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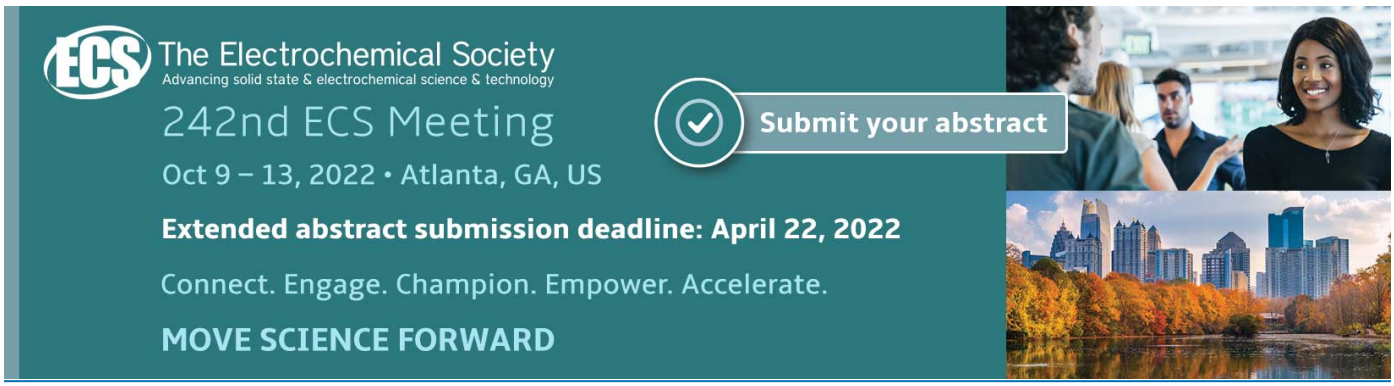

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Plasma jet stream simulation for formation coating and powder manufacturing processes

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Abstract. To carry out a comparative analysis of the parameters of the plasma jet flow, the configurations of the plasmatrons that are most common in industrial practice have been selected. The values of temperature, velocity and intensity of turbulence at the characteristic point are determined depending on the shape of the components of the plasmatrons. Recommendations have been developed for the configuration of technological equipment used in the processes of coating and powder production.

1. Introduction

Plasma method of deposition of powder metal materials has found wide application in industrial practice due to the special properties of coatings [1]. In addition, this method is used for the production of metal powder used in various industries [2, 3], including nanodispersed fraction in additive technologies. The result of coating and powder production is influenced by various parameters of the plasma jet flow, among which the temperature, flow rate and turbulence intensity play a special role [4]. At the moment, many variations of plasma installations with various design features have been invented in the world, which has a serious impact on the nature of the flow and, as a result, on the properties of the resulting powder material or coating.

The plasma installation includes such elements as a plasmatron (the head part of the plasmatron), a plasma-forming gas supply unit, and a raw material supply device. As a raw material for obtaining powder coatings and the production of metal powders with desired properties, both rods and powders can be used. The plasmatron consists of an anode, an interelectrode insert and a cathode. Depending on the purpose of the plasma installation, the internal shape of the plasma torch channel takes on a different configuration, which affects the parameters of the plasma jet flow. Known designs of plasma plants with an axial version of the input of raw materials in the form of a powder used for coating [5]. The Institute of Metallurgy of the Ural Branch of the Russian Academy of Sciences has developed and is using the MAK-100 flame installation with a radial input of raw materials [6]. MAK-100 allows working with subsonic and supersonic plasmas of various gases and their mixtures, works with arc plasmatrons of direct and indirect action. Due to the peculiarities of the power supply, it is possible to regulate its power in the range from 20 to 100 kW. MAK-100 can be used for such technological processes as: plasma hardening of the surfaces of metal parts; subsonic and supersonic plasma spraying of various metallic and non-metallic powder coatings; plasma cutting and welding; obtaining

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metal powders [7]. The MAK-100 plasma installation includes: a plasmatron, a plasma-forming gas supply unit, raw material feeding device, a cooling system, and other auxiliary devices and units. Depending on the purpose of the plasma installation, rods, wires or powders are used as raw materials for obtaining powder coatings or for the production of metal powders. The head part of the plasmatron consists of gas swirlers, an anode, an interelectrode insert, and a cathode.

The aim of the study is to create a computer model of modern plasma installations of various configurations in order to determine how the configuration of the inner channel affects the parameters of the plasma jet flow. A comparative analysis of the parameters of the plasma jet flow will make it possible to develop recommendations for choosing a rational configuration of technological equipment used in the processes of coating and powder production, depending on the features of the shape of the constituent parts. For comparative analysis, two types of plasmatrons with axial and radial feedstock input were selected.

In the problems of simulation the flow of a plasma jet, finite element calculation methods are widely used. For example, in [8], this method was applied to simulate the spheroidization of powder particles of a nanodispersed fraction.

2. Description of the computer model

In order to demonstrate the profile of the parts that form the shape of the inner channel of the plasmatron head of the considered plasma installations, figure 1 shows a section along the axis. To carry out a computer experiment, a three-dimensional mathematical model was created that copies the shape of the components of the MAK-100 multifunctional plasma installation (the first version of the design) and the plasmatron head of the installation with an axial feedstock input (the second version of the design).

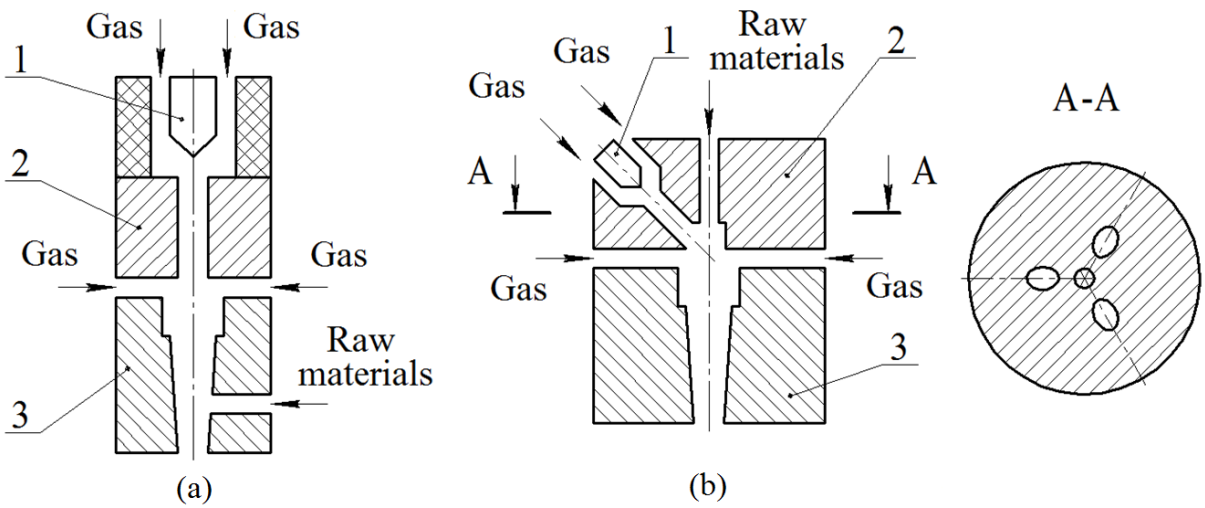

Figure 1. Diagram of the section along the axis of the considered versions of the designs: 1 - cathode, 2 - interelectrode insert, 3 - anode; (**a**) - plasmatron head of the MAK-100 installation with radial feedstock input (first design option), (**b**) - plasmatron head of the installation with axial feedstock input (second design option).

The goal set in the article was solved using two software packages SolidWorks and ANSYS by the finite element method. Two software packages were used in order to increase the accuracy of the computer experiment by comparing the results. The size of the finite element mesh was taken equal to 0.24 mm in order to take into account the surface and average values in the narrowest places of the inner channel of the plasma installation. To improve the accuracy of the numerical experiment, three parallel computer calculations were carried out in each of the software packages. More details about the choice of the size of the element of the partition of the finite element mesh and its influence on the accuracy of the computer experiment are described in [9].

The following were taken as the initial data for carrying out a computer experiment for the considered designs of plasma installations: type of gas - argon, volumetric gas flow rate - 50 l / min; plasma-forming gas pressure - 1.5 atm.; plasma temperature 7000 K. The inner channel of the anode for both considered variants of the design of the head parts of the plasmatron is a conical confuser section with a transition in diameter from 11 to 8 mm and a length of 58 mm. Also, for both variants, the same shape of the cathode with a hafnium insert was adopted. Computer models of plasma installations differ in the design of the interelectrode insert and in the units for supplying the plasma-forming gas and raw materials.

The inner channel of the computer model of the interelectrode insert of the MAK-100 plasma installation has the shape of a cylinder with a diameter of 8 mm and a length of 40 mm. The feedstock input unit is located perpendicular to the anode axis at a depth of 10 mm from the end surface of the outlet and has a diameter of 4 mm. The plasma-forming gas injection unit is set by the upper and lower swirlers having 6 channels, which are located tangentially to the inner surface, with an equal pitch relative to each other and a diameter of 3 mm. The lower swirler is located between the anode and the interelectrode insert. The upper swirler is located around the cathode. A detailed description of the computer model is presented in [10].

When simulating a plasma installation with an axial feedstock input, the internal inlet of the interelectrode insert has three channels with a diameter of 4 mm, in each of which a cathode is located. The channels are located at an angle of 120^0 relative to each other and at an angle of 45^0 to the axis of the plasmatron head. The raw material input unit is directed along the axis of the plasma head and has a diameter of 4 mm. The unit for supplying plasma-forming gases consists of four swirlers. The first is located between the anode and the interelectrode insert, the other three around the cathodes. The swirlers have six channels located tangentially to the inner surface, with an equal pitch relative to each other, and with a diameter of 3 mm.

The values of temperature, flow velocity of the plasma jet, and the intensity of turbulence of the flow at the characteristic point were calculated, which was taken as the point located on the axis of the plasma jet, located at a distance of 20 mm from the cut of the end part of the anode of the outlet hole. The parameters under consideration are selected based on their practical significance.

3. Results and discussion

The data obtained as a result of a computer experiment are presented in table 1.

Table 1. Results of Computer Experiment.

Parameter of the plasma jet at the characteristic point	Variant of the design of the plasmatron head	
	First	Second
Temperature (K)	5247.38	3458.87
Velocity (m / c)	52.11	32.23
Intensity of turbulence (%)	1.91	2.99

As can be seen from the data presented, of the two variants of the considered designs, the value of the plasma jet flow rate is higher for the MAK-100 plasma torch. The value of the turbulence intensity is higher in the plasmatron of the installation with axial feedstock input. The plasmatron of the MAK-100 installation has a higher temperature value.

Owing to the presented data, it can be seen that for the process of coating deposition, it is preferable to use the configuration of the head of the plasma torch with a radial input of raw materials, since the values of the speed and temperature are higher. For the powder production process, it is preferable to use the configuration of the head of the plasma torch with axial input of raw materials, since the values of the turbulence intensity are higher, and the value of the flow velocity of the plasma jet is lower.

4. Full-scale experiment and verification of theoretical research

To verify the data of the computer experiment, a full-scale experiment was carried out. For this, three rods with a diameter of 3 mm were selected. The selected rods had different melting points, for this the following materials were selected: copper M1 GOST 859-2014, Steel 10 GOST 1050-2013 and lanthanized tungsten TU 48-19-27-88. The rods were fixed in turn, so that one end of the rod was fixed in the clamp, and the other free end of the rod was on the axis of the plasma flow. The plasmatron head MAK-100 was mounted in a manipulator, which ensured its uniform movement along the axis towards the bar at a speed of 10 mm / min. The distance from the free end of the rod to the end plane of the anode of the plasmatron head was recorded. The initial distance between the free end of the bar and the plasmatron head was taken equal to 0.5 m. At the moment when the melting process begins on the surface of the bar, the distance from the bar to the plasmatron was fixed. To improve the accuracy of the full-scale experiment, three parallel experiments were performed for each of the selected rods, the results were averaged. A detailed description of the full-scale experiment is presented in [11]. The results are shown in table 2.

Table 2. Results of Computer and Full-Scale Experiments.

Rod material	Computer (mm)	Full-scale (mm)	Deviation (%)
copper M1	141	135	4.4
Steel 10	82	85	3.5
lanthanized tungsten	19	20	5.0

The total comparative analysis of the computer and full-scale experiments showed satisfactory agreement.

5. Conclusions

As a result of the study, a review of modern designs of plasma installations used for coating and powder production is carried out. Two options for the design of the head part of the plasmatron of the installations are chosen, the most common in production practice. Computer models have been created for the comparative analysis of the parameters of the plasma jet depending on the features of the shape of the constituent parts with equal initial data. The values of the flow velocity, temperature and turbulence at the characteristic point are determined.

As a result of a comparative analysis, we came to the conclusion that for the process of coating deposition, it is preferable to use the configuration of the plasmatron head with a radial input of raw materials, since the values of speed and temperature are higher. For the powder production process, it is preferable to use the configuration of the plasmatron head with axial input of raw materials, since the values of the turbulence intensity are higher, and the value of the flow velocity of the plasma jet is lower.

In order to verify the results of the computer experiment, a full-scale experiment was carried out, the results of which showed satisfactory agreement. The presented results are of practical use for manufacturers and consumers of technological equipment. The presented computer model makes it possible to predict the parameters of the plasma jet.

Acknowledgments

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