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A REVIEW ON DIFFERENT THERMAL SPRAY COATING PROCESS FOR INDUSTRIAL APPLICATIONS

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Abstract— In the past, coating have been developed to provide defensive shield against corrosion and erosion that is to protect the substrate material from chemical as well as physical interaction with its environment. Corrosion and wear problems are at a halt of great relevance in a wide range of industrial application and products as they end result with the degradation and eventual failure of components and systems, both in the processing and manufacturing industries and in the service life of many components. Thermal spray coating process is a technique that is being used for surface modification with different types of coating material like metallic, cermet's, ceramic and some other coating materials in form of powder which are than feed into a gun. The powder which is inserted into gun will be melted by high temperature which is developed by gun. Coating thickness (from 50 to 3000 µm) can achieve by applying multiple layer of melted coated material. This papers aims at the review of various coating techniques used for the corrosive wear applications. Thermal spray coatings are used on a large scale in industry for the following reasons: (i) To enhance the specific properties on the surface of substrate; (ii) Recoating can be applied on the damaged or worn component with changing the properties of substrate; (iii) Huge dimension components and expensive components can be coated by some movable spray coating technique.

1. INTRODUCTION

Coatings have traditionally been developed to provide resistance against erosion and corrosion which is to protect the substrate material from physical and chemical interaction with environment. To enhance the service life of different components that are being used in manufacturing industries or power generation organizations. Different surface technologies can be used to deposit thin films on material to protect the surface from all these problems. These film thickness can vary from 20 µm to 300 µm or even upto several millimeters. Coatings are used to improve the chemical properties as well as surface behavior like corrosion resistance and wear resistance.

Classification of Coatings

1. Thermal spray coating
2. Overlay coating
3. Diffusion coating

1. 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.

2. 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.

3. 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.

1.1 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:

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- 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:

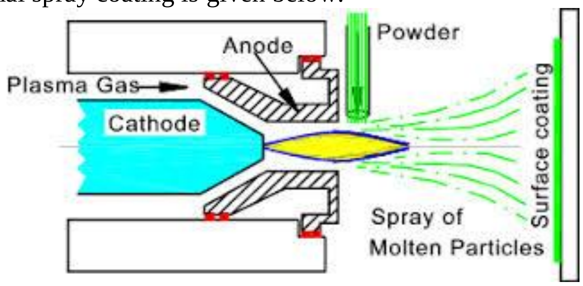

Fig. 1. Schematic of the thermal spray

1.2 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.

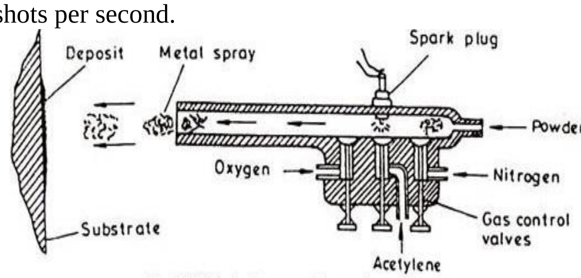

Fig. (2) Schematic diagram of Detonation Gun process

1.3 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.

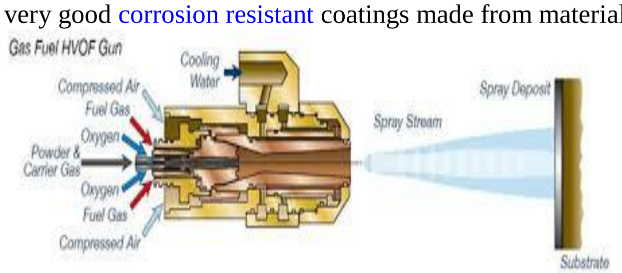

Fig. (3) Schematic diagram of HVOF spraying process

1.4 Literature Review:

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 Al_2O_3 -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 CrC75 (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 Cr_3C_2 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[21]. Although the Fine CrC–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 CrC–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 75CrC25NiCr50 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 75CrC25NiCr50 coatings provide superior performance with regard to mechanical and tribological properties. For future applications of 75CrC25NiCr50, [23]HVOF coatings are used as alternative to hard chromium, where many factors like wear resistance, friction coefficient, costs and environmental issues are considered collectively. Mustafa Ulutan et al.[7] 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. Pradeep Kumar Barthwal et al.[8].investigated the effect of WC-Co and Cr_3C_2- 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. A few examples are presented below. An important concern in the oil and gas production industry is the behavior of materials in an aggressive environment with the presence of suspended sand particles, which contribute to corrosion, erosion and overall wear of the surface. Al-Fadhli et al [9] have HVOF-sprayed Inconel-625 onto stainless steel components used in oil/gas industry. Coatings were applied on three different metallic surfaces: (a) plain stainless steel (SS), (b) spot-welded stainless steel (SW-SS), and (c) a composite surface of stainless steel and carbon steel welded together (C-SS-CS). [22]These coated surfaces were tested in a jet impingement rig under two fluid conditions: (i) free from added solids, (ii) containing 1% silica sand. The coating was found to be highly sensitive to the presence of sand particles in the impinging fluid. As the period of coating exposure to the flow of slurry fluid increased, weight loss increased significantly. This increment was dependent on the type of substrate material.` WC-Co HVOF-sprayed coatings present poor resistance to corrosive wear: the tungsten carbide in HVOF coatings dissolves as well as the cobalt-chromium matrix, leading to cobalt in solution. WC and Co go through an oxidation process before dissolut ion, the oxidation of WC to WO_3 makes the pH drop, accelerating the dissolution of cobalt and corrosion of hard phase leading to its removal. So, there are serious implications when coatings are used in corrosive-erosive environments. Chattopadhyay et. al.[10] 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. Souza and Neuville [11]. These authors have tested WC-Co- Cr HVOF-sprayed coatings. They have shown that the corrosion of these coatings is very complex and corrosion rate increases with temperature. However, chromium forms an oxide layer, which protects from dissolution and retards the corrosion. Toma et al [12] found similar results, concluding that due to its low erosion-corrosion rate the HVOF sprayed Cr_3C_2-NiCr coating can be considered to be an excellent replacement for the thermal sprayed Cr_2O_3 coatings. Espallargas et al[13] found that both WC–Ni and Cr_3C_2– NiCr coatings are promising alternatives to hard chromium from the point of view of erosion–corrosion resistance. Plasma-sprayed aluminium oxide and chromium oxide coatings are widely used to improve the resistance of metallic components against various types of wear and corrosion. However their corrosion resistance depends strongly on their porosity, especially open pores. M. R. Ramesh et al.[14] 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. Leivo etal [15] used aluminium phosphates to seal the structures of Al2O3 and Cr2O3 coatings. The abrasive wear resistance of sealed coatings did not decrease after immersion tests of 30 days in liquids of pH 0 to 10, except for the Al203 coating, which corroded in pH 0 and pH 14 solutions. No corrosion was found with aluminium phosphates in very acidic solutions. Aluminium phosphate is a good candidate to seal oxide coatings that are exposed in corrosive environments, excluding high basic environments of approximately pH. In diesel engines, sulfur contain in the fuel induces corrosive attack possibility. Uusitalo et al[16] have tested the newly developed ferrous powder (Fe–C–Ni–Cr–Cu–V–B alloy) plasma sprayed with the Rota-Plasma_ of Sultzer-Metco on Al-13Si cylinder wall. It presented excellent corrosion and wear resistances, compared with currently used bulk casting materials such as Fe – C – Si – B alloy and Fe – C – Si – Mo – B alloy for cylinder liners. Cho, J.Y.; Zhang, S.H.; Cho, T.Y [17] 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. Basak et al [18] have tested the corrosion and corrosion–wear behaviour of thermal sprayed nanostructured FeCu/WC–Co coating in Hank's solution and compared the results with that of stainless steel AISI 304 and nanostructured WC–Co coatings. The multiphase structure of the FeCu/WC–Co coating induces a complex corrosion behaviour. Under corrosion–wear conditions, the nanostructured FeCu/WC–Co coating exhibited a passivation/repassivation behaviour comparable to that of stainless steel AISI 304 and nanostructured WC–Co coatings. Generally speaking, thermal sprayed coatings behave better when their density is improved. For example Liu et al [19] have investigated the effects of laser surface treatment on the corrosion and wear performance of Inconel 625, and Inconel 625-based WC HVOF-sprayed metal matrix composite coatings. Significant improvement of corrosion and wear resistance were achieved after laser treatment as a result of the elimination of discrete splat-structure, micro-crevice and porosity, and also the reduction of micro-galvanic driving force between the WC and the metal matrix. In addition, the formation of faceted dendritic structure of the WC phase was considered to be beneficial for the wear performance. H. Ruiz Luna et al[20] 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. [24]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. [25]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.

2. CONCLUSIONS

Thermal sprayed thick (from 50 to 3000 μm) coatings, including cold spray coatings are more and more used in industry for the following reasons: (i) They provide specific properties onto substrates which properties are very different from those of the sprayed coating; (ii) They can be applied with rather low or no heat input to substrates (allowing for example sraying ceramics onto polymer substrates); (iii) Virtually any material that melts without decomposing or vaporizing can be sprayed including cermets or very complex metal or ceramic mixtures, allowing tailoring coatings to the wished service property; (iv) Sprayed coatings can be strip off and the worn or damaged coatings recoated without changing part properties and dimensions; (v) Some spray processes can be moved on site, allowing spraying rapidly big parts, which displacement would otherwise be rather long and expensive. The main thermal-sprayed coatings drawbacks are the following: (i) They are a line-of-sight technology, e.g. making it impossible to coat small and deep cavities; (ii) Most coatings have lamellar structures with contacts between layered splats that represent between 15 and 60 % of the splat surfaces depending on spray conditions; (iii) They have pores, cracks… that can be connected, depending on the spray process and spray conditions, and that must be sealed for certain applications. Most bulk materials used in corrosion conditions can be sprayed, however splat boundaries and cracks (for ceramics coatings) often dominate the corrosion properties of coatings. Sacrificial coatings (cathodic behaviour relatively to ions, for example Zn or Al on steel) are extensively used for the protection of large steel structures such as bridges, pipelines, oil tanks, towers, radio and television masts, overhead walkways and large manufacturing facilities, as well as for structures exposed to moist atmospheres and seawater such as ships, offshore platforms and seaports. Their porosity does not affect the anodic material protection, except when the whole cathodic coating structure is completely corroded. Painting as sealing or densification by shot peening are often used to extend their lifetime. No-sacrificial coatings, against corrosion or corrosive wear are extensively used in many industries: aerospace, land-based turbines, automotive, ceramic and glass manufacturing, printing industry, pulp and paper, metal processing, chemical, nuclear, cement, waste treatment. However, in almost all cases these coatings must be retreated to get rid of their porosity. This is achieved by using self-fluxing alloys that are fused after spraying, heat treating or annealing, laser glazing, austempering, sealing with organic, inorganic, metal peening densification, diffusion. Such post-treatments increase the cost of coatings. However, in many cases the cost of retreated coatings is lower than the use of bulk materials and this is especially the case for the repair of parts.

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