EFFECT OF MODE PARAMETERS OF PLASMA SPRAYING USING CURRENT-CARRYING WIRE ON FRACTIONAL COMPOSITION OF SPRAYED PARTICLES

G.M. RUSEV[1], **A.G. RUSEV**[1], **V.V. OVSYANNIKOV**[1], **O.G. BYKOVSKY**[2] and **A.N. PASKO**[2]
[1]SPE «Plazmatekh», 4 Gogol Str., 69000, Zaporozhie, Ukraine
[2]Zaporozhie State Technical University of the Ministry of Education and Science of Ukraine
64 Zhukovsky Str., 69063, Zaporozhie, Ukraine. E-mail: root@zstu.zaporizhe.ua

A connection was stated between the parameters of mode of plasma spraying using current-carrying wire and fractional composition of sprayed particles, process efficiency and strength characteristics of coating. Plasmatron «Ornitof-5M» was used for spraying of Np65G wire in a water-filled vessel. Collected drops were sifted. Formation of plasma coating mainly of 0.315–0.1 mm fraction size was determined at cathode deepening from 0 up to 1.5 mm, cathode–anode distance from 8 up to 14 mm, 120–220 A welding current, argon consumption of 15–37.5 l/min and 12–22.5 m^3/h air consumption. Movement of the sprayed particles in the center and on the periphery of plasma flow is different and main amount of them is transferred by periphery part of the flow. Distance of spraying was changed in the range from 40 up to 150 mm, content of the elements in the surface layer at optimum distance 100 mm made 0.4–0.43 % C, 0.7–0.77 % Mn, 0.17 % Si and the rest was Fe. Process efficiency makes 0.8–1.1 g/s, coating cohesive strength is 80 MPa at 90–100 mm distance of spraying, hardness makes *HB* 220–240 and porosity — 1–2 %. Layer-by-layer removal of smaller and dust-like fractions using high-speed wire brush provides 25–30 % increase of cohesive strength. Optimum mode parameters, i.e. d_e = 1.2–1.6 mm, I_w = 170 A, U_a = 65 V, Q_{Ar} = 30 l/min, Q_{air} = = 16.5 m^3/h, distance of spraying 100 mm with Np65G, PP-100Kh15M2G2R grade wires are used for spraying of wear protection coatings over the parts of power and metallurgical equipment. 2 Ref., 1 Table, 2 Figures.

Keywords: *plasma spraying, sprayed particles, current-carrying wire, fractional composition, mode parameters, cohesive strength, efficiency*

Plasma spraying using current-carrying wire can be performed in a wide range of technological parameters depending on plasmatron design. Change of the parameters provides effect on fractional composition of sprayed particles and their oxidation level, amount of transported heat, temperature of backing (part), thermal cycle of sprayed coating, its strength, density as well as efficiency of the process itself.

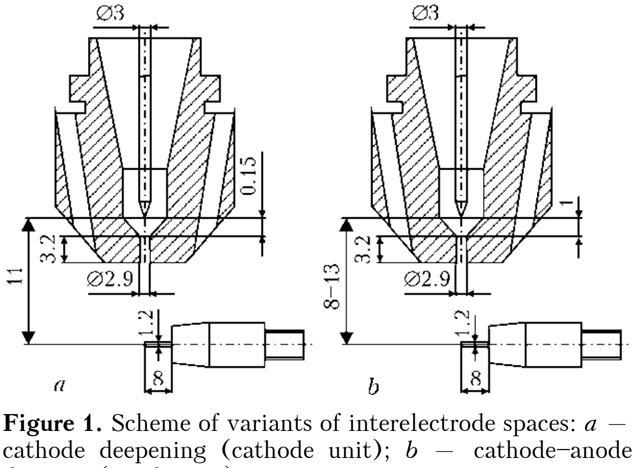

Figure 1. Scheme of variants of interelectrode spaces: *a* — cathode deepening (cathode unit); *b* — cathode–anode distance (anode unit)

Investigations were performed with the help of «Ornitof-5M» grade plasmatron [1] on scheme shown in [2]. Np65G wire of 1.2 mm diameter was sprayed in a water-filled vessel of 250 mm diameter from 320 mm distance. Formed drops (fractions) were gotten from the vessel, dried and sifted in sieves of 2.5; 1.6; 1.0; 0.63; 0.4; 0.315; 0.2; 0.16; 0.1; 0.063; 0.05 mm mesh.

Cathode deepening and cathode–anode distance, determining arc voltage, are the important parameters of the plasmatron having effect on mode of plasma spraying. Figure 1 provides the limits of their changing.

Spraying was performed using 160 and 170 A current, and the rest of parameters were as follows: argon consumption Q_{Ar} = 30 l/min, air consumption Q_{air} = 16.5 m^3/h, and time of spraying made 100 s. Increase of arc voltage from 60

Results of experimental evaluation of effect of spraying technological parameter on fractional composition of sprayed metal, %

Parameter	Dimensions of fractions, mm					
	2.5–0.4	0.315	0.2	0.16	0.1	<0.1 and dust
Cathode deepening, mm	4–8	8–10	26–28	15–16	20–24	12–13
Cathode–anode distance, mm	5	6–8	24–26	18–19	22–23	12–13
Welding current, A	5–8	34–23	18–13	18–22	10–15	7–9
Air consumption, m^3/h	5–4	9–10	30–29	16–17	19–20	7–12
Argon consumption, l/min	4–3	12–8	25–28	16–17	23–24	14–10

up to 66 V at 170 A current and from 59 up to 63 V at 160 A current was determined at change of cathode deepening from 0 up to 1.5 mm. Spraying efficiency makes 1 g/s at 170 A and 0.80–0.84 g/s at 160 A, and burn-out loss is 18–22 and 15–20 %, respectively.

Fractional composition of the drops shows no dependence on current change and being in the specified limits as the parameters' change (Table).

Increase of arc voltage from 54 to 69 V at 170 A and from 52 to 67 V at 160 A was determined for anode unit of the plasmatron at change of cathode–anode distance from 8 up to 14 mm. Efficiency of spraying rises from 0.83 to 1 g/s at 170 A, and this index is somewhat lower and lies in the range from 0.74 to 0.94 g/s at 160 A. The burn-out loss of metal is higher at 170 A (16–22 %) and they achieves 15–16 % at 160 A. There is small change of the fractional composition. It lies in the same range as for cathode deepening (see the Table). The cathode deepening should make 0.5 mm for 160–170 A currents and recommended cathode–anode distance is to be in the range from 9 to 11 mm as was accepted by result of the experiments. At that high process stability is preserved.

These parameters were used for study of effect of welding current changing in the range of 120–220 A.

Increase of the burn-out loss from 0.60 to 1.15 g/s and efficiency from 8 up to 14 % was determined as the welding current rise. Hardness of the layer sprayed over a reference specimen reduces from *HB* 278 to *HB* 222, that can be related with increased burn-out of carbon and alloying elements. Fractional composition of the sprayed particle changes in that or another side (see the Table), at that tendency to reduction of 0.315 mm size fraction is observed, however the latter remains the most coarse constituent.

Different speed of movement of the particles in the center and on the periphery was noticed at visual investigation of plasma flow. This is, obviously, connected with their various mass. Four glass water-filled vessels were used in order to study this effect. Vessels of 40, 65, 90 and 250 mm diameter were inserted one into another. The distance from the plasmatron to water surface level made 320 mm and I_w = 120–200 A. It was determined that the mass of fractions increases from 16 up to 24 g in the central part (40 mm diameter vessel) or somewhat reduces from 20 to 11 g (90 mm diameters vessel), and significant rise from 22 to 35 g is observed on the periphery part (250 mm diameter vessel) at current increase.

This indicates the preferred transfer of the sprayed material by the periphery part of plasma flow. Fractional composition of the particles also changes on plasma flow section. Thus, content of coarse particles of 0.2 mm in the center makes 33–37 %, and on the periphery it reduces up to 17–24 %. Fractions of 0.315, 0.16 and 0.1 mm size in the center of flow make 15–18 %, and on the periphery their presence reduces up to 11–14 %. Quantity of 0.1 mm fraction in presense of 0.16 fraction increases up to 18–25 %, and it reduces up to 8–10 %, in presence of 0.315 mm fraction with current rise. Coarse 0.4 mm fractions, fractions less than 0.1 mm and dust make 1–6 % in the flow center and 6–9 % on the periphery. Increase of welding current promotes somewhat reduction of content of coarse fractions and rise up to 20–23 % of fine ones.

Mass of transported particles significantly depends on consumption of transporting and plasma gases. Consumption of these gases also determines the oxidation level of sprayed particles, their speed, focusing and voltage.

Investigations were carried out using 160–170 A current, firstly changing consumption of air at constant consumption of argon and then — consumption of argon at stable air consumption.

Increase of voltage up to 60–64 V is observed at rise of air consumption, at that, maximum 0.9 g/ s efficiency is achieved.

Increase of Q_{air} in 12.0–22.5 m^3/h range provides smaller change of fractional content of particles (see the Table). Higher heating of nozzle,

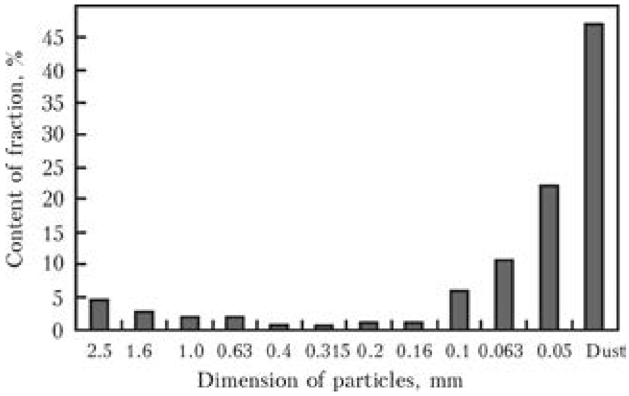

Figure 2. Fractional composition of sprayed particles removed layer-by-layer from the surface of part

that can result in its quick fail, takes place at Q_{air} less than 12.5 m^3/h.

Q_{air} = 15–17 m^3/h was considered as an optimum one. Increase of Q_{Ar} from 15.0 to 37.5 l/min promotes rise of process efficiency from 0.82 to 1.02 g/s, at that at Q_{Ar} = = 30 l/min reduction up to 0.73 g/s is observed (Q_{Ar} = 37.5 l/min at 160 A). Efficiency increases from 0.96 to 1.09 g/s at Q_{Ar} = 20 l/min, whereupon it reduces up to 0.85 g/s at Q_{Ar} = = 37.5 l/min.

It was noticed that less than 30 l/ min consumption of argon provides more intensive heating of the nozzle and rise of wear of tungsten electrode, that determined Q_{Ar} = 30 l/min as an optimum value. Stability of plasma process appeared to be higher at 170 A welding current. There was virtually no change of fractional composition of the particles (see the Table). Efficiency at that makes 0.98–1 g/s.

The composition of initial material, sprayed on the backing, changes since in a process of air-plasma spraying the particles are heated up to temperature significantly exceeding the melting temperature, their movement takes place in argon-air atmosphere and they steadily interact with oxygen and nitrogen of air. The level of interaction of metal with gas atmosphere will depend to significant extent on spraying distance.

Spraying distance was changed in 40–150 mm range and rest of the parameters of mode of plasma spraying were constant (d_e = 1.2 mm, I_w = 170 A, U_a = 65 V, Q_{Ar} = 30 l/min, Q_{air} = = 16.5 m^3/h).

It was determined that the highest coating strength, determined by pin probe method, was achieved at 90–100 mm spraying distance and made 80 MPa at coating thickness 0.5 mm. At that, content of elements in the surface layer was as follows, %: 0.4–0.43 C, 0.7–0.77 Mn, 0.17–Si, and the rest being Fe.

Hardness of coating made *HB* 220–240 and porosity of sprayed layer was in the range of 1–2 %.

Treatment of each sprayed layer of the surface using high-speed steel brush, which separates poorly-attached particles, is an important technological method. Figure 2 shows their fraction composition and based on it the main constituent (84 %) is a tiny and dust-like fraction, preventing valid cohesive adherence of the particles. Cohesive strength of coating adherence can be increased by 27 % as a result of layer-by-layer mechanical treatment.

Conclusions

1. Increase of welding current and argon consumption results in arc voltage rise.

2. Parameters of mode of plasma spraying, considered in present work, provide no significant effect on fraction composition of the sprayed particles which are manly of 0.1–0.315 mm size.

3. Particles of less than 0.1 mm size and dust-like fractions have low cohesive capacity and their layer-by-layer removal using high-speed steel brush allows increasing cohesive strength of coating by 27%.

1. Rusev, G.M., Kyseliov, S.M., Ovsyannikov, V.V. et al. *Electric arc plasmatron*. Pat. 45253 Ukraine. Int. Cl. 7H05H1/100, 1/24, H05B7/18, B23K10/00. Fil. 10.07.2001. Publ. 15.10.2003.
2. Rusev, G.M., Ovsyannikov, V.V., Kiselyov, S.M. et al. (2000) Technology of restoration and strengthening of surfaces of bodies of rotation and flat surfaces using plasma spraying. *The Paton Welding J.*, **12**, 60–61.

Received 06.09.2012