Formation of Composite Coatings by Sub- and Supersonic Plasma Spraying under and on Special Coating Materials

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Abstract. A technology was developed for the formation of a multilayer composite coating obtained by the sub- and supersonic plasma spraying method based on Al, Ti, Ni, and Mo. The results of the investigation of a coating of Al-Ti-Ni-Mo powder are deposited by subsonic plasma deposition on a steel substrate followed by the application of an anticorrosion coating from a paint coating material (PCM) of the CINEP brand, which is protected by the supersonic spraying powder Al-Ti-Ni-Mo. This coating layer is designed to protect the anticorrosive layers of the main multicomponent coating of products, which can be subjected to external mechanical stress during operation. It is shown that the resulting composite coating is sufficiently strong and withstands strains in the zone of elastic deformation of the matrix. Carried out corrosion tests showed a high resistance of these coatings.

Keywords: composite coating, plasma spraying, plasma

1. Introduction
The combination of technologies of supersonic plasma spraying, airborne plasma subsonic spraying and PCM allows to obtain a new generation of composite coatings with improved performance characteristics, maximize the service life of existing equipment and facilities while preserving the reliability of their operation, at minimal cost [1].

Optimization of technological modes of plasma spraying was carried out using modern numerical methods and available software tools. The choice of the parameters of the plasma flow made it possible to determine the velocity and maximum acceleration of the particles, the temperature of their heating, the residence time, the evaporation rate of the particles, and also the particle trajectory in the plasma jet.

Coatings used in environments with high corrosive activity are effective only in the complex of the coating system. It is proposed to apply polyurethane and epoxy varnish materials based on scaled pigments to plasma coatings. In this case, the covering layers enhance the barrier properties of the coating, shield it from the influence of aggressive factors, which slows down the oxidation of zinc present in the plasma coating and prolongs its protective action. In addition, they impart greater hardness, resistance to abrasion.

The use of high-speed plasma (with velocities of approaching the deposited particle to the surface of the substrate $v = 600-1500$ m/s) opens up new possibilities for realization the multi-purpose
protection of metal structures due to the following reason i.e. the possibility of a strong sputtering on products made from almost any material. 

The task was to create conditions and obtain a coating that, when deformed, would retain its operational properties for as long as possible. In the literature there is the concept of "multiple cracking" [2, 3], in the manifestation of which the onset of cracking does not immediately lead to the destruction of the layer or its detachment from the substrate. The cover is fragmented, but remains on the basis and continues to perform, though not fully, its task. There are many common methods for testing coatings [4, 5]. However, in most cases researchers and technologists are interested in strength (hardness, adhesion, cohesion) and tribological (resistance to abrasive and erosion wear, sliding friction parameters, etc.) coating properties. Adhesion characterizes the bond strength of the coating with the substrate [6].

2. Methods and materials

Intermetallic alloys based on titanium, aluminum, nickel and molybdenum have increased performance characteristics. The alloy was obtained by aluminothermic reduction of oxides in a Tamman furnace. Subsequently, it was subjected to grinding in a vibratory shredder to a particle size of 40-160 μm.

Using the method of supersonic plasma spraying using air and its mixture with methane as a plasma-forming gas, laboratory samples of Al-Ti-Ni-Mo coatings were obtained on plates of steel St45 with a size of 100x15x1 mm.

Three-point bending tests (Fig. 1) were carried out on a universal Zwick / Roell Z050 test machine (BT1-FR050THW / A1K). The distance between the supports was set at 20 mm. The moving speed of the movable crosshead was set to 4 mm/min and three tests of each coating were performed.

3. Results and discussion

Photographs of coated plates after a test with characteristic fractures for each coating and application conditions are shown in Figure 1. Tests have shown that the samples do not have fracture with a central crack.

Fig. 1. Characteristic fractures of the Al-Ti-Ni-Mo coating.

Plasma-forming gas: a, b - air, methane; c, d – air.

Rockwell hardness was also measured. The measurement was carried out by ultrasonic-measurer UZIT-3 in Rockwell in HRC units (measurement limits from 20-70 HRC, error of measurement no
more than ± 2.0 HRC). The results of the fixed hardness values of HRC coatings on Al-Ti-Ni-Mo samples obtained in air and air + methane are presented in Table 1. The scatter of the values of hardness is related to the features of the structure of the coating, its lamellar structure, and also to the multiphase nature of the applied material containing regions of different hardness. The load increase graph, shown in Figure 2, represents the measurements obtained with a three-point bend [7]. There are different areas of deformation, including the peeling of the coating.

Table 1. Hardness values of HRC coatings on Al-Ti-Ni-Mo samples obtained in air and air + methane.

| Measurement № | Methane + air | Air |
|----------------|--------------|-----|
| 1              | 77.5         | 88  |
| 2              | 81.4         | 79.5|
| 3              | 87.2         | 84.5|
| 4              | 85.2         | 78.8|
| 5              | 84.1         | 87.7|
| 6              | 80.1         | 80.0|
| 7              | 79.6         | 87.2|
| 8              | 84.2         | 71.9|

Fig. 2. Strain during deformation.

To investigate the corrosion resistance of combined coatings, tests were carried out in a salt mist chamber Q-FOG / SSP / 600 according to ASTM B117 standard test. This test consists in the continuous spraying of salt mist for a predetermined time. To create salt fog, a 5% aqueous solution of NaCl, pH 6.5-7.2 was used. The test temperature is 35 °C. The duration of the tests is until the appearance of visible damage to the coatings. For the criterion of the quality of the coatings, the appearance of the coatings, characterizing the protective properties, is adopted. During the tests, the appearance of the coatings was periodically monitored and evaluated according to GOST 9.407. As test specimens, plates of steel grade 08ps (GOST 16523) measuring 100x150x1 mm were used. The
total thickness of coatings was up to 170 and more microns. The test duration was 883 hours before the destruction, which is a good result.

4. Conclusions
It was possible to connect the technology of plasma (subsonic and supersonic) evaporation and the technology of applying coatings to create multifunctional composite coatings obtained by the method of plasma spraying of the Al-Ti-Ni-Mo system with the application of special paint and varnish materials to reduce porosity and enhance corrosion protection.

The properties of the Al-Ti-Ni-Mo coating applied to the steel substrate have been studied. It is shown that the coating is sufficiently strong and withstands strains in the zone of elastic deformation. It is shown that in the bending test there is a peeling of the coating without cracking.

Tests have been conducted to assess the protective properties of combined coatings consisting of a plasma-dust coating and a paint coating layer (zinc-primed CINEP primer). The test duration was 883 hours. During the tests, the main types of damage were pitting corrosion. The influence of the total thickness of the coating on the protective properties was found. A coating with a larger thickness showed higher protective properties. The coating based on Al-Ti-Ni-Mo has good strength properties and, taking into account good anticorrosion properties, can be recommended for use in various engineering fields.

Acknowledgements
This work was financially supported by the Ural Branch of the Russian Academy of Sciences (grant No. 15-17-3-41). The research was carried out using the equipment of the Ural-M Center for Collective Use.

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