Estimation of the cohesive strength of coatings made of powder materials

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Abstract. Methods for determining the mechanical properties of gas-dynamic coatings in shear (cut) and tensile tests are proposed to estimate the adhesive and/or cohesive strength of coatings more than 50 MPa. The results of studies on the strength of gas-dynamic coatings of copper, aluminum, zinc and nickel are presented. Dependences of mechanical properties of gas-dynamic coatings on the main technological modes of application are determined.

1. Introduction
Powder coatings of various application methods have proven themselves in the field of mechanical engineering. They are used to protect against corrosion of aggressive environments, improve the tribological properties of friction surfaces, restore the geometric dimensions of products, sealing compounds. One of the powder coating types is gas-dynamic spraying (GDS). This method allows the coating of metals having a relative elongation of more than 40%, such as copper, aluminum, nickel, zinc on various types of substrates. The surface temperature of the application does not exceed 140 °C. Mechanical properties of GDS coatings are highly dependent on the technological modes of sprayings: powder consumption, temperature, distance from the spraying nozzle to the spraying surface, the number of passes, composition and fraction of the sprayed mechanical mixture, etc. To estimate the properties of coatings the cohesive – strength of the coating and/or adhesive – strength of the coating with the substrate are determined. The properties of the coatings are determined by GOST 9.304-87, in which the adhesion strength is estimated by testing the separation of two cylindrical samples glued together, one of which is coated with another sample without coating with epoxy glue. The tenacity of such resins usually does not exceed 50 MPa, in addition, the GDS coatings have porosity, so the use of the adhesive separation method for coatings obtained by the considered method of application can lead to erroneous results. In this paper, alternative methods for estimating the cohesive or adhesive strength of coatings are proposed.

2. Shear cohesion estimate
To estimate cohesion or adhesion, it is advisable to use the shear test method [1]. Tests are carried out on a cylindrical sample, in its middle part in parallel to the end a coating belt width of 10 mm is formed. It is important to treat the ends of the coating with blade tool (cutter) to create a support pad, strictly perpendicular to the axis of the sample. Then the sample is placed into the matrix, basing with the coating on its edge (figure 1). A load is applied to the end of the sample and the moment of its
sharp fall is fixed. The maximum load prior to the fall is considered to be the load of the separation, and the shear strength is determined by the formula:

$$
\sigma_{ad} = \frac{P_{\text{max}}}{\pi dh},
$$

where $P_{\text{max}}$ – maximum load prior to separation; $d$ – sample diameter; $h$ – thickness of the coating (ring).

![Figure 1. Shear test scheme: 1 – sample, 2 – coating, 3 – matrix, 4 – housing.](image)

3. Assessment of cohesion in a tensile test

To estimate the cohesive tenacity of the coating it is advisable to use the method of "annular separation" [2]. The sample consists of two cylindrical symmetrical parts, which are fixed by means of a centering bush and connected by stud and nuts (figure 2). On the middle part of the forming sample surface the coating with a subsequent treatment of its blade tool to obtain the required thickness of the metal layer is applied. After that, the sample is released from the connection by the stud and the shanks are twisted into the service holes to install it in the grips of the test machine.

![Figure 2. Sample for tensile testing of the coating by "annular separation method": 1 – sample parts, 2 – centering bush, 3 – seal washer, 4 – nut, 5 – stud, 6 – coating.](image)

A tensile test is made, where the maximum load is fixed at which one part of the sample is separated from the other. The calculation of the cohesive strength of the coating material in the tensile test is carried out according to the formula:
\[
\sigma_{cog} = \frac{P_{\text{max}}}{F},
\]
where \(P_{\text{max}}\) – maximum load prior to separation (destruction); \(F\) – applied layer area.

4. Results and discussion

The results of the coating shear tests according to the proposed method showed that the metal area of the copper coating remaining on the substrate after the tests is less than 50%, this allows us to interpret the test results as the adhesive strength, which increases with the coating temperature from 17 MPa to 48 MPa. On the surface of the substrate of aluminum and zinc coatings after testing, there is a continuous layer of zinc and aluminum over the entire coating area. In this case, the obtained results should be interpreted as the cohesive strength of the coating of metal during the shear test. The cohesion of zinc and aluminum coatings decreases from 35 MPa to 17 MPa with increasing application temperature.

The results of the tensile tests of the coatings according to the proposed method showed that the cohesive strength of the zinc and nickel coatings with increasing application temperature varies slightly and is approximately 90 and 70 MPa, respectively (figure 3). However, the strength of aluminum and copper coatings decreases significantly with increasing coating temperature from 190 and 175 MPa to 53 and 86 MPa, respectively.

![Figure 3.](image)

Figure 3. Results of tensile testing of coatings: 1 – aluminum, 2 – copper, 3 – zinc, 4 – nickel.

5. Conclusions

The studies have shown that the proposed methods for determining the mechanical properties of gas-dynamic coatings during shear (cut) and tensile testing allow to estimate the adhesive and/or cohesive strength of coatings, so the shear strength of such coatings can reach 48 MPa for copper coatings and at least 35 MPa for zinc and aluminum coatings. The cohesive tenacity for copper and aluminum coatings reaches 175 and 190 MPa, and for nickel and zinc coatings 70 and 90 MPa, respectively. This allows gas-dynamic coatings to be recommended for use in critical products for various functional purposes.

References

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