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ELECTRIC ARC COATINGS WITH A COMPLEX OF IMPROVED PROPERTIES FOR REPAIRING AND HARDENING OF MINING MACHINE PARTS

Purpose. *Research and analysis of the possibilities of using electric arc coatings with improving properties in the repair of machines and mechanisms for mining industry.*

Methodology. *The porosity of the obtained electric arc coatings was studied using computer metallography. The hardness was determined on a Vickers-type device. The thermophysical properties of the coatings were studied using the dynamic calorimeter method. The adhesion strength of the coatings to the substrate was determined by the method of "pulling the pin". Determination of wear resistance was carried out on the SMC-2 friction machine according to the "roller-block" scheme in conditions of limited lubrication. The determination of coherent x-ray scattering regions to estimate the size of the substructure of the coating material was carried out by x-ray diffraction analysis on the DRON-3 installation.*

Results. *An electric arc sprayer has been improved, which makes it possible to improve the quality of composite coatings by increasing the particle velocity in a high-temperature heterophase jet and reducing its opening angle, which leads to an increase in the CMM during spraying from 0.63 to 0.74. At the same time, the increase in the hardness of the metal matrix in the composite electric arc coating is 21%, their adhesion strength to the base increases by 26%, wear resistance is 6.9 times compared to the unfilled coating. The optimal amplitude-frequency parameters of the electric pulse action during electric arc spraying of the SV-08G2S wire (pulse frequency – 6.5 kHz, amplitude – 5 kV) are determined, which provide an increase in hardness up to 35%, adhesion strength to the substrate up to 30% and wear resistance of coatings 1.7 times due to grinding and acceleration of the sprayed particles. The optimal temperature-time parameters of pre-recrystallization heat treatment are established, which provide a further increase in the hardness of coatings due to the grinding of subgrains to the nanoscale size inclusive. The possibility of thermal stabilization of the polygonization substructure of electric arc coatings obtained by spraying 12X18N10T wire by their additional plastic deformation is shown.*

Originality. *The electric arc coating method was further developed by improving the design of the spray head, which made it possible to increase the material utilization rate during their spraying and physical and mechanical, as well as operational properties. The regularities of the influence of electric pulse action on the microstructure and physical and mechanical properties (hardness, density, adhesion strength, thermal conductivity, wear resistance) of electric arc coatings are established. The process of pre-crystallization treatment of sprayed coatings in the direction of thermal stabilization of the polygonization substructure due to subsequent deformation of the obtained coatings was further developed.*

Findings and practical implications. *The application of the research results obtained in this work provides an opportunity to expand the range of cheaper sprayed materials for coating*

with increased physical, mechanical and operational properties on heavily loaded parts of mechanical engineering, electrical products and parts of the military-industrial complex.
Keywords*: electric arc composite coatings, electric pulse action, heat treatment.*

INTRODUCTION

Formulation of the problem. Equipment used in the mining industries is subject to extreme mechanical stresses: it has to operate in challenging climatic environments, yet has to work reliably with an operational lifespan frequently measured in decades. Maintenance of equipment is a vital consideration in all areas of the mining industry, where high mechanical stresses and the reliance on aging equipment can quickly impact asset availability. The cost of downtime is significant, and that of unplanned downtime even more so. Any necessary repairs frequently extend far beyond the single component that failed, with an unexpected failure often being the cause of damage to other components with the machinery further increasing costs.

The operational properties of parts and mechanisms, as well as their working time, are determined mainly by the physical and mechanical properties of the surface. As the statistical analysis shows, the majority of machines (85...90%) fail not due to breakage, but as a result of wear of the surfaces of individual parts. In practice, there are various ways to solve the problem of wear of parts of mining equipment, but the most profitable and promising is the deposition of protective coatings on the working surfaces.

Analysis of recent research. Most commonly use welding techniques (cladding) for deposition wear and erosion resistant coatings for repairing and strengthening of worn parts and mechanisms for mining industry. So, in work [1] use laser cladding for deposition WC-Fe composite coatings; authors [2] proposed use iron–chromium based hardfaced coatings deposited by shielded metal arc welding (SMAW); metal active gas (MAG) welding for deposition of NiCrBSi hardfacing alloy reinforced with tungsten carbide [3]; non-vacuum electron beam cladding for boride reinforced steel coatings [4]. However, cladding methods have some disadvantages like: high heat-affected zone and welding distortions, limitations by substrate materials, next machining operation is required and high equipment cost. Recently, thermal spraying has been increasingly used for deposition wear and abrasion-resistant coatings. As for mining industry most commonly use high velocity oxygen-fuel (HVOF) method for Reverse Circulation hammers [5]; convential plasma [6] and supersonic plasma spraying of cermet coating [7]; detonation spraying of hard composite coatings [8]. It should be noted that among all these thermal spray methods, electric arc spraying is differs by simplicity and manufacturability, high productivity, energy efficiency, and material utilization factor. The relative cost of electric arc coatings is 3...10 times lower than those obtained by other methods while ensuring their high strength. However, electric arc coatings deposited by convention spraying technologies do not always provide a sufficient level of physical, mechanical and operational properties necessary for the efficient operation of parts and mechanisms under specified conditions in mining industry, which is due to their high level of porosity, low bond strength, hardness and wear resistance.

Analysis of the effectiveness of modern methods of increasing the physical, mechanical and operational properties of electric arc coatings shows that the main result of their application is mainly to provide high energy parameters of sprayed particles and reduce their size, as well as to develop new compositions of composite coatings. Recently, the most promising methods are those that use pulsed action on the deposition process, in particular, mechanical, acoustic, electrical, laser, etc. [9], [10]. Among them, it should be noted the use of electrical impulse exposure, which is characterized by low power consumption and low cost of additional equipment [11].

In addition, the results of recent studies [12], [13], [14], [15] indicate the possibility of expanding the range of materials from which the electric arc coating is formed and a significant increase in their physical, mechanical and operational properties.

Also, one of the ways to improve the properties of sprayed coatings is the use of further pre-recrystallization heat treatment, the essence of which is to fix the polygonization substructure by cooling the coating material at the stage of formation of nanoscale subgrains [16], [17], [18].

However, the low speed of particles when using the traditional method of spraying does not always provide a sufficient degree of their deformation for the manifestation of the "size effect".

The aim of the work is to study and analyze the possibilities of using electric arc coatings with improving properties in the repair of machines and mechanisms for mining industry.

MAIN PART

To study and analyze the possibilities of using new restorative composite electric arc coatings in the repair of various kinds of machines and mechanisms, as well as technical means, their spraying was carried out using a KDM-2 installation, which includes an EM-14M electric arc apparatus.

On the basis of calculations of the optimal gas-dynamic and geometric parameters of the ejector, which is used for applying electric arc composite coatings [12] and with the help of which the possibility of uninterrupted supply of powders of various materials to the high-temperature zone of the atomizer was substantiated, the design of the atomizing head of the EM-14M apparatus was changed. This made it possible for the first time to form a composite metal-polymer, metal-ceramic and metal-glass coating due to the use of powders of the corresponding materials in free form.

The developed device for electric arc spraying of composite (multicomponent) coatings has a number of disadvantages: when the powder is supplied, a significant part of it falls on the periphery of the initial section of the jet, which worsens the heating of the powder particles and reduces their speed; there are restrictions on powder consumption when feeding it due to atmospheric injection; a large opening angle of a high-temperature jet leads to a decrease in the utilization rate of the material, especially when spraying on parts of the "shaft" type. The listed disadvantages negatively affect the quality of sprayed composite arc coatings and the content of powder particles in the structure of the resulting coating.

To eliminate the above disadvantages, changes were made to the design of the device for uninterrupted powder supply, which made it possible to increase the utilization rate of the material when spraying a composite electric arc coating and to improve its quality.

An experiment was carried out to establish and compare the characteristics of the developed devices. Using a device for uninterrupted powder supply [9] and an improved design of the cap of the spray head of the EM-14M electric arc apparatus [19], a composite metal-glass electric arc coating was obtained from the composition Sv-08G2S - A-glass (broken glass). Spraying in the first and second cases was carried out in the following technological mode: current 120 A, voltage 25 V, compressed air pressure 0.6 MPa, spraying distance 100 mm. The A-glass powder had a fraction of 40...50 microns and was supplied to the high-temperature zone of the atomizer only due to atmospheric injection. The diameter of the used wire grade Sv-08G2S was 1.2 mm.

Table 1 shows the comparative characteristics of the developed devices designed for the uninterrupted supply of powders.

As can be seen from Table 1, the jet opening angle decreased by 33%, the spray spot diameter by 28%. The study of the oxygen content in the composite electric arc coating using spectral analysis on a scanning electron microscope REMMA102-02 showed that its content increased from 0.46 to 0.80 wt. % (+ 74%). The maximum glass phase content also increased from 19.5 to 22.3 vol.% (+ 14%). The average size of metal particles decreased by 31%, while their speed increased by 19%, and the temperature remained almost at the same level (an increase of 0.15%), which led to a twofold decrease in porosity and an increase in the material utilization rate from 0.63 to 0.74.

It was also found that in the obtained metal-to-glass coatings, the microhardness Hμ50 and the hardness HV5 of the metal matrix made of Sv-08G2S wire increases due to the additional work hardening created by the glass filler. The microhardness Hμ50 in metal-glass electric arc coatings increased by an average of 14%, the hardness HV5 - 21%.

Table 1 - Comparative characteristics of devices for uninterrupted powder supply

Characteristic	Powder feeder [6]	Advanced Powder Feeder [16]	Indicators in%
Jet opening angle, degrees	9	6	-33
Spray spot diameter, mm	32	23	-28
Particle speed, m / s	89	106	+19
Temperature of metal particles, °C	2064	2067	+0,15
Average particle size, μm	64…76	43…54	-31
Oxygen content in the coating, wt. %	0,46	0,80	+74
Coating porosity, vol. %	6	3	-50
A-glass content, vol. %	19,5	22,3	+14
CMM	0,63	0,74	+17

The adhesion strength to the base increased from 28 MPa to 38 MPa when 11 ± 3% (vol.) A-glass was introduced into the Sv-08G2S electric arc coating. An increase in adhesion strength is due to the fact that non-melted A-glass particles in the coating, colliding with the surface of the base, additionally activate it due to their high kinetic energy and angular shape, and when colliding with already fixed plastic metal particles, they "drive" them into the microroughness of the surface foundations and subsequent layers.

Analysis of the results of studying the wear resistance of metal-glass coatings with A-glass content from 5 to 17% (vol.) Showed that a coating with 17% (vol.) Of the glass phase has 8 times less wear than bronze of the BrAZh 9-4 brand after heat treatment (39...41 HRC), but at the same time there is a catastrophic wear of the counterbody. The most optimal wear resistance has a pair with a metal-glass coating, with a glass phase content of 11% (vol.), The total wear of which is 6.9 times lower than that of a pair with an unfilled coating of Sv-08G2S and 2.8 times less than a bronze one.

Thus, an improved device for the uninterrupted supply of free-form powders makes it possible to control, over a wider range, the content of powder particles in a high-temperature jet and, accordingly, in a composite electric arc coating. Improves the quality of the resulting coating by increasing the speed of particles in a high-temperature jet and decreasing the angle of its opening, which leads to an increase in the utilization rate of the material during spraying and an increase in the hardness of the metal matrix in the composite electric arc coating, and an increase in their adhesion to the base and wear resistance.

On the basis of a set of theoretical and experimental studies, we have developed and brought to practical application the technological foundations of electric arc spraying of coatings using an electric pulse effect on a heterophase high-temperature flow, which make it possible to obtain a finer and more dense structure in the coating material with a complex of improved physical, mechanical and operational properties.

When developing the technological foundations of coating deposition, the optimal amplitude-frequency parameters of the electric pulse effect during the electric arc spraying of Sv-08G2S wire (pulse frequency 6.5 kHz, amplitude 5 kV) were determined, which ensure a decrease in the average size of the sprayed particles from 84 μm to 54 μm an increase in their average flight speed by 20% due to the intensification of the grinding process and the provision of additional kinetic energy in an external electric field, which in turn leads to a decrease in porosity from 6% to 3%, the thermal conductivity coefficient by 12% and an increase in the hardness of coatings by 35 %. As a result of determining the operational properties, it was found that the use of an electric pulse effect at optimal parameters provides an increase in the adhesion strength of electric arc coatings made of Sv-08G2S wire by 30%, and their wear resistance increases by 1.7 times [14], [20].

In works [13], [15], [16], [17], [18], it is noted that it is advisable to carry out pre-recrystallization heat treatment (PHT) of sprayed coatings to further increase their physical, mechanical and operational properties, based on fixing polygonization processes at the stage of the minimum subgrain size, by heating the material coatings to the temperature of the beginning of primary recrystallization, short-term exposure and subsequent rapid cooling to room temperature.

It is known [16] that at high degrees of deformation, a "cellular" dislocation structure and bulk dislocation plexuses of "cell walls" with a thickness of a fraction of a micron are formed. When heated, three-dimensional walls flatten and turn into flat low-angle subboundaries, and cells into subgrains. After further short-term exposure of the sprayed coatings at the temperature of the onset of primary recrystallization and cooling them in air, polygonization processes occur. Due to the high density of dislocations in the sprayed coatings, a large number of subgrains are formed, that is, substructural elements are formed, which can have nanoscale dimensions, which leads to an increase in the physicomechanical properties (in particular, the hardness) of the coatings.

To obtain subgrains (nanograins), which provide the "size effect", it is necessary to fix the moment of their largest amount with a minimum size, that is, to stop the polygonization process by cooling the coating material to ambient temperature in order to prevent the processes of collective polygonization.

The amount of deformation determines the degree of substructure refinement. The larger the deformation value, the smaller the subgrain size. On the basis of the above experimental studies, it has been established that the use of electric impulse action during electric arc spraying leads to an increase in the speed of the sprayed particles and, as a consequence, to an increase in their deformation. The deformation values of the sprayed particles upon impact on the base and subsequent layers of the electric arc coating are about 80...95%, and the cooling rate of the deformed particle can reach 108 deg/s. This high cooling rate prevents dynamic recrystallization processes in the coating material, which means that work-hardening is maintained. Therefore, a very urgent task is to study the effect of pre-recrystallization heat treatment on the physicomechanical and operational properties of electric arc coatings applied with the use of electric pulse action.

Samples of electric arc coatings applied using electric impulse action in the optimal mode (see above) were obtained, which were heated in a furnace to a temperature close to the beginning of the initial recrystallization of the coating material obtained from wire of the Sv-08G2S grade, which is 400...450 °C and kept for some time, as shown in Fig. 1.

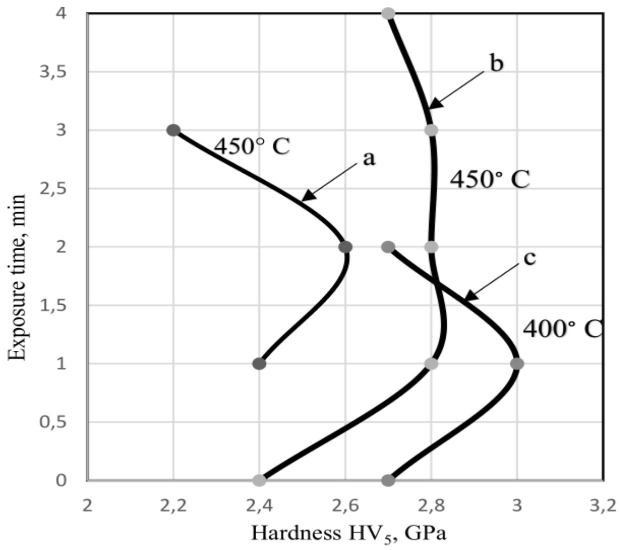


Figure 1 - Hardness of electric arc coatings obtained from wire of the Sv-08G2S brand:
a - applied in the traditional way; b, c - using electrical impulse action

According to the presented data, it has been established that the value of the hardness of electric arc coatings increases after pre-recrystallization heat treatment at a temperature of 450 °C and an exposure of 2 min for a coating applied by traditional technology from 2 GPa to 2.6 GPa. For a coating applied using an electrical impulse exposure, holding for 1 min at a temperature of 400 °C provides a maximum hardness value, which increased from 2.7 GPa to 3 GPa (+ 12%).

From the obtained results of determining the hardness (Fig. 1), it follows that for coatings deposited with the use of an electric pulse, the optimal mode of pre-recrystallization heat treatment, which provides the maximum hardness, shifts to the range of lower temperatures and exposures and makes it possible to increase the hardness by 12%. This dependence is explained by a higher degree of deformation of particles during the formation of a coating due to an increase in their speed.

The analysis of microstructures showed that no changes in the structure of the coatings before and after heat treatment were revealed. This indicates that the strengthening effect is provided by structural elements, the size of which is less than 0.5 μm, which is explained by the resolution of the human eye and optical microscope.

It is known [16] that when the structure is refined and nanosized elements are obtained, the thermal conductivity of the metal material decreases. Therefore, we conducted a study of the effect of pre-recrystallization heat treatment on the thermal conductivity coefficient of the resulting electric arc coatings. The analysis of the results obtained indicates a decrease in the coefficient of thermal conductivity of coatings by an average of 15% after pre-recrystallization heat treatment, which is explained by an increase in the number of boundaries between subgrains.

To quantify the effect of pre-recrystallization heat treatment on the substructure of electric arc coatings, we determined the sizes of coherent scattering regions (CSR) of X-ray radiation (Table 2).

Table 2 - Size of areas of coherent scattering of X-ray radiation in arc coatings

Coating	Spraying technology and particle deformation	Heat treatment	CSR size, nm
Electric arc coating applied from wire grade Sv-08G2S	Obtained by traditional technology. Deformation 83%.	Without processing	>200
		450 °C, 2 min	106
	Obtained using electrical impulse exposure. Deformation 87%.	Without processing	~200
		400 °C, 1 min	87

According to the data given in table. 2, when using an electric pulse during deposition, a decrease in the areas of coherent scattering of X-rays is observed, which is explained by the refinement of the substructure in the coating material, since it is known that the CSR size is identified with the average subgrain size [16], [17], [18]. After further pre-recrystallization heat treatment of electric arc coatings, the CSRs have significantly lower values compared to heat-treated coatings obtained by traditional technology. So the CSR of an electric arc coating decreases from 106 nm to 87 nm. Thus, the analysis of the data obtained suggests that carrying out pre-recrystallization heat treatment makes it possible in a number of cases to obtain a subgrain structure of a nanoscale size. This is explained by the fact that after the thermal treatment of the coatings sprayed with the use of an electric pulse effect, subgrains of a smaller size are formed due to the greater degree of particle deformation.

The main disadvantage of pre-recrystallization heat treatment is a short holding time of several minutes; therefore, it is urgent to study the possibility of fixing the polygonization substructure of the sprayed coating and ensuring a longer holding during pre-recrystallization heat treatment due to subsequent deformation.

For the research, we chose electric arc coatings obtained from wire 12X18H10T, since previous experiments showed that this material is characterized by a high increase in hardness after pre-recrystallization heat treatment [16]. The spraying was carried out according to the traditional technology and with the use of electric impulse action at optimal conditions. The subsequent deformation of the coating was carried out on a hydraulic press at a load of 20 tons. The amount of deformation was 15%. The obtained samples with coatings were heated in a furnace to the temperature of the onset of the primary recrystallization of the material of the electric arc coating obtained from wire 12Kh18N10T, which is 600 °C. The optimal mode of pre-recrystallization heat treatment was determined by hardness indicators. The hardness measurement results are shown in Fig. 2. The hardness of the coating after spraying, applied according to the traditional technology, was 2.4 GPa. With the use of electric impulse action, the hardness of the coating increased to 2.8 GPa.

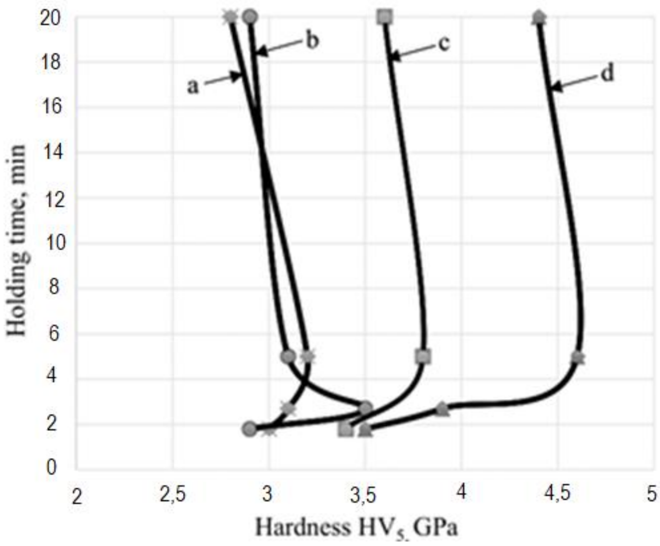
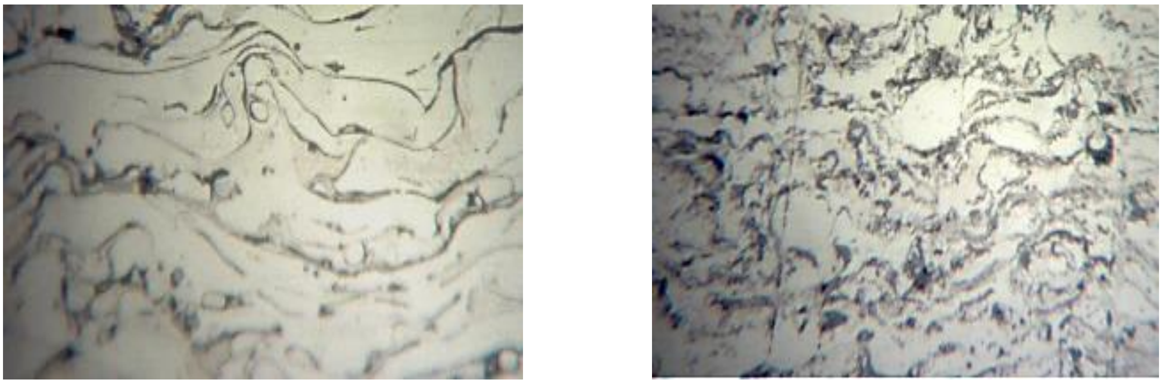


Figure 2 - Dependence of the hardness of electric arc coatings from wire 12X18H10T sprayed by different technologies on the exposure time during heat treatment:
a - after spraying using traditional technology; c - spraying + deformation (15%);
b - after spraying with the use of electric impulse action; d - spraying + deformation (15%)

Analysis of the data presented shows that the use of subsequent deformation provides a smaller decrease in hardness with an increase in the holding time during the pre-recrystallization heat treatment of coatings up to 20 min. This trend is observed for both methods of applying electric arc coatings. So, for example, the hardness of a coating sprayed by the traditional method, with an increase in the holding time from 5 min to 20 min without additional deformation, decreases from 3.2 GPa to 2.8 GPa (13%), and after deformation only from 3.9 GPa to 3.8 GPa (-3%). When using an electro-pulse effect on the spraying process, an increase in hardness is observed after additional deformation and heat treatment (holding for 20 minutes) by 83%, and when spraying without an electro-pulse effect - by 58%. This effect is explained by an increase in the deformation value of particles due to an increase in their average flight speed.

The microstructures of the coatings after the pre-recrystallization heat treatment are shown in Fig. 3. Analysis of microstructures showed that the coating sprayed with the use of electric pulse action is characterized by the presence of thinner lamellas.



a *b*

Figure 3 - Microstructure of sprayed electric arc coatings made of 12X18H10T wire after subsequent deformation and pre-recrystallization heat treatment in a mode that provides maximum hardness: a - by traditional technology; b - using electrical impulse exposure

Both microstructures have a flaky structure typical of thermal gas coatings. The porosity of the coating when spraying using the traditional technology is about 6%, when using an electric pulse it is 4%. Structural elements providing the manifestation of the size effect are not observed. To identify them, OCD was determined. The results of determining the CSR of the obtained coatings are given in table 3.

Table 3 - Size of the OKR of electric arc coatings obtained from wire of grade 12X18H10T

Coating	Treatment	CSR, nm
Sputtered on traditional technology	After spraying	>200
	After heat treatment (5 min, 600 °C)	153
	After heat treatment (20 min, 600 °C)	>200
	Deformation 15%	164
	Deformation 15% and heat treatment (5 min, 600 °C)	87
	Deformation 15% and heat treatment (20 min, 600°C)	>200
Sputtered using electrical impulse action	After spraying	>200
	After heat treatment (5 min, 600 °C)	123
	After heat treatment (20 min, 600 °C)	>200
	Deformation 15%	154
	Deformation 15% and heat treatment (5 min, 600 °C)	82
	Deformation 15% and heat treatment (20 min, 600 °C)	198

Both microstructures have a flaky structure typical of thermal gas coatings. The porosity of the coating when spraying using the traditional technology is about 6%, when using an electric pulse it is 4%. Structural elements providing the manifestation of the size effect are not observed. To identify them, OCD was determined. The results of determining the CSR of the obtained coatings are given in table. 3.

According to the data presented, as in the case of spraying wire Sv-08G2S, coatings sprayed with the use of electric impulse action are characterized by a lower value of the CSR and nanoscale size.

Heat treatment for 20 min of the re-deformed coatings provides a finer substructure than coatings after spraying. This is explained by the fact that when repeated deformation is carried out, from 50 to 75% of dislocation interactions ends with the emergence of dislocation barriers (Hirt, Lomer-Cottrell), the rest is involved in the formation of dislocation tangles. These dislocation barriers, appearing along the direction perpendicular to the deformation axis, restrain the movement of dislocations and, as a consequence, reduce the mobility of polygonization subboundaries, thus inhibiting the polygonization process, providing a stabilizing effect.

CONCLUSIONS and prospects of further research

The improved electric arc atomizer allows improving the quality of coatings by increasing the particle velocity in the high-temperature heterophase jet and decreasing its opening angle, which leads to an increase in the material utilization factor during spraying from 0.63 to 0.74 and an increase in the hardness of the metal matrix in the composite electric arc metal-glass coating on 21%, and as a result, to increase their adhesion strength to the base by 26%, wear resistance by 6.9 times in comparison with unfilled coating. Subsequent pre-recrystallization heat treatment of electric arc coatings applied using an electric pulse effect provides an increase in hardness by an average of 13% in comparison with similar heat-treated coatings applied by the traditional method, and the use of additional deformation (15%) makes it possible to increase the holding time to 20 min by reducing mobility of polygonization subboundaries.

The conducted research and analysis of the possibilities of improving the physical, mechanical and operational properties of electric arc coatings make it possible to recommend their use at the level with plasma coatings in the repair of machine parts and mechanisms, as well as other technical means.

Prospects for further research are in the optimization of spraying modes, deformation and heat treatment, as well as in the development of technologies for the automated application and processing of the resulting electric arc coatings on specific parts of machines and mechanisms for their effective operation under specified conditions.

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ЕЛЕКТРОДУГОВІ ПОКРИТТЯ З КОМПЛЕКСОМ ПІДВИЩЕНИХ ВЛАСТИВОСТЕЙ ДЛЯ ВІДНОВЛЕННЯ ТА ЗМІЦНЕННЯ ДЕТАЛЕЙ ГІРНИЧИХ МАШИН

Мета та завдання. *Дослідження та аналіз можливостей застосування відновлювальних електродугових покриттів при ремонті машин і механізмів, які застосовуються в різних галузях промисловості.*

Методи дослідження*. Дослідження пористості отриманих електродугових покриттів здійснювали за допомогою комп'ютерної металографії. Твердість визначали на приладі типу Віккерс. Вивчення теплофізичних властивостей покриттів проводили за методом динамічного калориметра. Міцність зчеплення покриттів з основою визначали методом "витягування штифта". Визначення зносостійкості проводили на машині тертя СМЦ - 2 за схемою «ролик-колодка» в умовах обмеженої мастила. Визначення областей когерентного розсіювання рентгенівського випромінювання для оцінки розмірів субструктури матеріалу покриття здійснювали методом рентгеноструктурного аналізу на установці ДРОН-3.*

Основні результати. *Отримав подальший розвиток електродуговий метод нанесення покриттів за рахунок удосконалення конструкції розпилювальної головки, що* *дозволило підвищити коефіцієнт використання матеріалу при їх напиленні та фізико-механічні, а також експлуатаційні властивості. Встановлено закономірності впливу електроімпульсного впливу на мікроструктуру і фізико-механічні властивості (твердість, щільність, міцність зчеплення, теплопровідність, зносостійкість) електродугових покриттів. Отримав подальший розвиток процесу передрекристалізаційної обробки напилених покриттів у напрямку термічної стабілізації полігонізаційної субструктури за рахунок подальшої деформації отриманих покриттів.*

Висновки та практичне значення. *Удосконалено електродуговий розпилювач, який дозволяє поліпшити якість композиційних покриттів шляхом збільшення швидкості частинок у високотемпературному гетерофазному струмені й зменшення кута її розкриття, що призводить до підвищення Кім при напиленні з 0,63 до 0,74. При цьому приріст твердості металевої матриці в композиційному електродуговому покритті становить 21%, їх міцність зчеплення з основою збільшується на 26%, зносостійкість в 6,9 раза в порівнянні з ненаповненим покриттям. Визначено оптимальні амплітудно-частотні параметри електроімпульсного впливу при електродуговому напиленні дроту Св-08Г2С (частота імпульсів – 6,5 кГц, амплітуда – 5 кВ), які забезпечують підвищення твердості до 35 %, міцності зчеплення з основою до 30% і зносостійкості покриттів 1,7 раза за рахунок подрібнення і прискорення напилюваних частинок. Встановлено оптимальні температуро-часові параметри передрекристалізаційної термічної обробки, які забезпечують подальше підвищення твердості покриттів за рахунок подрібнення субзерен до наномасштабного розміру включно. Показана можливість термічної стабілізації полігонізаційної субструктури електродугових покриттів, отриманих розпиленням дроту марки 12Х18Н10Т, шляхом їх додаткової пластичної деформації.*

Застосування результатів досліджень, отриманих в роботі, надають можливість розширити номенклатуру дешевших напилюваних матеріалів для нанесення покриттів з підвищеними фізико-механічними та експлуатаційними властивостями на важко навантажені деталі машинобудування, електротехнічні вироби та деталі військово-промислового комплексу.

Ключові слова: *електродугові композиційні покриття, електроімпульсний вплив, термічна обробка.*

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