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EQUIPMENT FOR APPLICATION OF PLASMA WEAR-RESISTANT COATINGS BASED ON M-CROLL

A set of equipment has been developed for the formation of plasma wear-resistant coatings based on M-rolls. The characteristics and parameters of the developed set of equipment for the formation of plasma coatings are presented, as well as the results of its testing. To implement new technological schemes for applying coatings with improved performance characteristics, a whole range of new equipment has been developed, patented and manufactured. The experiments carried out show that the PBG-1 plasma torch and the PPBG-04 powder feeder developed by the authors have at least a 2-3 times higher service life when spraying materials from M-rolls and ceramics compared to serial equipment from the Plasma-Tekhnik company, due to changes in the design of the cathode-anode unit of the plasma torch and the design of the feeding unit of the feeder, facilitating uniform supply of powder into the plasma jet and better penetration. The result is higher quality plasma coatings with improved performance characteristics: adhesion strength increases by 1.3-2 times, material utilization rate by 1.5-1.6 times, microhardness by 1.2-1.4 times, porosity decreases by 2-2.5 times.
Keywords*: plasma ceramic coatings, m-croll, plasmatron, powder feeder, performance characteristics, adhesion strength, porosity.*

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ОБОРУДОВАНИЯ ДЛЯ НАНЕСЕНИЯ ПЛАЗМЕННЫХ ИЗНОСОСТОЙКИХ ПОКРЫТИЙ НА ОСНОВЕ М-КРОЛЕЙ

Разработан комплекс оборудования для формирования плазменных износостойких покрытий на основе М-кролей. Приведены характеристики и параметры разработанного комплекса оборудования для формирования плазменных покрытий, а также результаты его тестирования. Для реализации новых технологических схем нанесения покрытий с повышенными эксплуатационными характеристиками разработан, запатентован и изготовлен целый спектр нового оборудования. Проведенные эксперименты показывают, что разработанные авторами плазмотрон ПБГ-1 и порошковый питатель ППБГ-04 имеют минимум в 2-3 раза выше ресурс работы при напылении материалов из М-кролей и керамических по сравнению с серийным оборудованием фирмы “Плазма-Техник”, за счет изменения конструкции катодно-анодного узла плазмотрона и конструкции подающего узла питателя, способствующих равномерной подаче порошка в плазменную струю и лучшего его проплавления. В результате получаются более качественные плазменные покрытия, с повышенными эксплуатационными характеристиками: прочность сцепления увеличивается в 1.3-2 раза, коэффициент использования материала в 1.5-1.6 раза, микротвердость в 1.2-1.4 раза, пористость уменьшается в 2-2.5 раза.
Ключевые слова*: плазменные керамические покрытия, м-кроль, плазмотрон, порошковый питатель, эксплуатационные характеристики, прочность сцепления, пористость.*

1. Introduction

The pressing issue of wear in machine components has spurred significant advancements in techniques for restoring and reinforcing the functional surfaces of these components. Across diverse sectors within the Republic of Belarus, a substantial number of machine parts and equipment undergo restoration and strengthening processes. Notably, parts restored using contemporary technologies often match the quality of newly manufactured counterparts, while offering a cost reduction of approximately 30-40%. While the application of protective coatings offers distinct advantages, it also presents certain drawbacks, making it crucial to select the appropriate method for a given application. Recent technological progress has led to substantial improvements in coating methodologies, enabling the creation of surface coatings with tailored physical, mechanical, and chemical properties designed to shield components from environmental factors. The suitability of each method hinges on a careful evaluation of its pros and cons, alongside consideration of the specific application domain. Factors such as available equipment, spray materials, gas consumption, part complexity, and overall technical and economic efficiency play a pivotal role in determining the optimal approach for each situation.

In recent times, thermal spraying techniques have gained increasing prominence. These methods involve introducing the coating material into a high-temperature stream, melting it, and propelling it onto the target surface to create a protective layer. Among the various gas-thermal coating methods, air plasma spraying stands out. Its ability to produce rapidly solidified and metastable structures, coupled with its versatility, accessibility, and relative affordability, makes it a particularly attractive option for coating various machine parts and equipment. The main characteristic of plasma coatings in most cases is the strength of its adhesion to the base [1-3]. In general, the coating is a multilayer system, including a metal sublayer and an outer layer. The main reason for the destruction of plasma coatings is thermomechanical stresses that arise due to a mismatch in the thermal expansion of the base metal and the coating layer, as well as the uneven distribution of the temperature field in the coating. Thermomechanical stresses are aggravated by the effect of residual stresses that arise in the coating during spraying, and are weakened by the effects of plasticity and creep occurring in the metal sublayer [4, 5]. Obtaining wear-resistant structures is possible through plasma spraying of coatings with certain technological parameters that ensure ultra-fast cooling of the melt of particles of the sprayed material. It should be noted that in order to obtain such structures during plasma spraying of coatings, further improvement of equipment for applying plasma coatings is necessary.

2. Development of equipment for applying wear-resistant coatings

Plasma-Tekhnik equipment is frequently employed for plasma spraying, but its plasma torches possess notable shortcomings. A major limitation is the cathode-anode unit's short lifespan. Furthermore, the intense turbulence generated by the mixing of the plasma stream with the surrounding cold air reduces both the velocity and temperature of the sprayed material particles. This increases the likelihood of undercooled particles reaching the coating formation area and promotes undesirable chemical reactions with the atmosphere. Under demanding conditions, characterized by high currents and plasma gas flow rates, the cathode experiences rapid wear. This necessitates interrupting the spraying process, shutting down the equipment, disassembling the plasma torch, and replacing the cathode-anode unit. Such frequent interventions introduce instability into the coating process, ultimately affecting the quality and consistency of the applied coatings. Therefore, the authors developed and patented an axial collet plasmatron PBG-1 [6-9], which is devoid of these disadvantages. The general disadvantage of plasma torches is the intensive turbulent mixing of the plasma flow with the surrounding cold gas, which leads to a decrease in the speed and a decrease in the temperature of the particles of the sprayed material. As a result, the probability of underheated particles in the coating formation zone increases. As well as the occurrence of uncontrolled chemical reactions with air. A plasma torch with a nozzle allows improving the protection of the plasma flow from the effects of the atmosphere. Heated inert gas (Ar) is supplied into the nozzle along its walls through a system of holes in the end part. The air around the plasma jet is displaced, additional compression of the plasma occurs, as a result of which the oxygen content in the coating decreases and the efficiency of material deposition increases. The listed advantages of a plasma torch with a nozzle contribute to an increase in the heating efficiency and an increase in the number of composite powder particles in the liquid phase colliding with the substrate. At the same time, the heating of the substrate is reduced, which accelerates heat removal and cooling of liquid-phase particles on it. All this refers to the positive factors of amorphization of the formed coating. At the same time, a significant disadvantage of the nozzle is the labor intensity of its manufacture. Fig. 1 shows the main type of the developed plasma torch. The plasma torch for coating contains a cathode 1 and an anode 2 units separated by an insulator 3. The cathode unit 1 consists of a cathode 4, which is attached to the body of the cathode unit 1 using a collet 5 fixed in a collet holder 6. Using the collet 5, the gap between the cathode 4 and the nozzle-anode 7 is adjusted during the operation of the plasma torch as the cathode wears out. The anode unit 2 consists of a nozzle-anode 7 and anode body 8, an insert in the form of a tungsten bushing 9, a nut 10 is attached to the anode body, a hole 11 is made in the nozzle-anode 7 and nut 10, into which powder is fed through an injector 12, and a nozzle 13 is attached to the anode body 8 through a nut 10 on a thread for feeding heated inert gas along its walls through a system of holes 14 in its end part. The plasma torch operates as follows. When voltage is applied to the electrodes, an electric arc occurs between the nozzle-anode 7 and the cathode 4. The plasma-forming gas - nitrogen, is fed through the tube 15 and the channel 16 in the body of the cathode unit 1 into the discharge chamber 17 of the plasma torch, formed by the cathode 4, the insulator 18 and the nozzle-anode 7 with the tungsten bushing 9, is ionized and exits the nozzle-anode 7 at high speed, forming a plasma jet, into which the powder material is fed through the injector 12, located in the channel of the nozzle-anode 7 and the bushing 10. Distilled water is used to cool the plasma torch, which enters the cavity of the body of the cathode unit 1 through the hole in the insulator 3 through the nozzle 19 and the tube 20, passes into the cavity 21 of the body of the anode 8 and cools the solo-anode 7. Then, the heated water is drained through the tube 22 and the nozzle 23. Inside the nozzle 13 along its walls through the system of holes 14 in the end part, heated inert gas (Ar) is supplied to the nozzle through the nozzle 24. The air around the plasma jet is displaced, additional compression of the plasma occurs, as a result of which the oxygen content in the coating decreases and the efficiency of material deposition increases. In the case of spraying powders based on oxide ceramics, they are uniformly distributed over the cross-section of the plasma jet and form a high-quality coating. As for temperature control by changing the thermal situation on the substrate, it is provided by varying the thickness of the applied composite coating and additional cooling of the substrate with a jet of compressed air. In the first case, the cooling rate of the coating particles on the substrate is regulated by the volume of the pore space of the applied composition, which hinders heat removal from the liquid-phase particles deep into the coating. In the second case, along with a jet of compressed air, additional cooling of the substrate is possible due to its contact with the metal, which is characterized by high thermal conductivity. Practical experience of such cooling is known in welding production. At the same time, its implementation both in welding-surfacing and in plasma spraying is complicated by solving problems caused by the creation of a sliding contact when applying coatings on cylindrical surfaces of a wide range of parts, usually rotating during the application process [10-13].

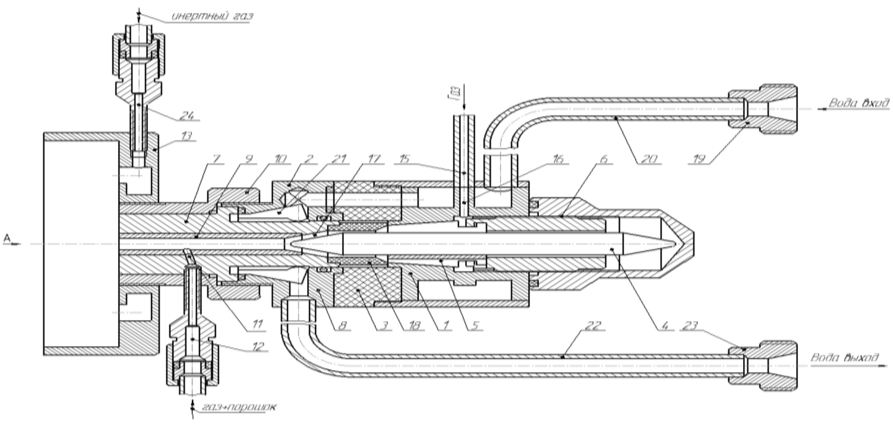

Figure 1. Plasma torch for coating application with a nozzle

When the electrode wears out and the interelectrode gap increases, the electrode can be moved in the collet, using a special device, measure the interelectrode space and continue the deposition process. The use of an attachment in the developed plasma torch makes it possible to improve the protection of the plasma flow from atmospheric influences. Inside the nozzle along its walls, heated inert gas (Ar) is supplied to the nozzle through a system of holes in the end part. The air around the plasma jet is displaced, and additional compression of the plasma occurs, as a result of which the oxygen content in the coating decreases and the efficiency of material deposition increases. The use of nozzles in the developed plasmatron contributes to an increase in heating efficiency and an increase in the number of composite powder particles in the liquid phase colliding with the substrate. At the same time, the heating of the substrate is reduced, which accelerates heat removal and cooling of liquid-phase particles on it. All this refers to the positive factors of amorphization of the formed coating. Figure 2a shows the main view of the developed plasmatron. Using a standard “Plasma-Tekhnik” installation with a TWIN-10 powder feeder, tests were carried out on a serial plasma torch and a PBG-1 plasma torch developed by the authors. Nitrogen was used as the working gas. At the first stage, the plasma torches were tested for the duration of continuous operation, at a current of 450 A, voltage of 70V, nitrogen flow rate of 35 l/min (standard mode of M-croll and oxide spraying). Both plasma torches worked continuously for 8 hours (the tests were interrupted after intense pulsations of the current and voltage parameters of a standard plasma torch from Plazma-Tekhnik). After disassembly, significant changes were revealed in the geometry of the cathode-anode assembly of the plasmatron: changes in the sharpening angle of the cathode (αe); melting and, accordingly, changes in the diameter of the cathode blunting (dп); melting and tears inside the anode nozzle. All this leads to a change in the depth of the electrode-cathode in the nozzle lз and, accordingly, the pulsation of the plasmatron parameters. No noticeable changes were detected in the geometry of the cathode-anode assembly of the developed plasmatron PBG-1. At the second stage, in the same modes, the plasmatrons operated according to the following scheme: operation for 15 minutes, switching off, switching on, etc. (15 min. technological time for spraying M-roll and oxide ceramics of the roller - lubricant). The Plasma-Tekhnik plasma torch failed after 4 hours of operation (16 technological cycles) - the electric arc did not ignite due to severe wear of the electrodes. Testing of the developed plasmatron PBG-1 was stopped after 8 hours of operation (32 technological cycles). At the third stage, M-kroll powder and zirconium oxide were sprayed on different plasma torches in the same mode: current - 450 A; voltage - 70V; nitrogen flow -35 l/min; spraying distance - 110 mm; powder fraction - 40-63 microns; powder consumption - 3 kg/hour.


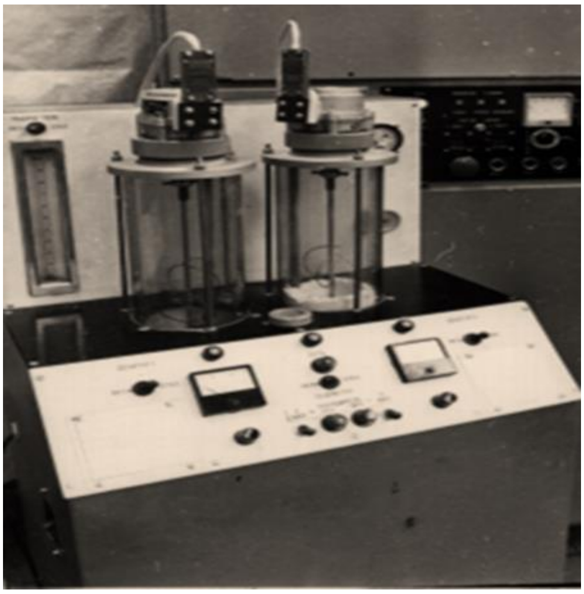

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Figure 2. Equipment for applying plasma wear-resistant coatings based on M-rolls: a – plasmatron ПБГ - 1 for applying coating with a nozzle; b – powder feeder ППБГ-04

After 30 minutes of spraying, the plasmatron from Plasma-Tekhnik had to be turned off and the nozzle cleaned; even when spraying finely dispersed ceramics, the plasmatron is unstable. The characteristics of zirconium oxide coatings deposited on a plasmatron 0890-6011 and the developed plasmatron are given in Table 1. Powder feeders are designed to supply sprayed powder into a plasma jet. The quality of the applied coating depends on the stability of the operation of this device. Powder feeder designs are as varied as plasma atomizers. The powder used for spraying is placed in a hopper (hopper capacities vary widely) of a feeder located at a short (1 m) distance from the plasmatron. The powder is supplied by a flow of transport gas to the plasma atomizer through an elastic tube and through a fitting or a special hole in the nozzle channel the gas-powder mixture is introduced into the plasma jet. The flow rate of the powder supplied to the sprayer is regulated by a dosing device, which is used as injectors (the flow rate of the powder depends on the flow rate of the transport gas), rods with holes of various sizes for the powder, rotating vertical or horizontal drums with grooves for the powder, horizontal or vertical screws, etc. To improve the flowability of the powder and prevent it from hanging in the hopper, electromagnetic, mechanical or pneumatic vibrators are used. In some cases, the powder is agitated by the transport gas. The greatest stability of powder supply is provided by feeders with mechanical dosing. The powder from the loading hopper of the powder feeder from Plasma-Tekhnik AG, the bottom of which is made in the form of an inverted cone, falls onto a flat disk rotating and vibrating along its axis, from where it is poured into the injection device of the powder feeder. The disadvantages of the Plasma-Tekhnik powder feeder include the difficulty of feeding fine powder with poor flowability. Therefore, the authors developed and patented a powder feeder PPBG-04 for coating compact materials [8, 9], which allows feeding powder with a particle size of 1-2 microns, and also has a minimum of control characteristics for use in coating (Fig. 2b). The design feature of the powder feeder being tested is the presence of two cylindrical hoppers with a capacity of 2.0 liters each and a conical mixing funnel. Each hopper is connected to a funnel by a tube with an internal diameter of 12 mm. A flexible auger passes through the hopper and tube, connected through a gearbox to a 27-volt DC electric motor. The rotation speed of the flexible screw varies from 0 to 140 rpm.

Table 1. Characteristics of coatings when testing a plasma torch

Plasma torch	Adhesion strength, MPa	Porosity, %	Material utilization rate, %	Microhardness, MPa
plasmatron “Плазма-Техник”	22,5	14	39	6400
ПБГ-1	35,4	5	61	8700

Rotation is ensured by a transistor power supply, which regulates the voltage supplied to the electric motor from 0 to 27 volts. The mixing funnel is connected by a pipeline to each bin above the level of the powder being poured. Compressed gas is also supplied to it. The powder, poured into hoppers by flexible screws, is fed into a mixing funnel, where it is picked up by a tangentially supplied compressed gas in the form of a gas-powder mixture through a flexible pipeline and fed into the spray head. The connecting pipe between the mixing hopper and the hoppers serves to equalize the gas pressure in the mixing hopper and hoppers and prevents pulsation of the powder supply by preventing the hoppers from being vacuumed as the volume of powder in them decreases. The rotation speed of the flexible screws of each bunker is controlled independently and therefore powder is supplied from each bunker alternately or together. If different powders are poured into bunkers, then a joint supply with different flow rates into one pipeline is possible.

The powder supply capacity from each bin is adjustable in the range from 0 to 2.5 l/hour. On the “Plasma-Technik” installation, in standard configurations, tested powder feeders TWIN-10 and PPBG-04, developed by the authors. Nitrogen was used as a working gas during spraying, and air was used when supplying powder. At the first stage, feeders were tested for the duration of continuous operation, using M-crawl powder and zirconium oxide, with a fractional composition of less than 50 microns. Powder consumption - 3 kg/hour; supply gas flow rate is 3.5 l/min. On the TWIN-10 feeder, the vibrator is turned on at maximum mode - 16 units. The powder feeder failed after 40 minutes. work, after disassembling it was found that the auger and receiving cone were clogged with tightly compressed powder. Attempts to improve the operation of the feeder while decreasing or increasing the powder consumption also did not give positive results; the feeder is not suitable for feeding fine ceramics. Testing of the developed PPBG-04 feeder was stopped after 2 hours of operation. At the second stage, the feeders were tested for stable reproduction of the given flow rate when the powder feeder was turned on again. In the same modes, the feeders operated according to the following scheme: operation for 15 minutes, switching off, switching on, etc., to check the stable reproduction of the given flow rate when the powder feeder was turned on again (15 min technological time for spraying M-crawl and ceramics lubricating roller). The TWIN-10 feeder could not reach the set powder supply mode after the first shutdown; after 4 shutdowns, it was not possible to resume powder supply without disassembling the feeder. The PPBG-04 feeder withstood 10 shutdowns before the experiment was terminated. At the third stage, aluminum oxide was sprayed using different feeders, at the same operating mode of the plasma torch: current - 450 A; voltage - 70V; nitrogen consumption -35 lit/min; spraying distance - 110 mm; powder fraction -50-63 microns; powder consumption - 3 kg/hour. The characteristics of coatings made of M-crawl and zirconium oxide, sawed using TWIN-10 and PPBG-04 feeders are given in Table 2.

Table 2. Characteristics of coatings when testing a powder feeder

Feeder	Adhesion strength, MPa	Пористость, %	Coefficient use material, %	Microhardness, MPa
TWIN-10	22,5	18	34	5800
ППБГ-04	35,4	10	56	7200

3 Conclusion

1. Achieving exceptionally wear-resistant surfaces relies on carefully controlled plasma spraying parameters, facilitating ultra-rapid cooling of the molten particles as they form the coating. Optimizing this process necessitates ongoing advancements in plasma coating equipment. To realize innovative techniques for applying wear-resistant coatings with enhanced performance, a suite of novel equipment has been conceived, patented, and produced.

2. The attributes and performance metrics of our newly developed plasma coating system, coupled with rigorous testing, demonstrate that the PBG-1 plasma torch and PPBG-04 powder feeder significantly outperform existing technology. Specifically, these components exhibit a lifespan at least two to three times greater than that of "Plasma-Tekhnik" equipment when spraying ceramic materials. This improvement stems from key design modifications to the plasma torch's cathode-anode assembly, nozzle configuration, and the powder feeder's delivery mechanism. These enhancements ensure consistent powder injection into the plasma stream and improved particle penetration, ultimately leading to superior coating quality and durability.

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