

A Review on Thermal Spray Coating

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ABSTRACT

A coating is a covering process that is applied to the surface of a material which is referred to as the substrate. The coating itself is either completely covered through the whole surface or the particular parts of the substrate. Different coatings are used to achieve the desired properties. Thermal spray coating is one of the most effective methods to protect the new parts from wear, high temperature corrosion, residual stresses, erosion, and to provide hard and dense coatings, thus life of material is increased. In this process, relatively thick metallic, polymer, ceramic and composite coatings is deposited. The optimum coating process is selected on the basis of desired coating properties. Coating material is either in the form of wire, powder, rod, cord or molten-bath form. The procedure is manual, mechanized or fully automated. This paper reviews the previous research in the field of thermal spray coating.

Keywords: Thermal spray coating, high velocity oxygen fuel coating, detonation gun coating, characterization

1. INTRODUCTION :

1.1 Introduction of coating :

A coating is a relatively thin layer of material which is applied to cover a substrate. Coatings are applied for a variety of reasons. One of the most common reasons is to improve the surface properties of a substrate. By using different coating processes, coating materials and the process parameters, the coating properties may differ. In the industrial applications the process properties include thickness, porosity, adhesion, deposition rate and surface finish. The optimum coating process is selected on the basis of desired coating properties.

Coating acts as a protective layer in the different infrastructure like pipelines, mining equipments, tunnels where durability is the major importance as well as in many industries like automotive, aerospace, oil and gas mining, shipbuilding etc. In some cases

the coatings are used to improve the surface properties like adhesion, corrosion resistance, wear resistance.

1.2 Classification of coating :

- 1. Overlay Coating:** This type of coating is performed by the application of new materials onto the surface of a component. A major issue of overlay coating is the adhesion of the coating to the substrate.
- 2. Diffusion Coating:** In this category, chemical interaction of the coating elements with the substrate by diffusion is involved. New element is diffused onto the substrate surface.
- 3. Thermal Spray Coating:** It is the process that involves the deposition of the molten or semi-molten droplets of powder onto the surface of a substrate to form a coating. For protective coating to material surfaces, thermal spraying is widely used in the

industrial process. It exhibits a very good wear resistance property but its corrosion resistance is not good as good as its wear resistance.

1.3 Thermal Spray Coating Processes:

Thermal spraying is an effective and low cost coating method which is applied for thin coatings to change the surface properties of the component. The production rate of the process is very high and the coating adhesion is also adequate. The wide range of application of thermal spraying are aircraft engines, bridges, automotive systems, chemical process equipment, dies, marine turbines, power generation equipments. We use different types of thermal spraying processes like: Flame spraying with a powder or wire, Electric arc wire spraying, Plasma spraying, High Velocity Oxy-fuel (HVOF) spraying, Detonation gun, Cold spraying.

The plasma coating is applied by heating the sintered coating material at extremely high temperatures (> 15,000°C). The most common plasma spray coatings are titanium and plasma sprays. In electric arc spraying, an arc is struck between two consumable electrodes of a coating material. Compressed gas is used to atomize and propel the coating material. In the industrial applications, Detonation Gun Flame Spraying and High Velocity Oxy-fuel (HVOF) spraying are commonly used techniques.

Some general remarks can be expressed in thermal spray coating:

- Different materials require different deposit conditions,
- Specific coating properties (high density or desired porosity) may require specific particle velocity/temperature characteristics,
- The heat fluxes to the substrate depend on the coating method and for some substrate materials they have to be minimized,
- Substrate preheating and temperature control during spraying strongly affect

coating properties and in particular residual stresses,

- And frequently a trade-off exists between coating quality and process economics.

The whole process concept of thermal spray coating is given below:

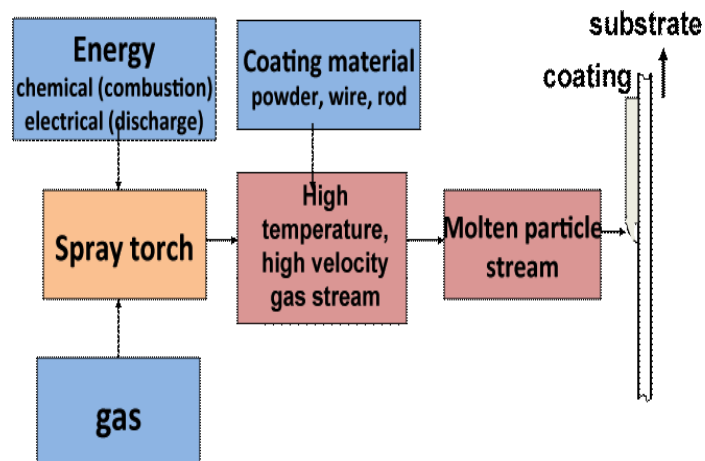


Fig. 1. Schematic of the thermal spray concept, Fauchais et al (2012)

There are some coating materials which are used according to type of wear for thermal spray coating:

Table No. 01- Different coating materials

Type of wear	Application	Materials
Abrasive wear	Cutting Blades Glass mould plungers Pump volute	WC-Co NiCr-Cr ₃ C ₂ Cobalt based hardfacing alloy Nickel/Cobalt self-fluxing alloy
Sliding wear	Piston rings Impeller shafts Cylinder bores	Cast iron-molybdenum Molybdenum-based self-fluxing Alumina-titania babbitt Cobalt chromium molybdenum
Impact,	Mid-span	WC-Co

vibratory fretting wear	dampers Sucker rods	Nickel-based self-fluxing
Erosion/cavitation wear	Steam turbine blades Water turbine application	WC-Co WC-Co-Cr NiCr-Cr ₃ C ₂

1.4 Detonation Gun Flame Spraying:

D-gun spray process provides an extremely good adhesive strength, low porosity and coating surface. A mixture consisting of oxygen and acetylene is fed through a tubular barrel closed at one end. To prevent the back firing, nitrogen gas is allowed to cover the gas inlets. Simultaneously, a fixed quantity of the coating powder is fed into the combustion chamber. The gas mixture is ignited by a spark plug. The combustion of the gas mixture generates high pressure shock waves (detonation wave), which propagates through the gas stream.. The hot gases accelerate the particles to the supersonic velocity. These particles then come out of the barrel and impact the component held by the manipulator to form a coating. The coating thickness of the material depends on the ratio of combustion gases, powder particle size, carrier gas flow rate, and frequency and standoff distance [1]. Depending on the required coating thickness and the coating material, the detonation spraying cycle can be repeated at the rate of 1-10 shots per second.

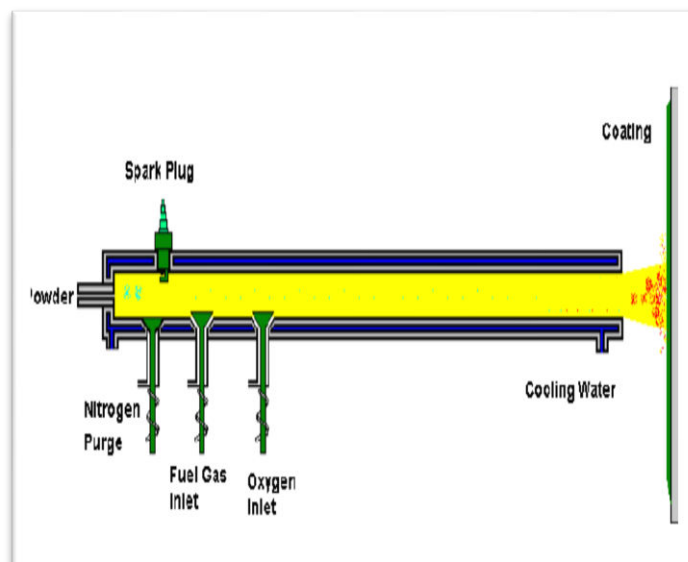


Fig. (2) Schematic diagram of Detonation Gun process

1.5 High Velocity Oxy-fuel (HVOF) spraying:

HVOF utilizes confined combustion and an extended nozzle to heat and accelerate the powdered coating material. The HVOF devices operate at hypersonic gas velocities. This high velocity provide kinetic energy which help produce coatings that are very dense and very well adhered in the as-sprayed condition [2]. HVOF is most commonly used to produce very coatings. Coatings of this type have wear resistance similar to sintered carbide materials. Since the HVOF produces dense coatings it can be used to produce very good corrosion resistant coatings made from materials.

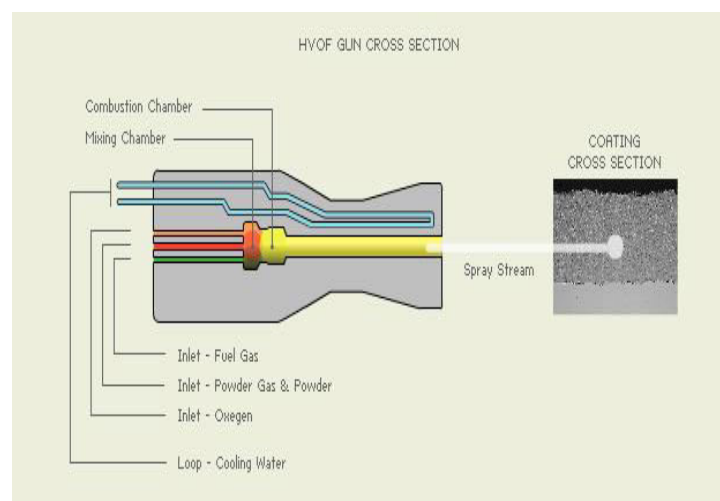


Fig. (3) Schematic diagram of HVOF spraying process

2. BACKGROUND:

Christian Coddet et al. [3] investigated and compared micro structural properties, wear resistance, and potentials of HVOF sprayed Tribaloy-400 (T-400), Cr₃C₂-25%NiCr and WC-12%Co coatings for a possible replacement of hard chromium plating in gas turbine shafts repair. For the testing of friction and wear behavior pin to disc (POD) and Amsler experiments were carried out. It was shown that thermal spray coatings exhibit the adequate properties compared to electrodeposited hard chromium coatings. In comparison to chromium plating, with regard to hardness, wear and abrasion resistance, HVOF sprayed WC-12%Co coatings were far superior. The surface damage loss under various applied loads was less than as compared to chromium plating.

E-Turunen et al. [4] studied process optimization and performance of nanoreinforced HVOF sprayed ceramic coatings by using Al₂O₃ -5% SiC powder. To improve the properties of the coatings is to decrease the grain size of the ceramic phase and to add toughening elements to the microstructure. Nanocrystalline materials offer better thermal shock resistance, lower thermal conductivity and better wear resistance than their conventional counterparts. Micro hardness and abrasive wear loss were determined for all coatings. It was found out that by introducing nanocomposite structure in to the dense ceramic coating the wear resistance and hardness of the coating can be improved. By varying alloying material, the microstructure and properties of the produced coating can be varied. Depending on the application each of produced coatings can offer potential protective capacity.

J.A.Picas et al. [5] described and compared the mechanical and tribological properties of HVOF Cr₃C₂75 (NiCr20) 25 coatings sprayed from three different feedstock powders with

various powder size distributions. These results have been compared with hard chromium plating. The objective of the present work is applying the HVOF coatings in piston rings and valve stems applications. The coatings in this work are Cr₃C₂ 75% + NiCr20 25% weight deposited on a steel substrate with a thickness of approximately 150 μm, Three different 2075-NiCr powders were used as feedstock powders in the present investigation are standard, fine 10 μm and fine 5 μm. Although the Fine Cr-NiCr agglomerates, which show a higher decomposition during spraying, produce coatings with lower hardness, the wear behavior of these coatings is up to 50% better than standard Cr-NiCr coating. In Fine coatings the carbide and binder phase seem to be intimately bonded and reduce the pullout of hard particles that involves the abrasive wear mechanism.

A.H.G.Rana et al. [6] compared 75Cr₃C₂5NiCr50 HVOF Coating and Hard Chrome Coating on pistons and valves. The HVOF coatings are applied on maximum wearpron area in engine which are piston rings and valve stems applications. So the HVOF coatings are produced with fine-powders in order to avoid the blasting and regrinding operations necessary when plasma spray coatings are used. We use three categories of powders which are standard, fine 5 μm and fine 10 μm. The Fine 75Cr₃C₂5NiCr50 coatings provide superior performance with regard to mechanical and tribological properties. For future applications of 75Cr₃C₂5NiCr50, HVOF coatings are used as alternative to hard chromium, where many factors like wear resistance, friction coefficient, costs and environmental issues are considered collectively.

K.N.Balan et al. [7] investigated process parameter optimization of D-gun coating for various coating materials. He selected two substrates of stainless steel which are Type-304 and Type-202. The coating materials are Al₂O₃ and Cr₃C₂ 75% - NiCr 25%. The four samples were prepared with the help of given substrates and coating materials which are given in table 1 :

Table 1. various compositions of substrate and coating material :

Sample No.	Substrate	Coating material
1	stainless steel Type-202	75% chromium carbide with 25% nickel chromium
2	stainless steel Type-304	Al ₂ O ₃
3	stainless steel Type-202	Al ₂ O ₃
4	stainless steel Type-304	75% chromium carbide with 25% nickel chromium

From the experiments it is shown that sample 1 and 4 has poor adhesive properties and less coefficient of friction while sample 2 and 3 has good adhesive properties and high coefficient of friction.

Mustafa Ulutan et al. [8] studied the microstructural and wear Characteristics of High Velocity Oxygen Fuel (HVOF) Sprayed NiCrBSi–SiC Composite Coating on SAE 1030 Steel. The coating materials having Powder mixtures with different weight mixing ratios, NiCrBSi + 10 wt% SiC, NiCrBSi + 20 wt% SiC and NiCrBSi + 40 wt% SiC were prepared. These different coating powders are compared in terms of their phase composition, microstructure and hardness. It is shown that the coefficient of friction and wear rate of all HVOF coating-applied samples were lower than that of the SAE 1030 steel. Under the employed spray conditions, NiCrBSi and SiC mixed powders have been deposited by HVOF process to develop coatings of average 250 μm thick on SAE 1030 steel substrates. Microhardness of the coatings is found in the range 550–830 Hv, which is higher than that of the substrate material.

H. Ruiz Luna et al. [9] investigated three deposition parameters which are fuel flow, oxygen flow and stand-off distance. NiCoCrAlY alloys are widely used for high-temperature coatings and structural materials

in turbine engines due to its oxidation and corrosion resistance. The effect of these processing variables was evaluated by the responses of porosity, oxide content, residual stresses, and deposition efficiency. Coatings with low porosity and with low residual stress were obtained using high fuel-rich mixtures at a stand-off distance between 250 and 300 mm. The results provides a correlation between the fuel and the oxygen ratio flow, the porosity and oxide content on the coatings based on the interaction between particle and the flame. The fuel-rich flames results in coatings with low porosity and oxidation, low residual stresses, and high deposition efficiency due to the high velocity and low temperature attained by the particles. Different spray distances produce coatings that are homogeneous and dense coatings.

M. R. Ramesh et al. [10] investigated oxidation resistance HVOF sprayed coating 25% (Cr₃C₂- 25(Ni₂₀Cr)) + 75%NiCrAlY on Titanium Alloy The titanium alloys posses good affinity towards oxygen at elevated temperature in air and thereby leading to oxidation. Cr₃C₂-NiCr HVOF sprayed coating have very good combat the erosion, corrosion and wear resistance. Titanium alloy Ti-31 was used as the substrate material in this study. Uncoated Ti-31 suffered a higher oxidation rate and spalling of oxide scale [11]. The stress developed due to higher volume of oxide scale leads to cracks, in turn resulted in spallation. The Cr₃C₂-NiCr HVOF sprayed coating has very good combat the erosion, corrosion and wear resistance. These coating were developed the oxide coating like Cr₃O₂ and NiCrAlY on the top layer and resist the degradation of the materials introducing new coating 25% (Cr₃C₂-25(Ni₂₀Cr)) + 75% NiCrAlY posses the properties of not only excellent oxidation and hot corrosion but also improve the sufficient toughness.

M. Krishnan et al. [12] investigated HVOF sprayed Cr₃C₂ – NiCr cermet carbide coating on erosive performance of AISI 316 Molybdenum steel. The coating material has three categories given in table 2:

Table 2. composition of coating materials:

S.No.	Coating Material
1.	Cr ₃ C ₂ 85% + NiCr 15%
2.	Cr ₃ C ₂ 90% + NiCr 10%
3.	Cr ₃ C ₂ 95% + NiCr 5%

From the experiments, it is shown that erosion rate decreases with the increase of NiCr metallic binder and among all these three mixtures, Cr₃C₂ 85% + NiCr 15% provides better corrosion and oxidation resistance.

Pradeep Kumar Barthwal et al. [13] investigated the effect of WC-Co and Cr₃C₂-NiCr coatings on Die Steels by HVOF process under abrasive wear conditions. After the experiments, it is conclude that HVOF thermal spray process is suitable for carbide coatings on Die Steels.

Maria Oksa et al. [14] reviewed HVOF thermal spray techniques, spraying process optimization, and characterization of coatings. Procedures and parameters for controlling the spray process are studied as well as their use in optimizing the coating process. He has mentioned the three generations of HVOF systems. Table 3 is the summarized form of the differences between the generations:

Table 3. The differences between three generations of HVOF coating

	Nozzle type	Power level (kW)*
1st generation	straight	80
2nd generation	De laval	80 to 120
3rd generation	De laval	100 to 300

The HVOF Process Optimization includes statistical methods such as Taguchi and design of experiments (DoE), numerical modeling and simulation, and Finite Element methodology.

Chattopadhyay et. al. [15] conducted experiments to determine slurry erosion characteristics of AISI 316L, 15 wt % Cr-15 wt % Mn stainless steel and satellite powder alloy applied as overlay to cast ferritic stainless steel of CA6NM type, which was used as a normal turbine runner material. The

different wear rates of the alloys were explained in terms of the microstructure, hardness and work hardening rate. The samples were rectangular in section and of size 65 mm×14mm×20mm and thick sand slurry was erodent. The author had concluded that 15 wt % Cr-15 wt % Mn stainless steel and stellite powder alloy applied as overlay showed better erosion resistance properties as compared with base material CA6NM steel.

Harpreet Singh et al. [16] investigated the Slurry Erosion Behavior of Plasma Thermal Sprayed (50%) WC-Co-Cr and Ni-Cr-B-Si Coatings of Different Thickness on CA6NM Turbine Steel Material. The comparison has been done for mass loss for coated and uncoated materials at different conditions. The study reveals that the impact velocity, slurry concentration and impact angle are most significant among various factors influencing the wear rate of these coatings. After a fix time weight loss on samples are compared. This technique helps in saving time and resources for a large number of experimental trials and successfully predicts the wear rate of the coatings both within and beyond the experimental domain. The coated samples show better results as compared to uncoated. SEM analysis gives the information about the surface topography of samples.

Akhilesh K Chauhan [17] investigated Nitrogen strengthened austenitic stainless steel (termed as 21-4-N steel) in as cast and hot rolled conditions as an alternative to 13/4 steel (termed as CA6NM) to overcome the problems of cavitation erosion in hydro turbine underwater parts. The cavitation erosion of 21-4-N and 13/4 steels was investigated by means of an ultrasonic vibration processor. The cavitation erosion is highly dependent on microstructure and mechanical properties. The results show that hot rolled 21-4-N steel is more cavitation erosion resistant than the 13/4 and 21-4-N steels in as cast condition. The eroded surfaces were analyzed through optical microscope and scanning electron microscope for study of erosion mechanisms.

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