Comparison of corrosion resistance of gas-dynamic coatings, obtained using standard and electroerosive powder material

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Abstract. The paper presents the results of a study and comparison of the corrosion resistance of gas-dynamic coatings, obtained using standard powder material grade A-20-11, and aluminum-containing powder material, obtained by the method of electroerosive dispersion of electrical aluminum wastes in distilled water. The study of the corrosion resistance of gas-dynamic coatings was carried out according to the method of accelerated testing using a multichannel potentiostat-galvanostat "Elins P-20X8". 3,5% NaCl was used as working solution. The ESr-10101 electrode (Ag/AgCl/KCl) was used as a reference electrode, the KCl concentration in the potential-forming half-cell was 4,2mol/dm3. The reference electrode was connected to the working solution via an electrolytic switch (bridge). The area of the investigated surface was 1 cm2. The volume of working solution used for each sample was 1 l. The measurement time was 5 hours. As a result of the corrosion resistance study of gas-dynamic coatings, it was experimentally established that in coatings, obtained using standard powder materials, the electrolyte penetrates into the coating, which contributes to the rapid exfoliation. It was also established that the corrosion resistance of the coating obtained using electroerosive powder materials is 22% higher than the corrosion resistance of the coating obtained using standard powder materials.

1. Introduction
Currently, one of the most promising methods for applying coatings is gas dynamic spraying. One of the problems of using the technology of gas-dynamic spraying is the quality of the used powder materials. One of the promising ways to obtain powder materials to restore defective cylinder heads of automobiles from virtually any conductive material, including aluminum waste, is the electroerosive dispersion method, which is distinguished by relatively low energy costs and ecological cleanliness of the process [1-4]. However, these materials have not been used to date in the technology of restoring defective parts of cars by gas-dynamic spraying, including the cylinder heads.

A distinctive feature of the gas-dynamic spraying method is that the process of increasing the coating occurs due to the metal particles being given significant accelerations by the gas flow, which is passed through a supersonic nozzle.

When applying coatings, powder particles of metals and alloys are used, as well as mixtures with abrasive particles are used. Adjusting the parameters of the installation allows you to control the...
porosity and thickness of the coatings, as well as to perform either abrasive cleaning or increasing the
gas-dynamic coating.

The purpose of this work was to study and compare the corrosion resistance of gas-dynamic
coatings obtained using standard powder material grade A-20-11 and aluminum-containing powder
material obtained by electro-erosion dispersion of electrical aluminum waste in distilled water.

2. Materials and methods

Aluminum wire GOST 14838-78, previously cut into 5-7 cm, was used to obtain an aluminum-
containing powder material by the method of electroerosive dispersion [5-11]. The wire was loaded
into a reactor filled with a working fluid – distilled water. The process was carried out at the following
electrical parameters: the capacitance of the discharge capacitors is 65 \( \mu \)F, the voltage is 100 V, the
pulse frequency is 140 Hz. As a result of the local impact of short-term electrical discharges between
the electrodes, the material was destroyed with the formation of dispersed powder particles. Then, the
powder material was used to restore defective cylinder heads with gas-dynamic spraying using a
DIMET-404 unit.

Clean metal and ceramic surfaces usually do not require special preparation before spraying. Coating in this way is possible even on surfaces contaminated with oil and paint. However, if more
serious contaminants are present, it is desirable to conduct an abrasive surface treatment. Abrasive
surface treatment was also carried out on the DIMET-404 unit; as the powder material aluminum-
containing powder material, obtained by the method of electroerosive dispersion with the following
installation parameters, was used: the capacity of the discharge capacitors was 65 \( \mu \)F, voltage 90 V,
pulse frequency 60 Hz. X-ray diffraction analysis of the obtained powder material on an X-ray
diffractometer RigakuUltima IV showed that \( \text{Al}_2\text{O}_3 \) is its main phase.

After cleaning the surface, the powder material was sprayed under the following installation modes
DYMET-404:
- air pressure (according to the pressure gauge on MPV-K at the rack) – 5,0 kgf/cm\(^2\);
- temperature mode No. 3 (switch position "temperature mode");
- consumption of powder material – 0,2 g/s.

As a result, two samples were obtained:
- a sample with a standard powder material was obtained on the surface of a sample, cut from the
cylinder head of an automobile engine ZMZ – 406, by the gas-dynamic spraying method using
standard A-20-11 powder material.
- a sample with an experimental coating was obtained on the surface of a sample, cut from the
cylinder head of an automobile engine ZMZ – 406, by the gas-dynamic spraying method using
aluminum electroerosive powder material, obtained by EED dispersion using the following installation
parameters: discharge capacitor capacity 65 \( \mu \)F, voltage 100 V, pulse frequency 140 Hz.

After applying the gas-dynamic coatings, the samples were subjected to corrosion resistance tests.

Tests of corrosion resistance of gas-dynamic coatings were carried out according to the method of
accelerated tests using the multichannel potentiostat-galvanostat “Elnis P-20X8”. Potentiostat
-galvanostat R-20X8 is entered in the State Register of Measuring Instruments of the Russian
Federation under registration number 70702-18. The method of calibration MP 206.1-001-2018, the
verification interval is 2 years. Also, the device is certified under the GOST R certification system.
Certificate of Conformity No.ROSS RU.AD44.N04368.

Electrochemical measurements were performed using a multichannel potentiostat-galvanostat
“P-20X8” (Elnis, Russia) with ES8 software. 3.5% NaCl was used as working solution. The Esr-10101 electrode (Ag/AgCl/KCl) was used as a reference electrode, the KCl concentration in the potential-forming half-cell was 4,2mol/dm\(^3\). The reference electrode was
connected to the working solution via an electrolytic switch (bridge). The area of the investigated
surface was 1 cm\(^2\). The volume of working solution used for each sample was 1 l. The measurement
time was 5 hours.
At the first stage, the measurement of the potential of the open circuit $E_{oc}$ was performed. After measuring $E_{oc}$, the current-voltage characteristic was removed from the samples using a three-electrode circuit. High-purity graphite was used as an auxiliary electrode. The sweep step was 1 mV. Further, the obtained anodic polarization curves $I(E)$ were analyzed. At the next stage, the obtained polarization curves were rearranged according to the Tafel extrapolation method and the potential and the corrosion current were determined by the intersection of the approximations of the graph sections.

3. The study of the assessment of the wear resistance of electro-spark coatings

The results of measurements of the open circuit potential of the $E_{oc}$ materials for coatings are shown in Figure 1.

![Figure 1. $E_{oc}$ potential: 1 - sample with standard PM; 2 - sample with experimental PM](image)

For the sample with experimental PM, $E_{oc}$ rises from 876.08 to 793.41 mV. This potential behavior means that a layer of oxide film is present on the surface of the material before being immersed in the working solution, and it is modified as a result of two processes - dissolution and reduction. Due to this, potential fluctuations occur.

For a sample with a standard PM, the $E_{oc}$ decreases from 994.99 to 1029.4 mV. Typically, a decrease in potential means that the electrolyte penetrates the coating. When the electrolyte reaches the substrate, a galvanic couple is formed and corrosion at the “coating / substrate” boundary can be accelerated. As a result, the substrate may be affected by the working solution and the coating peels off. The dissolution of the oxides leads to the appearance of defects, pores and cracks, facilitating the penetration of the electrolyte, and the corrosion of the substrate occurs through the attack of chloride ions leading to pitting corrosion.

As a result, it can be concluded that when immersing samples with coatings for three hours on a 3.5% NaCl medium, the potential of the open circuit of the sample with the experimental PM is 22% higher, which should indicate a structure that is more resistant to corrosive than the sample with standard PM.

The results of measurements of the polarization curves of coated samples are presented in Figure 2. The results of the investigation of the potential and current of corrosion are presented in Table 1.

From the study of the curves of the dependence of current on the potential of the effect of passivation for all the studied coatings were not identified.
Figure 2. Polarization curves: 1 - sample with experimental PM; 2 - sample with standard PM;

From the graph (Figure 2) it is clear that the destruction of the sample with a standard PM is uneven, with the formation of defects and cracks. As a result of the formation of a crack, the electrolyte reaches the substrate locally, changing the potential and causing jumps in the graph.

The rebuilding of the graphs according to the Tafel method for coatings is presented in Figure 3. The results of the investigation of the potential and current of corrosion are presented in Table 1.

Table 1. The results of the corrosion resistance study of coatings

| Sample                  | $E_{oc0}$, mV | $E_{oc3}$, mV | $E_c$, mV | $I_c$, mA | $E_{cT}$, mV | $I_{cT}$, mA |
|-------------------------|---------------|---------------|-----------|------------|--------------|--------------|
| with standard PM        | -1029,8       | -1328,2       | 43,90     | 113,01     | -1095,5      | 0,0025735    |
| with experimental PM    | -795,91       | -1094,7       | 271,13    | 134,91     | -766,7       | 0,0064171    |

Note: $E_{oc0}$ – open circuit potential at the beginning of the test; $E_{oc3}$ – open circuit potential three hours after the sample is immersed in the working solution; $E_c$ – corrosion potential; $I_c$ – corrosion current; $E_{cT}$ – corrosion potential, obtained by Tafel extrapolating; $I_{cT}$ – corrosion current obtained by Tafel extrapolating.
As a result of research, it was found that the sample with the experimental PM showed the highest corrosion resistance.

4. Conclusions
The gas-dynamic spraying method is the most promising for restoring the working surfaces of defective cylinder heads, and the PM, obtained by EED with the following installation parameters: discharge capacitor capacity 65 μF, voltage 90 V, pulse frequency 60 Hz., - cleans the surface well before spraying.

As a result of the corrosion resistance study of coatings, it was experimentally established that in coatings, obtained using standard PM, the electrolyte penetrates into the coating, respectively, the coating, obtained using EED PM, has a corrosion resistance 22% higher and less susceptible to flaking.

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