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A Review on Thermal Spray Coating Processes

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Abstract— Surface coating is an economic method for the production of materials, tools and machine parts that require the desired surface properties such as corrosion, erosion and wear resistance. 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 paper an attempt has been made to focus on Plasma Spray, Electric Arc Wire Spray Flame Spray, High Velocity Oxy-Fuel Spray (HVOF) techniques - their basic principles, benefits, application, comparison.

Index Terms— Plasma Spray, Electric Arc Wire Spray, Flame Spray, High Velocity Oxy-Fuel Spray (HVOF),Thermal Spray Coating

I. INTRODUCTION

Thermal spraying processes have been widely used for many years throughout all the major engineering industry sectors for component protection and reclamation. Recent equipment and process developments have improved the quality and expanded the potential application range for thermally sprayed coatings. Thermal spraying is a well established technology for applying wear and corrosion resistant coatings in many key industrial sectors, including aerospace, automotive, power generation, petrochemical and offshore. In recent years, improvements to equipment and material quality have enhanced the technical credibility of the thermal spraying processes, leading to a significant growth in new markets, e.g., biomedical, dielectric and electronic-coatings. As a consequence, there are many options open to the spray coating supplier in terms of thermal spraying equipment, coating materials and gas selection, but these are often dependent on the environment to which the coating is subjected.

II. LITERATURE SURVEY

Early experiments in which liquids were broken up into fine particles by a stream of high-pressure gas. Efforts more directed at producing powders rather than constructing coatings. Molten particles impinge on the substrate surface and on themselves which cool and form a coating [1].
A coating of the order of 20 micron to several millimeters can be formed using thermal spraying depending upon the methods and feed rate. This entire process is associated with very small heat

transfer to the substrate and mechanical interlocking which going to act as major adhesion mechanism, which ultimately facilitates us of coating of almost any materials on to any substrate material with thermal spray method [2]. The quality of the coatings is assessed by the phase stability, coating density, adhesive strength, hardness, toughness, oxide contents and surface roughness. The coatings made with thermal spray methods have wide range of applications. These include thermal barrier, wear resistant, and corrosion resistant coatings. These coatings find application in oil and gas sector, aerospace, power plants, textile, mineral processing, chemical and paper industries. The major advantages of thermal spray coatings include their wide variety of coating and substrate materials. The coatings can be strip off and substrates can be recoat without any damage or dimensional changes to the components. The line-off-straight nature is the major disadvantage of these processes. Small, deep and very intricate substrates are difficult to coat.

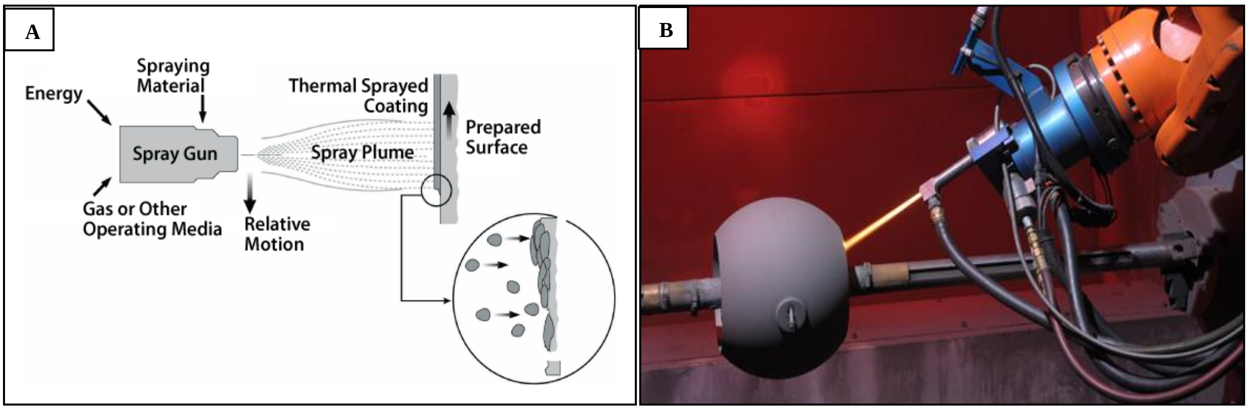

Figure 1. (A) General schematic diagram of thermal spray coating processes and (B) Thermal spray coating set-up.

Thermal Spray is a generic term for a group of processes in which metallic, ceramic, cermet, and some polymeric materials in the form of powder, wire, or rod are fed to a torch or gun with which they are heated to near or somewhat above their melting point. The resulting molten or nearly molten droplets of material are accelerated in a gas stream and projected against the surface to be coated (i.e., the substrate). The process is as such simple but need extreme skill and control. Upon impact of the molten droplets on the colder surface, the droplets flow into thin lamellar particles adhering to the surface, overlapping and interlocking followed by their solidification. The total coating thickness can be varied and it is depended upon number of passes. There are three variety of processes (1) Manual, (2) Mechanized and (3) Fully automated [3] [4]. Fig. 1 clearly reveled that the general principle (A) and actual set up of the thermal spray coating set up (B). Base on the heat source, the thermal spray coating process can be classified as shown in following flow chart, fig. 2. [5].

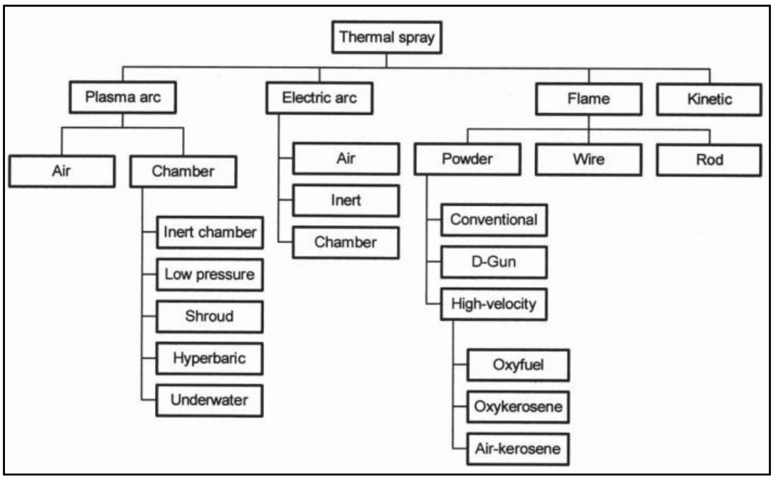

Figure 2. Classification of various thermal spray coating processes

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A major advantage of the thermal spray processes is the extremely wide variety of materials that can be used to make a coating. Virtually any material that melts without decomposing can be used. A second major advantage is the ability of most of the thermal spray processes to apply a coating to a substrate without significantly heating it. Thus, materials with very high melting points can be applied to finally machined, fully heat-treated parts without changing the properties of the part and without thermal distortion of the part. A third advantage is the ability, in most cases, to strip and recoat worn or damaged coatings without changing the properties or dimensions of the part. A major disadvantage is the line-of-sight nature of these deposition processes. They can only coat what the torch or gun can "see." Of course, there are also size limitations prohibiting the coating of small, deep cavities into which a torch or gun will not fit [3].

Plasma Spray

Plasma arc spraying is one of the most sophisticated and versatile thermal spray methods. As indicated in fig. 3, the plasma spray process uses a DC electric arc to generate a stream of high temperature ionized plasma gas, which acts as the spraying heat source [8] [9].

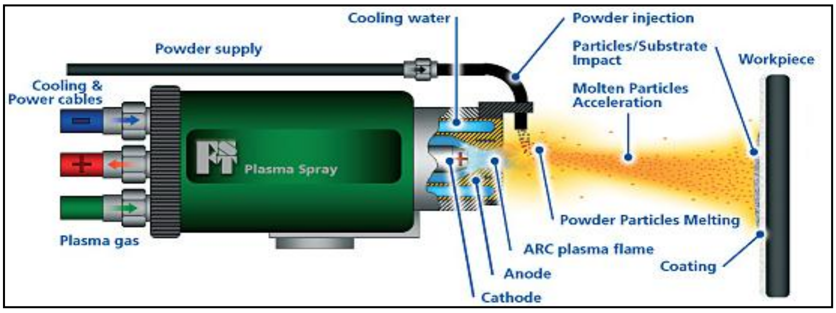

Figure 3. Schematic diagram of plasma arc process

The plasma gun comprises a copper anode and tungsten cathode, both of which are water cooled. A high frequency arc is ignited between them. Plasma gas (i.e., He, H_2, N_2 or mixtures) flows around the cathode and through the anode which is shaped as a constricting nozzle and ionized such that a plasma plume several centimeters in length develops. The temperature within the plume can reach as high as 16000° K. The spray material is injected as a powder outside of the gun nozzle into the plasma plume, where it is melted, and hurled by the gas onto the substrate surface. Provisions for cooling or regulating the spray rate may be required to maintain substrate temperatures in the 95 to 205 °C (200 to 400 °F) range. Plasma spraying has the advantage that it can spray very high melting point materials such as refractory metals. But 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 [6][10].
Plasma spraying is becoming the main process of the thermal spray methods and is commonly used to apply hydroxyapatite to dental implants and orthopedic prostheses. Powder is injected into the plasma flame and accelerated to about 200 m/s before impacting the substrate. Mainly due to high impact velocities which supply kinetic energy is spreading the molten droplet and creates lamellar with a large surface area. The large contact area with the substrate associated with the lamellar gives rapid heat transfer which may be sufficient to form the amorphous phase [7] [8]. The rate of spray or spray rate is greatly depend on various parameters namely, gun design, plasma gases, powder injection schemes, and materials properties, particularly particle characteristics such as size, distribution, melting point, morphology, and apparent density [3].
The conventional plasma, is also commonly known as air or atmospheric plasma spray (APS). In APS, plasma is generated by superheating an inert gas- typically argon or argon-hydrogen mixture by a dc arc. Commercial guns operate at a power range of 20 to 200 KW [11].

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Vacuum plasma spraying (VPS), also commonly referred to as low-pressure plasma spraying (LPPS), uses modified plasma spray torches in a chamber at pressures in the range of 10 to 50 kPa (0.1 to 0.5 atm). Advantages of this low-pressure plasma technique include improved bonding and density of the deposit, improved control over coating thickness (even with an irregular work surface), and higher deposit efficiency [10]. At low pressures the plasma becomes larger in diameter and length, and through the use of convergent/divergent nozzles, has a higher gas speed. The absence of oxygen and the ability to operate with higher substrate temperatures produce denser, more adherent coatings with much lower oxide contents [9].

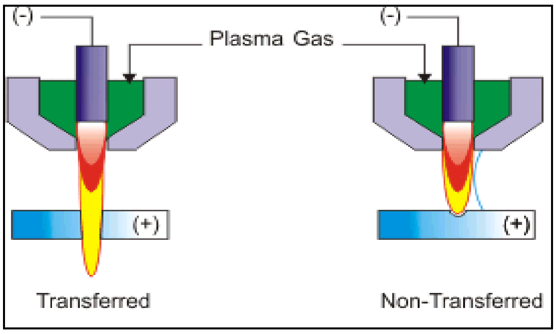

Figure 4. Comparison of transferred and non-transferred plasma arc process

*The transferred plasma-arc process (fig. 4)***,** adds to plasma spray the capability of substrate surface heating and melting. A secondary arc current is established through the plasma and substrate that controls surface melting and depth of penetration. Several advantages result from this direct heating: metallurgical bonding, high-density coatings, high deposition rates, and high thicknesses per pass. In addition, less electrical power is required than with non-transferred arc processes. This process eliminates many of the problems related to using powders with wide particle size distributions or large particle sizes. It is used in hard-facing applications such as valve seats, plowshares, oil field components, and mining machinery [3].

Electric Arc Wire Spray

In the electric arc spray process, fig. 5 (a.k.a. the wire arc process), two consumable wire electrodes connected to a high-current direct-current (dc) power source are fed into the gun and meet, establishing an arc between them that melts the tips of the wires. The process is energy efficient because all of the input energy is used to melt the metal. The molten metal is then atomized and propelled toward the substrate by a stream of air. Spray rates are driven primarily by operating current and vary as a function of both melting point and conductivity. Substrate temperatures can be very low, because no hot jet of gas is directed toward the substrate. Electric arc spraying also can be carried out using inert gases or in a controlled-atmosphere chamber [12].

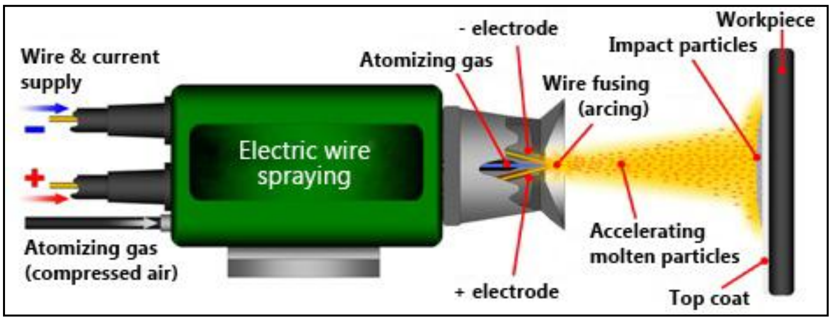

Figure 5. Schematic diagram of electric arc wire spray process

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Flame Spray

Flame spraying (fig. 6), is the oldest of the thermal spraying processes**,** characterized by low capital investment, high deposition rates and efficiencies, and relative ease of operation and cost of equipment maintenance. Flame spray uses combustible gas as a heat source to melt the coating material. A wide variety of materials can be deposited in rod, wire, or powder form as coatings using this process Flame spray guns and vast majority of components are sprayed manually.

Most flame spray guns can be adapted to 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. Flame temperatures and characteristics depend on the oxygen-to-fuel gas ratio and pressure. Flame spray' includes low-velocity powder flame and wire flame processes as shown in figure and high velocity processes such as HVOF (high velocity oxy-fuel) and detonation gun (D-Gun) [3][13].

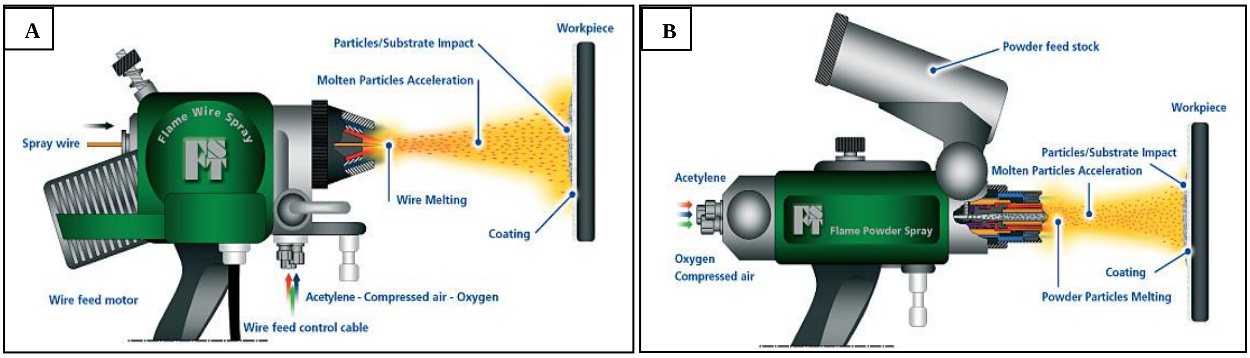

Figure 6. Schematic diagram of (A) wire flame and (B) powder flame processes

High Velocity Oxy-Fuel Spray (HVOF)

The high velocity oxy-fuel spray (HVOF) process is a relatively recent addition to the family of thermal spray processes [16]. In the early 1980s Browning and Witfield, using rocket engine technologies, introduced a unique method of spraying metal powders, the technique was referred to as High Velocity Oxy-Fuel (HVOF). The process utilizes a combination of oxygen with various fuel gases including hydrogen, propane, propylene, hydrogen and even kerosene.

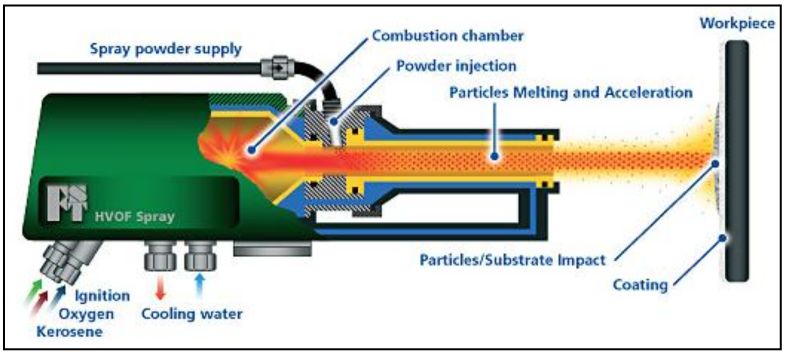

Figure 7. Schematic diagram of high velocity oxy-fuel spray (HVOF) process

In the HVOF process, fuel and oxygen are introduced to the combustion chamber together with the spray powder. The combustion of the gases produces a high temperature and high pressure in the chamber, which causes the supersonic flow of the gases through the nozzle. The powder particles melt or partially melt in the combustion chamber and during the flight through the nozzle. The flame temperature varies in the range of 2500 °C to 3200 °C, depending on the fuel, the fuel gas/ oxygen

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ratio and the gas pressure. In the HVOF process the particles melt completely or only partially, depending on the flame temperature, particle dwell time, material melting point and thermal conductivity [6]. As it uses a supersonic jet, setting it apart from conventional flame spray, the speed of particle impact on the substrate is much higher, resulting in improved coating characteristics. The mechanism differs from flame spraying by an expansion of the jet at the exit of the gun [16].
The benefits of this process are that the process temperature is reasonable but the particle velocity on impact is very high. The resultant coatings are generally very dense, adherent and contain few oxides. These processes are suited to spraying high quality metallic coatings as well as cermets. The quality of the coatings makes them very attractive as an application method for a bond coat within a TBC system [14] [15]. The HVOF process, having high kinetic energy and comparatively low thermal energy, results in a positive effect on the coating characteristics and is favorable for spray materials such as tungsten carbide coatings [16].
There are two distinct differences between conventional flame spray and HVOF. HVOF utilizes confined combustion and an extended nozzle to heat and accelerate the powdered coating material. Typical HVOF devices operate at hypersonic gas velocities, i.e. greater than MACH 5. The extreme velocities provide kinetic energy which help produce coatings that are very dense and very well adhered in the as-sprayed condition [13].
The ability to produce dense coatings with low amount of degradation, oxidation of metallic materials, and phase transformations is the main feature of the HVOF process. This is due to the short dwell time of the particles in a relatively cold flame. It is widely used to produce cermet and metal coatings, but the HVOF process has also been demonstrated to be able to deposit dense ceramic coatings. However the drawback of this technique is that coating is not 100% crystalline [6].
Following table shows comparison of heat source, flam temperature, gas velocity porosity and coating adhesion in various thermal spray coating processes:

Table-1. Comparison of several common thermal spray processes

Process	**Coating Material form**	**Heat Source**	**Flame Temp °C**	**Gas velocity Mts/Sec**	**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 Spray	Wire	Oxy-Fuel combustion	3000	< 300	5-10	14-21
HVOF	Powder	Oxy-gas Fuel combustion	3200	1200	1-2	> 70

III. DISCUSSION

In this paper, we have focused on general introduction of some of the important thermal spray coating processes like Electric Arc Wire Spray, Flame Spray in brief and explain in detail about High Velocity Oxy-Fuel Spray (HVOF) and Plasma Spray process. We can say that among these processes HOVF has more advantages than other. All processes are used according to properties required, cost, suitability of process for particular material, etc. All methods of thermal spraying involve the projection of small softened particles onto a cleaned and prepared surface where they adhere to form a continuous coating. Thermal and kinetic energy both together causes the particles ’splat’ onto the surface, and onto each other, to produce a cohesive coating of successive layers and coating properties are varies with the process parameter of the process used.

IV. SUMMARY

Surface coating improves the life of the component and reduces the cost of replacement. The purpose of surface technology is to produce functionally effective surfaces. A wide range of coatings can improve the corrosion, erosion and wear resistance of materials. We can conclude that thermal spray coating is one of the most important techniques of the surface modification method. This study was an effort to give basic information regarding some of the main thermal spray techniques among which HVOF coating process is best suited. By using HVOF spray technique uniform coating thickness, continuous layer of coating and high hardness can be obtained. It has more advantages over the high strength, hardness, porosity, wear and corrosion as compared to other process.

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