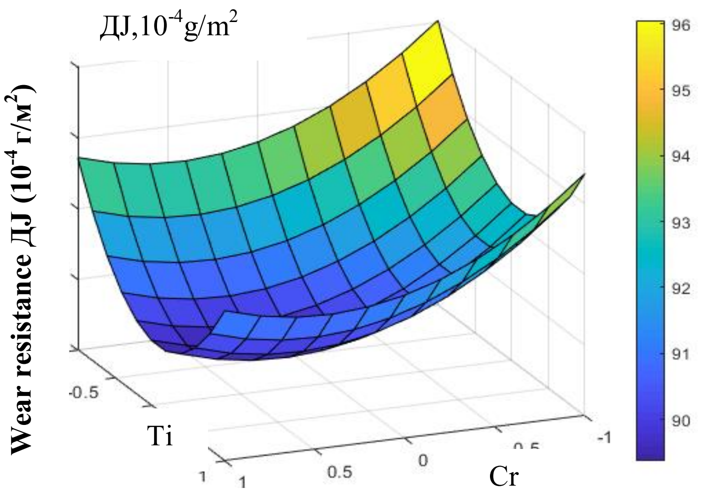


Fig. 1. The influence of the content of Ti and Cr (% by mass) in the CPS-charge on wear resistance ДJ

The rational content of titanium is 22—26 % by mass, and chromium is 4—7 % by mass. (for the Ti-Cr system), thus, these values of the content of titanium and chromium make it possible to obtain minimum indicators of wear of steels with alloyed protective coatings. Recommended rational

CPS charge for obtaining wear-resistant alloyed protective coatings: 25% CS + 25% Ti + 5% Cr + 39% Al_2O_3 + 2% I_2 + 4% NH_4Cl.

Microhardness is an important characteristic of the physical and mechanical properties of coatings, it determines the resistance of coatings to the influence of an aggressive environment. This especially applies to the upper layers of the coating, which are primarily in contact with corrosive-erosive environments. Microhardness tests are carried out either with the help of desktop devices, which use the scheme of a vertical portable microscope with a turret head and direct load using weights (PMT-2 and PMT-3 devices), or in the form of an attachment to horizontal metal microscopes with a spring load (device Hahneman and others).

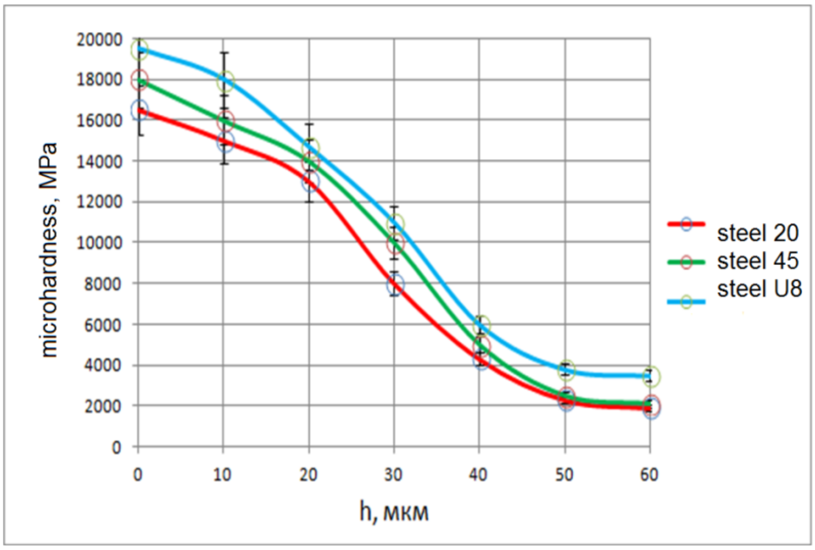
Microhardness testing has found important applications where other methods are unavailable:

1) determination of the hardness of individual microstructural components; microhardness allows, along with a qualitative microscopic study, to evaluate the properties of micro areas, it changes during the transition from the central zones of micrograins to the peripheral ones;

2) determination of the hardness of thin surface layers; conventional hardness tests evaluate the properties of relatively thick surface layers [11—12].

The highest microhardness is on the surface of the coatings, which gradually decreases to the surface of the material and is equal to the hardness of the material being processed. This distribution of microhardness leads to the minimization of surface indentation in operating conditions.

The surface microhardness of chromium-doped titanium coatings (Fig. 2) is: on steel 20 – H_{100}= 16000 MPa, (phases: $(Cr,Fe)_{23}C_6$, $(Cr,Fe)_7C_3$, alloyed with titanium, Fe_2Ti, Cr_2Ti, б-solid solution Ti and Cr in б-iron), on steel 45 – H_{100} = 18000 MPa (phases: $(Cr,Fe)_{23}C_6$, alloyed with titanium, б-solid solution chrome in iron with inclusions Cr_2Ti), on steel U8 – H_{100}= 19500 MPa (phases: the carbide zone is located directly on the outer side of the coating $(Fe,Cr)_{23}C_6$, $(Fe,Cr)_7C_3$, Cr_3C_2, Cr_2Ti, $(Ti,Cr)C$).



У8: $y = -0{,}0001x^5 + 0{,}018x^4 - 0{,}8305x^3 + 7{,}589x^2 - 172{,}87x + 19519$

45: $y = -0{,}0003x^5 + 0{,}0468x^4 - 2{,}5142x^3 + 47{,}847x^2 - 475{,}48x + 18006$

20: $y = -0{,}0003x^5 + 0{,}0454x^4 - 2{,}1665x^3 + 33{,}142x^2 - 296{,}45x + 16485$

Fig. 2. Distribution of microhardness along the thickness of the titanium chrome coating on the structural material

According to the research results, it was found that in comparison with coatings obtained in isothermal conditions, the microhardness of steel 45 with CPS-coatings is 1.8—2.0 times higher.

Conclusions

Modeling was carried out to find optimal mixtures of EDP powders to produce intermetallic wear-resistant protective coatings on technical iron and steels 20, 45, and U8A using EDP technology of high-temperature synthesis. The structures of protective layers and their wear resistance under sliding friction conditions were investigated. The best wear resistance among the considered coatings have titanium coatings on steels 45, and U8A. It was established and experimentally confirmed that the microhardness depends on the thickness of the obtained titanium coatings on the composition of the composite saturating medium, which is described by a fifth-order polynomial.

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МОДЕЛЮВАННЯ ТА ОПТИМІЗАЦІЯ ОТРИМАННЯ ПОКРИТТІВ, ЛЕГОВАНИХ ХРОМОМ З ВИКОРИСТАННЯМ КПС

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Реферат

Сучасні умови експлуатації деталей машин, агрегатів, обладнання, інструмента та механізмів висувають підвищені вимоги до їх фізико-механічних характеристик та робочого ресурсу. У зв'язку з цим велике значення мають властивості їх поверхневого шару та набуває актуальність розробка нових технологій зміцнення деталей з конструкційних матеріалів. Для обробки виробів з вуглецевих та легованих сталей широко застосовують методи створення різноманітних функціональних покриттів. Покриття — локально змінений поверхневий шар, що характеризується певним хімічним та структурно-фазовим складом, який якісно відрізняється від матеріалу основи.

Метою роботи є пошук раціональних композиційних порошкових середовищ, що дозволяє сформувати зносостійкі захисні шари на конструкційних матеріалах з різним вмістом вуглецю з використанням технологічних процесів ЕСД В якості оптимізуючого фактору прийнято поверхневу твердість, що прямопропорційно впливає на зносостійкість в умовах різних видів тертя. Вирішення цієї задачі дозволяє забезпечити довговічність обладнання в умовах коксохімічного виробництва та деталях комунального підприємства «Водоканал».

У результаті регресійного аналізу отримуються рівняння, що показують залежність зносостійкості захисних покриттів від режиму теплового самозаймання та вмісту легуючих елементів. У результаті розрахунків отримуються наступні рівняння: $Y_1 = 87{,}6 - 1{,}3X_1 - 1{,}3X_2 - 0{,}6X_3 - 1{,}5X_1^2 + 1{,}5X_2^2 + 3X_3^2 - 0{,}875X_1X_2 + 2{,}125X_1X_3 - 0{,}25X_2X_3$. Перевірка адекватності моделей показує, що їх можна використовувати для прогнозування функцій відгуку при будь-яких значеннях факторів, що перебувають між верхнім і нижнім рівнями. За допомогою математичного планування експерименту значно зменшується кількість досліджень необхідних для розрахунку коефіцієнтів рівняння регресії та отримання адекватної моделі, яка характеризує вплив елементів КПС на експлуатаційні властивості сталей з легованими захисними покриттями. Поверхні відгуку отриманих математичних моделей представлено тривимірною графічною залежністю.

За результатами досліджень, виявлено, що у порівнянні з покриттями отриманими в ізотермічних умовах мікротвердість сталі 45 з покриттями отриманими в КПС вища в 1,8—2,0 рази.

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