STUDIES ON THE APPLICABILITY OF THE HIGH VELOCITY THERMAL SPRAY USED IN THE AUTOMOTIVE INDUSTRY

D. PETRE[1] R. IOVANAŞ[1] A. PASCU[1]

Abstract: *The thermal spray is a domain connected to the welding process that obtains layers with special properties by using ferrous and non-ferrous add-on materials or ceramic ones, polymers, composites and others. Depending on the selected material, the obtained layers gain several types of resistance, such as: resistance to abrasion, corrosion, thermal shocks, electric and thermal insulator. This paper analyses the different aspects of the high-velocity thermal spray such as High Velocity Oxygen Fuel, High Velocity Air Fuel and Cold Spray, with their advantages and drawbacks, both from a technical and financial point of view. We will discuss their applicability in the automotive industry for producing new high-quality prices or for reconditioning weathered surfaces.*

Key words: *HVOF, HVAF, cold spray, automotive.*

1. Introduction

Thermal spray was invented in Switzerland by Ultich Schoop in 1910, when for the first time, he managed to decant melted metal in atomized state by using the oxy-acetylene flame as heat source, and the compressed air as atomization agent.

The procedure was created due to two requirements:

- covering the parts that are highly demanded with add-on materials that are not compatible with the welding procedure;
- covering the thin pieces or those with a small diameter.

Lately, the thermal spray has underwent a great deal of progress, and has found applicability in almost all industrial domains such as aviation, navy, extracting industry, automotive and chemical industry, everywhere where the layers with special properties are needed.

The main thermal spray processes are: thermal spray with low-speed flame, high-speed thermal spray, through plasma, laser, induction, cold spray or detonation spray, where the add-on materials can be either powder or wire.

2. High Velocity Oxygen Fuel (HVOF)

High Velocity Oxygen Fuel is a procedure where the thermal energy has low values and where the kinetic energy is far more superior to the classic spray procedures.

The principle on which the procedure HVOF works is presented in Figure 1.

The pioneer of these installations was JET KOTE. The international adopted name for this type of procedure is the generic term of HVOF (high velocity oxy-fuel).

During this process, the combustion gas

[1] Dept. of Materials Engineering and Welding, *Transilvania* University of Braşov.

is mixed with the oxygen in a combustion chamber, where the burning of the two produces a pressure over 10 bar.

Due to this pressure, the flame speed reaches more than 600 m/sec. Powder may be fed axially into the HVOF combustion chamber under high pressure or fed through the side of naval type nozzle where the pressure is lower. Another method uses a simpler system of a high pressure combustion nozzle and air cap. Fuel gas (propane, propylene or hydrogen) and oxygen are supplied at high pressure, combustion occurs outside the nozzle but within an air cap supplied with compressed air. The compressed air pinches and accelerates the flame and acts as a coolant for the gun. HVOF spraying is now well established and a number of systems are commercially available including the JP5000 from Praxair Surface Technologies, the Diamond Jet Hybrid from Sulzer Metco and the Met Jet II from Metallization Ltd.

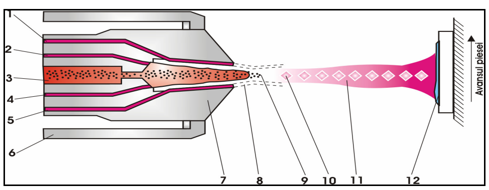

Fig. 1. *The working principle of the HVOF procedure: 1,5 - compressed air; 2,4 - oxygen; 3 - powder and nitrogen carrier gas; 6 - torch body; 7 - laval nozzle; 8 - compressed air jet; 9 - powder; 10 - shock diamonds; 11 - melted powder jet; 12 - deposited material*

The sprayed coatings have a low porosity, high density and a good adherence to the surface of the support metal. The materials suitable for this procedure can have a high melting point (ceramics, refractory materials, tungsten carbides, chrome oxides and others).

The HVOF procedure is easily adaptable with excellent results: weathering resistance, anti-corrosive protection, thermal and electric isolation.

Due to the high kinetic energy of the particles, it is not necessary for them to be totally melted in order to form high-quality layers, which represents an important advantage especially for carbide cermet.

The advantages of the HVOF procedure:

- produces layers with low porosity, high density and homogeneous structure;
- low residual tensions in the decanted layers;
- recommended for carbide cermet, compared to the classic systems;
- it allows decanting thick layers;
- low roughness of the obtained surfaces;
- excellent for wear and corrosion resistance;
- enables Coating of complex geometries;
- the process can be fully automatized.

HVOF disadvantages:

- lower temperature than plasma spray. There are certain materials that are more suitable to the plasma spray;
- the use of pure oxygen requires special protection measures;
- more complex installation than the ones used for the classic spray.

3. High Velocity Air Spray (HVAF)

The principle on which the HVAF system is based is very similar to the one used by the HVOF system, where unlike using the oxygen it uses compressed air. The add-on material is represented by powder or wire.

The HVAF system based on powder is used for the same application as the HVOF. Still there are equipments with a higher productivity than the HVOF ones, and when using the carbides, due to the lower working temperature the resulted layers have a higher density without thickness limitation (Figure 2) [4].

The powder HVAF procedure uses combustion gas and compressed air for projecting the powder with supersonic speeds.

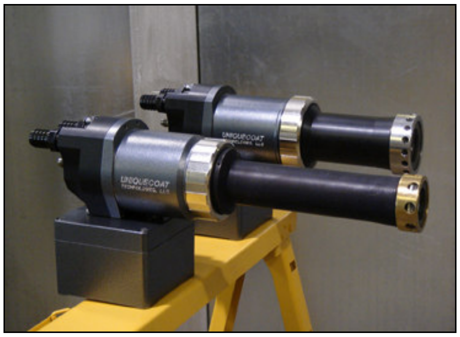

Fig. 2. *HVAF with powder*

The particles reach a speed over 800 m/sec, while remaining under their melting point. And because the melting limit is not reached, the carbides are neither destroyed, nor suffer dissolution in the metallic binder. In HVAF with electric arc and wire, the wire is melted by operating an electric arc and a supersonic flow of combustion air (propane, propylene, GPL) for atomizing the melted metal and speed up the resulted fine particles.

The torch head contains a toroidal combustion chamber with a ceramic catalytic insertion for controlling the burning process where the propylene is burnt. The burning gases form a supersonic oxygen-free flow (that does not oxidize the melted metal) that is positioned in the direction of the electric arc (Figure 3 and 4) [3]. The melted metal, resulted in the electric spring and formed between the two wired is atomized and accelerated to an undercoating (piece) where it's decanted and by quick cooling it forms the cover.

HVAF advantages:

- it does not require pure oxygen;
- long terms between the service works;
- obtaining high-quality carbide coatings;
- lower oxidation of the decanted material, compared to the HVOF system.

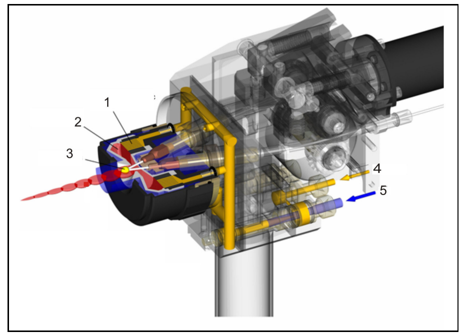

Fig. 3. *HVAF Gun: 1 - catalytic ceramic insert; 2 - combustion chamber; 3 - electric arc; 4 - fuel gas; 5 - compressed air*

HVAF disadvantages:

- it requires the use of a large sized air compressor - minimum 10 m^3/min;
- the producers of these equipments are rather smaller companies;
- it requires using fine powders, ~30 micron in order to obtain over 45% efficient decanting.

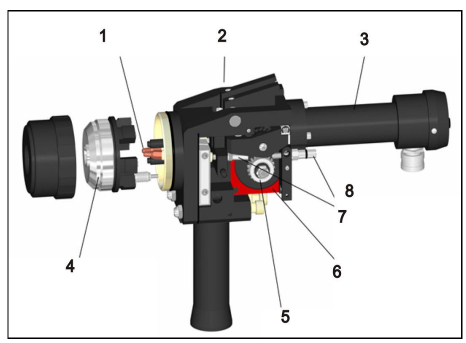

Fig. 4. *HVAF Gun: 1 - copper electrode; 2 - composite frame; 3 - handle; 4 - combustion chamber; 5, 6 - rolls for wire feeding; 7, 8 - wire guides*

4. Cold Spray (Kinetic Spray)

The cold spray represents the next step in developing the coating processes that use high kinetic energy (the development of high kinetic energy coating processes). Dr Anatolli Papyrin from the board of the Russian Academy of Sciences was the first who demonstrated the cold spray process in the middle of the '80 s. The principle is similar to other thermal sprays, by increasing the speed of the particle and lowering the temperature, - similar to the HVOF/HVAF procedures - but on such a high level that the question rises whether it should still be called thermal spray.

The process is based on the energy deposited in compressed gas which is supposed to project the particles at a speed of over 1500 m/sec (Figure 5). The procedure is still limited, allowing only ductile materials to be used, such as aluminum, stainless steel, copper.

The advantages of the cold spray:

- low temperature of the process;
- no phase changing take place in the sprayed metal;
- very low oxidation;
- it does not require combustion gases or other electric equipment for extreme heating;
- the low caloric supplement transferred to the piece reduces the cooling requirements.

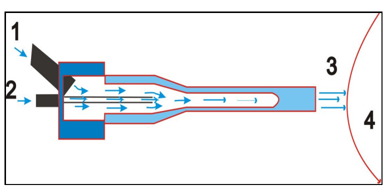

Fig. 5. *Cold Spray Gun: 1 - gas supply; 2 - powder supply; 3 - supersonic gas and powder flow; 4 - piece to be sprayed*

The disadvantages of the cold spray:

- large use and debit of gas;
- helium is an expensive gas;
- its a new and less tested procedure;
- the carbides cannot be powdered by using this procedure.

At the moment there are rather few commercial applications of this procedure, but due to the quality of the decanted coatings, they are of great technological interest.

Applications of the high-velocity thermal spray in the automotive industry:

- **Linear bearings.** By using HVOF spraying with atomized metal alloy powders, it is possible to deposit bearing alloys as coatings on a steel backing and obtain ultra-fine micro structures with a more homogeneous distribution of the soft phase than is possible by casting and roll bonding.

Thanks to the high-velocity spray particle and the good control of particle heating, the coatings are provided with the necessary required low levels of porosity and oxide, whilst maintaining the composition of the original sprayed powder. These alloys have been deposited using HVOF systems of different design and atomized powders with a range of particle sizes. The optimized coatings are very dense with porosity measured well below 1 vol% and oxide levels of about 1 wt% or less [2].

- **Hard chrome plating.** HVOF and HVAF represent an alternative to the hard chrome plating on pistons and valves.

Automotive manufacturers have specified chrome plating for decades because of its appearance, wear and corrosion resistance; however chrome plating affects human health due to the use of substances in the galvanic process, whose toxicological features have not always been recognized. Historically the challenge of piston ring coating development was much simpler: "Produce a material which would stay on the ring and not wear out, while not also wearing the bore". Now with corrosion concern added to the mix, things become much more difficult because some properties which retard one problem actually promote another. MAHLE has recently introduced the High Velocity Oxygen Fuel "HVOF" process to its piston ring manufacturing capabilities. The coating (applied to the running face of the rings) is a ceramic-metal coating based on chromium carbides and a nickel alloy [5]. The HVOF process produces particles with very high kinetic energy leading to dense and compact coatings.

Hard chrome plating is not easy to replace, since it is a very simple technology that is widely available, very versatile and up to the present moment it remained a relatively inexpensive alternative.

However, many modern coatings can now be used instead of chrome plating, and most of them with visible better results (higher reliability, greater hardness, less wear).

- **Hydraulic pistons.** The new pieces can be metallised in order to increase the quality of the surface material. The thermal spray represents the suitable solution for reconditioning the worn pieces with a low budget.

- **Cylinder Rods Rolls, Rods, Plungers and Shafts.** Many rolls, rods, plungers and shafts are coated for a variety of reasons. Many rod and shaft manufactures have realized that using a thermal spray coating eliminates the need for heat treating, where heat treating was used to provide wear resistance by hardening the surface. Thermal spray coatings commonly provide much better wear resistance than heat treatments.

- **Brake discs.** Iron brake discs are used in the vehicle production due to their high endurance, resistance and good performance. Aluminum metal matrix composite plates were developed to give similar strength characteristics to cast iron, however they do not provide the wear resistance at the surface and also require thermal protection from the heat generated by the braking action.

The aluminum oxide coated discs are approximately half the weight of cast iron and offer improved fuel economy, better acceleration, exceptional wear resistance, a high coefficient of friction, improved braking performance, and unlike carbon/ carbon plates, they function just as well in humid conditions.

- **Diesel engine.** Fuel Injector Nozzles: Corrosive products (sulphuric acid), from the combustion of the diesel fuel, condense on the nozzle and attacks the base metal, impairing function and reducing the lifetime of the component. A plasma sprayed Molybdenum based coating is applied on the nozzle surface to provide protection against these aggressive condensates.

- **Synchronizer, clutch plates** for drive away elements, limited slip differentials can be thermal sprayed.

- Shifter fork. The refurbished part has the same performance as a new one, at a fraction of the cost of a replacement.

- **Crankshafts.** The worn parts of the crankshafts can be reconditioned.

- **Turbochargers.** Initially derived from aerospace, abradable coatings give excellent clearance control resulting in improved efficiency and performance. The thermal barrier coating system (TBC) is the standard technology for aircraft engine turbine blades and combustors [1] and can be applied in auto industry for automotive turbines.

- **Bearing areas.** By thermal spraying it can be repaired damaged surface to outlast replacement parts at a fraction of the cost of a new piece.

- Heavy duty diesel Valves. Heavy duty diesel engines suffer from high levels of erosion and wear. This is due to a combination of causes such as high combustion temperatures, poor quality fuel and the variable heavy loads the engines are subjected to. Heavy duty diesel engines such as those used in locomotives, marine and earth moving equipment are increasing their use of functional coatings to improve performance and reliability.

- Electronic & Electrical. As most thermal spray processors utilize powders as 'feedstock' materials, and almost every material is now accessible in powder form, there is a near infinite number of coatings and coating composites available. The benefits of thermal spraying, to the electronic and electrical industries are now becoming exploited. Components can be coated to provide the exact level of electrical conductivity required.

Applications can be broken down into two areas:

a) Conductive workings. Typically these may be copper, aluminum and zinc etc. Precise conductive paths can be created using masking techniques. These conductive coatings can be deposited onto a wide variety of substrates such as carbon fiber, glass reinforced plastics and numerous other polymeric materials.

b) Insulator Coatings. Typically these may be pure ceramics, such as Alumina or Titania. As with the conductive coatings, deposits can be laid down accurately to customer specifications. Conductive and Isolative coatings can also be used together to produce a composite insulated component with an integral electrical path.

Also cold spray can be use for the weathering surfaces of the different pieces with low tolerances where the piece needs to be replaced after having been worn for less than 1 mm.

5. Conclusion

The high-speed thermal spray represents a procedure that found its applicability in the automotive industry and that is about to increase in the future, due to the given opportunities, namely producing high-quality pieces with no additional costs.

In many cases it is possible to increase the lifetime of a component 2 or 3 times, being in the same times a viable solution for reconditioning the worn pieces.

References

1. Feuerstein, A., Knapp, J., Taylor, T.: *Thermal Barrier Coating Systems for Gas Turbine Engines by Thermal Spray and EBPVD - A Technical and Economic Comparison.* In: Proceedings of the International Thermal Spray Conference, Seattle, Washington, USA, May 15-18, 2006, p. 35-42.
2. Sturgeon, A.J., Perrin, C., McCartney, D.G.: *Development of Thermal Sprayed Plain Bearings for Automotive Engine Applications.* In: Surface Engineering & Tribology for Future Engine and Drivelines Conference, London, 2006, p. 16-22.
3. www.uniquecoat.com/index-ARC.html. Accessed: 19-04-2009.
4. www.uniquecoat.com/index-AC-HVAF.html#HX. Accessed: 18-04-2009.
5. http://www.plasmathermalcoatings.com/applications.htm. Accessed: 6-04-2009.