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STRENGTH CHARACTERISTICS OF COATINGS IN ELECTRIC-ARC METALLIZATION

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The adhesive and cohesive strengths of powder-wire metal coatings as functions of the technological parameters in electric-arc metallization are investigated experimentally.

Restoration of worn-out parts of machines, brought for repair, is an important reserve for improving the efficiency of their use. Of them, 65% have wear of working surfaces of 0.15 mm and 30% have 0.15 to 0.5 mm, retaining a sufficient fatigue-strength reserve [1].

At present, tens of methods and technologies for restoring specific products depending on their operating conditions have been developed [2, 3]. However from an analysis of literature data it follows that the problems of restoration of heavily loaded parts, for example, diesel-engine crankshafts (CSs), are least studied. This is related to the fact that bulk products are deformed in heating (welding-fusion technologies), fractures due to thermal stresses appear, and the existing technologies of spraying either are very expensive (plasma and detonation sprayings) or do not ensure (flame spraying and electric-arc deposition) the required physicomechanical properties of the metal coating (a high porosity of approximately 10%, low adhesive and cohesive strengths).

Improving the quality of coatings on working surfaces of products restored (in particular, crankshafts as the most expensive parts of engines) by the method of electric-arc metallization is the central problem of this work.

The operating life of the friction surface of a "plain bearing-crankshaft journal" pair depends not only on the wear resistance of the sprayed layer but also on the strength of its adhesion to the base metal. Taking into account that the actual load on the journals of diesel-engine crankshafts attains 30–40 MPa [1], it is necessary to ensure an adhesive bond of the coating with the substrate of no less than 60–70 MPa and a cohesive bond of no lower than 160 MPa on the crankshaft restored [4].

The strength of the bonding of the deposited metal with the base is an effective quantity, determined to a large extent by the residual temperature and structural stresses, at high values of which the coating can crack and peel off from the substrate.

Mechanical adhesive forces and van der Waals forces ensure the strength of the bonding with a part at a level of 15 MPa [5]. To attain 60–70 MPa, we need to realize a chemical interaction of the coating and substrate materials. For this purpose, powder wires with alloying additives have been developed that form intermediate spinel layers on the surface restored.

The presence of grit, corrosion, and other contaminants on product parts leads to a decrease in the strength of the adhesion of the coating to the base material to zero. After cleaning the article of dirt we should remove oil from the cavities and pores of the surface layer, for which purpose it is burned out in an electric furnace at a temperature of 250–270°C, i.e., in a range characterized in heat treatment of steel as low-temperature tempering. The holding time depends of the part size, the furnace capacity, etc., and is approximately 2 h.

Among different methods of preparation of the base surface for deposition of a metal coating, jet-abrasion treatment is the most acceptable from the viewpoint of efficiency and the possibility of practical application. Corundum with a grain size of 0.5–2 mm was used as an abrasive.

It is generally agreed that abrasion treatment contributes to adhesion growth owing to certain factors: the required relief of the surface is formed, the roughness increases, and the surface layer of atoms is activated. The fatigue strength of the part can also be improved by plastic deformation of the treated surface [6].

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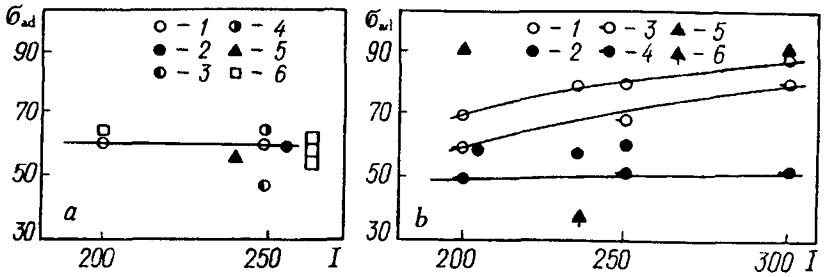

Fig. 1. Effect of some technological parameters on the adhesive strength of V1+V3 (a) and V3 (b) coatings as a function of the arc current: a: 1) propane-butane; 2) air; 3) propane-butane, the time of jet-abrasion treatment is 90 sec; 4) the same, 135 sec; 5) the air flow rate is increased by a factor of 1.5; 6) V0, V1, and V2 powder wires and combinations of them; b: 1) propane-butane; 2) air; 3) without air blowing after jet-abrasion treatment, propane-butane; 4) the same, air; 5) the air flow rate is increased by a factor of 1.5; 6) the rotational speed of the part is 65 rpm. σ_{ad}, MPa; I, A.

To determine the strength of the bonding of the coating with the base, a variety of methods (adhesive, pin, section, sclerometric, bending, and other methods) are known and widely used, of which the adhesive and pin methods, which provide quantitative data, are used most frequently. A drawback of both methods is the presence of a concentration of stresses on the specimens' edge along the circumference [7], which, among other factors, leads to a dependence of the results obtained on the specimen diameter and makes the absolute data to a large measure relative.

We used specimens with tapered pins with a circular shape of the end cross section with a diameter of approximately 4 mm. Since the results of the tests are correct for a coating thickness $\sigma > 0.25d$, where d is the pin diameter [8], in our case $\sigma > 1$ mm, which corresponds to real conditions of spraying (in restoring the CS of the engine of an Ikarus bus, the coating thickness was 1.5–2 mm).

The composition of the sprayed material, the coating thickness, the technological regime of plant operation (the current, the working gas, its flow rate, the distance to the surface, the linear velocity of part transfer, etc.), and the temperature and velocity of the sprayed particles, determined by them (the pressure in the contact zone, the interaction time, the contact temperature, etc.), in addition to the parameters of the jet-abrasion treatment (the form and size of the abrasive, the time of shot-blast cleaning and the time after it to spraying, the velocity of the particles, and the angle of attack), have a great effect on the strength characteristics of the sprayed layer.

The specimens were sprayed with an ADM-7 electric-arc metallizer under conditions similar to restoring CS, for which purpose holes were milled in the latter, into which the specimens with tapered pins were mounted. The coating was deposited both in an air flow and in a supersonic jet of propane-butane combustion products.

Results of investigating the effect of some technological factors on the adhesive strength of the sprayed layer are presented in Fig. 1.

When V0, V1, and V2 powder wires and combinations of them are used as filler material the strength of the bonding of the coating with the base decreases by approximately 10–15% as the arc current increases from 200 to 275 A (Fig. 1a), which is in agreement with results of investigations of [9] in which, for V0 wire, a 20% decrease in the bonding strength of the coating with increase in current from 200 to 300 A is found. The effect of the working-gas composition and the air flow rate on the adhesion of the coatings of these wires and the combination V1+V3 is not revealed. This is due to the fact that as a chemical analysis showed, the type of working gas had no effect on the chemical composition of the coating material. The adhesive strength increased by approximately 15 MPa when the time of the jet-abrasion treatment of the restored surface was increased from 90 to 135 sec.

A different picture is observed when coatings produced by spraying V3 wire are investigated. An analysis of the data of Fig. 1b shows that, in the case of use of propane-butane combustion products as the working gas, the strength of the bonding of the deposited material with the base is higher (by approximately 10 MPa with a

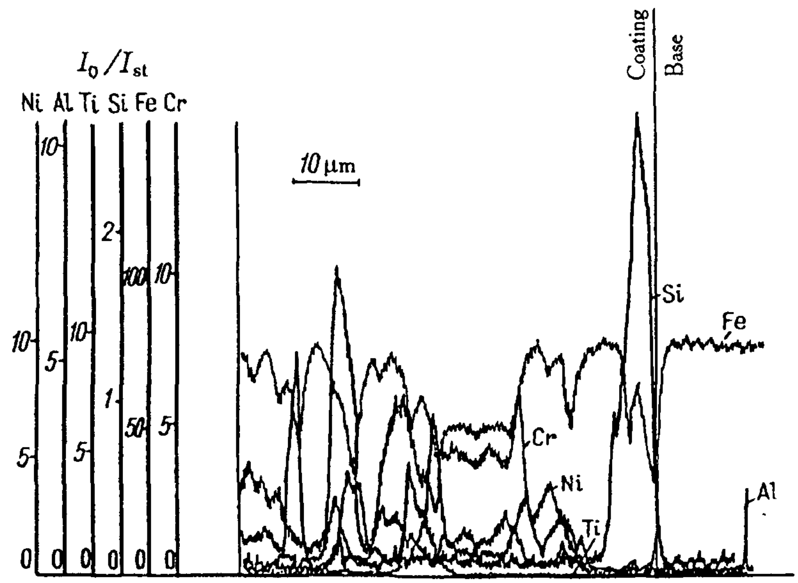

Fig. 2. Concentration curves of the distribution of alloying elements in a specimen of a V3 coating. The working gas is air. The coating hardness is 46 HRC, and the porosity is 4.7%. I_0/I_e, %.

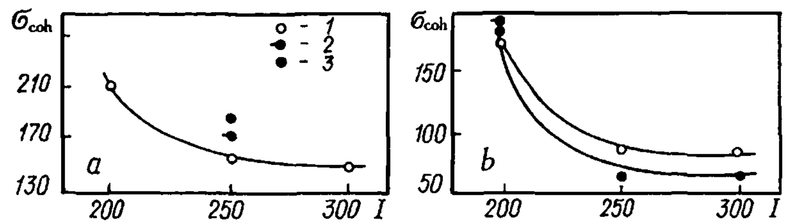

Fig. 3. Effect of the arc-discharge current on the cohesion of V1+V3 (a) and V3 (b) coatings: a: 1) propane-butane; 2) the same, the rotational speed of the part is decreased by a factor of 4; 3) air; b: 1) propane-butane; 2) air; 3) the same, the rotational speed of the part is decreased by a factor of 4. σ_{coh}, MPa; I, A.

current of 200 A) and increases with the current. At the same time, the adhesion of the layer with the substrate is independent of the current in operation in air (for two flow rates) but increases significantly with it.

The data of a micro x-ray spectrum analysis of a coating and the transition zone showed (Fig. 2) that its thickness is approximately 2–3 μm. Near the boundary, there can be contaminants (Si, Al, and their oxides) that decrease the strength of the adhesion of the coating with the base. It is revealed that, in all cases, cleaning the surface of pulverized residues of the abrasive with compressed air prior to coating deposition improves the adhesive strength by approximately 10 MPa while an increase in the rotational speed of the restored part from 50 to 65 rpm decreases it by approximately 20–30%.

An important characteristic of the coating material is the breaking strength in the direction perpendicular to the vector of the particle velocity. An increase in this quantity contributes, on the one hand, to an improvement in the wear resistance of the surface that is due to both fatigue and abrasion mechanisms of wear and, on the other, to an increase in the heat resistance of the deposited material since, in restoring heavily loaded CSs of diesel engines, large thermal stresses develop in the metal coatings, and fractures are formed at the sites of stress concentration (openings of oil galleries).

Results of investigating the strength of layers of V1+V3 and V3 powder wires sprayed onto a compound cylindrical specimen 19 mm in diameter (the coating thickness is 1.5 mm) are presented in Fig. 3. To retain the same linear velocity of surface motion, we performed metallization at a higher rotational speed of the specimen (160 rpm).

An analysis of the data of Fig. 3a shows that the breaking strength of the coating of V1+V3 wires exceeds significantly the adhesive strength and decreases as the current increases. With spraying in an air medium, it is higher than in propane-butane combustion products. A fourfold decrease in the rotational speed virtually did not lead to a change in the results.

The coatings of V3 wire have a much lower strength (Fig. 3b), and for currents of 225–250 A it is similar to the strength of adhesion of the coating to the base when the failure is of both adhesive and combined characters. A decrease in the linear velocity of motion of the sprayed surface, as in the previous case, does not have a substantial effect on the layer strength.

Unlike the coating sprayed from V1+V3 wires the breaking strength of the layer in the air flow, in this case, is lower than in the jet of propane-butane combustion products. However the effect of the type of working gas is small and is due to the gas-dynamic action on the melt zone on the electrodes rather than to the chemical composition, which is practically the same in the coatings. As a result of a change in the type of working gas and the current the temperature of the sprayed particles changes, which increases by approximately 70–80°C with increase in the current from 200 to 300 A. It is higher by the same value in the air flow, although, in this case, the particles are blown by the cold air and not by the high-temperature jet of propane-butane combustion products. Possibly, this is due to the large diameter of the particles blown by the air flow. Thus, in photographs of the specimen microstructure, the characteristic linear dimensions of the particles in the coatings produced in air are approximately twice as large as in the coatings produced in the propane-butane jet.

The investigations performed showed that the coatings of V3 wire, having much better adhesion characteristics, rank below the coatings of the combination of V1+V3 wires in breaking strength. However, in both cases, the attained parameters of the coatings – an adhesive strength of approximately 70 MPa, a breaking strength of 200 MPa, and a hardness of 40–45 HRC – enable us to use them for restoration of diesel-engine CSs.

NOTATION

I_0 and I_{st}, x-ray radiation intensities for the coating specimen and the standard specimen, respectively.

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