precipitate, that is confirmed by X-ray phase analysis. Powder feed rate has a similar influence.

CONCLUSIONS

1. Influence of parameters of laser cladding mode (powder feed rate and nozzle displacement speed) on the structure and properties of coatings from material of a graded composition of Ti–NiCr and Ti–Si systems was studied.

2. A refinement of grain size from coating lower layer (Ti–12 wt.% NiCr) to the surface layer (Ti–30 wt.% NiCr) with lowering of powder feed rate (at v_n = 3000–5000 rpm) and increase of nozzle displacement speed up to 500–1000 mm/min is established, as well as increase of intermetallic content from coating lower layer (Ti–12 wt.% NiCr or Si) to surface layer (Ti–30 wt.% NiCr or Si) with increase of powder feed rate and decrease of nozzle displacement speed.

3. An increase of coating layer hardness towards the surface layer is established, and the change of parameters of laser cladding process has only a minor influence on hardness of Ti–NiCr material layers.

4. In Ti–Si system materials surface layer hardness decreases with increase of nozzle displacement speed and increases with increase of powder feed rate.

5. Deposition of layers of Ti–NiCr and Ti–Si system materials by laser cladding can be recommended for improving the hardness and wear resistance of the titanium base.

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ELECTRIC ARC SPRAYING OF CERMET AND METAL-GLASS COATINGS

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Upgraded unit of the electric arc sprayer for deposition of composite coatings is described. The possibility of formation of cermet and metal-glass coatings is shown. Optimal spraying parameters are given. Wear resistance and strength of adhesion of the electric-arc metal-glass coatings are considered.

Keywords: *electric arc spraying, electric metallizator, spraying head, upgrading, cermet and metal-glass coatings, wear resistance, strength of adhesion, optimal parameters*

Composite materials and coatings, obtained using powder metallurgy methods, plasma, flame and detonation spraying [1–4], get wider application in the friction assemblies of different machines and mechanisms. However, process of obtaining of the composite materials by powder metallurgy is sufficiently power-consuming and requires significant power inputs [1, 2].

The cermet coatings, obtained by flame, plasma and detonation methods, are mainly used for strengthening and repair of worn surfaces of the parts, that allows increasing their life time several times [4, 5].

A method of coating deposition depends on requirements making to the coating properties. These requirements, on the one hand, are determined by composition of the material of coating and, on the other hand, by parameters of the process of its spraying and achievable values of heat and kinetic energy of the particles. Others criteria are costs of coating deposition, including cost of power input and consumables per unit of coating being sprayed.

Heat efficiency of a flame torch makes 0.8–0.9 in flame spraying, however, a level of effective application of heat of a jet for heating up of powder particles and their acceleration makes only 0.02–0.10 [6]. Higher level of the coating properties (adhesion strength, porosity) is achieved at supersonic flame spraying, however, process performance requires increased fuel consumption (gas, liquid fuel), that results in rise of the cost of coating unit. The flame spraying has limitations in spraying materials, related to temperature of combustion materials.

The coatings from all the materials, which do not decompose at heating to melting temperature, can be formed using plasma spraying. Heat efficiency of a plasmatron usually lies in the ranges from 0.55 to 0.70 depending on its structure and operation parameters [6]. Quantity of plasma jet heat consumption for heating and acceleration of particles makes 0.02–0.27 depending on a way of powder feeding in the jet [7].

The process of electric arc spraying of the coatings is based on a phenomenon of melting of a material by high amperage arc and dispersion of forming melt by compressed gas jet. Absence of the necessity to heat the high-speed particles of the coating up to melting stage during a short period of their movement in a jet volume provides the process of high-level of energy-saving. Index of thermal efficiency of the process achieves 0.7–0.9, that in combination with simplicity of the equipment provides its mass application. Comparative assessment of the costs for obtaining of the coatings by different thermal spraying methods shows that the electric arc coatings have 3–10 times below cost than others [7–13].

The electric arc spraying gained the highest distribution in deposition of corrosion-resistant coatings, mainly, from aluminum and zinc on different structures and constructions [13–16]. The electric arc coatings from different steels, bronze etc. are used as wear-resistant ones. Pseudoalloy coatings from steel and copper, copper and tin and other combinations [4, 10–13, 15, 16] are being perspective. One of the main disadvantages of this method is possibility of application only current conducting wire materials as spraying ones. Application of the flux-cored wires for obtaining cermet coatings allowed significantly widening a list of compositions of the electric arc coatings, that became a new stage of development of electric arc metallizing [10, 17].

The aim of the present paper was development of a method for formation of cermet and metal-glass coatings by electric arc spraying method using upgraded electric arc apparatus EM-14M. Upgrading of a cap of spraying head of EM-14M apparatus was carried out for obtaining the composite coatings by electric arc method. It allowed formation of the coatings with participation of flux-cored material by means of feeding it in a high-temperature zone of arc discharge.

Intensive injection of ambient air in the jet took place after flow of the compressed air jet from the nozzle. Thus, if spraying powder is supplied to the nozzle opening, located in the cap of spraying head, it will be drawn in the air jet flowing out of the nozzle opening. The air flow, shooting out from the nozzle opening, is turbulent, that promotes good mixing of the particles of spraying powder with the drops of molten metal and uniform distribution of the particles of spraying powder in the coating.

The upgrading of EM-14M apparatus lied in development of a unit for continuous feeding of powder material in the high-temperature zone of arc discharge (Figure 1) [18, 19]. Structural changes were made in the spraying head since feeding of powder material should be performed into the flow of metal molten particles. Additional bronze nozzle *7* with opening bigger than opening of the main nozzle is installed before bronze nozzle *9*. Main nozzle *9* comprises eight slots entering in the cavity between additional nozzle *7* and main nozzle *9*, positioned normal to the axis of gas flow. Nozzles *7* and *9* are embedded in fluoroplastic inserts *8* which being pressed to cap *5* with the help of shield screen *4*. Spraying powder from hopper *1* is supplied in dosing apparatus *2*. Powder due to injection at pressing on control arm *3* is supplied in the cavity between additional nozzle *7* and main nozzle *9*. Adapter *6* is designed for regulating zone of powder feeding. Powder, passing additional nozzle *7* and arc between the two wire-electrodes, mixing with the compressed air flow and molten particles of metal, is directed toward the surface being sprayed.

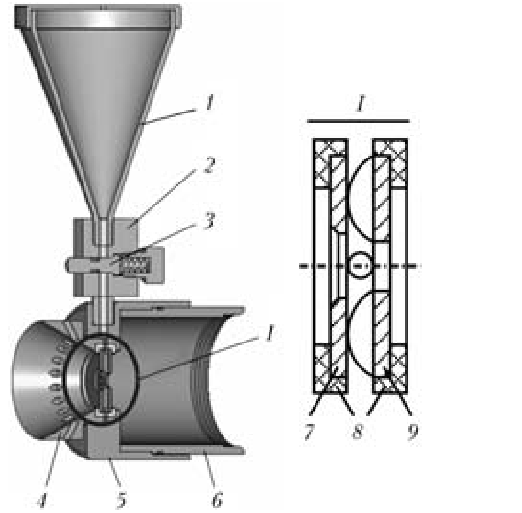

Figure 1. Scheme of upgraded cap of spraying head (designations see in the text)

The composite coatings with different concentration of powder particles in a sprayed layer can be obtained regulating powder supply with the help of dosing apparatus and rate of wire feed.

1.2 mm diameter seamless wire of Sv-08G2S-O grade and powders (40–80 μm particles of glass breakage of group A, ZrO_2, Al_2O_3) were used in the experiments.

«Remdetal» 026–7 machine was used for jet-abrasive machining of the substrate surface before deposition of the metal-glass and cermet coatings. Electrocorundum of 7B grade of abrasive grit 125 was used as an abrasive. The coatings of the following compositions were obtained as a result of spraying with upgraded apparatus EM-14M (Figure 2): Sv-08G2S-O–A-glass, Sv-08G2S-O–ZrO_2, Sv-08G2S-O–Al_2O_3.

Microhardometer PMT-3 was used for identification of phases in the coatings at indenter loading 50 g. An average microhardness of metal matrix from Sv-08G2S-O in all composite coatings made 1900 MPa

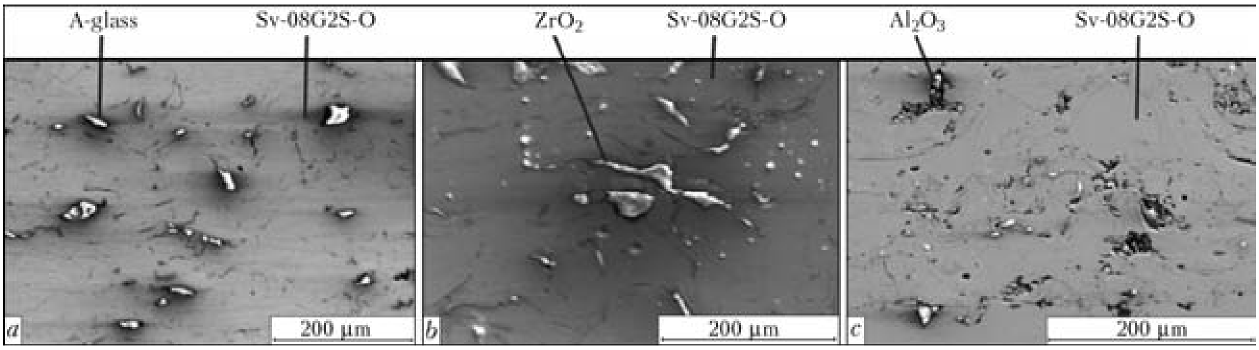

Figure 2. Microstructures of composite coatings: *a* — Sv-08G2S-O–A-glass; *b* — Sv-08G2S-O–ZrO_2; *c* — Sv-08G2C-O–Al_2O_3

and in fillers A-glass it was 5850, ZrO_2 — 12880 and Al_2O_3 — 16104 MPa.

Difficulties, related with spraying of the coatings of specified composition, appeared during development of a technological process of deposition of the metal-glass and cermet coatings. They lied in a complexity of experimental selection of parameters providing specified content of filler for obtaining optimal physical-mechanical properties.

The method of complete factorial experiment of 2^k type was selected for determination of the possibilities for regulation of content of the coatings from compositions Sv-08G2S-O–A-glass, Sv-08G2S-O–Al_2O_3 and Sv-08G2S-O–ZrO_2. A response surface (optimization parameter) is a content of the filler in coating Y. Current intensity X_1, powder consumption X_2 and pressure of compressed gas X_3 were selected as parameters determining the process of coating deposition.

Known techniques [20] were used for carrying out calculation of the coefficients of regression equation and verification of the conformity of built models. The following regression equations were obtained after mathematical processing of a design matrix at 5 % level of importance of polynomial coefficients:

$$Y + 5.56 = 0.07Y_1 + 0.134X_2 + 13.5X_3$$

for composition Sv-08G2S-O-A-glass;

$$Y + 7.62 = 0.007X_1 + 0.23X_2 + 11.41X_3$$

for composition Sv-08G2S-O–Al_2O_3, and

$$Y + 3.96 = 0.01X_1 + 0.28X_2 + 6.34X_3$$

for composition Sv-08G2S-O–ZrO_2.

It was determined as a result of analysis of regression equations that the first main factor, having influence on output parameters of the process, is current intensity. It increase rises a concentration of molten particles of metal in the jet and their enthalpy, that results in higher content of the filler in the coating. The second important factor is pressure of compressed gas. Intensity of powder injection in the high-temperature jet and speed of particles in it rise with pressure increase, that results in a rise of content of the filler in the coating. The third factor is powder consumption: the higher amount of it is supplied in the high-temperature jet, the higher amount of the filler will be in the coating.

Computer metallographic program MEGRAN [21] and stereometric methods of metallography were used for studying microstructure of the metal-glass and cermet coatings. Structural composition of the coatings was determined by volume using spot method [22]. The following upper limits of volume content of the fillers were determined as a result of computer metallographic analysis through regulating composition of the electric arc coatings, %: cerment Al_2O_3 — 9 and ZrO_2 — 12, metal-glass of A-glass — 18.

Tests on wear resistance and adhesion strength were carried out for determining optimal content of A-glass in the metal-glass coatings. Their wear resistance was determined on SMTs-2 fraction machine by roller–block scheme under following conditions: circumferential speed 0.8 m/s, specific pressure 5 MPa, consumption of oil of M-10-DM grade under conditions of limited lubrication made 30 drops per minute,

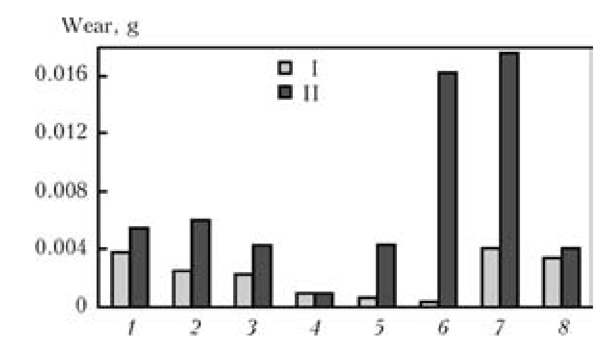

Figure 3. Histogram for results of determination of wear resistance by roller (II)–block (I) scheme: *1* — Sv-08G2S; *2* — 5 % A-glass; *3* — 8; *4* — 11; *5* — 14; *6* — 17; *7* — Br.AZh 9-4 (*HRC* 20–23); *8* — Br.AZh 9-4 (*HRC* 39–41)

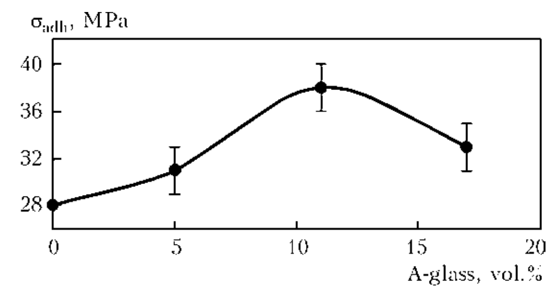

Figure 4. Dependence of adhesion strength on content of A-glass in the coating

traversed path after run-in 10 km. Wear was measured by mass loss.

Composite metal-glass coatings were deposited on the blocks. The rollers were manufactured from steel 45 after *HRC* 30–32 heat treatment. The wear of Br.AZh 9-4 bronze before and after heat treatment under similar conditions was determined for comparison of wear resistance of the metal-glass coatings with bronze.

Analysis of results of wear resistance investigation of the coatings with content of glass phase from 5 up to 17 vol.% (Figure 3) showed that the coating with 17 vol.% of glass phase has 13.5 times less wear than Br.AZh 9-4 grade bronze after heat treatment (*HRC* 39–41), but at that disastrous wear of the roller is observed. Optimal wear resistance has a pair with the metal-glass coating: content of glass phase 11 vol.% at total wear 5.6 times less than in the pair with unfilled coating from Sv-08G2S-O, and 4.5 times less than in bronze one (*HRC* 39–41).

Adhesion strength of the coating with the base (Figure 4), determined by method of «pin pulling» on tensile-test machine UMM-5, rises with increase of A-glass content in the coating and then reduces. Increase of the adhesion strength, probably, related to the fact that the infused particles of A-glass in the coating, colliding with surface of the base, additionally activate it due to their high kinetic energy and fragment form, and colliding with already fixed plastic metal particles introduce them into surface microirregularities of the base and further layers. Reduction of the adhesion strength connected with the following increase of content of the glass phase as a result of which actual zone of contact of the metal particles with the base is reduced.

Results of experiments on determination of wear resistance and adhesion strength allowed making a conclusion that optimal content of the glass phase in the metal-glass coatings makes from 8 up to 14 vol.%. At that, such coatings have maximum wear resistance and adhesion strength with the base.

Optimal parameters for deposition of the metal-glass coating, providing content of the glass phase from 8 up to 14 vol.%, are calculated based on obtained regression equation and as follows: current intensity 100 A, voltage 30 V, pressure of compressed gas 0.5 MPa, powder consumption 25 g/min, spraying distance 100 mm.

It is well-known that optimal content of the oxides, providing high wear resistance of Me + ZrO_2, Me + + Al_2O_3 compositions, makes 5–10 % [1]. Thus, the electric arc cerment coatings, filled with ZrO_2 and Al_2O_3 and deposited by upgraded apparatus EM-14M, are perspective for providing high wear resistance of friction pairs.

Thus, upgraded electric arc sprayer EM-14M allowed obtaining the cerment and metal-glass coatings through introduction of powder-filler in the high-temperature zone due to injection between the main and additional nozzles. Optimal parameters were set for spraying of the metal-glass coatings, providing their maximum wear resistance and adhesion strength.

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