INTERACTION OF FINELY DISPERSED PARTICLES WITH THE COLUMN OF A CONSTRICTED ARC

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It is shown that when particles of powder interact with the column of a constricted arc, repulsive forces are created.

The application of protective coatings by means of arc plasmotrons has already become conventional [1-3]. Usually the sprayed-on powder is fed into the plasma jet at a section of the nozzle below the region of shunting of the arc. At the same time, it seems obvious that there are advantages in introducing the powder for its effective melting in the region of the arc discharge. We should expect an increase in the jet energy utilization factors (EUF) and the powder material utilization factor (MUF). However, this method of input has not yet been adopted in industry, since there is no sufficiently reliable plasmotron design capable of yielding reproducible results with respect to the quality of the coating.

The introduction of the powder into the region of the arc discharge is made more difficult by a number of factors. In the first place, the constricted arc has a diameter much smaller than the channel of the plasmotron nozzle. The cross-sectional area of the arc is 2-5% of the nozzle channel area [4]. In the second place, the constricted arc is constantly changing its position in the cross section of the channel, rotating in a volume 8-12 times its own volume. In the third place, a powder particle interacting with a constricted arc is acted upon by forces which hurl the powder out toward the periphery, creating conditions which are favorable to the formation of a crust, and consequently to a change in the operating regime of the plasmotron.

Let us consider the force acting on a particle of powder interacting with the column of a constricted arc.

The force of viscous friction has the same order of magnitude as the Stokes force

$$F_1 = -6\pi r_s \eta_p v_s. \tag{1}$$

The thermophoretic force arising as a result of the temperature gradient, when $r_s \gg l$, is found from the expression [5]

$$F_2 = -3\frac{\pi R r_s \eta_p^2}{P_p \mu_p}\frac{\partial T}{\partial r}. \tag{2}$$

The magnetic-pressure force appearing as a result of the constriction of the arc by its own magnetic field [6] is

$$F_3 = -\frac{\partial P_p}{\partial r} v_s. \tag{3}$$

Since $\frac{\partial P_p}{\partial r} = j_b(r) B_b(r)$, we can replace the local values of the quantities by the average values to obtain

$$F_3 = -\frac{2}{3}\frac{I_b^2 \mu_0 r_s^3}{\pi r_b^3}. \tag{4}$$

The reactive force arising as a result of the vaporization of the material of a particle when it comes into contact with the arc is

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TABLE 1. Physicochemical Properties of the Material of the Powder Particles

Oxide	μ_s, g/mole	T_b, °C	Heat of vaporization, kJ/mole	ρ_s, kg/m^3
Al_2O_3	101,96	2980	485,67	3970
SiO_2	60,084	2950	573,59	2651
CaO	56,079	3500	625;33	3370

TABLE 2. Relative Variation in Powder-Particle Velocity When the Particles Interact with the Column of a Constricted Arc

$\varnothing\cdot 10^5$ m	Al_2O_3, %				SiO_2, %				CaO, %			
	$\frac{dv_1}{v_s}$	$\frac{dv_2}{v_s}$	$\frac{dv_3}{v_s}$	$\frac{dv_4}{v_s}$	$\frac{dv_1}{v_s}$	$\frac{dv_2}{v_s}$	$\frac{dv_3}{v_s}$	$\frac{dv_4}{v_s}$	$\frac{dv_1}{v_s}$	$\frac{dv_2}{v_s}$	$\frac{dv_3}{v_s}$	$\frac{dv_4}{v_s}$
1	0,45	0,74	0,1	980	0,68	1,10	0,01	480	0,53	0,87	0,01	334
5	0,09	0,14	0,05	196	0,14	0,22	0,07	96	0,11	0,17	0,06	66
10	0,05	0,07	0,10	98	0,07	0,11	0,15	48	0,05	0,08	0,12	33,4

$$F_4 = -v\frac{dm_s}{dt}. \tag{5}$$

In conventional spraying of protective coatings the condition $r_s \gg l$ is always satisfied; then

$$\frac{dm_s}{dt} = \frac{\lambda_p r_s \mu_s (T_p - T_b)}{H_s}. \tag{6}$$

From (5) and (6) we have

$$F_4 = -\left(\frac{RT_b \mu_s}{2\pi}\right)^{1/2} \frac{\lambda_p r_s (T_p - T_b)}{H_s}. \tag{7}$$

Under the action of these forces the powder particles will be slowed down or thrown outward toward the periphery and be sprayed onto the surface of the plasmotron nozzle channel, changing its geometry.

Let us estimate the influence of the contribution made by each of these forces on the relative change in the particle velocity when the particle penetrates into the arc column to a depth of $2r_s$, using the condition

$$F = \frac{2}{3}\pi r_s^2 \rho_s v dv. \tag{8}$$

For the viscous-friction forces

$$\frac{dv_1}{v_s} = \frac{9\eta_p}{r_s \rho_s v_s}, \tag{9}$$

for the thermophoretic force

$$\frac{dv_2}{v_s} = \frac{9}{2}\frac{R\eta_p}{P_p \mu_p r_s \rho_s v_s^2}\frac{\partial T}{\partial r}, \tag{10}$$

for the magnetic-pressure force

$$\frac{dv_3}{v_s} = \frac{I_b^2 \mu_0 r_s}{\pi^2 r_b^3 \rho_s v_s^2}, \tag{11}$$

and for the reactive force

$$\frac{dv_4}{v_s} = \frac{3}{2}\left(\frac{8RT_b}{\pi\mu_s}\right)^{1/2} = \frac{\lambda_p (T_p - T_b)}{\pi H_s r_s \rho_s v_s^2}. \tag{12}$$

Calculations according to formulas (9)-(12) were carried out for particles of powdered Al_2O_3, SiO_2, and CaO with fraction dimensions of 0.2, 1.0, and $2.0 \cdot 10^{-4}$ m and flying into the region of the arc discharge with a radial component of velocity equal to 10 m/sec. The physicochemical properties of the powders needed for the calculation are shown in Table 1 [6].

The characteristics of the arc discharge were taken to be the following: the working gas was argon, $J_b = 500$ A; $T_p = 130{,}000$°K; $\rho_p = 3.1 \cdot 10^{-2}$ kg/m^3; $\mu_p = 39$ kg/kmole; $\mu_0 = 4\pi \cdot 10^{-7}$ V·sec/A·m; $\lambda_p = 2$ W/m·K; $\eta_p = 2 \cdot 10^{-4}$ N/m^2.

The results of the calculations carried out according to formulas (9)-(12) are shown in Table 2. The viscous-friction forces, the thermophoretic force, and the magnetic-pressure force produce practically no change in the velocity of the powder particle, and only the reactive force has a substantial effect on the variation of the powder-particle velocity when the particles interact with the column of the constricted arc. Under the action of this force the powder particles directed toward the region of the arc discharge will be ejected toward the periphery of the jet and be atomized onto the plasmotron nozzle channel.

The above analysis of the forces acting on a particle of powder when it interacts with the column of the constricted arc in the plasmotron nozzle channel shows that it is preferable to direct the powder not perpendicularly but parallel to the column of the constricted arc. As it is displaced parallel to the arc, the particle of powder will be in the high-temperature zone and be intensely heated.

NOTATION

r, radius; ρ, density; P, pressure; m, mass; v, velocity; l, free path length; T, temperature; μ, molecular weight; I, current strength; μ_0, magnetic permeability of the vacuum; H, specific heat of vaporization; λ, coefficient of dynamic viscosity; R, universal gas constant; k, Boltzmann's constant. Subscripts: s, particle of powder; b, arc discharge; p, plasma; av, mean value; boil, boiling; mol, molecule.

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