Plasma-clustered deposition of infusible coatings

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Abstract – A new promising technology of infusible coatings deposition based on acceleration of powder material particles in plasma jet is under consideration. The main difference from analogous techniques is that both jet expanding and coating deposition are performed in vacuum. This gives the following advantages: particles reach higher velocities, there is a possibility to regulate medium atmospheric conditions. As the result, coating quality is higher – adhesive strength is up to 400–500 MPa, microhardness is up to 2000 HV MPa, and durability coefficient of cutting tools (drill bits, hard metal tips) increases 2–2,5 times (using $TiC+Cr_3C_2$ coatings).

A technology considered in the paper is based on a delivery of powder material sprayed into a plasma generator channel where various thermophysical transformations, acceleration of two-phase flow in a nozzle and jet expanding to a medium with a lower pressure take place. Thermophysical transformations include melting, dispersion, evaporation, as well as condensation of sprayed material both in the plasma generator channel and jet.

There is a widely known technology of the plasma-arc application of coatings in atmospheric conditions, that is realized on installations of various classes [1]. However, deposition by spraying in atmosphere has some disadvantages limiting a sphere of using these coatings: moderate size of a spraying spot, sample superheat, low enough velocities of particles deposited by spraying (no more than 200 m/s).

The plasma applications of coatings in dynamic vacuum is more perfect. A plasma jet outflow occurs thereat into a vacuum chamber from which continuous pumping is proceeding. Installations of such a type are put on the market by some foreign firms. In particular, on the installation by the firm "Plasmadyne" (USA), the vacuum chamber pressure is maintained at the level of 10^4 Pa [2]. The method stated in this work is oriented to deposition by spraying at background pressures less by two and more orders. This gives the following advantages. By the outflow with such a low pressure the outflow character corresponds to the jet outflowing into vacuum, in so doing, shock-wave structure degenerates: barrel shock waves, Mach disk. Starting with a certain distance from the nozzle exit, a character of flowing past an obstacle subjected to the application by spraying becomes shockless, i.e., upstream of the obstacle there is no shock wave, characteristic of supersonic flowing past. Therefore, flying up particles do not experience deceleration, their collision with the obstacle occurs practically at velocities up to which they are accelerated in the nozzle and jet. Estimation reveals particles with the size of about 10 μm and less are accelerated up to the velocity of about 1 km/s and above. At these velocities at the initial stage of the application, a superdeep penetration of particles into the obstacle [3] and the formation of an adhesion layer with a high strength of bonds may take place.

Reduction in size of deposited particles can be achieved through two ways. The first consists in using fine raw powder of micron and submicron size. The other way, much more promising, implies synthesizing shallow particles in the plasma flux. This can be attained by either dispersion of raw coarse powder in the plasma generator channel or complete evaporation thereof in the channel with subsequent condensation in the nozzle and jet. Size of particles (clusters), thereby being generated, will change in the range from 10 to 1000 Å, subject to conditions of flow expansion, velocities – from 1 to 3 km/s. First particles, hitting a surface, apart from the effect of superdeep penetration, destroy also the oxide film at the sample surface with the formation of juvenile surface on it. Subsequent particles are capable of reacting with a sample substance, if their materials have chemical affinity for solid phase [4]. This results in an increase in the adhesion capability of coating.

For the maximum use of electric arc power, a special design of the d.c. plasma generator is used. It was developed at KeRC.

The carrying gas (being at the same time a plasma-generating gas) with the powder deposited by spraying passes through the whole plasma column, as distinct from widely-used constructions with individual inputs of the carrying gas with powder and plasma-generating gas. Technical parameters of the installation and its scheme are shown in the table and figure below.

The optimization of the plasma generator high-temperature section has resulted in the complete absence of deposition of sprayed material onto cathode and anode of the plasma generator which, in its turn, has allowed a sample to be applied with coating during the whole time required for the attainment of a due thickness of coating without stopping the plasma generator.

Table I. Technical characteristics of the installation

Electric power of plasma generator arc	up to 20 kW
Flow rate of plasma-generating gas	up to 5 g/s
Flow rate of powder materials	up to 2 g/s
Rate of the application of coatings	up to 10 μm/s
Plasma generator cooling	water
Pressure in vacuum chamber	less than 50 Pa
Material deposited by spraying:	metals including high-melting ones, oxides, carbides, powder mixtures

Consider some examples of using this technology.

For large-scale and mass productions (batches of a few tens and hundreds of thousands of uniform parts), the application of tools strengthened through the application of coating, in particular, drills, can provide the maximum efficiency. Cutting tools with a wear-resistant coating allow operation at higher velocities of cutting, which, in its turn, allows an essential rise of productivity.

Tests of drills with deposition by spraying were conducted in regimes with an increased cutting velocities (30 to 40 m/min which is higher than the normative, with a feed from 0.12 to 0.18 mm/min) at a semi-automatic machine of the "Wessermann" firm without using cooling liquid. As a material machined, structural carbon steel 45 was used. The tests conducted revealed the best compounding of powder is a mixture ($Ti+Cr_3C_2$). Coatings out of powders of steel P18, P12 and P6M5 have ensured raising durability of drills by a factor from 2 to 2.2. Measurement of a tangential component of the adhesion capability brought out the magnitude ~500 MPa on this coating, the Vickers microhardness of the coating at drills has attained the magnitude of about 2000 to 2500.

This technology was used in conjunction with the Khrunichev GK NPTs for the application of heat-radiating two-layer coatings (WC – the 1st layer, $TiC+Cr_3C_2$ – the 2nd layer) to one of outside components of the space station "Mir". This coating had increased the emissivity factor of the surface, ε, of the unit's outside component from 0.4 to 0.84. In the course of ground tests the coating has retained this value of ε and adhesion capability after heating of samples up to ~1500 K with a subsequent allowance for 3 minutes.

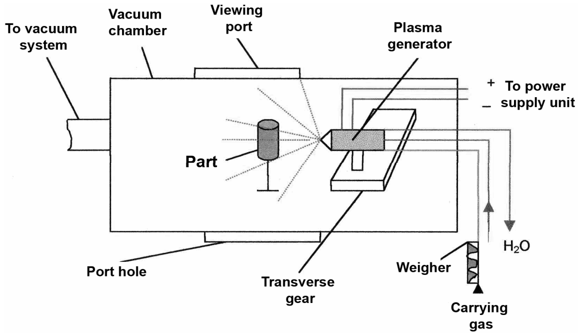

Fig. 1. The installation scheme

For an improvement of characteristics of shield-vacuum insulation the technology of the application of coating $ZrO_2 \cdot SiO_2$ to 20 μm thick. foil of molybdenum has been refined. The coating in itself has the thickness of about 18 to 20 μm. The coating out of a weakly heat-conductive matter was a so-called "gasket layer" between adjacent foil layers. Tests of the coating on the molybdenum foil, performed in vacuum chamber during ~6 hours, have revealed its operability at temperature of about 1500 K.

Conclusions

The technology for the application of plasma-cluster coatings, approbated with involving a wide range of materials applied to, including high-melting metals, oxides, carbides, has been developed.

Coatings applied with this technology have brought out a satisfactory serviceability in a variety of articles: cutting tools, heat-radiating and heat-insulating surfaces subjected to heavy heating.

References

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