Application of nanostructured coatings by plasma spraying

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Abstract. Nanostructured coatings demonstrate lower porosity by an order of magnitude, a far higher tenacity to wear, corrosion and erosion. The article presents the investigations of new method of nanostructured coatings application consisting in plasma spraying of material supplied into plasma jet and nanoparticles in suspension or solution followed by coating surface melting by air plasma jet.

Key words: coating, plasma, wear, nanoparticles, plasma jet, wear resistance, carbides, oxides, additive, microstructure, substrate

1. Introduction.
Gas thermal spraying technologies are developing intensively during the last years [1-16]. Such coatings are characterized with multilayer structure, porosity, limited values of adhesion and cohesion. Reduction of the particles forming coating considerably improves their quality. Coatings from finely divided powders and nanostructured materials demonstrate lower porosity by an order of magnitude, a far higher tenacity to wear, conditioned with abrasive particles presence, and to corrosion and erosion. In modern times of science and technology development there is a possibility to obtain new nanostructured coatings with grains sized less than 100 nm. These coatings possess improved mechanical features [17, 18].

At the correctly selected parameters nanoparticles of the sprayed material will form coating layer oncoming by integrity to the coating material in compact state. As a result of formation of complex of mechanical and technological characteristics it is possible to expect principal improvement of performance property of parts and assembly components of equipment. Over the long term it will allow to replace expensive materials with cheaper ones. One of these characteristics is wear resistance.

2. The work objective is to create nanostructured coatings based on nickel-chrome matrix, which are more resistible to wear in comparison with well-known and widely used coatings.
3. Methods.
To study the possibility to increase wear resistance of coatings based on Ni-Cr-B-Si-alloy several variants of nanostructured coatings with wear resistant additive different content of wear resistant additive in the form of tungsten carbide and aluminum oxide nanoparticles plasma sprayed with subsequent melting were obtained.

Investigation of element composition and microstructure of coatings was carried out by X-ray microanalysis (XRMA) and scanning electron microscopy (SEM) methods. Nanostructured coatings being applied on low-carbon steel samples were tested on wear resistance according to GOST 23.208-79 (method of testing materials on wear resistance at friction on not rigidly fixed abrasive particles) [19]. The essence of the method is in the fact that at equal terms we produce the friction of the tested and reference material on the abrasive particles supplied in the friction area and pressed against the sample by means of rotary rubber roller. The wear of the samples of the tested and reference material is measured. Wear resistance of the tested material is estimated by comparing its wear with the reference material wear.

4. Investigation results.
Sprayed coatings microstructure is presented in figure 1. Basic phases of coating – γ – Ni (matrix) and carbides of different types. After melting close to base carbides acicular shape is unchanged. (Fig. 1, b). It is typical for coating deposition using plasma spraying method, carbides at the surface take a form of polygons and globes (Fig. 1, a). Tungsten carbide particles are distributed close to the coating surface. Their dimensions are distributed in the range from several hundreds of nm to 10 µm.

For the samples being obtained by plasma spraying method with the following melting. It is typical that there is an intermediate layer on the boundary «coating-base» (Fig. 2). Ni content in the intermediate layer is more than in the base material.
Figure 1. Coating microstructure: a – external surface of coating; b – boundary «coating-base»

Figure 2. Formation of the interlayer and distribution of Ni on boundary «coating-base» (X-ray microanalysis (XRMA) and scanning electron microscopy (SEM))

Under test nanostructured coatings of granulated silicium boron powder (GSBP), granulated silicium boron powder (GSBP) with nanoadditives of aluminum oxide and tungsten carbide, generally acquire the characteristics, presented in table 1.

Nanostructured coatings of granulated silicium boron powder (GSBP) with Al₂O₃ and WC demonstrated the best tenacity to abrasive wear. Application of nanosized additives of tungsten
carbide allows reducing residual stresses in coatings, which terminate in failure on application of conventional powder mixtures.

**Table 1.** Results of sample testing on wear

| Coating material     | Sample weight before test, g | Test Time, s | Sample weight after test, g | Weight loss of sample, g | Relative wear resistance |
|----------------------|-----------------------------|--------------|-----------------------------|--------------------------|--------------------------|
| Steel 45             | 93,44                       | 480          | 92,81                       | 0,63                     | 0,68                     | 0,65                     | 1,00                     |
|                      | 92,61                       |              | 91,93                       |                          | 0,66                     |                          |                          |
|                      | 90,01                       |              | 89,35                       |                          |                          |                          |                          |
| GSBP                 | 176,60                      | 480          | 176,17                      | 0,43                     | 0,45                     | 0,44                     | 2,76                     |
|                      | 176,18                      |              | 175,73                      |                          | 0,44                     |                          |                          |
|                      | 178,24                      |              | 177,80                      |                          |                          |                          |                          |
| GSBP + WC            | 165,72                      | 480          | 165,34                      | 0,38                     | 0,36                     | 0,38                     | 3,89                     |
|                      | 168,07                      |              | 167,71                      |                          | 0,40                     |                          |                          |
|                      | 173,50                      |              | 173,10                      |                          |                          |                          |                          |
| GSBP + 15% Al₂O₃     | 94,011                      | 480          | 93,531                      | 0,48                     | 0,50                     | 0,48                     | 3,25                     |
|                      | 94,61                       |              | 94,11                       |                          | 0,47                     |                          |                          |
|                      | 95,72                       |              | 95,25                       |                          |                          |                          |                          |

The obtained results can be explained that inadequate penetration of particles, forming the coating, results in its brittleness and porosity increase. Hence, micro-hardness and wear resistance of coating are decreased. In contrast, increase of carbide phase mass fraction in coating composition, results in its wear resistance increase. This is because particles of tungsten carbide have high kinetic energy that is transformed into heat energy at particle impact on the surface at spraying. It provides more sound coating at the account of increase of coating particle cohesion among themselves.

**5. Conclusion.**
Plasma sprayed with powder material supplied into plasma jet and with nanoparticles in the suspension or solution form with the following melting by air plasma jet, coatings demonstrate high resistance to abrasive wear. Probably nanostructured coating properties are connected with saving nanostructure in coating during spraying. As follows from the analysis of wear resistance of sprayed nanostructured coatings the importance of qualitative characteristics of materials being selected to achieve the required level of coatings properties has become obvious.

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