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EFFECT OF THE STARTING TEMPERATURE OF A PLASMA JET ON THE CHANGE IN ITS AXIAL PARAMETERS

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The effect of the starting temperature of a submerged argon plasma jet on its axial parameters is studied, and their dependences on dimensionless gas density from 11 to 81 are obtained.

Mathematical modeling and numerical computation are an effective method for studying processes occurring with the plasma deposition of protective coatings. In developing engineering methods for calculating the motion and heating of the particles of powder [1] it is necessary to employ dependences that describe the change in the velocity and excess heat content of the gas mixture on the axis of the jet. It is well known that on the main section of the jet these parameters drop rapidly owing to intense mixing of the high-temperature gas with the surrounding medium. Increasing the starting temperature of the jet

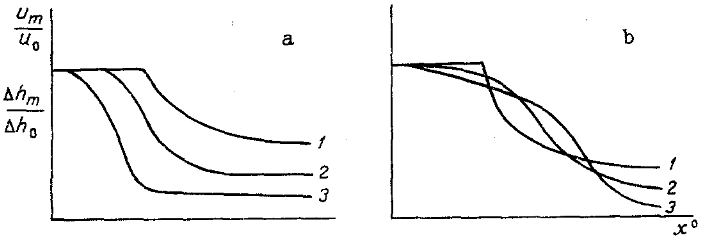

Fig. 1. The dimensionless velocity and excess heat content of gas along the axis of an argon plasma jet as a function of its starting temperature: 1) T_{01}; 2) T_{02}; 3) T_{03}; $T_{01} < T_{02} < T_{03}$; a) calculation using (1)-(2); b) from [6, 7].

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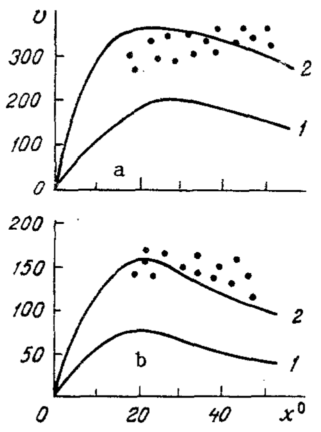

Fig. 2

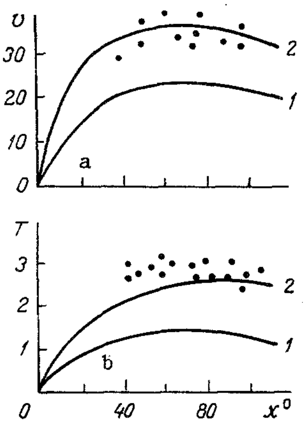

Fig. 3

Fig. 2. The velocity of particles in an argon plasma jet: 1) calculation using (1)-(2); 2) calculation using (3)-(9). The dots are the experimental points; a) aluminum oxide (d = 50 μm; G = 0.005 kg/sec; $\bar{G} = 2$; T_0 = 12,300 K); b) Br-OF-10-03 bronze (d = 60 μm; G = 0.0012 kg/sec; $\bar{G} = 0.5$). v is given in m/sec.

Fig. 3. Comparison of the computed and experimental velocities (a) and temperatures (b) of tungsten particles in an argon plasma jet: 1) calculation using (1)-(2); 2) calculation using (3)-(9); the dots are the experimental data of [8] (G = 0.00121 kg/sec; d = 60 μm). T is given in 10^3 K and x is given in 10^{-3} m.

increases the degree of its turbulence [2, 3], which accelerates the drop in the velocity and excess heat content of the flow on the main section. The length of the starting section of the jet decreases at the same time.

In the calculations the following dependences are usually employed [2, 4]:

$$\frac{u_m}{u_0} = \frac{12,4}{x^0\sqrt{\rho^0}}, \tag{1}$$

$$\frac{\Delta h_m}{\Delta h_0} = k\,\frac{12,4}{x^0\sqrt{\rho^0}}, \tag{2}$$

the character of whose variation is shown in Fig. 1a. The coefficient k takes into account the fact that the thermal and dynamic boundaries of the starting section are different [5]. However the results of experimental investigations [6, 7] give a significant difference in the character of the change in the axial parameters of plasma jets (Fig. 1b).

The purpose of this work was to determine more accurately the dependences describing the change in the velocity and excess heat content of gas along the axis of a plasma jet. For this the experimental data of [6, 7] and the measurements of the velocity and heat content of an argon jet, performed by Mirgorodskii et al. [1], are analyzed. Computer analysis of the data established that the drop in the axial parameters of the plasma jet is described, with an error of up to 8%, by the following dependences:

$$\frac{u_m}{u_0} = \frac{a_1}{\sqrt{\rho^0}x^0 + a_2} + a_3, \tag{3}$$

$$\frac{\Delta h_m}{\Delta h_0} = \frac{kb}{(x^0 - x_c^0)^\alpha + b}, \tag{4}$$

$$a_1 = 2.35\,(\sqrt{\rho^0} - 1)^{3.07} - 14.43, \tag{5}$$

$$a_2 = -12.4 + \frac{a_1}{1 - a_3}, \tag{6}$$

$$a_3 = -0.57 \ln(\sqrt{\rho^0} - 2.13), \tag{7}$$

$$b = 4 \cdot 10^{-5} (\sqrt{\rho^0})^{9.5} + 11.45, \tag{8}$$

$$\alpha = 1.05 \operatorname{arctg}(\sqrt{\rho^0} - 3.25) + 1.9. \tag{9}$$

The dependences (3)-(9) generalize the experimental data for the initial temperature of the plasma jet in the range 4000-13000 K, dimensionless density of the gas mixture 11-81, and initial velocity of the plasma jet 300-1500 m/sec.

As follows from (5)-(9), as $\sqrt{\rho^0} \to 3.3$ we obtain $a_3 \to 0$; $a_1 \to 12.4$; $a_2 \to 0$; $b \to 12.4$; $\alpha \to 1$ and the dependences (3) and (4) transform into the dependences (1) and (2). Therefore the parameters of the gas along the axis of the argon jet can be calculated using the dependences (3) and (4) for values of $\sqrt{\rho^0}$ in the range 3.3-9. Up to values of $\sqrt{\rho^0}$ equal to 3.3 the dependences (1) and (2) can be used; these dependences are correct only at some distance from the nozzle cutoff, when the temperature of the gas on the axis of the jet drops significantly and the argon concentration is low, and for this reason the propagating jet is for all practical purposes an air jet.

It has thus been established that the character of the change in the axial parameters of an argon plasma jet is determined by its starting temperature.

The empirical dependences obtained for the drop in the dimensionless velocity and excess heat content along the axis of an argon jet were employed to calculate the heating and motion of particles of aluminum oxide, tungsten, and BrOF-10-03 bronze (curves 2 in Figs. 2 and 3) with the help of the program constructed using the mathematical model of [1]. As a result the agreement between the computed parameters of the particles of powder and the experimental values was greatly improved compared with the computation using the dependences (1) and (2) (curves 1 in Figs. 2 and 3).

NOTATION

u_0, starting velocity of the jet; $x^0 = x/r$, dimensionless coordinate; $\rho^0 = \rho_\infty/\rho_0$, dimensionless density; ρ_∞, density of the surrounding medium; ρ_0, starting density of the jet; r_0, radius of the nozzle; Δh_0, starting excess heat content; x_c, dimensionless coordinate along the starting section; v, particle velocity; T, particle temperature; d, particle diameter; G, mass flow rate of the plasma-forming gas; G, relative mass flow rate of the dispersed phase; and T_0, starting temperature of the plasma-forming gas.

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