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DEVELOPMENT OF TECHNOLOGICAL PRINCIPLES FOR APPLYING A COMPOSITION OPTIMIZED COMPOSITE COATING OF CERAMICS

The article presents the developed technological scheme for applying composition-optimized ceramic composite coating based on Al_2O_3-TiO_2-NiCrAlITa and Al_2O_3-TiO_2-Mo materials. It includes a number of technological operations: preliminary preparation of the developed powders and the working surface of the samples, coating, subsequent high-energy processing in order to improve the operational characteristics of the coating. The most promising for obtaining wear-resistant plasma coatings that increase the durability and reliability of mechanisms and machines are those materials that can withstand maximum loads without plastic deformation in friction pairs in a wide range of operating temperatures and have the highest resistance to abrasive wear, the ability to work in aggressive environments and vacuum. The most promising for operation under such conditions are compositions that consist of a ceramic-metal matrix and an oxide component evenly distributed in it. To increase the adhesive and cohesive strength of the plasma coating and reduce the residual stresses formed in the resulting "coating-substrate" system, it is advisable to use pre-spraying of the sublayer. In this case, the sublayer used should have an increased strength of adhesion to the substrate and be characterized by sufficient plasticity and a thermal expansion coefficient that closely corresponds to the coefficient of the material of the outer layer of the formed coating. When forming plasma coatings based on ceramics with the use of metal additives, it is effective to spray intermediate sublayers based on nickel and molybdenum with a size of 0.10-0.20 mm. Structural elements in the working surface of the applied powder materials must be distributed evenly. The level of energy impacts on the layers of the formed coating is correlated with the change in distances during processing. Under shock and wave effects of pulses of the compression plasma flow, plastic deformation and significant compaction of the treated layer of the applied plasma coating occur. Ultrafast cooling and corresponding heat removal to the substrate, after melting of the formed layer with a thickness of about 20-30 microns, is the result of the thermal effect of compression plasma pulses.

Keywords: *ceramic-metal plasma coatings, compression plasma flows, processing distance, molded structures, surface layers, molded wear-resistant coatings.*

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РАЗРАБОТКА ТЕХНОЛОГИЧЕСКИХ ПРИНЦИПОВ НАНЕСЕНИЯ ОПТИМИЗИРОВАННОГО ПО СОСТАВУ КОМПОЗИЦИОННОГО ПОКРЫТИЯ ИЗ КЕРАМИКИ

В статье представлена разработанная технологическая схема нанесения оптимизированного по составу композиционного покрытия из керамики на базе материалов Al_2O_3-TiO_2–NiCrAlITa и Al_2O_3-TiO_2-Mo. Она включает в себя ряд технологических операций: предварительную подготовку разработанных порошков и рабочей поверхности образцов, нанесение покрытий, последующую высокоэнергетическую обработку с целью улучшения эксплуатационных характеристик покрытия. Самыми перспективными для получения износостойких плазменных покрытий, повышающих долговечность и надежность механизмов и машин, являются те материалы, которые могут выдерживать максимальные нагрузки без пластической деформации в парах трения в большом интервале эксплуатационных температур и обладающих наивысшей стойкостью при абразивном износе, способностью работать в агрессивных средах и вакууме. Наиболее перспективными для работы в таких условиях являются композиции, которые со-

стоят из металлокерамической матрицы и равномерно распределенной в ней оксидной составляющей. Для увеличения адгезионной и когезионной прочности плазменного покрытия и снижения формируемых остаточных напряжений в полученной системе "покрытие - подложка" целесообразно использовать предварительное напыление подслоя. При этом используемый подслой должен иметь повышенную прочность сцепления с подложкой и характеризоваться достаточной пластичностью и коэффициентом термического расширения, близко соответствующим коэффициенту материала внешнего слоя сформированного покрытия. При формировании плазменных покрытий на основе керамики с применением добавок металлов эффективно напыление промежуточных подслоев на основе никеля и молибдена размером 0,10-0,20 мм. Структурные элементы в рабочей поверхности нанесенных порошковых материалов необходимо распределять равномерно. Уровень энергетических воздействий на слои сформированного покрытия коррелируется изменением дистанций при обработке. При ударно-волновом воздействии импульсов компрессионного плазменного потока происходит пластическая деформация и значительное уплотнение обрабатываемого слоя нанесенного плазменного покрытия. Сверхбыстрое охлаждение и соответствующий отвод тепла к подложке, после расплавления сформированного слоя толщиной порядка 20-30 мкм, является результатом теплового воздействия компрессионных плазменных импульсов.
***Ключевые слова**: металлокерамические плазменные покрытия, компрессионные плазменные потоки, дистанция обработки, сформованные структуры, поверхностные слои, формованные износостойкие покрытия*

1. Introduction

Atmospheric Plasma Spraying (APS) is an affordable technique used by researchers to create a range of protective coatings. The use of high temperatures and energy densities makes it possible to deposit coatings of refractory materials such as ceramics and cermets, which are difficult to melt using other traditional thermal spraying processes [1-3]. Compared to ceramic plasma coatings, cermet coatings consisting of ceramic particles bonded to metal particles exhibit superior thermal shock resistance in a high temperature atmosphere. In addition, they share advantages of ceramics and metal, such as hardness and toughness. In addition, the effective use of wear-resistant coatings can be significantly improved by applying a subsequent modifying effect on their structure [4-6]. When processing wear-resistant plasma coatings with high-energy effects, their sources have a number of advantages: firstly, the locality and high concentration of the input energy, which makes it possible to act on the necessary area of the formed wear-resistant coating, thereby not violating, due to the general heating of the entire volume of its microstructure and required properties; secondly, the possibility of strict control of all parameters of influences, which allow to form the structure of the layer being created, to regulate its roughness and the necessary geometric dimensions, to obtain the necessary parameters of wear resistance, total porosity, and hardness. However, one should always keep in mind the ability of a high-energy modification to change and redistribute residual stresses in the formed coating, especially at small coating thicknesses [7,8].

2. Schemes of technological processes for the formation of composition-optimized composite coatings from ceramics

The developed schemes of technological processes for the formation of composition-optimized ceramic composite coatings using additives of refractory metals and subsequent high-energy modification on a steel substrate. They consist of a number of technological operations and include the preliminary preparation of the developed powders and the working surface of the samples, the application of coatings, and the subsequent high-energy processing in order to improve the operational characteristics of the coating. Powder preparation. The particle size of sprayed powders largely determines the properties of the plasma coating, and the stability of the fraction determines the limits of change in properties. The required sieving of powder materials by fractions is carried out in powder material classifiers. The desired particle sizes of the powder material for the formation of NiCrAlI and Mo sublayers by plasma spraying of the main Al_2O_3-TiO_2-NiCrAlTa and Al_2O_3-TiO_2-Mo layers are 40-100 μm. To remove traces of adsorbed moisture from the materials, the prepared fractions of the powder material are dried at a temperature not lower than 90 ° C for at least 1-2 hours with a thickness of no more than 20 mm of the powder filling layer on the baking sheet. Preliminary preparation of the surface for plasma spraying of the coating. The surface prepared for spraying should not have dents or cavities. Preliminary control of defects is carried out visually using a measuring magnifier. Cleaning of the surfaces of parts from the presence of traces of oil and other contaminants is carried out in an ultrasonic bath, preferably in an ethyl alcohol environment for at least 1 hour. To increase the adhesive and cohesive strength of adhesion of the applied powder material, an important step in the developed technology is the preparation of the surface of the product for spraying. During cleaning, the samples are processed on a pneumatic abrasive unit using electrocorundum. To prevent defective samples, it is not recommended to use a compressed air pressure of more than 0.6 MPa during processing to supply an abrasive particle. This is followed by blowing the samples with compressed air. To remove abrasive residues from the surface of the product, ultrasonic cleaning in an environment of ethyl alcohol is sometimes used.

Jet-abrasive processing modes:

1. Pressure in the compressed air system - 0.5-0.6 MPa;
2. The distance from the cut of the nozzle of the shot blasting gun to the surface to be treated is 60-80 mm;
3. The angle of inclination of the abrasive jet to the surface of the part - 60-90oC;
4. The abrasive material is zirconium electrocorundum with a grain size of 0.1-0.2 mm.

The presence of a metallic sheen on the treated surface during visual inspection is not allowed. The surfaces of the parts that are not subject to plasma spraying must be reliably protected from the effects of jet-abrasive processing. After the treatment, the part should be blown with a stream of dry compressed air to remove abrasive particles from the surface.

Application of undercoat and top coat. Along with the previously mentioned preliminary surface preparation, in order to increase the adhesive and cohesive strength of the plasma coating and reduce the residual stresses formed in the resulting "coating-substrate" system, it is advisable to use preliminary spraying of the underlayer. In this case, the sublayer used should have an increased adhesion strength to the substrate and be characterized by sufficient plasticity and a thermal expansion coefficient that closely corresponds to the coefficient of the material of the outer layer of the formed coating. When forming plasma coatings based on ceramics using additives of refractory metals, it is effective to spray intermediate sublayers based on nickel and molybdenum with a size of 0.10-0.20 mm. Structural elements in the working surface of the applied powder materials must be distributed evenly. In the technological process developed by us, this is created by using the initial composites in the form of powder materials formed using a plasma torch. The sequence of technological operations:

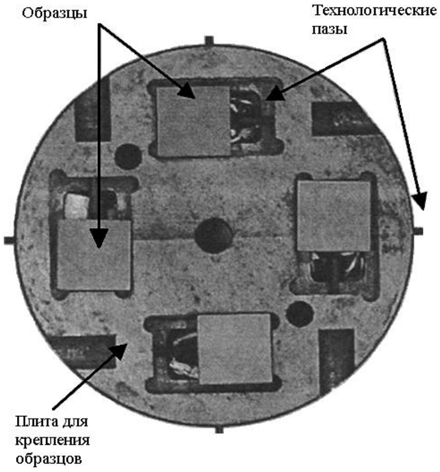
1. Install the mandrel with samples in the plasma chamber (Figure 1).

2 Unscrew the reducers on gas cylinders for supplying gases to control panels, on the compressed air line, with preliminary draining of condensate from the accumulator.

3 Switch on the control panel of the plasma unit. Visually check the operation of the monitoring sensors.

4 Switch on the powder feeder. Check the supply of conveying gas and the operation of the feeder, turn off and pour material into separate containers of the powder feeder to form sublayers and the main coating layer.

a



b

Figure 1. Sample for spraying (a) and mandrel for samples (b)

5. To prevent overheating of the coatings during the spraying process, they must be cooled, either compressed air (GOST 17433-80) or carbon dioxide is used at a pressure of 0.5-0.6 MPa and a coolant flow rate of 100-150 l/min.

6. Set the characteristics of the process for the formation of sublayers from NiCrAlITa on the instruments of the spray control panel: current of the arc of the plasma torch - 550 A; spraying distance (from the torch cut to the sprayed surface) - 100 mm with a flow rate of plasma-forming gas (nitrogen) - 45 l / min and a flow rate of powder material - 4.0 kg / h; fraction of powder material - 40-63 microns.

Set the characteristics of the process for the formation of Mo sublayers on the instruments of the control panel for the deposition process: the arc current of the plasma torch is 600 A; spraying distance (from the torch cut to the surface to be sprayed) - 110 mm with a flow rate of plasma-forming gas (nitrogen) - 50 l / mini powder material flow rate - 4.0 kg / h; fraction of powder material - 40-63 microns.

7. Turn on the powder feeder, turn on the horizontal feed of the carriage with the attached burner (relative travel speed Vp=300 mm/s) and apply the undercoat.

8. Set the characteristics of the process to form a wear-resistant coating layer for Al_2O_3-TiO_2-NiCrAlITa on the instruments of the spray control panel: current of the plasma torch arc - 550 A; spraying distance (from the torch cut to the sprayed surface) - 110 mm with the flow rate of plasma gas (nitrogen) - 50 l/min; consumption of compressed refrigerant for cooling 1-1.5 m3/min; pressure p=4-5 atm; consumption of powder material - 4.0 kg / h; with a fraction of powder material - less than 40-63 microns.

Set the characteristics of the process for forming the main layer for Al_2O_3-TiO_2-Mo on the instruments of the control panel for spraying: the arc current of the plasma torch is 550 A; spraying distance (from the torch cut to the surface to be sprayed) - 130 mm with a flow rate of plasma gas (nitrogen) - 600 l/min with a flow rate of compressed air for cooling 1-2 m3/min; p \u003d 4-5 atm. and consumption of powder material - 4.0 kg/hour with a fraction of powder material - less than 40-63 microns.

9. Turn on the powder feeder, turn on the horizontal feed of the carriage with the attached burner (relative travel speed for Al_2O_3-TiO_2-NiCrAlITa - Vp=300 mm/s and for Al_2O_3-TiO_2-Mo - Vp=250 mm/s) and apply on the main layer.

After applying the main coating layer, the plasma torch is moved from the mandrel with the part, then the spraying unit and the powder feeder are turned off, and the gas supply is closed. Waiting for the cooling of the sprayed part to carry out quality control of the formed coating. Next, layer-by-layer compression-plasma treatment to modify the formed coating. It is carried out in a vacuum chamber on a quasi-stationary plasma accelerator. The level of energy impacts on the layers of the formed coating is correlated with the change in distances during processing. The technological version of the installation is equipped with equipment that provides a minimum time for managing modification modes, installing and removing products for processing. Technological recommendations (the scheme of the main operations for the formation of composite coatings of increased wear resistance are shown in Figure 2.

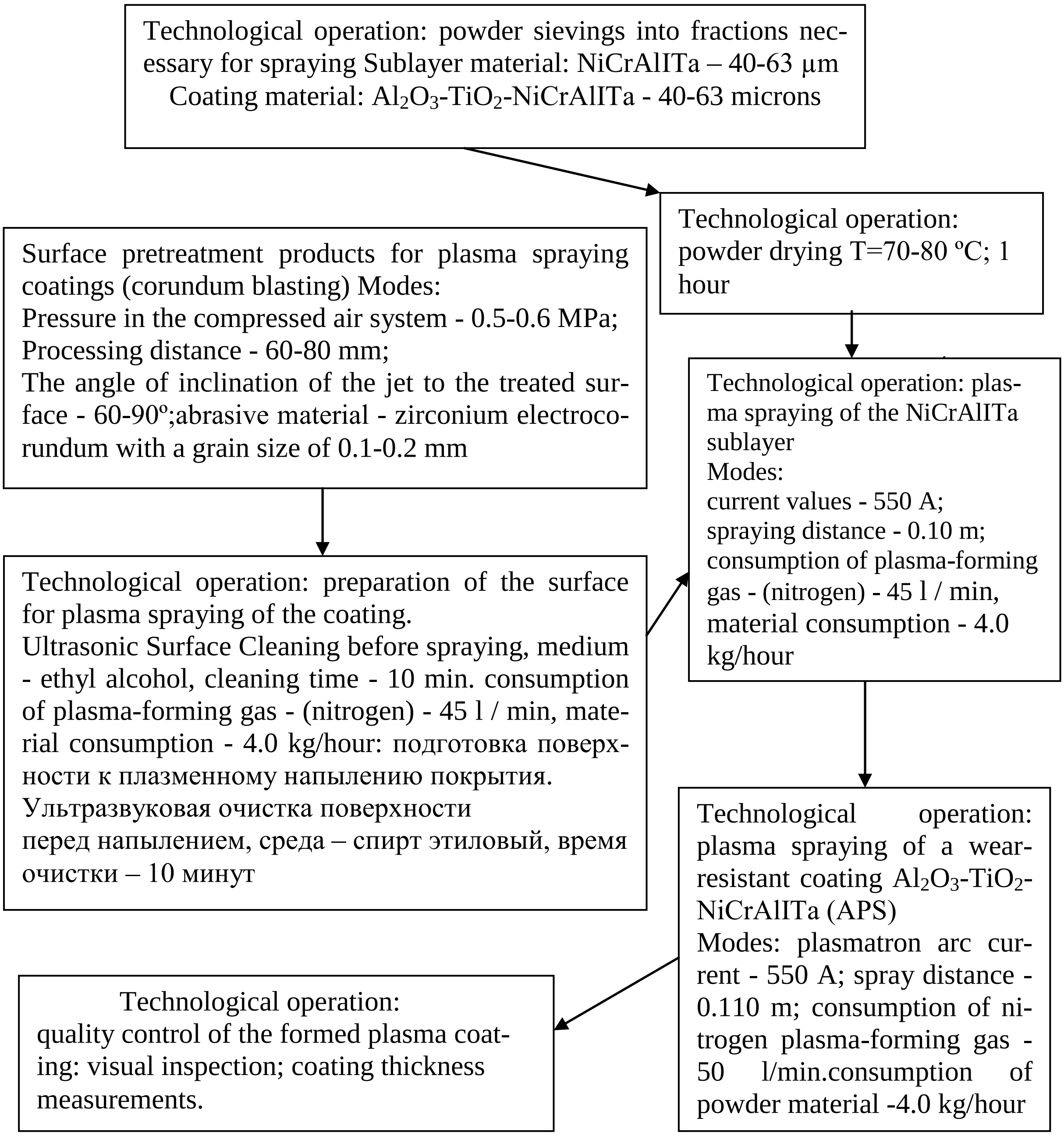


Figure 2. Scheme of the technological process of plasma spraying composite coatings of increased wear resistance based on Al_2O_3-TiO_2-NiCrAlITa powder

3. Conclusion

Based on the review of methods for modifying high-energy plasma coatings based on ceramics, it can be stated that these coatings have a number of significant defects, such as high residual porosity, lamellar structure, and not always sufficient adhesion. Subsequent high-energy processing, as a surface hardening technology, is an effective way to eliminate these defects and improve the quality of the plasma-welded coating. Schemes of technological processes for the formation of composition-optimized ceramic composite coatings using additives of refractory metals and subsequent high-energy modification on a steel substrate are developed. They consist of a number of technological operations and include preliminary preparation of the developed powders and the working surface of the samples, coating, subsequent high-energy processing in order to improve the operational characteristics of the coating. Consistent execution of all developed technological operations leads to the production of high-quality wear-resistant plasma coatings, able to work in conditions of intensive wear and high temperatures.

LITERATURE

1. Obtaining a composite ceramic material for thermal spraying / V.A. Okovity [and others] // Science and technology, BNTU. - Minsk. - 2017. Issue. 3. - P. 193-199.

2. Panteleenko, F.I. Investigation of plasma two-layer composite coatings zirconium dioxide - nichrome / F.I. Panteleenko, V.A. Okovity, E.F. Panteleenko // Actual problems in mechanical engineering, NSTU. - Novosibirsk - 2017. Volume 4. No. 3. - P. 100-105.

3. Formation and study of plasma two-layer composite coatings (viscous metal layer NiCr and solid ZrO2) / V. A. Okovity [and others] // Science and Technology, BNTU. - Minsk. - 2018. - Issue 1. - P. 21-28

4. Plasmatron for coating / V. A. Okovity [and others] // Science and technology, BNTU. - Minsk. – 2019. - Issue 1. - S. 5-10.

5. Analysis and selection of possible options for spraying composite multilayer coatings from ceramic powders on protective screens / F. I. Panteleenko [et al.] // Fundamental and applied problems of engineering and technology. - 2019. - No. 4-2 (336). - P.166-171.

6. Analysis and selection of possible options for spraying composite multilayer coatings from ceramic powders on protective screens / F.I. Panteleenko [et al.] // Dynamics, reliability and durability of mechanical and biomechanical systems: abstracts of the international scientific and technical conference. - 2019. - Moscow. - C.42-45.

7. Formation of plasma powder coatings from ceramics with subsequent high-energy modification to improve the operational characteristics of the surface / F.I. Panteleenko [and others] // Welding in Russia - 2019. Current state and prospects: abstracts of the international conference, Tomsk, September 3-7. 2019 / Tomsk Polytechnic University. in-t; editor: Yu.N. Saraev. - Tomsk, 2019. - P. 198.

8. Okovity, V. A. Formation and study of multilayer composite oxide plasma coatings on elements of screen anti-meteor protection "for an international scientific and technical journal / Okovity V.A., Panteleenko F.I., Devoino O.G., Okovity V.V., Astashinsky V. M., Khramtsov P.P., Chernik M.Yu., Uglov V.V., Sobolevsky S.B. // "Science and technology" BNTU, 2016. - Issue 5.- P.357-364.

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