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Thermal Sprayed Coating using Zinc: A Review

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Abstract - *Failure of engineering components due to surface deterioration is a common phenomenon. However, the productive life of components can be augmented by giving a proper surface coating with a suitable material. Thermal Spray Coating is a popular technology used to improve and enhance the surface of a solid material, restoring it to its best or improving it. In the literature, we are going to discuss various thermal spray processes like Electrics arc spray, HVOF, Plasma Spray, Flame Spray which are used to protect against wear, cavitation, corrosion, abrasion, heat and erosion. All these processes have different characteristics and application. Therefore, any process is selected according to final desired result. Although there are various materials present for coating, Zinc coating is widely used in industries because of its excellent adhesive properties and also it won't damage the substrate.* Moreover, zinc coating provides bright finish and works as an extremely effective undercoat.

Key Words: **Thermal spray coating, Flame Spray method, Zinc coating, Corrosion Study**

1. INTRODUCTION

Surface coating is a reliable and cost effective process which is widely used to obtain desired surface properties like corrosion, erosion and wear resistance for various components [1]. Thermal Spraying is a type of surface coating which uses combination of thermal and kinetic energy leads to coating particles flattening and spreading on the substrate surface and creating full cover coating [2]. Thermal Spraying have been widely used for many years throughout all the major engineering industry sectors like automotive power generation, aerospace, offshore marine environments, energy sectors for component protection and reclamation. Zinc thermal spraying is process where zinc or zinc alloys are melted and then sprayed onto a prepared substrate to create coating and is highly effective method for corrosion prevention, giving galvanic as well as barrier protection to iron and steel [3]. Thermal spray process provides thickness range of 20 microns to several mm depending upon process and feedstock. Numerous coating materials are available like Zn, Al, Ni, Sn, Cu, chrome carbide, tungsten carbide and many more for this process.

2. LITERATURE SURVEY

- In industries, nowadays, there are number of methods available to solve surface deterioration problem along with various substrate materials.
- The selection of the correct method to obtain desired result is depended on various factors which include coating thickness, availability of coating material, cost, desired characteristics etc. [4]
- Thermal Spray Coating is one of those kinds of method. In the simplest terms possible, thermal spray coating involves heating a material in a powder or a wire form to a molten or semi-molten state. The material is propelled using a stream of gas or compressed air to deposit it, creating a surface structure on a given substrate.

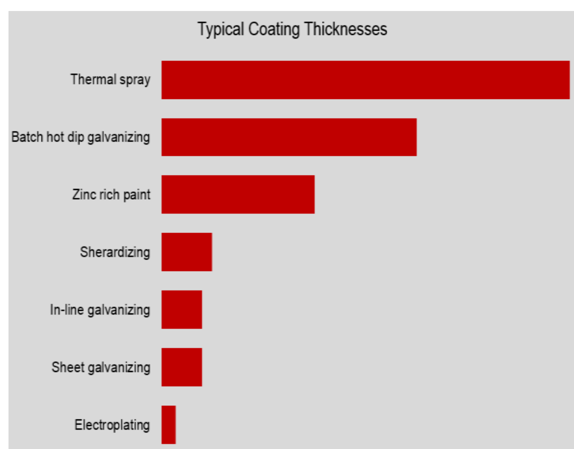

Figure-1: Value of coating thickness for different processes

- Depending upon the form of energy used to melt coating material, Thermal Spray Coating method is further classified into various techniques. The classification is as below:

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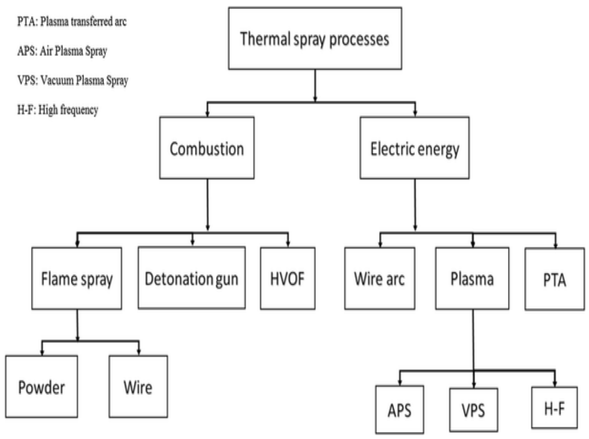

Figure-2: Classification of Thermal Spray Processes

2.1 Electric Arc Wire Spray

In an electric are wire spray, arc is formed by contact of two oppositely charged metallic wires, usually of the same composition. This leads to melting of substrate material. Compressed air atomizes and accelerates the material and sprays it onto work piece surface [4]. Spray rates are driven primarily by operating current and vary as a function of both melting point and conductivity. The process is energy efficient because all the input energy is used to melt the metal [5]. This process is gaining potential due to lower operating costs, higher material output and more coarse coating than Plasma or HVOF methods [1]. Wire arc coatings are exceptionally suited for dimensional restoration of both mis-machined and worn parts. Hence offers versatility and high reliability [6]. Electric arc spraying can also be carried out using inert gases or in a controlled-atmosphere chamber [7].

2.2 Plasma Spray Process

This is one of the most mature and versatile thermal spray methods. In this technique, a DC electric arc is used to generate a stream of high temperature ionized plasma gas, which acts as the spraying heat source [8] [9]. This ionized gas develops a plasma plume several centimeters in length having temperature as high as 16000 K. The main advantage is that refractory material can be sprayed on different types of substrate material (metals, plastics, ceramics, and glass) [10]. It is widely used to apply hydroxyapatite to dental implants and orthopedic prostheses. However, main weakness of this technique is the generation of amorphous calcium phosphate and bioactive calcium phosphate phase such as Tetra Calcium Phosphate(TTCP), Tri-calcium Phosphate (TCP) and meta-stable crystalline products such as oxy-hydroxyapatite which may cause mechanical and adhesive instabilities of the coating [11] [12]. The large contact area with the substrate associated with the lamellar gives rapid heat transfer which may be sufficient to form the amorphous phase [13] [8]. Apart from the conventional Plasma spray method, Vacuum Plasma Spraying, commonly referred as low-pressure spraying is often used modified method. Because of low pressure, plasma becomes larger in diameter and length and has a higher gas speed. The absence of oxygen and the ability to operate with higher substrate temperatures produce denser, more adherent coating [9].

2.3 High Velocity Oxy-fuel Spray (HVOF)

In this process, oxygen (O_2) and fuel gases (such as hydrogen, propane, propylene, kerosene) are introduced into the combustion chamber with spray powder. The high temperature and pressure produced in the chamber due to combustion of gases, causes very high velocity flow of gases through nozzle [1]. In this process, powder particles melt entirely or partially depending on the flame temperature, particle dwell time, melting point and thermal conductivity of the material [14]. The main advantage of this process is lower porosity because of higher particle velocity. The process is also suited for spraying high quality metallic coatings as well as cermets [15] [16]. Moreover, this process having high kinetic energy and low thermal energy is favorable for spray materials such as tungsten carbide coatings [14].

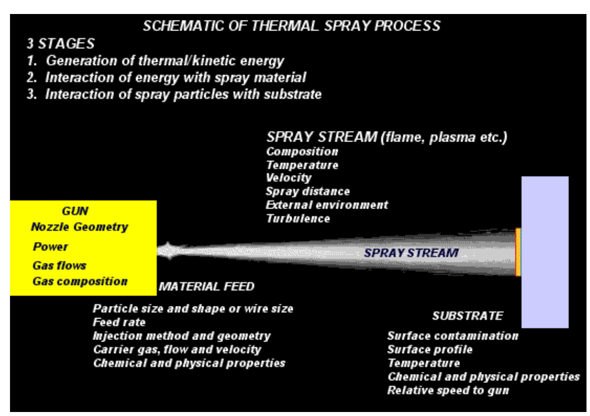

Figure-3: Parameters affecting thermal spray coating process

2.4 Flame Spray Process

This process is the oldest of all thermal spraying processes. Flame spray uses combustible gases as a heat source to melt the coating material [1]. Most flame spray guns use several combinations of gases to balance operating cost and coating properties. Acetylene, propane, methyl-acetylene-propadiene (MAPP) gas, and hydrogen,

along with oxygen are commonly used flame spray gases [5]. For this process, flame temperature and characteristics depend on the oxygen-to-fuel gas ratio and pressure. Depending upon the form of coating material used, there are mainly two types of this process: **WIRE FLAME SPRAY** and **POWDER FLAME SPRAY**. In wire flame spray, wire is fed concentrically into flame, where it is melted and atomized by the addition of compressed air that also directs the melted material towards the substrate surface. The powder flame spray is based on the same operational principle only with the difference that the coating material is in powder form and thus larger selection of spray material is there. The utilization of the flame spraying surface treatment allows the spraying of a wide variety of metallic or ceramic coatings on to a large range of component materials where good wear resistance and excellent impact resistance are required [17] [18].
The key benefits of this process are:

- Low capital investment
- High deposition rates and efficiencies
- Relative ease of operation
- Low cost of equipment maintenance
- Easy to carried out in an environment requires manual thermal spraying
- Possible to coat complex areas of component
- Availability of variety of coating material

Because of having these much advantages, Flame spray is used for number of applications:

- Process is widely used where a cost effective thermal spray coating is desired and a lower quality can be tolerated
- In various structures and components for corrosion protection
- Reclamation worn shafts, particularly of bearing areas with materials such as stainless steel or bronze alloys
- The surface coatings produced are porous and lubricants can be absorbed into the coating, enhancing performance of the bearing.

Comparison of several common thermal spray processes

Process	Coating Material form	Heat Source	Flame Temp C	Gas velocity m/s	Porosity %	Coating Adhesion MPa
Plasma Spray	Powder	Plasma Flame	12000-16000	500-600	2-5	40-70
Wire Arc Spray	Wire	Electric Arc	5000-6000	<300	5-10	28-41
Wire Flame	Wire	Oxy-Fuel combustion	3000	<300	5-10	14-21
HVOF	Powder	Oxy-gas Fuel combustion	3200	1200	1-2	>70

Figure-4: Comparison of several common thermal spray processes

2.5 Coating Material

In principle, any material that does not decompose as it is melted can be used as a thermal spray coating material [4]. Depending upon the process, the coating material can be in wire or powder form.

Zinc is the most widely used metal for coating to gain protection against corrosion. The reasons behind the wide application of zinc for coating are as below:

- Zinc is much more abundant and affordable than any other metals used for coating
- Because of attractive appearance helpful in decorative purpose
- Zinc coating can be produced in wide range of textures and patterns
- Zinc coatings are easy to apply and won't damage the substrate. Also, zinc can be used with a wide range of bath chemistries.
- If application involves painting, zinc can be an extremely effective undercoat due to its excellent adhesive properties.

2.6 Coating and Corrosion

The different types of corrosive attack, especially for coatings can be classified as (i) general corrosion, corresponding to about 30% of failure, where the average rate of corrosion on the surface is uniform and as (ii) localized corrosion, corresponding to about 70% of failures. The latter comprises: (i) Galvanic corrosion occurring when two dissimilar metals are in contact with each other in a conductive solution (electrolyte), the more anodic metal being corroded, while the more cathodic one is unaffected. (ii) Inter-granular corrosion, occurring when a chemical element is depleted during the coating or bulk material manufacturing, e.g. during heat treatment, (iii) Pitting, which is a localized corrosion characterized by depression or pit formation on the surface. (iv)

Transgranular corrosion, mainly due to high static tensile stress in the presence of a corrosive environment. The coating material and its microstructure play an important role in this type of corrosion [19].

Thus coatings can be used against corrosion: (i) As sacrificial coatings (for example Zn or Al on steel): the thicker they will be the longer will be the protection (typical thickness varies between 50 and 500 µm, the most frequent one being around 230 µm), (ii) As dense as possible (even sealed) if they have an anodic behavior and used against either atmospheric or marine corrosion, and high temperature corrosion. Temperature and time are the key factors controlling the rate and severity of high temperature corrosive attack [20].

The main use of thermal sprayed coatings is as sacrificial coating with typical thicknesses between 50 and 500 µm. Such coatings must have a cathodic behavior relatively to the ions of the metal to be protected, in almost all cases steels. The cathodic protection can be porous without any corrosion of the underneath metal. Metals used are then **zinc, aluminum and zinc-aluminum**. Zinc performs better than aluminum in alkaline conditions, while aluminum is better in acidic conditions. For the protection of steel reinforcement in concrete, zinc is generally used, but titanium has also been used. In that case the coating is applied directly on the concrete substrate [21]. Aluminum must be avoided where thermite sparkling may occur. That is due to the reaction of rusted steel and aluminum smears when this combustible mix is ignited by an impact [21]. Thus they must be avoided whenever there is a thermite-sparking hazard. Murakami and Shimada [22] have studied the corrosion and marine fouling behaviors of various flame sprayed coatings. They used the following powders as coating material: aluminum-copper alloy powders, aluminum-copper blend powders, aluminum-zinc blend powders and a zinc powder. After immersion in the sea, the aluminum-copper coatings showed poor anti-corrosion and anti-fouling properties. The aluminum-zinc coating with high zinc content and the zinc coating possessed the best anti-corrosion and anti-fouling properties.

From above discussion, one can say that Zinc is the best suitable coating material for steels to gain protection against corrosion attack.

Apart from this, there are various accelerated tests for the corrosion rate measurement. Some common tests include Weight loss method, Salt spray testing, cyclic polarization, Potentiodynamic test and others. These techniques can provide significant useful information regarding the corrosion mechanisms, corrosion rate and susceptibility of specific materials to corrosion in designated environments. Weight loss is monitored as difference in original and final specimen dimension and reduction of thickness, both function of time. Salt spray test used to determine corrodibility of nonferrous and ferrous metals and to determine degree of protection afforded by both inorganic and organic coatings. Cyclic polarization test is done to determine pitting behavior of an alloy, pitting potential and corrosion potential. In Potentiodynamic testing, different metallic materials have different polarization characteristics as dictated by the open circuit potential, breakdown potential and passivation potential of the material. The detection of these electrochemical parameters identifies the corrosion factors of a material [23] [24].

2.7 Application of Thermal Spray Coating and Zinc Coating

Thermal Spray coatings are used for a variety of applications in industry. They provide a wide range of functions and are often used to treat aeroplanes to protect them from extremes of temperature and the elements. Thermal spray coatings are also used in marine environment and in automotive industries to enhance longevity of vehicles and bring them back to their best. It is also used to protect buildings from environmental conditions such as rain and humidity.

Figure-5: Thermal spray coating application in aerospace and in automotive (to coat exhaust system) industry

Thermal coatings may be used for cathodic coating, dielectric coating and for resurfacing. Cathodic coating provides excellent corrosion protection and involves applying a metal coating which is cathodic to the base and hence it gives strong, protective barrier. In industries such as electronic packaging, automotive, aerospace, ceramic dielectric coating is a common choice. Thermal Spraying is an established choice for surfacing metal parts in industry and in vehicles. It can increase the lifespan of components, such as bearings or printing rolls, and improve its engineering performance [2].

One of the most important uses of thermal spray coatings is for wear resistance. HVOF and detonation gun coatings provide the greatest wear resistance for a given composition. Thermal spray coatings are used in some applications to provide specific frictional characteristics to a surface. The textile industry provides, as an example, applications covering the complete range of friction characteristics. Flame sprayed aluminum and zinc coatings are frequently used for corrosion resistance on bridges, ships, and other structures. Plasma spray coatings are used as thermal barriers. In particular, partially stabilized zirconia coatings are used on gas-turbine combustors, shrouds, and vanes and on internal combustion cylinders and valves to improve efficiency and reduce metal temperatures or cooling requirements. Because of their unique lamellar microstructure and porosity, the thermal conductivity of thermal spray coatings is usually anisotropic and significantly less than that of their wrought or sintered counterparts. A variety of other applications have been developed for thermal spray coatings, including coatings used as nuclear moderators, catalytic surfaces, and parting films for hot isostatic presses. Thermal spray materials can also be used to produce freestanding components such as rocket nozzles, crucibles, and molds [25].

Figure-6: Coated Bridge structure for protection against corrosion

Figure-7: Turbine blade sprayed with ZrO_2 coating using Plasma Spray

Zinc coatings are widely used to protect finished products ranging from structural steelwork for buildings and bridges, to nuts, bolts, strip, sheet, wire and tube. Zinc coatings for iron and steel provide excellent corrosion resistance in most atmospheres, in hard fresh waters, and in contact with many natural and synthetic substances. The following are the some principal methods of applying zinc coatings.

In **hot dip galvanizing,** steel components or fabrications are immersed in a bath of molten zinc at about 450°C. In the galvanizing bath a series of zinc-iron alloy layers are formed by a metallurgical reaction between the iron and zinc. As the steel is withdrawn, a layer of molten zinc remains on the surface. Applications include structural steelwork, lampposts, crash barriers, power transmission towers, railway electrification supports, security fencing, trailers and many others. Roofing and cladding for industrial and commercial buildings, domestic appliances and automotive bodies is done by continuous hot dip galvanizing. All car manufacturers now use steel strip that has either been continuously hot dip galvanized or zinc plated.

Figure-8: Galvanized car body in automobile sector

For structural components which are too large to be dipped in a galvanizing bath, and to structures which are likely to distort during hot dip galvanizing, **Zinc Spraying** is used in which molten zinc are projected on to a grit-blasted steel surface from a special flame or arc pistol fed with zinc or zinc alloy wire. In **Zinc Plating**, a zinc coating is electrodeposited onto prepared steel from a solution of zinc salts. The process is used to protect smaller articles - such as nuts, bolts and other fasteners and small pressings – which require a finer finish than galvanizing can normally provide, although the coating is thinner. The process has also been adapted to provide thin coatings on steel strip and wire.

Figure-9: Zinc coated fasteners

Zinc-rich paints contain very high levels of fine zinc dust. Zinc dust paints can be applied to any rust and scale-free steel surface by brushing, spraying or dipping. They are mainly used to protect factory steel work, ship's hulls and parts of car bodies and also to repair damage to other types of zinc coatings. Automatic grit blasting and zinc dust paint spraying equipment are widely used in steel workshops and shipyards to protect steel plates during storage before fabrication and until application of the final coating system [26].

3. SUMMARY

The main aim of surface coating is to extend life of component and reduces maintenance cost. The surface technology produces wide range of coatings which improve corrosion, erosion and wear resistance of materials. Thermal spray process is considered as the most important surface modification technique. It is used for electromagnetic shielding, heat resistant coating, corrosion resistant coating and for thermal insulation. From all thermal spray techniques, HVOF provides high hardness and continues uniform coating thickness. Moreover, HVOF gives the least amount of porosity in coating compared to all other processes. Although, Flame spray is the most widely used technique in industries due to less capital investment and maintenance cost, easy to operate and possibility of coating complex areas. It is also used to coat zinc on steel components for prevention against corrosion.

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