EFFECTS OF DEPOSITION PARAMETERS UPON THE DENSITY AND ADHESION OF PLASMA-SPRAYED SILICATE COATINGS

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The effects of deposition conditions upon the properties of plasma-sprayed coatings have already been investigated by a number of authors [1-5]. Summarizing the results obtained, it may be noted that the shape of a curve of a property vs a deposition parameter will depend, firstly, on the material being sprayed and, secondly, on the equipment employed. It must be pointed out, however, that up to now such relationships have been studied in relation to the deposition of refractory metals and oxides. These fail to meet industry's present-day requirements for protective coating materials, and it is therefore necessary to provide a broader spectrum of deposition materials, covering both low- and high-melting-point coatings.

In the work described below a study was made of the influence exerted by deposition parameters upon the density and adhesion of plasma-sprayed coatings from a vitreous silicate powder, with the aim of determining the optimum conditions for the plasma spraying of this particular material. The material chosen for investigation was a glass of melilitic composition (granulated ChMZ blast furnace slag) containing 39.84 $\text{SiO}_2$, 11.43 $\text{Al}_2\text{O}_3$, 34.37 $\text{CaO}$, 7.87 $\text{MgO}$, 0.7 $\text{MnO}$, 0.17 $\text{FeO}$, and 1.29 wt.% $\text{S}$. The slag is a typical example of acid blast furnace slags which could become a source of cheap and readily available raw materials. A powder suitable for plasma spraying was prepared by dry milling in a porcelain barrel. Its particle size, chosen as a result of special experiments, was $\leq 60 \mu\text{m}$. Coatings were applied, in a UPU-3 plasma apparatus fitted with a UMP-5-68 powder feed unit, to 08KP rimmed carbon steel specimens. The spraying parameters investigated were divided into three groups:

a) parameters characterizing the plasma jet (arc current $I$ and rate of flow of plasma-forming gas $Q_{pl}$);

b) parameters linked with powder supply (rate of flow of powder $Q_{pow}$ and rate of flow of carrier gas $Q_{car}$);

c) process parameters (spraying range $L$, substrate temperature $t_{sub}$, and coating thickness $\delta$).

In constructing property vs deposition-parameter curves, all the parameters except that being investigated were maintained constant: Deposition was performed, using nitrogen as plasma-forming gas, at an arc current of 300 A, a voltage of 75-80 V, a plasma-forming gas flow rate of 48 liters/min, a carrier gas flow rate of 0.058 ma/h, a powder flow rate of 12 g/min, and a spraying range of 100 mm.

The density of deposits $\rho$ was determined, after they were detached from the substrates, by the method of hydrostatic weighing in water [6]. With this method, to obtain comparable results the specimen weight must exceed 0.2 g. The thickness of deposits intended for measurements of $\rho$ was 800-1000 $\mu\text{m}$. The strength of adhesion $(\sigma_{ad})$ was evaluated by a tear-away test. The specimens used were cylinders of 22-mm diameter and 60-mm length. Before being plasma-sprayed, the end faces of the specimens were shot-peened. For testing, two specimens, the end face of one of which was coated and that of the other uncoated, were joined end-to-end with ED-5 epoxy resin containing a hardener. The strength of adhesion of the resin bond was not less than 150 kg/cm$^2$. The thickness of the coating in the tear-away test was 150-200 $\mu\text{m}$. The bonded pairs of specimens were pulled apart in a special device eliminating all bending loads. The rupture of deposits was adhesive in character at thicknesses of $\approx 300 \mu\text{m}$ and cohesive at thicknesses $> 300 \mu\text{m}$. The UralNIAlstromproekt Institute, Chelyabinsk. Translated from Poroshkovaya Metallurgiya, No. 1(157), pp. 35-39, January, 1976. Original article submitted November 25, 1974.
Fig. 1. Geometry of plasma arc spray at currents of 200 (a), 300 (b), 350 (c), and 500 A (d). The indicator is located at a distance of 100 mm from the nozzle.

Effects of Parameters Characterizing Plasma Jet upon $\rho$ and $\sigma_{ad}$ of Coatings

The parameters $I$ and $Q_{pl}$ control the conditions under which the particles being deposited melt and their residence time in the plasma jet. In our experiments the arc current was varied from 200 to 500 A. With increase in $I$ the length of the brightly glowing part of the spray grew (Fig. 1). Deposits of satisfactory quality were obtained at $I = 300-350$ A. At currents below this range the particles being deposited heated up unevenly in the spray and most of them failed to adhere to the substrate. As the current $I$ was increased to 400-500 A, overheating of the metal became possible and the useful life of the nozzle and electrode sharply decreased.

Plots of $\rho$ vs $I$ and $\sigma_{ad}$ vs $I$ (Fig. 2a) indicate that the best conditions for plasma spraying prevailed at $I = 350$ A. The rate of flow of the plasma-forming gas ranged from 30 to 70 liters/min. Increasing the emission velocity of the plasma jet reduced the residence time of the particles being deposited in the plasma jet. This accounts for the relationship observed between the density and the rate of flow of the plasma-forming gas (Fig. 2b), since longer residence times of particles in the plasma stream promote the formation of denser coatings.

On the other hand, powder particles being entrained by the plasma stream acquire a certain amount of kinetic energy and can thus form an adherent deposit on the substrate. Under these conditions the amount of this kinetic energy should not exceed a certain limit if the particles are to be prevented from rebounding from the substrate. This circumstance explains why the maximum strength of adhesion of deposits did not coincide with their maximum density. The results obtained indicate that the optimum rate of flow of the plasma-forming gas is 30-40 liters/min.

Effects of Parameters Linked with Powder Supply upon $\rho$ and $\sigma_{ad}$ of Coatings

The powder used for spraying consisted mainly of flat, acute-angled particles. With this powder the injection type feeder normally fitted to the UPU-3 plasma unit failed to ensure an even supply. Satisfactory results were obtained, however, with a metering ring feeder designed at the All-Union Scientific-Research Institute of Autogenous Machines, which enabled the powder flow rate to be varied from 5 to 20 g/min, although $Q_{pow} > 15$ g/min proved unsuitable as it resulted in the blocking of the channel of the plasma unit.

Increasing the powder flow rate from 5 to 13 g/min had no significant effect upon $\sigma_{ad}$ of deposits. The coating density was a maximum at low powder flow rates (Fig. 3b), but generally the variation of $\rho$ was negligible. The other parameter associated with powder supply is the rate of flow of carrier gas. The carrier gas imparts to a particle being deposited kinetic energy which is necessary for introducing