GENERAL METHODOLOGY OF WORKING WITH HVOF INTEGRATED TECHNOLOGICAL SYSTEM

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Abstract: *Article "General methodology of working with HVOF integrated technological system" aims to present some information about the thermal spraying process and all major stages of working with the integrated technological system for thermal spraying, created in the SC ICTCM - Mechanical Engineering and Research Institute, both in the case of metallic coatings for new pieces and general methodology for working with this system*

Keywords*: HVOF installation, integrated technological system, thermal spraying process, spraying parameters, process structure of thermal spraying*

1. Introduction

In S.C. ICTCM – Mechanical Engineering and Research Institute - SA by project no. 614 SMIS code/NSRF: 12537 "Applied researches, technology and technological equipment for high strength thermal spraying by HVOF process used in industrial and medical applications", co-funded by the Regional Development European Fund, under the contract financing 270/ 27.10.2010, in the Operational Programme " Increasing Economic Competitiveness " (SOP IEC), Priority Axis 2 Research, Technological Development and Innovation, Operation 2.1.2- „High scientific level R&D Projects attended by specialists from abroad" with the participation of foreign experts was conducted an integrated technology system for thermal spraying by HVOF

2. HVOF thermal spraying process.

Thermal spraying consists of a group of processes for making thin layers in which fine powders, metal or non-metal, is deposited in the molten state to form a coating layer with properties required of the of the applicability field. The process consists in continuously introducing a mixture of metallic powder and the axial high pressure gas in a combustion chamber. Thus, in the combustion chamber, result a high pressure to the combustion of the mixture of the flue gas – oxygen and especially through the expansion in the combustion nozzle located at the output, resulting a high-speed gas jet. As a result, the metal powder particles are accelerated to very high speeds which leads to layers of particles deposited with high density and very good adhesion.
Characteristics of the HVOF thermal spraying process are briefly the following:

- energy source is the gaseous oxygen and the fuel gas is ethylene, propylene or propane, and the liquid is kerosene;
- flame has the temperature of up to 2700 C and speeds up to 1600 m/s;
- the deposited material is powder with particle size of 5-45 μm;
- type of powder for deposition: generally are carbides with matrix of metal alloys
- speed of particles during deposition: 400-800 m/s;
- spray distance: 150 – 300 mm;

The features of layers deposited by HVOF process include superior characteristics to those deposited by other processes thermal deposition. They are:

- high density: normally are obtained porosities lower than 2% and in special conditions, porosity of 0.2%;

- high degree of adhesion to the base material; e.g. typical deposition of carbides such as the HVOF have the adhesion over 82 MPa, and the materials deposited by this process have significantly higher adhesion values than the same materials deposited by other thermal deposition methods in the atmosphere, such as plasma deposition;
- high hardness; e.g. a carbide with wolfram and cobalt, with 12% wolfram has typical microhardness 1100 ... 1350 DHP300;
- good fatigue resistance; depending on the chemical composition, the low temperatures of the deposited material by HVOF may produce coatings with good wearing resistance with excellent resistance to impact;
- greater thickness of layer; HVOF coatings have the thickness of coated layer greater than plasma coatings, by combustion or by wire to the same material, due to the effect of flattening the previously deposited layer by increased particle impact at high speed; thus, the thickness of layers of wolfram carbides can be up to 6.4 mm;
- excellent wear resistance; HVOF deposition are resistant to the wear caused by sliding friction, friction, erosion or cavitation depending on the material and the parameters of selected process;
- superior corrosion resistance; high density and metallurgical properties of layers deposited by HVOF confer resistance to corrosion effects, including hot corrosion, oxidation and corrosion of acid and alkaline environments;
- very good finishing of the covered surface; HVOF coated surfaces are smooth and can be used as such in many applications, can also be machined, grinding, lapping, honing or super-finished to applications that require precise tolerances and very good surface quality.

3. The general structure of a HVOF coating technological process

In general, a metal coating is in one of two situations: applied in the mass production for new parts or used in the reconditioning process of existing parts.
In the first case all necessary technological parameters are known to meet the technical requirements of respective pieces, the carried activities being only those of process control.
If it is necessary the development of a new application, in which are known only to the quality requirements of the future piece are needed research/development activities on both materials that can be used to cover and parameters of the technological process used. This is the case of this project, in which is necessary to conduct researches to achieve coatings by HVOF process to meet the requirements of each application separately.
In *figure 3.1* is presented the methodology of research/development of new metallization applications, valid for HVOF process.
In general, the structure of a thermal coating technology process through HVOF process (High Velocity Oxygen Fuel) is:

• Prepare surfaces for coating; techniques commonly used for this are the following:
  - cleaning the surface;
  - formation of the substrate;
  - activating the surface;
  - masking.

• HVOF deposition of the material layer on the support material;

• Apply treatments/technological operations after depositing material layer; techniques commonly used for this are the following:
  - thermal treatment, which can be:
    - electro-magnetic treatment;
    - treatment in an oven;
    - hot isostatic pressing (HIP);
    - remelting with flame;
  - impregnation, which can be:
    - coating of the surface/seal with organic substances;
    - coating of the surface/seal with inorganic substances;

- finishing, which can be:
    - grinding;
    - polishing and lapping;

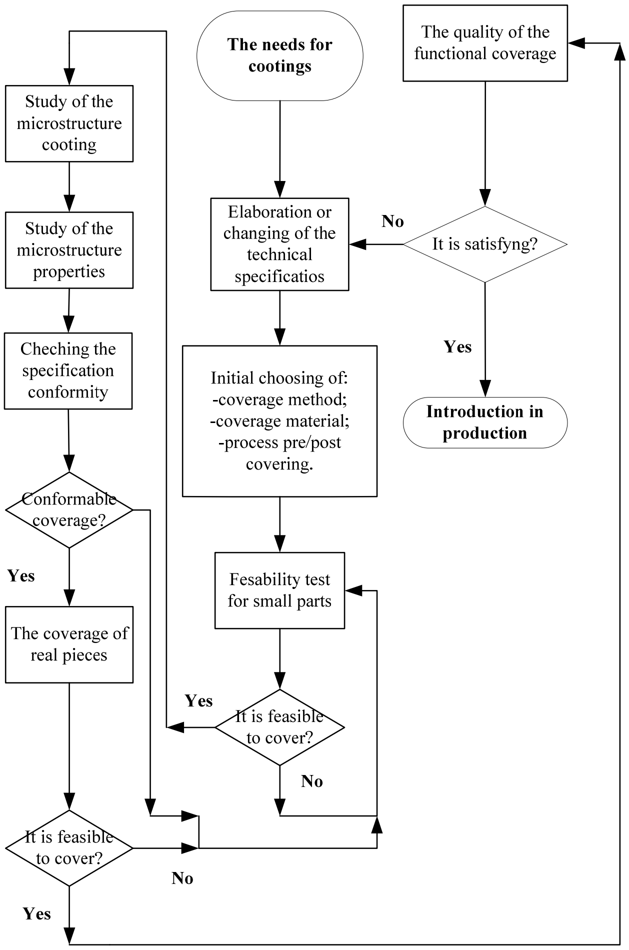

Fig. 3.1 – Methodology for the elaboration of new coatings

4. General Methodology of working with the HVOF technological integrated system

In the HVOF technological process one of the most important steps is cleaning the workpiece surface to remove impurities such as rust, paint residues. This step is performed using a blasting booth. Blasting is the process of cleaning or finishing through blowing abrasive of metal surfaces. One of the materials used to blasted is corundum, which is blown by means of a jet compressed air. Corundum is a mineral classified as hardness 9, second after diamond on the Mohs scale, because the Moissanite mineral with hardness 9.25 (very rare in nature) is not considered. From the point of view of the chemical composition is an aluminum oxide with the formula Al_2O_3. Color is very varied depending on the existing impurities in the crystal.
The steps of the blasting operation are the following:
- is started the compressor's dryer and is waiting until the indicator reaches on green zone of the scale;
- is adjusted the compressor's working pressure from 6 to 7 bars;
- is started the compressor and is waiting until the operating pressure is reached in the compressed air system;
- is supplied the blasting booth with air and is adjusted the working pressure at 6 bar from the resident air regulator;
- is started the blasting booth, the pieces to be blasted are putted in the cabin, is pushed the compressed air filling pedal and is blowed the corundum over the pieces surfaces until they become cleaned;

- are visually inspected the blasted pieces and is measured the surface's roughness;
- if the blasted surface quality is adequate, the air supply is interrupted and blasting booth is stopped;

After preparing the pieces through the blasting process, the thermal spraying process is achieved by the HVOF process.
For this, perform the following operations:

- pieces for spraying are fixed in clamping brackets mounted in handling devices for pieces with horizontal shaft (type lathe - between centering peaks mounted in the universal headstock and in tailstock) and vertical (rotary table – with clamps on the plateau with T channels);
- is started the electrical installation for driving the manipulation devices, is switching on the type of device used and is started adjusting the corresponding speed to the type of HVOF coverage; is checked the centering of the fixed pieces in the handling device in question; if the operation is properly is stoped the handling devices;
- is established on the mobile console of the robot FANUC (teach pendant) the moving program properly for sprayed pieces, including movement speed and number of passes properly for thickness layer which will provide, and spray distance specified; is checked the program in operation mode T1 and AUTO (closes the spray booth door which will be locks by the safety module "open door");
- is started the PLC control cabinet;
- is started the feeding/dosing powder system and are filled the two cans of the system with adequate powder properly for cover, in equal amounts (weighed with a precision analytical balance) depending on the specific consumption/min (tested depending on the speeds dosage discs from prescription of spray);
- is started the pistol cooling system, is checked the level and is adjusted the temperature of the cooling water; are opened the water valves flow/return;
- are opened the cylinders of oxygen and nitrogen:
    - is adjusts the working pressure 20 bar on the oxygen supply system regulator
    - is adjusts the working pressure 6 bar on the nitrogen supply system regulator
- is ensured sufficient kerosene in the recipient;
- is adjusted to 6 bar pressure for the compressed air used for cooling sprayed parts from the air regulator found in the gas control cabinet.

After all the above steps have been performed, can be started the HVOF operators console command:

- is unlocked the emergency stop button on the front panel of the console;
- is inserted the key and turn the power switch on the control panel to the ON position and is waiting for the computer to start the process and to display the startup menu display command console;
- the red button "fault" for errors on display will flash warning that there are some errors;
- is setting the program language (ie English), and are admitted errors using the touchscreen "acknowledge".
- are checking on the display the parameters of the cooling gun system, supply kerosene, supply oxygen, nitrogen, compressed air and possible gas leaks and kerosene;
- are established the technological parameters of the specific spray recipe: the pressure and the flow rate of oxygen, nitrogen, kerosene, type of powder used, feeding/dosing powder system's speed; the spray recipe is saved with a specific name;
- is pressed the button „Power On";
- is closed the spray booth door and press the button "Door locked"; lights the lamp "Door locked" and the door is locked by the user's safety system module;
- is pressed the button "User safety" and if module safety system is activated, will light the indicator "Customer safety";
- is started the emissions filter system from the button with three positions on its switchboard (1 emissions filtration installation + inside air introduction system, 2 emissions filtration installation, 3-OFF;
- is started from the specific menu, the compressed air supply of pieces' cooling nozzle;
- is pressed the button "Ignition" and is primed the flame of the spray gun;

- is checked the priming mode (no failures), color (should be blue), focus and continuity of the flame (flame must be continuous without interruption);
- is pressed the button "Powder Start" then the button "START" and the jet is primed and is checking the focus (jet must be focused and otherwise modify the flow of nitrogen from two feed powder) and its continuity (jet must be continuous without interruption);
- is started appropriately handling device and adjust the speed required;
- is started the robot program in operation mode AUTO;
- after spraying is pressed the button "Stop Powder", "STOP";
- is waiting about 15 min for cooling pieces then is stopped the feeding of cooling nozzles and emissions filtration system;
- is stopped the device for handling pieces, from the electrical installation of drive devices;
- is pressed the button "Door unlocked" and can enter in the spray booth;
- is rotated the key in the power switch on the control panel to the OFF position;
- are removed the pieces from the handling device and are controlled the parameters of the sprayed layer: thickness, hardness, adhesion, porosity, metallographic structure.

5. Methods of characterization and control of HVOF deposited layer

In general the HVOF deposited layers are characterized by strong links with the base and a good quality and porosity of the surface. Thus, for wolfram carbide can be achieved resistances to separation of 90 MPa with porosity of less than 1%.
The characterization of deposited layers by metal coatings is important for: research/development activities for a new product or quality control in production. The easiest way to control the quality of the surface is a careful visual observation of it. Such a method allows the detection of defects such as incomplete coverage of the entire surface or superficial cracks.
More advanced methods for the surface investigation are those of analysis of the microstructures that are made by scanning electron microscopy (SEM), X-ray diffraction (XRD), electron microscopy by transmission (TEM), porosimetry by inclusion of mercury (MIP) or other techniques.
The properties of the metal coating cause its behavior during use. The best test is done under conditions that simulate actual conditions of use of the piece. The mechanical properties such as microhardness, tensile strength and modulus of elasticity, wear-resistance are often determined.
Thermophysical properties and in particular the thermal conductivity, usually determined by measuring the expansion to 300 K, specific heat and diffusivity are frequently tested. These tests are frequently accompanied by tests of resistance to thermal shock. Magnetic and electrical properties of the coating are frequently tested. Non-destructive tests such as the use of thermal or acoustic waves have been introduced to characterize the quality of the coating. Finally many properties are closely interlinked so it is possible to measure a property by determining another.
An example for determining of a property by another's measuring is correlation between anisotropy of NiCr coatings, electrical conductivity and modulus of elasticity. These properties interlinked helps to reduce the number of tests required.
The methods for characterization of metal coatings are the following:

1) Methods for characterization of the microstructure: chemical analysis; crystallographic analysis; analyzes of the microstructure;
2) Methods for characterization of mechanical properties: determination of the adhesion; determination of the hardness and microhardness; determination the modulus of elasticity, friction resistance, ductility; properties related to fracture mechanics of the metal coatings; determination of the resistance to friction and wear; determination of residual stresses;
3) Methods for characterization of physical properties: determining the thickness, porosity and density; determining thermophysical properties; determining resistance to thermal shock;
4) Methods for characterization of electrical properties: determination of electrical conductivity; determination of dielectrics properties; determination of electron emission from surfaces; determination of wet corrosion; determining gaseous corrosion (hot gas);
5) Methods for characterization the quality of the metal coatings: acoustic methods; thermal methods.

6. Hydraulic and pneumatic applications

HVOF process has extensive applications in highly various domains, but it is important to specify the particular applicability of the HVOF deposition both in the domains of the hydraulic components and the pneumatic. Special properties required by the environment and operating conditions are ensured by HVOF process for the components of hydraulic or pneumatic cylinders, valves, pumps, taps and other hydraulic/pneumatic components which can equip building machinery, forestry machinery, agricultural machinery, equipment and industrial installations etc.
In the case of a hydraulic or pneumatic cylinder, there are surfaces that can be deposited in different ways to obtain the functional properties of the cylinder - deposits can be specific for rod or pipe, or piston, or cap but their combination and the final result provide getting a high quality product with very good durability, extremely reliable in operation.
The HVOF depositions give them specific properties both at the manufacturing stage, as new product, but and as reconditioning able to provide at least the initial quality of the remanufactured parts. Increased service life, is a considerable advantage but and the providing of special tribological properties, or adherence or porosity and wear resistance are equally important.
Finally, an important aspect is the opportunity to research obtaining of a specific deposition, a specific requirement, or a plurality of requests, the process can be optimized.

7. Conclusions

By the project "Applied researches, technology and technological equipment for high strength thermal spraying by HVOF process used in industrial and medical applications", was developed a technological system - prototype - technological equipment and laboratory equipments - which allows performing of the applied researches to achieve high mechanical strength metal coatings, thermal, anticorrosive on materials used industrial or medical applications using HVOF process (High Velocity Oxygen Fuel). Also the conditions of market access were created for the new technological system by conducting theoretical and applied researches of the optimal technological parameters for solving practical requirements of industry and the production of medical equipment.
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