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Research of Thermal Coatings of Composite Materials

I O Sokorov[1], Zadeh E Ghazban[2], D V Kuis[3]

[1] Belarusian National Technical University, Minsk, Belarus
[2] BPPC "BelPekaPaint" Industrial company, Minsk, Belarus
[3] Belarusian State Technological University, 13a Sverdlova St., 220006, Minsk, Belarus

E-mail: dmitrykuis@mail.ru

Abstract. This study was carried out in compliance with the State program of scientific research of the Republic of Belarus on the task "Formation of wear-resistant composite coatings with high-technology. Development of streams in the machine parts with high contact load". The achieved level of physical, mechanical and performance properties of the thermal coatings developed compositions makes them suitable for hardening-restoring parts of friction pairs, working in conditions of fretting corrosion, a wide range of specific loads and sliding speeds. Based on the goal of the research, developed composite materials based on abrasion-resistant, anti-friction and thermo-reactive powders form composite anti-friction coating provide the required level of physic-mechanical properties and performance characteristics (wear resistance, porosity and bond strength). Applying nickel, iron, copper (bronze, Babbitt) as base materials helps to improve wear resistance, resistance to fretting corrosion, anti-friction properties and adhesion. The study of the structure determined that the structure of the resulting coatings matches with the Charpy rule; spraying particles are well plasticized substantially, not surrounded by oxide films. The coating has a low porosity (less than 5%); the individual phases micro-hardness is up to 10000 MPa and bases on 7500 MPa. Reduction of the quantities of residual stresses produced a heated base and spraying of the intermediate layer of thermo-reactive material NiAl. Study of residual stresses and their distribution across the thickness of the composition "cover, sub layer, the basis" made it possible to determine that the application of the selected sub layer and spraying modes combined with compositions developed can reduce the level of residual stress in the coating up to 3 times.

1. Introduction

Increased wear resistance and corrosion resistance, anti-friction properties and fatigue resistance of friction surfaces are relevant for different branches of engineering. One of the most effective and efficient ways to improve the wear resistance of surfaces, working in conditions of friction, is the creation of such solid surfaces of wear-resistant coatings to significantly increase fatigue resistance, resistance to grasping surfaces under friction. Spraying on the working surface of the wear-resistant materials allows saving costly alloy and other scarce materials, improving life and reliability of mechanisms to reduce the energy intensity of production, successfully solve the problem of repair in order to re-use of worn parts, etc. However, these coatings do not always develop their resources due to premature adhesive and cohesive failure induced in a complex state of stress caused by the difference in thermal expansion coefficients of different materials and the influence of specific loads during operation. Using thermal spraying for hardening-restoring parts (shafts) is limited to insufficient strength of adhesion of the coating with the substrate. Among a large number of wear-resistant materials, there is most widely used self-fluxing powder coating based on nickel and cobalt, which have a relatively low melting point, high wear resistance, hardness, good adhesion with steel. However, these materials are expensive, and also to improve the performance properties of coatings of self-fluxing alloys, one must perform their subsequent melting, which is unacceptable for many parts as there is residual stress that can lead to the formation and (or) the increase of fatigue cracks. Coming from delivered purposes of research, developed the composition based on wear-resistant, anti-friction and thermo-reactive materials. Powder materials were selected in accordance to obtain a high level of physical and mechanical properties of coatings that protect against various types of wear (abrasive, fretting corrosion) and adhesive strength, ensures availability of parts with coatings. Furthermore, according to wear resistance, fretting is possessed by materials based on nickel, iron, aluminum, copper and chromium containing carbides, titanium, and vanadium. In the ongoing research, the authors examined the effectiveness of thermal spraying composite coatings on the basis of the following materials: self-fluxing materials based on iron, thermo-reactive NiAl and alloys of copper. In the development of models and their optimization, the authors used statistical analysis package “Statistica 6.0” company “StatSoft” (USA) and the software package “MathCAD” companies “Math Works Inc.” (USA). For studied physical and mechanical properties of the sprayed coatings, there were compositions (table 1) composed of powders whose chemical composition is listed in table 2 [6–10].

Table 1. Proposed composition for thermal spraying.

№	Structure of composition
1	PT-NA-01 + PG-19M-01 + PR-H4G2P4S2F
2	PR-ND42SR + PR-H4G2R4S2F + PT-NA-01
3	PT-UNH16SR3 (1/2) + PR-H4G2R4S2F (1/2)
4	PR-ND42SR + PR-H4G2R4S2F

Table 2. The chemical composition of powders

№	Mark	Chemical composition
1	PT-NA-01	base Ni; 4,0-5,5% Al
2	PR-H4G2R4S2F	base Fe; 3,7% Cr; 2,2% Mn; 3,8% B; 2,5% Si; 0,8% V
3	PG-19M-01	base Cu; 4% Fe; 8,5-10,5% Al
4	PR-ND42SR	base Ni – Cu; 42,5% Cu; 0,2% C; 0,9% Si; 1% B; до 3% Fe
5	PT-UNH16SR2	base Ni; 0,7% C; 16% Cr; 3,2% Si; 2,6% B; 1,2% Al

To justify the choice of the composition, the authors performed express test wear resistance (Figure 1), as well as visual inspection of the resulting coatings, the lack of delamination from the substrate. The diagram shows that the greatest wear-resistance has a coating derived from the number of compositions 1 and 4. Moreover, some samples were observed with coating exfoliation, and performance parts of coating composition number 3 were not guaranteed.

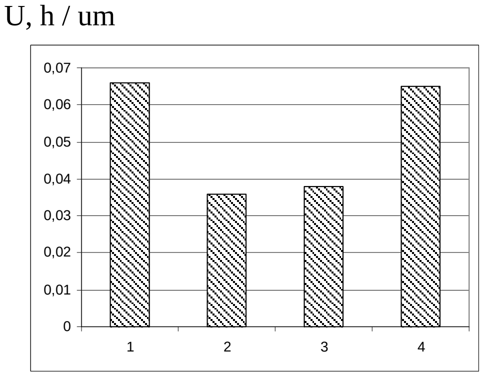
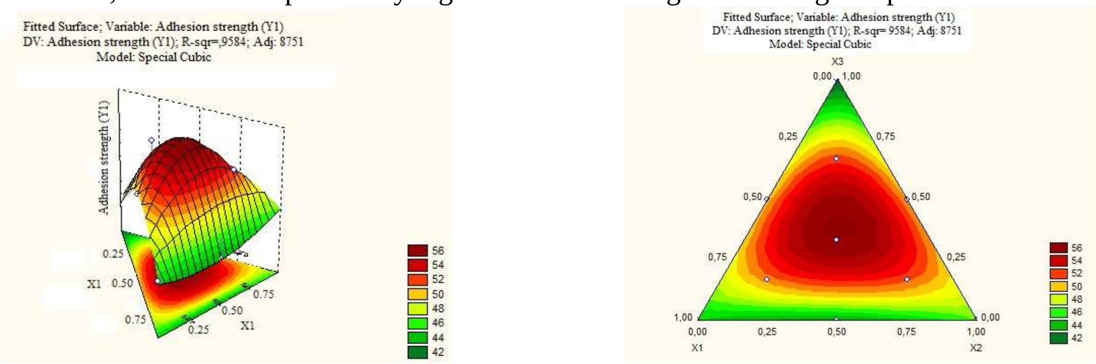


Figure 1. Diagram of wear resistance

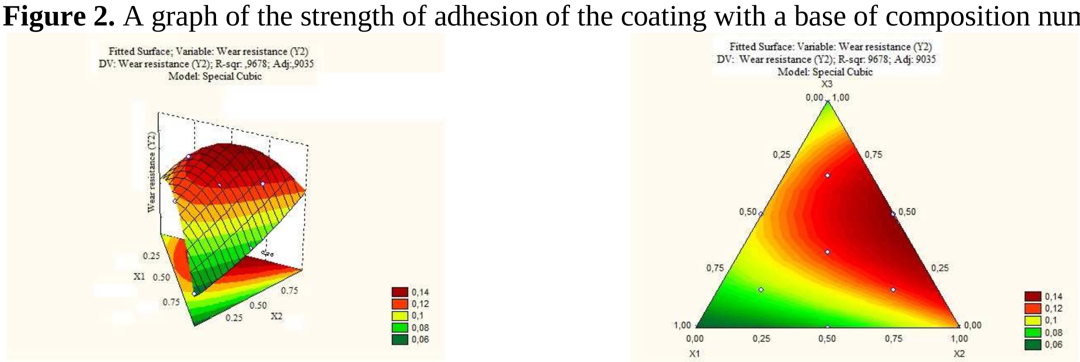
2. Optimization of composite materials

Conducting experiments determines the degree of influence of components of the composition on the strength of coating adhesion with base and wear resistance. For processing the results of the experiment and to obtain the dependence of the response function on factors, the authors used the standard program “Statistica 6.0”. From the analysis of graphs of mathematical models and the effect of composition on the properties of the coatings compositions, one can conclude that the most positive influence on the adhesive strength of the coating composition number 1 components is based on the copper and thermo reactive component that caused the first fusible and second exothermic. Abrasion influences the component based on copper and iron, as well as their mutual influence, due to the formation of the coating structure with the plastic matrix having antifriction properties with solids in the form of particles alloyed with the iron-based powder. In composition number 2, there are two thermo-reactive components, the basis of one of them is a copper-nickel matrix which is formed from an iron-based component that a corresponding coating structure, according to Charpy rule, and moreover, this can be explained by higher adhesion strength of coating composition number 2.



a) - The surface of the screen in response. b) - On the response surface plane.

Figure 2. A graph of the strength of adhesion of the coating with a base of composition number 1.



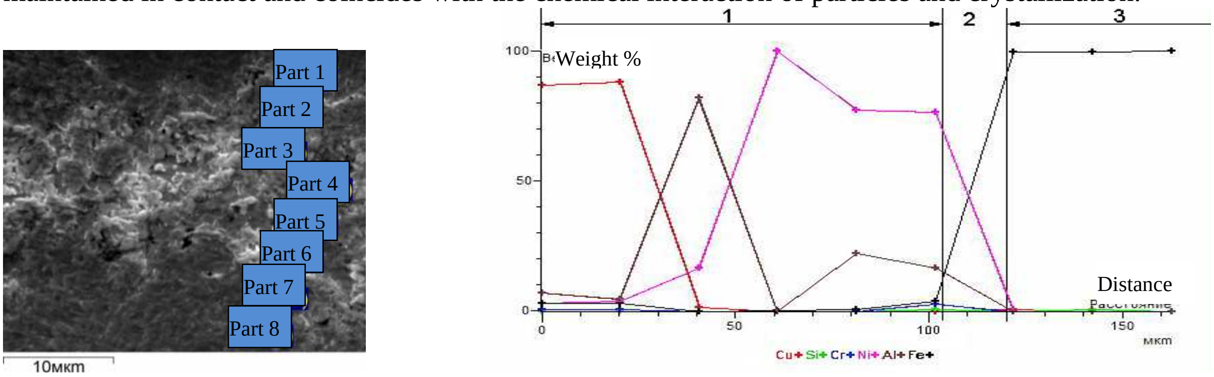
a) - The surface of the screen in response. b) - On the response surface plane.

Figure 3. A graph of wear-resistant coatings of composition number 1.

As a result of experimental studies, the authors determined optimal compositions for hardening shafts of paper-making equipment: composition number 1: 30,9% (1) + 32,7% (2) + 36,4% (4); composition number 2: 18,9% (1) + 41,4% (3) +39,7% (2) [10].

3. Structure and physic-mechanical properties of composite materials

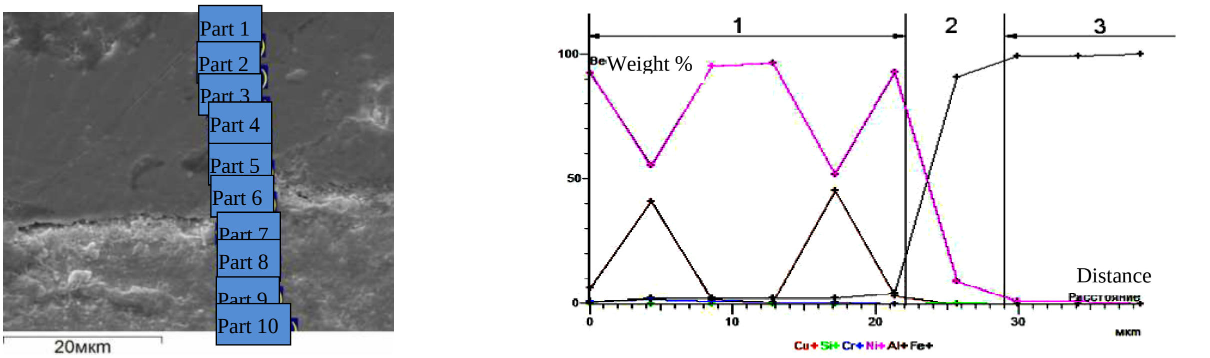
Apparently, the presence of the particle surface-melting copper and its later crystallization, and the presence of the thermo-reactive components in the compositions when sprayed releasing additional heat, contribute to a certain increase in time of the intensity of the chemical interactions, and diffusion processes. Chemical interaction and the formation of the diffusion zone between the coating and the substrate confirmed the quantitative analysis. MRSA results are presented in Figures 4, 5. From the graph, the distribution of chemical elements (Figure 4b, 5b) shows that the nickel diffuses into the base (purple line), iron coating (black line). During plasma spraying under the layer of thermo regulating powder, there is almost instantaneous softening of the substrate surface and as a consequence of its high-speed plastic deformation caused by the pressure of accelerated and heated by the powder particles to the melting point in the plasma jet and their collision with the base, which contributes to the diffusion zone between the coating and the base metal. The temperature is maintained in contact and coincides with the chemical interaction of particles and crystallization.



a) b)

Distribution of alloying elements: (b) 1- floor, 2 - transition zone (diffusion zone), 3 - base

Figure 4. Microstructure of coatings (a) of composition number 1.



a) b)

Distribution of alloying elements: (b) 1 - coating, 2 - transition zone (diffusion zone), 3 - base

Figure 5. Microstructure of coatings (a) of composition number 2.

The additional heat generated by the exothermic reactions contributes to the further heating of the deposited particles and the substrate, which increases the crystallization of the particles and, thus, the time of chemical interaction between the sprayed material and the substrate leakage. This step interaction ensures diffusion interaction of the material, being deposited, and the substrate consequently increases adhesion strength. The formation of the diffusion zone between the coating and the substrate confirmed X-ray analysis (Figure 6, 7). The penetration depth of the coating elements is up to 10 - 12 microns. The spraying in optimal conditions with increasing pressure and temperature of the particles, the diffusion zone can reach a value of about 25 microns. The main physical and mechanical properties of the hardening layer is micro-hardness. A study of micro-hardness showed that the individual phases of gas-thermal composite coatings reach values of 10805 MPa and 10025 MPa for compositions number 1 and number 2. The average micro-hardness of the coating is 7584 MPa and 7513 MPa.

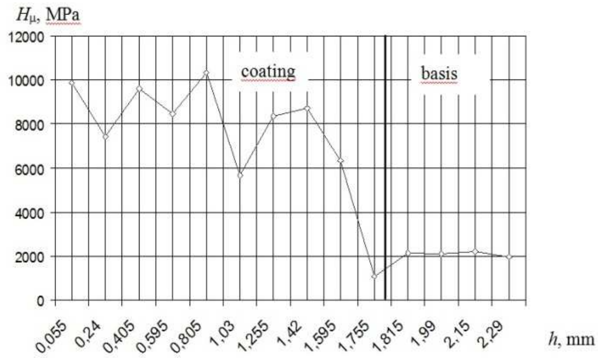


Figure 6. The micro hardness of coating composition number 1

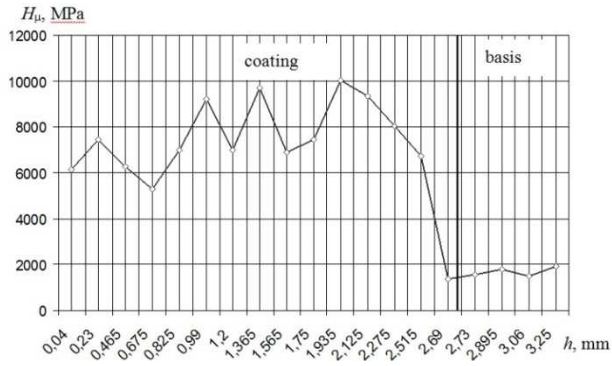
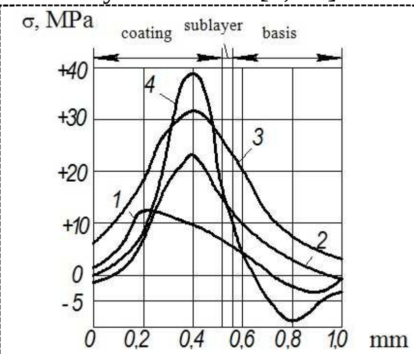


Figure 7. The micro hardness of coating composition number 2

A lower value of micro-hardness composition number 2 is due to a high content of copper. The coating structure included components based on copper (composition number 2), copper and nickel (composition number 1), and the iron-based, alloyed with chromium, vanadium, boron, silicon. Thus obtained coatings have the plastic substrate (copper - nickel - iron) and the solids in the form of carbides and borides. This explains the spread of micro-coating thickness (5660 – 10327 MPa - composition number 1, and 6720 – 10025 MPa - composition number 2). Such structure is optimal in terms of wear resistance and corresponds to the structure of the Charpy rules, inclusion of solid components dispersed in a softer matrix. The high values of micro-hardness near the bases leads to the conclusion about the origin of a chemical interaction between the components of the spraying material and the basis with the formation of the transition zone, which leads to achieving high adhesion coating with a base.

Investigation of porous coatings showed that the pores are irregularly shaped. The pore area in the section, the interface between the coating and the substrate are smaller than the cross section parallel to the boundary. This factor is due to the peculiarities of the formation of layered coatings. The porosity reduces the strength of the coating and can be hotbeds by origin of the fatigue cracks, so you must strive to reduce it for parts operating under cyclic loading. Open porosity of the resulting coatings without reducing the strength of the coating contributes to maintaining lubrication under boundary lubrication [9, 10].

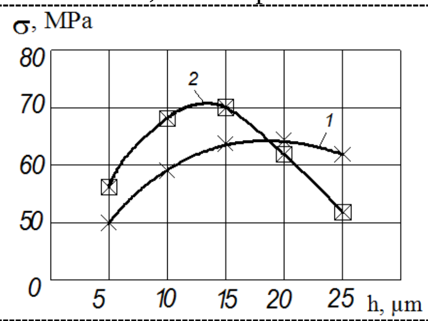


1 - composition number 1; 2 - composition number 2; 3 - composition number 1 without sub layer; 4 - composition number 2 without under layer.

Figure 8. Distribution of residual stresses in thickness of composition "cover, under layer, basis"

Residual stresses can highly influence the strength of adhesion with the substrate. With the weak development of contacts between the atoms of the particles coating and substrate and also a high level of residual stresses, delamination of the coating immediately after spraying may occur. Therefore, the effect of residual stresses must be considered when studying the overall picture of the formation of coatings. The residual stresses appear after blasting 160 - 200MPa, after grinding 22 - 27MPa. To reduce the magnitude of the residual stresses, there was a produced heated base and an intermediate layer of thermo-reactive material NiAl (Figure 8).

The influence of the sub layer thickness of thermo-reactive material is on the adhesion strength of thermal spray coatings designed compositions (Figure 9). The experiment confirmed the sub layer thickness for which the adhesion strength is the maximum. For coating compositions number 1, it is 15 - 20 microns, for composition number 2 10 - 15 microns.



1 - composition number 1; 2 - composition number 2

Figure 9. The dependence of the bond strength on the coating thickness (h) of the sub layer.

Investigation of residual stresses and their distribution across the thickness of the composition "coating, sub layer, the basis" allowed one to determine that the application of the selected sub layer and its modes of spraying in combination with developing compositions can reduce the level of residual stress in the coating up to 3 times.

4. Conclusion

The achieved level of physical, mechanical and performance properties of the thermal coatings of the developed compositions makes them suitable for hardening-restoring friction pairs operation under fretting corrosion, a wide range of specific loads and sliding speeds. The ability of coatings to withstand the impact of wear in the process affects the character of the load application, as well as the shape and stiffness of the parts.

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