CHOICE OF OPTIMAL MODES OF PLASMA-ARC SPRAYING USING DIFFERENT TYPES OF CONDUCTIVE WIRES

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Abstract

The work is devoted to the study of the process of plasma-arc sputtering using a conductive wire as a moving anode. It was established that this process provides effective control of the technological parameters of the plasma jet, increases the utilization rate of materials up to 72%, reduces the porosity of sprayed coatings to less than 3%, and allows to achieve adhesion strength of coatings to the base of more than 40 MPa. The specified increase in the material utilization factor significantly increases the cost-effectiveness of plasma-arc spraying with anode wires with a diameter of 1.2-1.6 mm made of carbon steels 1020 and 1070, stainless steel AISI304, nichrome NiCr80-20, copper Cu99, aluminum alloy 5083 and others, and increasing the adhesion strength of coatings to the base expands the limits of application of this process. The use of optimal parameters of plasma-arc sputtering with anode wires makes it possible to obtain non-porous copper coatings with increased adhesion strength to the base, which can be used to create electrical contacts and intermediate layers when making soldered joints of aluminum and steel parts.

Keywords: plasma-arc spraying, moving wire-anode, wire melting, use of material, adhesion strength of coatings.

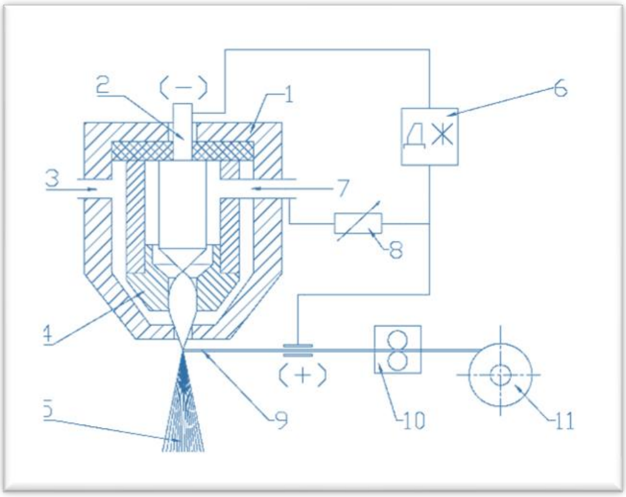
At the current stage of the development of science and technology, there is a need to apply functional coatings with specified properties without the risk of residual deformations or stresses [1]. Examples can be the restoration of overall parts such as axles or shafts, with a fairly insignificant (0.1...0.5 mm per diameter) production of seats, increasing the service life of friction pairs due to increasing the wear resistance of their components, reducing fuel consumption due to improving the coefficient of thirds sliding of certain parts of internal combustion engines, etc.

To solve such problems, the process of plasma-arc spraying with the use of a current-conducting wire-anode can be applied. The essence of the plasma-arc spraying process consists in the melting of the current-conducting wire-anode, which is introduced into the zone of the high-speed plasma jet, and the further crushing of the melt that breaks off from the end of the wire [2, 3]. But in order to fully use the advantages of this process, it is necessary to optimize its technological parameters, taking into account the materials of the sprayed wires. This work is dedicated to this problem.

The purpose of the work is to optimize the parameters of plasma-arc spraying of a compact metal wire-anode from various types of steels and alloys based on the determination of technological features of the process according to the criteria of increasing the coefficient of material utilization and increasing the indicators of the density of coatings and the strength of their adhesion to the base.

A number of technological studies were carried out to achieve this goal. For this, the methodology proposed in [4] was chosen as the basic approach to conducting research. In addition, research was conducted on the change in the material utilization factor depending on the change in the parameters of the spraying mode when using different materials of sprayed wires, and also determined the porosity and adhesion strength of the coatings applied from those wires.

According to the applied technological scheme, the arc burns between a non-fusible tungsten cathode and a current-conducting wire-anode, which is fed through the section of the plasmatron nozzle. The working (plasma-forming) gas entering the working chamber is heated by an electric arc and flows out of the nozzle in the form of a plasma jet. The open area of the discharge, outside the plasma-forming nozzle, is blown by the gas stream flowing from the annular gap between the plasmatron nozzles. The features of this method include the fact that the melting and jet spraying of the wire material is carried out by an argon plasma, while the crushing of the melt and the acceleration of dispersed particles is carried out by a stream of cold, accompanying gas. This ensures minimal losses due to evaporation of the wire material (up to 2%) and obtaining the optimal fractional composition of the dispersed phase. Technological experiments were carried out in an open atmosphere using the PLAZER 30 plasma-arc spraying installation [3, 4], in which a conductive electrode wire is used as a fusible anode (Fig. 1). In order to catch the sprayed titanium particles, the wire was sprayed into a vessel filled with water from a distance of 500 mm.



а)

б)

Fig. 1. Scheme of the process of plasma-arc spraying and spheroidization of the conductive wire (a) and the appearance of the spraying process (b), where: 1 – the working chamber of the plasmatron; rod electrode (cathode); 3 – accompanying gas supply channel; 4 – plasma-forming nozzle; 5 – stream of sprayed particles; 6 – power source; 7 – plasma-forming gas supply channel; 8 – current limiting resistance; 9 – wire (anode); 10 – feed mechanism; 11 – coil with wire.

The optimization of the modes of plasma metallization with a moving wire-anode for the investigated compositions of the wires used as the anode was carried out using the methods of mathematical planning of the experiment [5]. The following wires with a diameter of 1.2-1.6 mm were used: carbon steels 1020 and 1070, stainless steel AISI304, nichrome NiCr80-20, copper Cu99, aluminum alloy 5083.

The technological parameters were changed in the following intervals: plasmatron operating current – 160-300 A; arc working voltage 60-80 V; consumption of plasma-forming gas (argon) 1.0 -1.5 m^3/h; air consumption to create an accompanying flow that cools the nozzle and compresses the high-temperature jet, 0-20 m^3/h; spraying distance – 150-250 mm; feed speed of anode wire 2-10 m/min.

As an optimization criterion, we used the parameter of the material utilization ratio (MUR), which is determined by the formula:

$$MUR = (m_w / m_c) \times 100\%,$$

where m_w is the mass of the anode wire sprayed per given unit of time; m_c is the mass of the sprayed coating applied per given unit of time.

To determine the coefficient of material utilization, the coating was applied to 1020 structural steel plates measuring 100×100×4 mm. Plates were preweighed to the nearest 0.1 gram. The coating time was 10 seconds. Before applying the coating, the surface of all samples was subjected to jet-abrasive treatment with electrocorundum.

The values of MUR in the process of optimizing modes for selected types of materials varied in the range of 58-72%. Such parameters as pressure and consumption of working gases, current strength, and spraying distance significantly affect the value of MUR.

The conclusions and recommendations made in the process of mathematical modeling of the processes of gas dynamics and heat transfer in the plasma jet were experimentally confirmed. Namely: the most significant influence on the quality of the coating and the value of MUR depends on the pressure or flow of air used to form the accompanying flow. The transition from the turbulent to the laminar regime of the plasma jet exit and, accordingly, the degree of interaction of the sprayed material with oxygen and nitrogen depend on this parameter.

As a result of the conducted research, the optimal modes of applying coatings from the studied materials were selected, which are listed in Table 1. Using the example of a stainless steel coating, it is shown that plasma-arc spraying using modes different from the parameters given in Table 1 does not provide the required quality of the coating. Coatings applied under suboptimal regimes are characterized by increased structural defects, namely: porosity of 3% and above, the presence of a large number of oxide layers, defects at the boundary between the sprayed particles (lamellas) and at the boundary between the coating and the base, as well as an increased share of spherical particles (Fig. 2, 3).

Table 1.

Optimum regimes of plasma-arc coating of the investigated wire-anode materials, determined by the criterion of MUR increase.

Material of the wire-electrode	Naming parameters of plasma-arc spraying							
	Gas pressure when the plasmatron is switched on, MPa			Gas pressure in the metallization process, MPa	Voltage, V	Strum, A	Electric power, kVA	Coating spraying distance, mm
	air	Ar	air	Ar				
1020	0,64	0,52	0,31	0,44	70	220	15,4	104
1070	0,64	0,52	0,31	0,44	70	220	15,4	104
Stainless Steel AISI304	0,64	0,44	0,31	0,38	75	220	16,5	104
Nichrome NiCr80-20	0,64	0,44	0,31	0,38	70	220	15,4	104
Copper Cu99	0,64	0,44	0,31	0,38	80	180	14,4	104
Aluminum alloy 5083	0,64	0,44	0,31	0,38	70	200	14,0	104

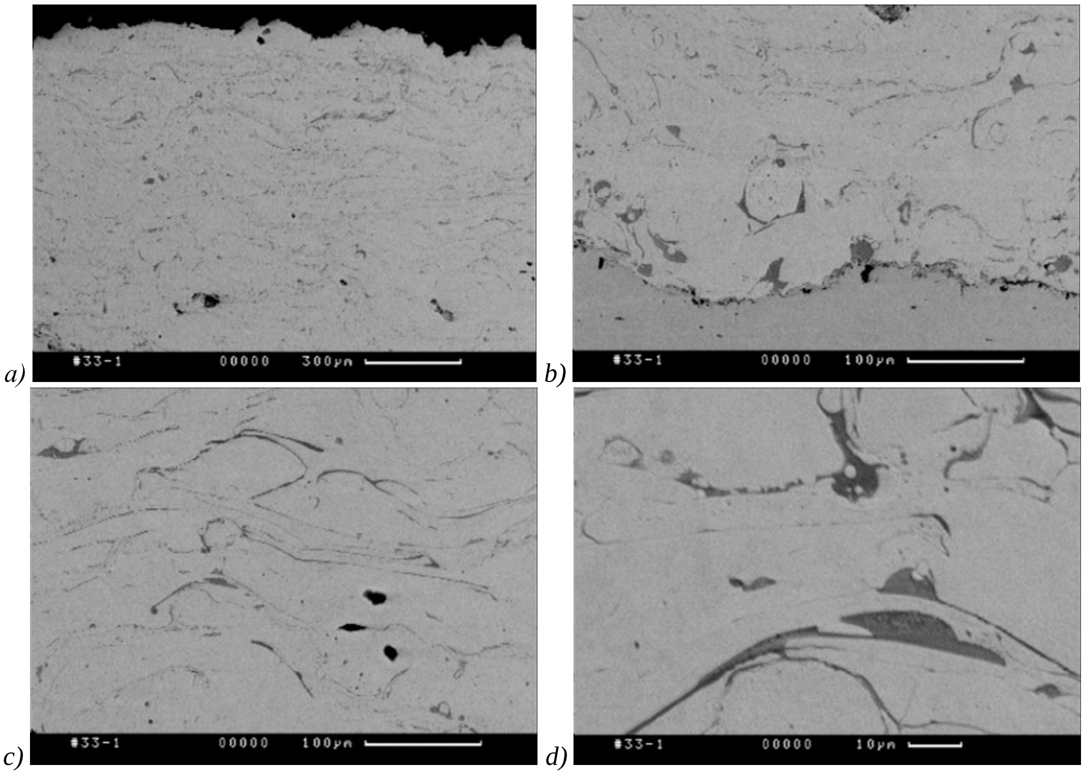
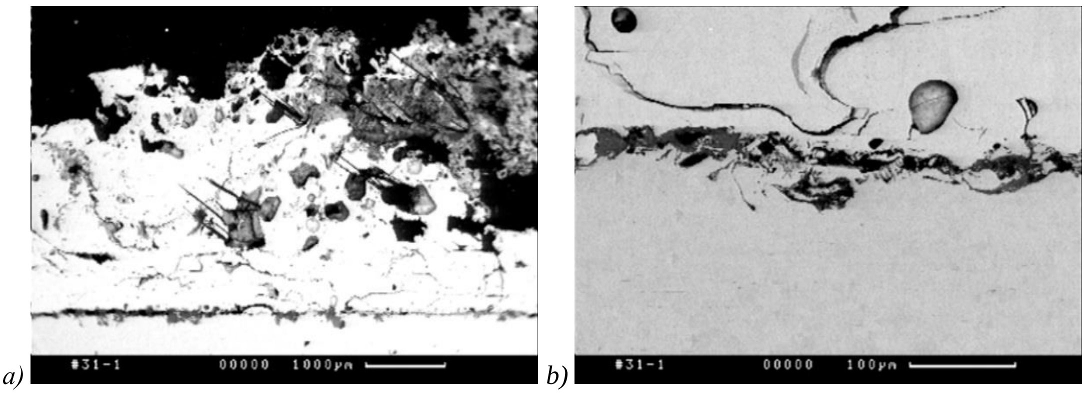
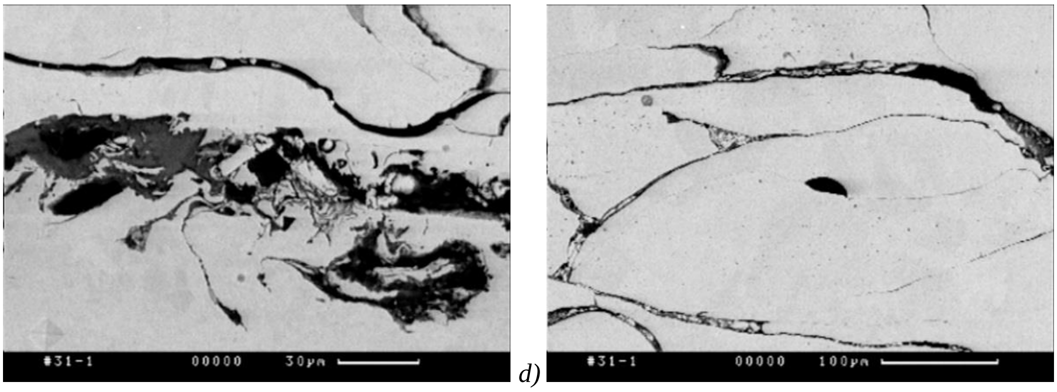


Fig. 2. The microstructure of the coating applied by plasma-arc spraying of a moving anode wire made of stainless steel AISI304 at optimal modes (Table 1).





c) d)

Fig. 3. Microstructure of the coating applied by plasma-arc spraying of a moving anode wire made of AISI304 stainless steel under suboptimal conditions.

The adhesion strength of the coatings to the base was determined by the pin method described in sufficient detail in the paper [6]. It was established that the adhesion strength of the coatings to the base depends on the technological parameters of the application of the material. Thus, when using the optimal parameters indicated in Table 1, the strength of AISI304 stainless steel coatings applied to a similar base is 35-40 MPa, and the strength of Cu99 copper and aluminum alloy 5083 coatings is 40-60 MPa. At the same time, the adhesion strength of plasma-arc coatings applied under suboptimal technological parameters is 30-35% lower than the given values corresponding to the application of optimized modes.

Conclusions.

1. The researched process of plasma-arc sputtering using a conductive wire as a moving anode provides effective control of the technological parameters of the plasma jet, increases the utilization rate of materials up to 72%, reduces the porosity of the sputtered coatings to less than 3%, and makes it possible to achieve adhesion strength of the coatings to the base of more than 40 MPa.

2. An increase in the material utilization rate of more than 70% significantly increases the cost-effectiveness of the process of plasma-arc spraying with anode wires, and an increase in the adhesion strength of the coatings to the base expands the application limits of this process.

3. The use of optimal parameters of plasma-arc sputtering with anode wires makes it possible to obtain non-porous copper coatings with increased adhesion strength to the base, which can be used to create electrical contacts and intermediate layers when making soldered joints of aluminum and steel parts.

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