COMPOSITION AND STRUCTURE OF PLASMA-SPRAYED HIGH-CARBON STEELS

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The arc-plasma method of application of coatings has been attracting the attention of numerous investigators because it possesses several distinct advantages, such as technological simplicity, short duration and relatively high productivity of the deposition process, low cost, and the possibility of varying within wide limits the properties of sprayed coatings. In the majority of cases, however, deposition is performed with the object of fulfilling one specific and clearly defined requirement, namely, to produce coatings having certain desired (e.g., heat insulating, oxidation resistant, or antifriction) characteristics.

The few investigations [1-3] undertaken with the aim of discovering the general laws governing the plasma spraying process were concerned primarily with the temperatures and velocities of both the plasma jet and the particles being sprayed. The effect of these factors on the deposit formation process is indeed enormous (the temperature in a low-temperature plasma arc reaches 30,000°C, while the particle flight velocity may reach 500 m/sec or more [4]). However, it is of considerable interest also to examine metallographically the fundamental processes taking place in materials being sprayed, since the structure of coatings exerts a decisive influence on the operating characteristics of parts.

In the present work, an attempt was made to assess, using physical methods of investigation, the quality, structure, and properties of plasma-sprayed coatings. High-carbon steels produced by spraying U8A (GOST 1435-54 standard) and PK-2 (GOST 9386-60 standard) wires, which are extensively used in the reclamation of worn machine parts, were chosen for investigation. Spraying was performed in a UPU-3 plasma unit, the distances from the substrate to the torch nozzle tip being 50, 120, and 200 mm, the current intensities 350, 450, and 550 A, the voltage 30 V, and the plasma-forming gas (argon) flow rate 17 liters/min. The substrate material was Type 45 medium-carbon steel. Plasma-sprayed steel coatings were applied by the technique described in detail in [5].

In common with gas-flame- and electric-arc-sprayed coatings, plasma-sprayed coatings have a laminar structure, which is a result of the specific character of the deposition process (Fig. 1a). The structure is determined chiefly by the technological parameters of the plasma spraying process.

When a layer 1.5-2 mm thick is deposited from a distance of 50 mm, the dimensions of the part being coated and the cooling conditions prevailing fail to ensure a sufficiently high rate of heat removal, as a result of which the part becomes overheated and warps. When the torch nozzle is removed to a distance of 200 mm from the surface being coated, there is an appreciable inflow of air into the plasma jet, which causes intense oxidation of the metal particles, and the resulting coating structure is characterized by the presence of oxide inclusions at the grain boundaries (Fig. 1b). In addition, as the spraying range is increased, the flight velocity of the particles and the extent of their deformation during their collision with the surface decrease, in consequence of which the grains assume a more rounded shape. These factors decrease the strength of adhesion of the coating to the substrate, which, as shown by our determinations, in this case equals 245 kg/cm^2.

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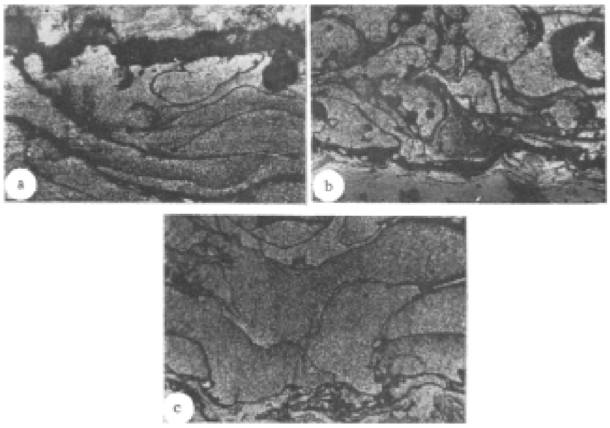

Fig. 1. Structures of plasma-sprayed steel coatings produced at current intensity of 450 A, gas flow rate of 17 liters/min, and spraying range of: a) 50; b) 200; c) 120 mm.

TABLE 1

Intensity	Glacing angle, deg	d, Å	Phase	(hkl)
w.	27,80	2,069	α	(011) (101)
w.	28,75	2,01	α	(110)
w.	28,95	2,00	Fe_3C	(022)
m.	32,45	1,80	γ	(102)
w.	42,85	1,42	α	(020) (200)
s.	49,10	1,278	γ	(022)
m.	52,85	1,212	α	(112)
m.	54,85	1,181	α	(121) (211)
m.	62,25	1,09	γ	(113)

The maximum strength of adhesion (325 kg/cm^2) was obtained when spraying was performed from a distance of 120 mm. A characteristic feature of the structure of such coatings (Fig. 1c) is that the sprayed layer contains only a very small quantity of oxides and that there is a distinctly metallic bond between the coating and the substrate.

Increasing the current intensity raises the temperature of the molten particles, thereby lowering their viscosity and improving their wetting characteristics. As a result of this, the grains have an elongated shape (Fig. 2). However, because of the increased thermal power of the plasma jet, the substrate in this case becomes overheated, which adversely affects the strength of adhesion of the coating.

Examined metallographically, the structure of coatings sprayed under the conditions employed in this study resembles sorbite. X-ray phase analysis revealed the existence in diffraction pictures of lines of martensite and residual austenite, indicating that phase transformations take place in molten and solidifying particles during the coating formation process. Specimens were photographed in iron radiation, using an RKD camera. Data yielded by indexing the x-ray diffraction picture of a spray-deposited coating from U8A wire are presented in Table 1.

The martensite line pairs in diffraction pictures are virtually unresolved (a single diffuse line is formed), which demonstrates that the martensite exhibits very little tetragonality. The reason for this is either a low carbon concentration in the steel after deposition or an insufficiently high rate of cooling of the particles being deposited.

Chemical analysis established that the carbon content of the steels investigated changes in the course of plasma deposition from 0.79% in the initial condition (in the wire) to 0.63%. However, spectral analysis, performed in an ISP-28 spectrograph, showed that the plasma spraying process leads to substantial changes in chemical composition and a nonuniform distribution of alloying elements within local volumes of U8A steel coatings. In particular, depending on the process parameters, the carbon concentration in individual areas of a coating may range from 0.16 to 0.7%.

These substantial variations in the amounts of alloying elements in steel in the course of plasma spraying are brought about mainly by scatter of particles in the spray cone. Particles in the central zone