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HARDNESS OF COATINGS OF VARIOUS FILLER MATERIALS IN ELECTRIC-ARC METALLIZATION

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The effect of the electrode material on the hardness of coatings in electric-arc metallization is studied experimentally.

One means for improving the efficiency of technology and saving materials is restoration of the worn-out parts and units of machines, which allows their repeated and sometimes multiple use. For these purposes, the domestic and foreign practice widely uses electric-arc metallization (EAM), which allows the application of coatings with a thickness of from 0.1 to several millimeters.

One of the basic mechanical characteristics of coating materials defining the fatigue resistance is tensile strength, for whose determinatioon it is necessary to fabricate special specimens and to perform studies in laboratory conditions. In practice, it is preferable to measure hardness. There is a fairly steady relationship between hardness and strength that has been established experimentally [1].

The procedure for ascertaining hardness is sufficiently simple; it tests the surfaces of bodies of various shapes and dimensions, and, because surface damage is insignificant, it is practically harmless. Specifically, in restoring the crankshafts (CS) of internal combustion engines at repair plants, the hardness of the coating is the main criterion characterizing its quality.

The hardness of the material has a great effect on its abrasive resistance. Dustiness of the air, fuel, and oil leads to the occurrence of foreign particles on the friction surface and increases their wear. The microhardness of these particles is much higher than that of steel [2]: 0.94 GPa for steel, 064 GPa for quartz glass, 28.5 GPa for green SiC, and 20–23 GPa for electrocorundum, whereas the microhardness of an Al_2O_3 coating produced by microarc oxidation is as low as 6–8 GPa [3], i.e., the hardness of the coating of CS journals is practically always lower than the hardness of the impurities in the engine. However, it should be noted that the commonest oxides SiO_2 and Al_2O_3 are most frequently encountered not in the form of quartz or corundum but as parts of minerals whose hardness is significantly lower. The hardness of the coating should be higher than the hardness of the most frequently found minerals in order that the penetration of the latter into the soft material of the bushing does not entail scratching of the shaft journal by these minerals and abrasive wear.

Analysis of bench and operational tests of restored CS indicates that the hardness of the metal coating on rod and crank journals of the shafts of diesel engines should be not lower than 35 HRC. The hardness of the typical 12Kh2N4A medium steel used for manufacturing diesel engines is HB 310-370.

To select the material and ensure the needed coating hardness in EAM, we used the following wires produced in the CIS: continuous wires (40Kh13, 20Kh13, 65G, Sv-08G2S, U8A, and Kh18N10T), powder wires PP-MM-2 (V0), PP-MM-2S (V1), PP-MM-65 (V2), PP-TP1 (V3), PP-AN141A, PP-FMI-2, and their combinations (V1+V3, V0+40Kh13, V1+40Kh13, V1+Sv-08G2S, V1+V2, V2+40Kh13 and V2+V3, etc.).

All these wires are based on iron, and deposition leads to the formation of a large amount of ferrooxides. In the air flow and on the restored surface, ferrooxides dissociate, are oxidized, transform into one another, etc. The kinetics of formation and the number of disproportionation of phases can be controlled by varying the spraying parameters, starting with a change in the substrate temperature, which strongly affects the structure formation. By

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TABLE 1. Measuring Results for Microhardness over Cross Section of Sprayed Coating of V3 Wire, kg/mm^2

Working medium	$l = 50\,\mu$m	$l = 0.5L$	$l = L - 50\,\mu$m
Propane–butane + air	322	313	297
Air	314	300	304

TABLE 2. Measuring Results for Microhardness in Cross Section of Sprayed Coating, kg/mm^2. Working Medium is Air

Pressure P, atm	Filler material											
	V0+V3 at w, rpm						V3 at w, rpm					
	50			41			50			41		
	I, A											
	200	250	300	200	250	300	200	250	300	200	250	300
10	258	238	224	232	236	278	322	317	315	347	332	298
6	209	234	222	208	255	299	289	306	319	333	284	280

varying the process parameters it is possible to obtain a wide spectrum of ferrooxides with different contents of oxygen and different hardnesses (9 GPa is the microhardness for Fe_2O_3, 6 GPa for Fe_3O_4, and 5 GPa for FeO).

In spraying of oxides, the microhardness of the coating increases across the thickness from 4 to 10 GPa [4] (the rate of crystallization decreases with an increase in the coating thickness), and its density also rises. The existence of oxide structures in an overstressed state (microhardness of 15–18 GPa) with 5–20 μm dimensions is possible. On their breakdown the element dimensions are smaller than 1–2 μm.

A similar effect of variation in the coating hardness across the thickness was noted in [5]. In spraying of Al_2O_3 + 5% Cr_2O_3, the coating microhardness at the base was 10–14 GPa, at a distance of 0.15 mm from the substrate 14–21 GPa, and at the outer boundary of the coating at a distance of 0.25 mm from the base 18–23 GPa. According to data [4], with distance from the substrate, the microhardness of a ceramic coating increased from 5–9 to 13–18 GPa.

We studied the microhardness distribution across the coating thickness using specimens with a 1–3 mm thick coating produced by spraying a V3 wire at an arc current of 235 A. Measurements were performed on a "Micromet-II" microhardness meter of the "Buller-Met" firm by a Vickers pyramid with a 50 g load at a distance l = 50 μm from the coating boundaries and in the coating center. The microhardness proved to be practically the same across the coating thickness L (see Table 1) for the given specimen.

Taking into account that spraying is associated with the formation of a layered structure and that hardness is related to the strength and abrasion resistance of the layers, apart from the microhardness distribution across the coating thickness, particular attention was given to the microhardness in the midsection of the applied layer as a function of the arc current I, pressure of the working gas P, and rotation frequency of the specimen w (see Table 2). The Vickers microhardness was determined (State Standard 9450).

Analysis of the results reveals that the microhardness of the V0+V3 coating increases with an increase in the arc current at a rotation frequency of 41 rpm. In our opinion, this is explained by the fact that, with a smaller linear velocity of the sprayed surface of the specimen and with a rise in the arc current the coating is "superheated," and at 50 rpm its temperature falls and, as a consequence, the bonds are weakened, which is verified by a study of cohesive strength [6].

The decrease in the microhardness of the V3 coating with an increase in the arc current is due to a change in the bond strength between the particles and layers, and at currents over 270 A, in the considered pressure range of the working gas, cracks develop in a sprayed layer thicker than 2 mm.

The hardness of the sprayed layer normal to the spraying plane was determined by a TPTs-4 meter (designed by the Institute of Applied Physics of the National Academy of Sciences of Belarus). Measuring results are presented in Fig. 1, from which it is seen that the coatings produced by EAM have a hardness above 35 HRC when continuous (40Kh13, 20Kh13, 65G, U8A, Sv-08G2S, and Kh18N10T) or powder (PP-AN141A, PP-FMI-2,

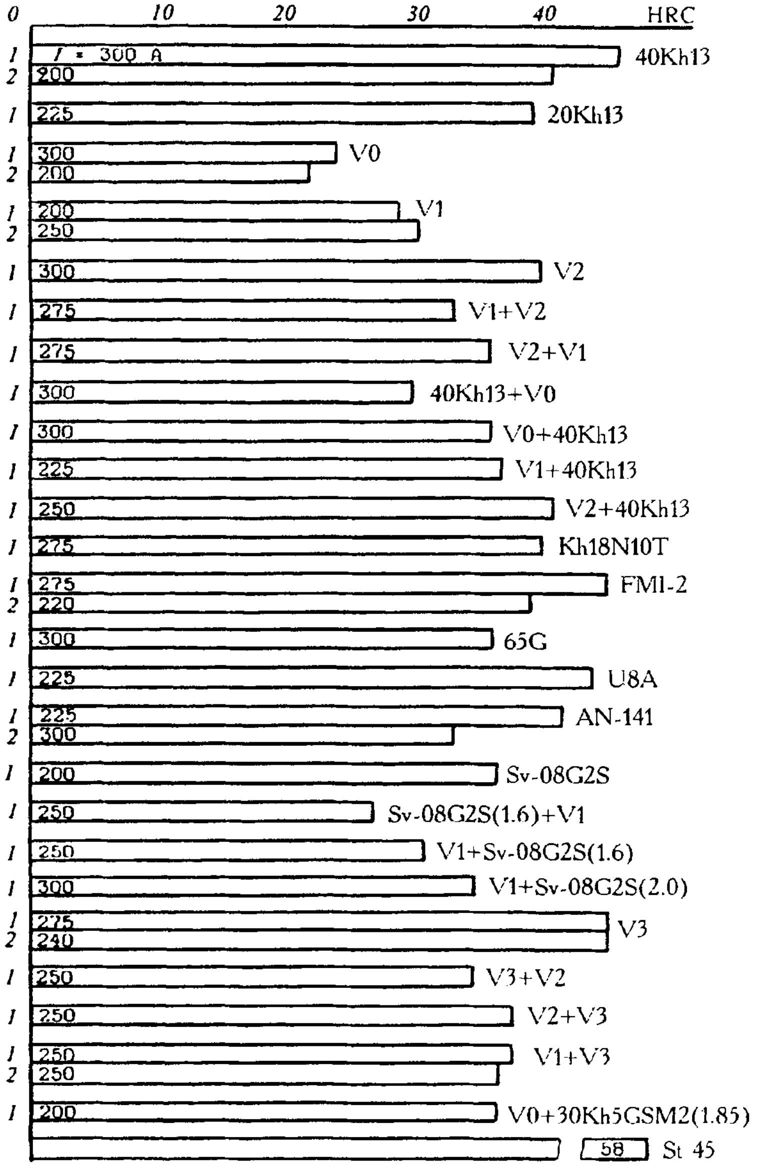

Fig. 1. Measuring results for hardness of coatings of various alloys produced by EAM. Working medium: 1) propane-butane + air, 2) air. Coatings hardness, HRC (wire diameter is in brackets).

V2, and V3) wires were used. The hardness of the combined coatings from two different wires is approximately equal to the arithmetic mean for the compositions of the filler materials [7]. In this case, in order to increase hardness, a harder wire should be used as the cathode. Figure 2a plots results for the effect of the rotation frequency of the part (the linear velocity of the treated surface) in applying continuous (40Kh13) and powder (V0) materials. It is established that in spraying of the CS journals of diesel engines, the optimum linear velocity of the treated surface is 12–13 m/min. Its decrease below the above value results in superheating of the applied layer and in the emergence of longitudinal cracks when the coatings are formed by a 40Kh13 continuous wire with a Nichrome sublayer and a V0 powder wire with no sublayer.

The coating quality is greatly affected by the arc current. With its increase, the hardness of the layer rises when it is sprayed by continuous wires (Fig. 2b). This is due to the formation of a denser coating due to a rise in the particle temperature and a reduction in porosity. At the same time, the variation in hardness of the sprayed layer with the use of a V0 powder wire is insignificant. In our opinion, this is explained by a partial burnout in the molten bath of alloy components, which is supported by the much higher hardness of the sprayed layer from this wire (of about 41–43 HRC).

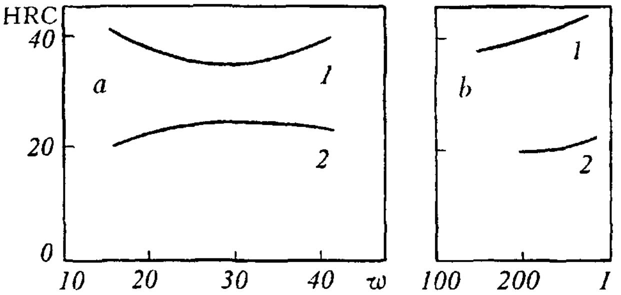

Fig. 2. Coating hardness at $U = 40$ V and spraying distance $s = 150$ mm (the working medium is propane–butane+air) vs rotation frequency of part at $I = 200$ A (a) and vs arc current at $w = 41$ rpm (b): 1) 40Kh13, 2) V0. Coating hardness, HRC. w, rpm; I, A.

TABLE 3. Measuring Results for Microhardness of Coating Surface, kg/mm^2 [1) pronane–butane+air, 2) air]

Filler material, working medium	Microhardness, HB			Hardness, HRC
	maximum	minimum	average	
V1+V3, 1	825.20	295.90	442.99	43.8
V1+V3, 2	677.30	283.00	466.00	45.7
V1, 1	429.40	176.80	337.70	35.3
V1, 2	501.30	184.80	325.45	33.6
V3, 1	557.10	348.60	485.01	47.1
V3, 2	603.00	246.30	484.15	46.8

Along with the study of the structure, porosity, and element composition of the coating, one of the most applicable methods of evaluating serviceability of the applied layer is the determination of microhardness. Only this method permits both assessment of the effect of individual structural components on strengthening and determination of the alloy components playing the primary role in strengthening. With the same wear resistance of the coatings, preference should be given to a harder coating as more resistant to abrasion wear, since impurities are always present in lubricating oil. For example, the surfaces of the first and seventh journals of the crankshaft of the "Ikarus" bus sprayed by a V3 wire in six months of operation had a smooth lustrous surface and fewer marks than did the remaining journals sprayed by V0+V3 wires.

Analysis of the measuring results for microhardness of the coating surface in Table 3 reveals that the coatings from a V1 powder wire have the highest plasticity. They also have a more uniform distribution of the alloy components, and the presence of double oxides and spinels provides a sink for vacancies on the incoherent boundaries.

It is of interest to study time variations of the coating hardness as a result of restructuring and transformations during operation. Measurement of the hardness of the coatings of CS that was in use for about six months indicated a hardness variation from 30 to 33 HRC for the coating sprayed from a V1 wire and from 39 to 37 units for a V1+V3 composition. For a shaft sprayed by a V1+V2 wire composition, after two years of service (at the first repair dimension) the hardness of the crankshaft journals was practically unchanged and equal to 33 HRC.

The structural features and complex phase composition of the metal coatings stipulate the selection of methods and modes of their mechanical treatment other that those used in fabricating parts from a homogeneous metal. As a rule, it is carried out not sooner than 48–50 h after metallization, when shrinkage of the sprayed layer ceases and inner stresses relax.

Although coatings from less expensive continuous wires have the needed hardness, the process of their application is more complicated and requires spraying of a sublayer for relaxation of the stresses resulting from mismatching of the physicochemical properties of the sprayed layer and the base. Therefore, for restoring the crankshafts of diesel engines, as filler materials it is recommended to use V1 and V3 powder wires, as they are the easiest to manufacture (coatings from them do not require a sublayer application) and are now produced by Russian and Ukrainian factories in sufficient quantity.

By the technology of electric-arc metallization using V1+V3 powder wires developed at the Heat and Mass Transfer Institute of the National Academy of Sciences of Belarus, about 500 crankshafts of "RABA-MAN" engines for "Ikarus" buses for "Minskpassazhiravtotrans" have been restored, which improved the operating efficiency of municipal transport.

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