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Application of high-speed gas-flame technology for hardening the surfaces of machines and robots of automatic gas-flame spraying

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The article discusses the main types of installations (HVOF / HVAF (High Velocity Oxy / Air-Fuel), the Russian analogue of which is HPS/SGV (gas-flame supersonic/supersonic gas-air, activated arc metallization ADM devices) and the use of high-speed gas-flame technology for surface hardening for machine parts. Here we considered all types of flame treatment (welding, oxyfuel cutting, brazing, surface hardening, flame straightening, metallization, welding and spraying of non-metals), the performance of various methods of thermal spraying (GTN), and also considered the properties, methods of production and use of gases used in flame processing, modern equipment and equipment for all considered processes. The main task of the coating obtained by the method of flame spraying is also considered. It is shown that the deposition of coatings by the method of high-speed gas-flame spraying and effective materials for protection is promising. In addition, safety precautions for gas-flame processing are considered. The state is analyzed that the abrasive wear resistance of steel is a structurally sensitive characteristic, therefore, an effective wear-resistant material must have the ability to harden under the influence of working loads, during operation, and from this, materials are effective materials for protection under abrasive wear; corresponding to the principle of metastable austenite. The characteristics of a heterophase jet obtained under optimal spraying modes are estimated on the basis of a calculation using a mathematical model of a two-phase flow.

Key words: thermal spraying, electroplating, flame technology, corrosion, robots of automatic gas – flame spraying.
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Introduction

The protective layer is applied by thermal spraying. The nanocoating provides significant advantages for the protection of contact devices for oil refining and chemistry, steam heater pipes and wear surfaces of pumping and compressor equipment [1].

About 20% of the equipment produced in the world is lost annually due to corrosion and wear. Usually both of these factors affect only certain areas of the surface of the parts. One of the most effective solutions to this problem is the creation of wear-resistant nanocoatings. Significant results have been achieved in extending the life of equipment through the application of nanocoatings in various industries [2].

Most of the methods used to strengthen anti-corrosion protection are prohibited for use in many countries due to strong carcinogenic factors. On the other hand, nanocoatings have made it possible to improve the ecological situation in many cities. Due to the use of this method, the number of works on repair and restoration of equipment has been significantly reduced, which significantly reduced air emissions [3]. The use of nanocoatings made it possible to reduce the cost of expensive materials, since it became possible to create parts with a smaller wall thickness or from cheaper raw materials. As a result, the economic efficiency of many enterprises has been increased.

The quality of HPS/SGW coatings, excluding oxides, is similar to the alternatives (detonation, plasma, cold gas-dynamic). The rapid development of these methods is due to high productivity and manufacturability, combined with a decrease in unit costs [2-4].

Materials and methods

In the last decade, a group of gas-flame high-speed powder coating methods has been rapidly developing, united, in English, by the terms HVOF/HVAF (High Velocity Oxy/Air-Fuel), the Russian analogue of which is GFS/SGV (gas-flame supersonic/supersonic gas-air) (Figure 1). This makes it possible to reduce the saturation of the sprayed particles with atmospheric gases while ensuring a high impulse pressure when the particles hit the surface of the base. As a result, the structure of the coating combines low porosity and oxidation state with high adhesive strength, 80 ... 150 MPa. GPS/SGV coatings are effective for protection against various influences [4, 10, 11]: Gate valves and ball valves in oil and gas processing are subject to intense wear at T> 600C. The erosion resistance of HPS coatings is 1.5 ... 2 times higher than that of similar detonation coatings. In the power engineering and aerospace industry, they are used to increase the resource of steam and gas turbine blades, during the repair of heat exchanger elements of thermal power plants. Replace electrolytic chromium (aircraft landing gear, printing equipment).

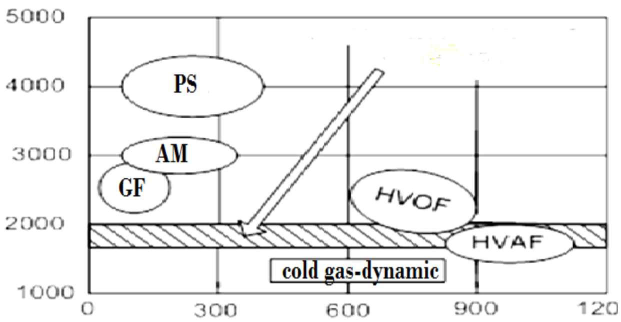


Figure 1 – Comparative characteristics of the methods of thermal spraying in terms of temperature and particle velocity. Types of spraying: GP – flame, EM – arc metallization, PN – plasma, CGN – cold gas-dynamic. [4]

At the same time, the processing purity is the same, the wear resistance is increased and the costs for ensuring the environmental friendliness of production are reduced.

Analysis of the published materials of the manufacturers showed the presence of several types of equipment, differing in the gases used, cooling methods, powder feeding and productivity. In GPS units, oxygen is used as an oxidizing agent. Basic GPS models are JP-5000/8000 (Tafa-Praxair, USA), DJ 2600/2700 (Sulzer Metco, USA), CJS (Thermico, Germany). There is also equipment from other manufacturers, which is similar in design schemes, but with patented design differences. So, analogs of JP-8000 are WokaStar (Sulzer Metco, USA) and K2 (GTV, Germany). In metallurgy, they are used to protect against contact loads, corrosive environments and high temperatures. Several hundred GPS / SGW installations are currently in use abroad. More than a dozen GPS / SGV systems are serially produced; a number of companies are represented on the Russian market – Sabaros, TZSP, the Ural Institute of Welding. JP-8000 has improved control system compared to JP-5000. [7-8]

Quasar M3 has made design changes in comparison with Intelli-Jet, which allowed to improve the output parameters. All installations are stable in operation, equipped with remote computerized control units and comply with electrical and fire safety requirements. They differ in the types of gases and powders used, as well as in the schemes of their supply.

In the JP-5000/8000 and Diamond Jet Hybrid (DJ2600 / 2700), oxygen and combustible gas are fed into the combustion chamber. The differences are in the design of the powder supply, the gas mixing scheme and the type of combustible gas. For JP-5000 it is kerosene, for DJ it is propane, propylene, ethylene (DJ2700) or hydrogen (DJ2600). These systems provide for water cooling, and in DJ installations, heat-loaded units are additionally cooled with air. Intensive heat transfer to the walls of the nozzle and barrel during water cooling causes high energy losses of the jet of combustion products. This forces a reduction in productivity to maintain quality levels. [5-7]

Results and discussion

Performance of various methods of gas turbine pumping is given in Figure 2. Spraying metals [1-4], where spraying types are marked as: DM – arc; HGN – cold gas-dynamic; GP – gas flame; PN, PDV – plasma methods (typical, in a dynamic vacuum); GPS – gas-flame supersonic; SGV – supersonic air-gas; DN – detonation. In metallurgy, they are used to protect against contact loads, corrosive environments and high temperatures.

Several hundred GPS / SGW installations are currently in use abroad. More than a dozen FPS/SGV-systems are serially produced, and companies such as Sabaros, TZSP, and the Ural Institute of Welding are represented on the Russian market [6-8].

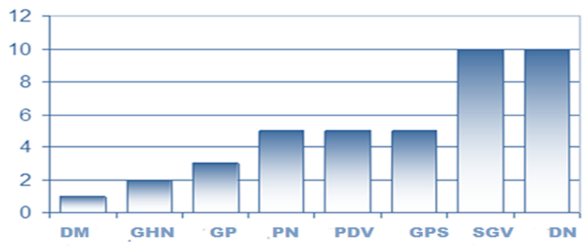


Figure 2 – Productivity of various methods of gas turbine pumping. Spraying metals [1-4].

However, the quality (porosity, oxidation state) and CMM of coatings obtained with a typical DM are insufficient to ensure the stable performance of parts. This has hindered the expansion of the use of this simple and cheap coating method. On the basis of modeling the DM process, equipment and technologies of activated arc metallization (ADM) have been developed and introduced into production [7].

The distinctive features of ADM include the joint use of the combustion products of reducing mixtures as a carrier gas, a certain mutual arrangement of nozzles and electrodes, a targeted effect on the arc burning zone (Figure 3).

Figure 3 – Spraying with an ADM apparatus.

For ADM devices, the spray angle is reduced to 10 degrees, the material utilization rate reaches 85%, the particle velocity is 140 ... 500 m/s, the oxidation state of the steel coating is 2.1 ... 2.9%, and the porosity is 2%. On average, the level of parameters is 40% higher in comparison with both domestic and foreign DM-installations [6 – 8] (see Figure 4). At the same time, the productivity and thermal efficiency of the process remained at the DM level. The results of industrial tests have shown that for a large group of coatings the quality of metal wear-resistant and anticorrosive ADM coatings is of the same level as plasma coatings. The costs of organizing the ADM-restoration section of parts on average pay off within six months, as experience has shown [8-11].

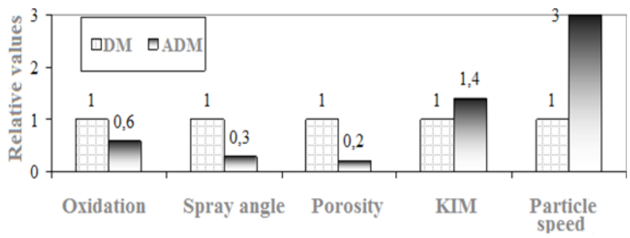


Figure 4 – Comparison of the parameters of the DM and ADM.

ADM allows to apply coatings of steel, bronze, zinc, aluminum, nichrome with a capacity of up to 18 kg/h. For the application of wear-resistant coatings by metallization, an economical alloyed flux-cored wire of the Fe-C-Cr-Ti-Al alloying system, grade PPM-6, of a number of modifications was specially developed [9-13].

Theory of basic gas-flame powder spraying processes

Gas temperature and velocity equations. Proceeding from the assumption of one-sided interaction of a particle and a gas jet, the calculation of the particle dynamics should begin with the determination of the gas dynamics and temperature fields of the gas jet.

At the initial section of the jet, the velocity and temperature of the gas flow can be considered constant [13]. Further, in the transitional and main sections, the values of the temperature and gas velocity begin to change sharply due to the intense interaction with the surrounding air. The considered dependences of the velocity and temperature of the gas flow behind the nozzle exit can be described with sufficient accuracy for this calculation by the following empirical relations [14, 15]:

$$\frac{v}{v_0} = 1 - \exp\frac{\alpha}{1 - x/Lis}, \qquad (1)$$

$$\frac{T - Tdt}{T_0 - Tdt} = 1 - \exp\frac{\beta}{1 - x/Lis} \qquad (2)$$

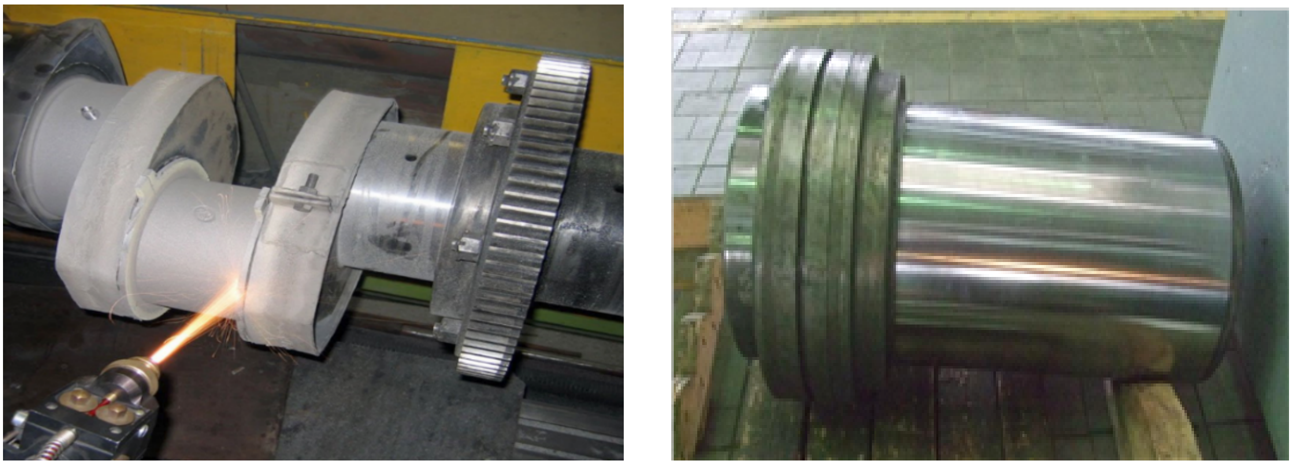
where x is the distance along the jet axis from the nozzle exit; a and ß are experimental coefficients (in these calculations, we can take α , β [7]); Lnu is the length of the initial section of the gas jet, is a function of the Mach number for the gas flow at the nozzle exit (MO) and the nozzle diameter (D)

The equations describing the acceleration of an individual particle in a two-phase flow have the form [14-15]:

$$mp\frac{dv}{dt} = \frac{1}{2}C_D pgAp(v_g - v_p)|v_g - v_p| \quad (3)$$

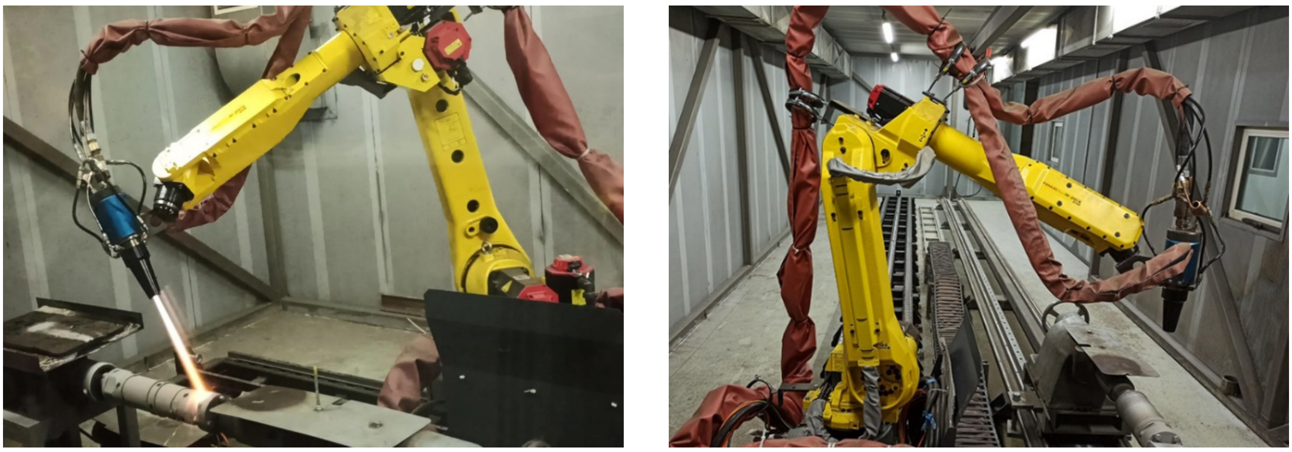
Results

The microhardness of the coating is 500 – 700 HV100, which ensures its wear resistance in case of abrasive wear from 1.5 to 2 times higher than that of a 20X13 solid wire. At the same time, the adhesion strength according to the cut method is higher than that of nichrome by 10 – 15%, and 3 times in comparison with 08G2S. ADM-process combines high productivity of 2-5 times higher, low unit costs from 4 to 10 times lower, as well as with protection against wear and atmospheric corrosion, the quality of coatings of the same level, in comparison with other methods of thermal spraying (plasma, HPS / SGV) (see Figure 5) [14].



a) b)

Figure 5 – Typical examples of ADM-spraying: a) crankshaft;
b) the piston rod of the hydraulic cylinder of the press, L 1090 mm, diameter 657 mm.



a) b)

Figure 6 – Robot for automatic flame spraying.
Equipment for high-speed spraying PLAKART HV-2 [9-16].

The main task of the coating obtained by the method of flame spraying is corrosion resistance when working in aggressive environments, including in environments with abrasive properties. HV-2 is one of the best universal high-speed HVOF flame spraying equipment in the world (shown in Figure 6). The flow rate at the outlet from the nozzle of the installation is 7-9 times the speed of sound. Due to the possibility of obtaining repeatable coatings with porosity from 0.5% and adhesion> 80 MPA, the supersonic spraying unit is widely used for solving problems of production optimization, replacing galvanic chromium plating, nickel plating, detonation, vacuum and ion-plasma spraying. The modular design and easy layout make this HVOF kerosene-oxygen liquid fuel plant quick to learn and use [16].

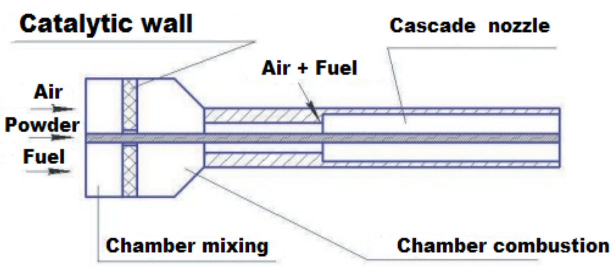


Figure 7 – Scheme of the spraying process.

All software and documentation are in Russian. More than 50 installations are successfully operating in the world. Using a robot, a mixture of compressed air and combustible gas (propane, propylene, MAF) is burned in the combustion chamber of the burner, and the atomized powder is fed axially through it. In a jet, particles of the sprayed material accelerate to 800 m / s without heating above the melting point [11-19]. General scheme of the spraying process is shown in Figure 7 below.

To reduce energy losses, the high-speed jet of combustion products is additionally heated by the combustion products of the secondary air-combustible gas mixture in a cascade nozzle. Compressed air is also used to cool heat-loaded elements [3-21].

Conclusions

1. In developed countries, there is a rapid growth in the application of the process of gas-flame supersonic spraying of coatings (FPS / SGV) as applied to parts operating under the influence of shock-abrasive and chemically active media, high thermal loads.

2. GPS / SGV successfully competes with plasma in a dynamic vacuum, detonation spraying methods in terms of coating quality and productivity. The section for thermal spraying is equipped with an American high-speed flame spraying installation. The device can work both in manual and mechanized mode and using a robot.

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