MODIFICATION OF PLASMA-SPRAYED COATINGS USING CLAD AND NANODISPERSED POWDERS

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Abstract. *Some regularities of formation of plasma-sprayed coatings from clad aluminum oxide powders that enhance mechanical characteristics of substrate-coating system were studied. It has been established that the addition of a nanosized alumina powder into self-fluxing alloy powder also improves adhesion strength and wear resistance of plasma-sprayed coatings.*

Keywords*: plasma-sprayed coating, claded powders, nanosized powders, microstructure.*

1. INTRODUCTION

Increase of strength and tribological properties of plasma powder coatings is possible by use of modifiers, which are injected into a coating together with powder. Functions of modifiers is usually carried out by ultradispersed components, which provide creation in a coating of a certain structural state that is typical for solid and wear-resistant materials. At the same time chemical compounds of simple oxides like Me_2O_3 (Me - Al, Cr), MeO_2 (Me - Ti, Zi, Si), and also pure metals which have high chemical activity can be applied. It is reasonable to impart modifiers to powders by a conglomeration using mechanochemical synthesis or cladding of powder particles by ion-plasma spraying process methods.

Many works are devoted to processing of powders by mechanochemical synthesis. In work, Mazaheri (2013) by means of a high-energy planetary ball mill it was received the nanocomposition powder Al-Al_2O_3 with aluminum oxide particle size of 20-40 nanometers that provided increase of hardness and wear resistance of sprayed coats.

Concerning cladding of powders by ion-plasma spraying process methods, the number of works is limited. Some results on application of nanostructural coatings from such metals as copper, titanium, platinum, in powder by method of magnetron spraying are given in work Schmid (2013). Despite high quality of the received powders, a method of magnetron spraying has rather low deposition rate of coatings that considerably increases cladding time. In this case, the method of vacuum arc evaporation, which allows receiving of qualitative coatings from different materials, alloys and super hard connections with high adhesion of a coating to a substrate that is important at plasma-powder sputtering, can have big efficiency.

The objective of this work consisted in establishment of the modifying influence of the plated powders and nanodispersion particles of aluminum oxide on structure and wear resistance of plasma sprayed coats.

2. EXPERIMENTS' DETAILS

The powder of Al_2O_3 fraction of 40-63 microns plated by metal coats from Ti and Al, and also composition self-fluxing the powder ПГ-СР2 (NiCrFeBSi) with addition in number of 0.5-1.0 mas.% of the nanodisperse powder Al_2O_3 fraction of 40-50 nanometers, was used for sputtering of coatings.

Coats on particles of Al_2O_3 consisted of two layers, the first coat is from titanium 70-160 nanometers thick, the second is from aluminum 2-3 microns thick (in the text the plated powder is designated by Al_2O_3/Ti/Al). Titanium as chemically active element is capable to moisten aluminum oxide and by that provide interrelation with other layer of a coat. Aluminum as cementing material, promotes porosity reduction, increase of cohesive and adhesive properties of sprayed coats. Cladding was carried out on the vacuum arc installation equipped with specially developed vibration device for powder hashing. The equipment and technology processes, happening during cladding of powders by a vacuum arc method, are described in work Smirnov (2011). Al_2O_3 oxide fraction of 40-50 nanometers, received by cryochemical engineering, was used as nanopowder. Advantages of this technology are the possibility of receiving powders with a controlled size of nanoparticles and high degree of chemical uniformity and a specific surface, and also hydrophobic chemicals and materials that are chemically stable in the conditions of long storage.

Preparation of a homogeneous mixture of the micropowder ПГ-СР2 with the nanopowder Al_2O_3 was carried out by using of mechanochemical treatment in the XQM-2 planetary ball mill with additional pumping out of working tanks. In the conditions of vacuum and mechanochemical treatment aluminum oxide nanoparticles pass into the activated state and join particles of other elements, forming physical bonds between components, that allows to transfer them to the coating during further plasma spraying.

Powders evaporated using a plasmatron with partially taken out arch and additional blowing of a plasma spray by a concentric flow of protective gas. Current of an arch was established within 80-90 A, voltage of 50-60 V, a consumption of plasma-forming and protective gas of argon made 2-3 l/min with a diameter of nozzle of 2 mm. Because of such design features and the technology modes, character of a current of plasma spray was close to laminar that provides favorable conditions for preservation and transfer of the plating coats and nanoparticles to a coating. Plasma coatings 200-300 microns thick were applied on flat samples 5×10×20 mm^3 from carbon steel ASTM A570 Grade 36.

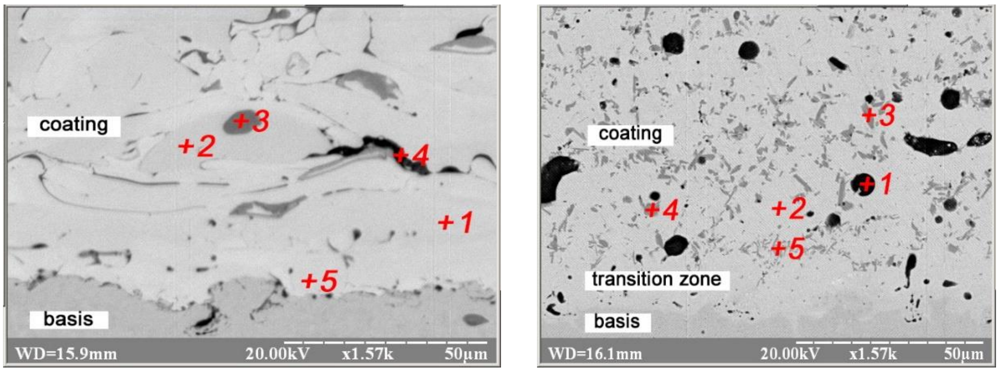
3. RESULTS

Owing to deformation and crystallization, plasma-sprayed “splets” of aluminum oxide particles have the developed network of microcracks that leads to sharp deterioration in mechanical properties of coatings and first of all adhesive and cohesive properties. It is possible to reduce, and in certain cases to eliminate, microcracks at the expense of the metal coats that have strong connection with a surface of ceramic particles. Results of metallographic analysis have shown that plasma sprayed coats, when plated powder of aluminum oxide used, have considerably smaller porosity (4-6%) in comparison with a coating from pure aluminum oxide (10% and more).

Thus, usage of the plated powders leads to formation of ceramics sites around particles with the increased cohesive bonds, at the expense of what the dense coating with the increased hardness, cohesive resistance and tribological characteristics forms.

Application of nanodisperse powder of aluminum oxide in combination with particles of large fraction leads to forming of heterogeneous structure of a coating. In a powder particle, which gets on a basis surface when plasma spraying with speed no more than 200 m/s, there are normal physical and chemical processes, however because of presence of nanoparticles conditions of coatings forming change. Deformation of the evaporated particles is carried out at the lowered viscosity and density that can lead to reduction of the area of physical contact and deterioration in mechanical properties with increase in amount of nanopowder in a coating. During crystallization and cooling there can be also chemical reactions and polymorphic transformations in a coating under the influence of nanoparticles that leads to forming of difficult structure of a composition coating which phase structure and properties depend on reaction development, both in a plasma flow, and on a basis surface.

For creation of homogeneous structure samples with sprayed coats were subjected to flowing in the muffle furnace at a temperature (1050±20) °C within 5 min. After flowing the structure of a coating created in a form of a matrix of solid solution on the basis of nickel with inclusion of the phases enriched with chrome (dark sites), at the same time there were also processes of coalescence and coagulation of non-metallic inclusions Fig. (1b). In turn, additional flowing is resulted in orderliness of a coating structure, increasing of adhesive durability that is typical for formation of conversion diffusion zones. Chemical composition of plasma-sprayed coats in separate sites with the absence of boron is investigated by means of the PEM 106i microanalyzer are provided in Tab. (1).



a) b)

Figure 1. A microstructure of a plasma coating of the system NiCrFeBSi + Al_2O_3 before (a) and after flow (b)

Table 1. Chemical composition of a plasma coating of the system NiCrFeBSi + Al_2O_3 before flow

Ranges / Elements, %	Before flow					After flow				
	1	2	3	4	5	1	2	3	4	5
Ni	85.02	80.87	4.63	64.86	83.50	34.37	83.47	9.79	69.25	56.21
Cr	10.90	12.05	93.64	15.88	9.73	8.86	9.75	87.22	24.30	39.41
Fe	3.29	5.47	1.50	5.89	6.17	5.88	5.61	2.83	5.60	3.72
Si	0.78	1.49	0.11	2.77	0.55	48.96	1.09	0.16	0.85	0.65
Al	–	0.12	0.12	10.61	0.06	1.93	0.08	–	–	–

Results of the microanalysis demonstrate non-uniform distribution of elements in structure of a coating, in particular aluminum is generally concentrated in not alloyed coating sites (a range of 4 Fig. (1a)), and after flowing in non-metallic inclusions (a range of 1 Fig. (1b)). Basing on these data it is possible to state indirectly about availability and distribution in a coating of nanodispersion particles of aluminum oxide.

For the received coatings cohesive resistance, residual stresses, hardness and wear resistance were defined (Tab. (2)). Cohesive resistance was determined by method of a normal separation in accordance with Standard GOST 9.304-87. Microhardness was determined by indentation of a Vickers diamond pyramid at load of 0.98 H on the PMT-3 device. Process of wear was investigated in the conditions of dry friction by the machine SMTs-2 according to the roller scheme (a counterbody is AISI W1-7 hardened steel) - a flat sample with a coating. Rotational speed of a roller was 330 min^{-1} with enclosed load of 55 H. During determination of comparative wear resistance of coatings from the plated powders, the coating from pure aluminum oxide was taken as a reference, and for the coatings, modified by nanopowder, a standard was a basis material. Samples of $0.2\times9\times85$ mm^3 size from low-carbon steel which were exposed to abrasive and jet processing from two parties and were rigidly fixed on a plane surface to exclude deformation at sputtering were applied to determination of residual stresses.

Residual stresses were determined by measurement of radius of a sample curvature by a Eq. (1) (Dong *et al*. 2013):

$$\sigma = \frac{E_c h^3 + E_s H^3}{6hR(h+H)} \tag{1}$$

where E_c, E_s – modulus of elasticity of a coating and basis, respectively; h, H - coating thickness and the bases respectively; R - radius of curvature of a sample. The module of elasticity of coatings was determined by test results of flat samples with a coating on stretching by a technique Dolgov (2004).

Table 2. Mechanical characteristics and wear resistance of coatings

Coating	Cohesive resistance, MPa	Residual stresses, MPa	Microhardness, HPA	Comparative wear resistance
Al_2O_3	16	– 26	9.7	1.0
Al_2O_3/Ti/Al	37	– 17	11.3	6.3
NiCrFeBSi	53	83	3.1	2.1
NiCrFeBSi+Al_2O_3	58	67	4.3	3.9

Thus, results of the carried-out tests (Tab. (2)) demonstrate that use of the plated powder provides increase of wear resistance of plasma sprayed coats by 6.3 times, with slight increase of microhardness to 11.3 HPA. When using of the pure (not plated) aluminum oxide powder, the counterbody wears out 2-3 times more that is related to abrasive influence of wear products of a ceramic coating. Increase of hardness by 1.4 and wear resistances by 1.9 times was observed also at addition in composition of self-fluxing powder of nanodisperse aluminum oxide. Besides, in all cases, changes led to reduction of residual stresses therefore cohesive resistance of plasma sprayed coats increased.

4. CONCLUSION

Modifying of plasma sprayed coats using the plated ceramic powders with coats from such metals as titanium and aluminum, promotes forming of dense coating, decrease in residual stresses and increase in strength characteristics, in particular microhardness, cohesive resistance and wear resistance by several times. Addition in composition of nanodisperse aluminum oxide self-fluxing powders also leads to increase of wear resistance, cohesive resistance and reduction of residual stresses of plasma sprayed coats.

5. REFERENCES

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