Properties of the protective powder coating made on the basis of nickel and received by the cold spray method

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Abstract. The structure, porosity, microhardness, adhesion strength of gasdynamic powder coatings have been investigated. Patterns of the process of electrochemical breakdown and passivation of coatings have been studied during comparative tests in the seawater in accordance with time factors. It is established that the protective coating on the basis of nickel with increased thickness in combination with low apparent porosity and high adhesion strength provides reliable electrochemical protection of the electric contacts made of titanic VT3-1 alloy in the sea water.

1. Introduction

The method of cold spray, which is based on dispersion of powder mixtures by compressed air, is used both for the grit blasting, and for the deposition of protective coatings on the surface of metal details [1, 2]. Deposition of coverings was carried out with the unit "Dimet-403" in which mixture of hot air and powder forms the high-speed stream at the exit of supersonic nozzle. Clean metal and ceramic surfaces of details usually do not demand any special preparation. However, to clean surface, to remove oxidic film and to increase adhesion strength of covering with substrate (due to creation of roughness) it is desirable to carry out preliminary grit blasting during the coating application on steel and titanic alloys. The cold spray method allows carrying out the preliminary abrading of the product's surface with the unit "Dimet-403". The advantage of this method is the possibility of using powder mixtures with addition of particles of corundum, which allows combining the process of deposition and abrading of the surface in one production cycle.

2. Objects and methodology of the study

Powder blends of the following brands were used for the cold spray: N3-00-02 (nickel – 57%, alumina (corundum) Al₂O₃ – 43%); C-01-01 (copper – 57%, Al₂O₃ alumina – 43%); P-01-01 (lead – 57%, Al₂O₃ alumina – 43%).

Spraying of the one-layer and layered protective coating was carried out with the unit "Dimet-403" with the following alternatives:
- covering on the basis of nickel; a covering on the basis of nickel and copper (50% of Ni of 50% of Cu);
- two-layer covering (50% of Ni of 50% of Cu) + Ni;
- two-layer covering (50% of Ni of 50% of Cu) + Pb.

Coverings have been applied on a working part of the electrical link (made of VT3-1 alloy) entering a structure of the subsea acoustic beacons (SAB) which are operated in all climatic zones on aircrafts of both domestic and foreign airlines. The increased requirements for the quantity of working
hours of SAB (up to 90 days) defined greater stability of electrochemical characteristics of the contact (ensuring stability of the voltage drop for no more than 0.5 V) as a purpose.

The following target was established during electric tests: to study regularities of the electrochemical breakdown and passivation of the examined protective coating. According to the technical requirements for the contact, the voltage drop in the circuit (composed of an exemplar of 1 cm$^2$, a conducting medium on the basis of sea water, a titanic alloy VT3-1) has to be for no more than 0.5 V with the value of the flow of current 50 mA (figure 1). The laboratory facility was designed to carry out the experimental electrochemical tests. The voltage drop at the contact in a conducting medium was carried out in accordance with the time factor.

![Figure 1. Electrical circuit diagram](image)

Comparative electrochemical tests were carried out on the laboratory facility. The voltage drop at the contact in the seawater was carried out in accordance with the time factor.

The phase constitution of coatings was investigated by the method of X-ray diffraction analysis with a diffractometer "Drone-3M" (Cu-K$_\alpha$-radiation, the symmetric shooting according to Bragg-Brentano). Metallographic examination was conducted with a scanning electron microscope "VEGA//TESCAN". Microhardness was measured with a microhardness tester PMT-3 in accordance with the State Standard 9450-76.

The porosity of the coating was measured by the method of hydrostatic weighing with an assay balance VIBRA in accordance with the State Standart 18898-89.

The adhesion strength of the coatings was assessed by the method of micro-indentation on the interface between the base and the coating on a microhardness tester PMT-3.

3. Results of the research

Curves of voltage drop at the contacts – without coating and with the above-stated coatings in the seawater in accordance with the time factor are given in figure 2.

![Figure 2. Voltage drop at the contacts with different gas dynamic powder coatings depending on time when the test were carried out.](image)
Thick sparkly bluish-green sediments were found during short-term electrochemical tests on a working surface of contacts with the coatings containing copper. This is due to the electrochemical reaction resulting in precipitation of a copper sulfate. The one-layer gasdynamic powder coating on the basis of nickel was selected for further research as optimum according to the main selection criteria (value of a voltage drop, appearance). The photo of appearance of an electrical contact with the coating (on the basis of nickel) applied on a working surface is in the figure 3.

![Figure 3](image3.png)

**Figure 3.** Appearance of the contact made of VT3-1 alloy with the gasdynamic coating on the basis of Ni after deposition (a) and the following tooling (b).

In the original condition the coating surface of nickel has the 5th degree of roughness (figure 3a), after mechanical refinement – the 7th degree of roughness (figure 3b). Photos of cross-sections of contact and the coating applied on a working surface (a) and the coating of Ni itself (b) are in the figure 4. The method of X-ray diffraction analysis established two-phase structure of the formed coating: Ni and α-Al₂O₃ (corundum) (dark color inclusions in figure 4(b)). Nickel is the main phase in coating.

![Figure 4](image4.png)

**Figure 4.** Cross-sections of the electrical contact with coating of Ni (a), x20 and the protective coating on the basis of nickel (b), x20000.

Using the cold spray method make the majority of the corundum solids (possessing a high kinetic energy) undergo bumping collision with a surface. Nevertheless, some particles get to a substrate. Therefore, inclusions of Al₂O₃ are present both at a demarcation "coating-basis", and at the surface layer of the treated material (figures 4(b), 5(a)). The study of distribution of elemental composition showed synchronous splash in reflexes of aluminum and oxygen in places of inclusions (figure 5(b)).
In the original condition, thickness of coating of nickel is \( \sim 400 \mu m \) (figure 4(b)). The general porosity of coating is 17.7\%, including, closed porosity – 13.1\% and apparent porosity – 4.6\%. It is important to note that the share of apparent porosity in general is small in comparison with closed. It is important for ensuring protective properties. The average value of microhardness of the nickel matrix of coating is \( H_{200} = 2.4 \) GPa.

![Microstructure and element composition](image)

**Figure 5.** Microstructure (a) and distribution of element composition (b) in cross section of the protective coating on the basis of nickel.

The adhesion strength of the nickel coatings was assessed by the method of micro-indentation and it showed that cohesive strength between the base and the coating is satisfactory. Layer separations, cracks and deformation of the print of microhardness tester were not revealed on the "coating-basis" demarcation.

Dependences of the voltage drop at contacts during 90 days of tests are given in the figure 6. Curves of voltage drops reach a constant level after about 20 days of tests: \( U \sim 0.75 \) V – for initial contact (\( \sim \) is 1.5 times higher than the standard level of a voltage drop) and \( U \sim 0.3 \) V – for a contact with the covering on the basis of Ni (\( \sim \) is 1.7 times lower than the standard level of a voltage drop).

![Voltage drop graph](image)

**Figure 6.** Voltage drop at contacts with coating on the basis of Ni in accordance with the time factor.
The analysis of the received results of the research established that the protective gasdynamic coating on the basis of nickel forms a layer on the surface of electrical contacts of titanic VT3-1 alloy and provides stable electric potential (not higher than 0.5 V) for 90 days and high rust resistance in the seawater.

4. Conclusion
The designed protective coating on the basis of nickel with the two-phase structure (nickel and corundum) and of the increased thickness (~ 400 microns), received by the cold spray method (with the unit Dimet-403) has low apparent porosity (~ 4.6%) and high adhesion strength. All these features allowed providing stability of the voltage drop (no more than 0.5 V) and reliable electrochemical protection in the seawater of the surface of an electrical contact of titanic VT3-1 alloy.

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References
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