EFFECT OF PLASMA-SPRAYING CONDITIONS ON THE ADHESION OF STEEL COATINGS

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Depending on the heat source employed, spraying may be performed by gas, electric-arc, high-frequency, or plasma processes. At the present time, increasing use is made of the last of these processes. The fact that it enables high temperatures (up to 30,000°C) and particle flight velocities in the region of that of sound to be attained [1] suggests that almost any material could be sprayed by this technique.

In recent years, a number of authors have described investigations of the plasma-spraying process [2-6]. In most of them, however, attention was focused primarily on various theoretical topics (mainly the kinetics of the process), preparation of oxidation-resistant coatings, etc. The principal factor determining the practical usefulness of sprayed coatings is the strength with which they adhere to their substrates. Even the most attractive properties of a sprayed coating become useless when the deposit itself does not firmly adhere to the base surface.

The few available literature data on the strength of adhesion of plasma-sprayed coatings are frequently contradictory. Thus, it has been reported that the strength of adhesion of Al_2O_3 and ZrO_2 coatings on steel ranges from 40-70 [2, 3] to 670 kg/cm^2 [4] and that of molybdenum coatings from 150 [2] to 460 kg/cm^2 [4]. Such an appreciable scatter of data must, of course, be attribted to differences in both the adhesion testing techniques and spraying conditions employed. It has been reported [4, 6] that the strength of adhesion of aluminum is 470 kg/cm^2 and that of tungsten on steel, 160-250 kg/cm^2. The investigations referred to above were primarily concerned with refractory metals and oxides.

The present work was undertaken with the aim of studying the possibility of employing the plasma-spraying technique for increasing the wear resistance of automobile and tractor components and for the reclamation of worn parts. It has already been indicated [7-9] that, when the arc-spraying process is used, high-carbon steels are the most suitable materials for this purpose. In view of this, it was decided to determine the strength of adhesion of plasma-sprayed steel coatings and study the effect of the geometric and electrical plasma-spraying parameters on this characteristic. Spraying was performed, using the "neutral wire" arrangement, in a UPU-3M plasma unit. The high-carbon steel U8A was deposited on normalized Type 45 steel, which is extensively used in automobile and tractor construction.*

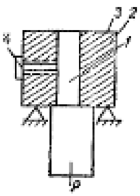

Fig. 1. Device for adhesion testing by pin technique: 1) pin; 2) block; 3) coating; 4) fixing screw.

Strength of adhesion was determined by the pin technique (Fig. 1). During the spraying operation, the pin 1 was positioned flush with the surface of the block 2. A layer 2-mm thick was deposited. Before the application of a coating, specimens were degreased in a 5% caustic soda solution and polished with steel powder. Such treatment rids surfaces of oxides and adsorbed films and induces in them a cold-worked state, which

*U8A and Type 45 steels are carbon grades with 0.8 and 0.45% C, respectively – Publisher's Note.

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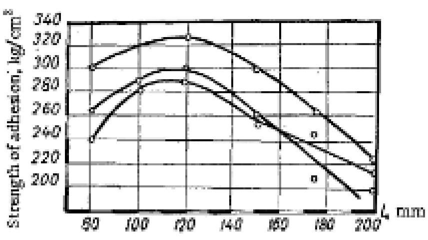

Fig. 2

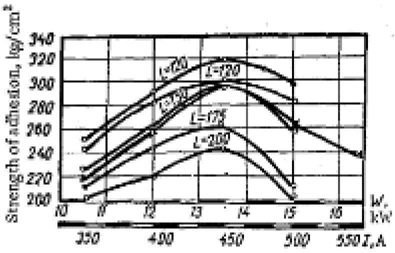

Fig. 3

Fig. 2. Effect of distance on strength of adhesion. I = const = 450 A, V = const = 30 V, G = const = 0.86 m/min, Q = const = 17 liters/min.

Fig. 3. Effect of current power and intensity on strength of adhesion.

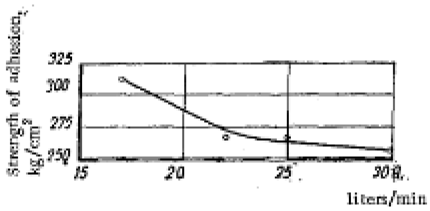

Fig. 4. Effect of flow rate of plasma-forming gas on strength of adhesion. I = const = 450 A, V = const = 30 V.

is accompanied by a buildup of energy and, consequently, an increase in the activity of their surface layers. This creates favorable conditions for the generation of intermolecular bonds produced by the propagation of electronic reaction processes [10].

Krasnov and Sharivker [11] interpret the mechanism by which a coating adheres to its substrate on the basis of intermolecular and mechanical reactions and consider the former factor to be the more important. The mechanical effect is linked with the shape of the surface microirregularities generated by shot peening, which promotes wedging of the particles being deposited.

The spraying conditions employed and the results obtained are illustrated in Figs. 2-5. It can be seen from these figures that, at a short distance between the torch nozzle and the surface being sprayed, the strength with which the coating adheres to its substrate is relatively low. The reason for this is that the plasma jet in this zone is severly constricted and has a sharp maximum in its center, which leads to local overheating of the substrate [11], distortion of the coating, etc. As the torch is moved away from the surface being sprayed, the jet target increases in size and the thermal flux power decreases, lowering the temperature of the sprayed particles and reducing their velocity [5]. At a certain distance from the nozzle (in our case, 120 mm), optimum thermodynamic conditions of spraying prevail, giving maximum strength of adhesion (Fig. 2).

The dependence of strength of adhesion on electrical parameters (Fig. 3) has been explained from the viewpoint of the thermodynamics of the process. Increasing the current intensity raises the operating power of the plasma device. At an optimum current intensity (in our investigation, 450 A), steel particles become melted to such an extent that, at the instant of collision with the surface being sprayed, they remain sufficiently hot and plastic, without, however, overheating the substrate. The decrease in strength of adhesion (Fig. 4) accompanying an increase in the flow rate of the plasma-generating gas (argon) may be attributed to an increase in the velocity of the steel particles and a reduction in their residence time in the plasma jet. The latter factor lowers the temperature of the particles and decreases their plasticity.

Table 1 lists the optimum geometric and electrical plasma-spraying parameters together with comparable data reported upon the welding-arc-spraying process by other authors [7, 12-14] who also investigated steel deposits.

An examination of the data in this table reveals a wide scatter of optimum welding-arc-spraying parameters. The diversity of recommendations is particularly remarkable in view of the strong influence exerted by spraying range on strength of adhesion. Both Vadivasov [7] and Troitskii [12] regard 200 mm as the optimum spraying range, although this quantitative agreement would appear to be purely accidental, since the electrical process parameters are quite different. Nevertheless, the optimum spraying ranges established by these authors must be regarded as qualitatively similar.

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