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THERMAL SPRAY COATING: A STUDY

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ABSTRACT

Surface coating is a reliable and cost effective process, used for the production of tools, materials, and machine components that requires desired surface properties like corrosion, erosion and wear resistance. The main purpose of applying the coating may be decorative, functional, or both. To improve surface properties such as adhesion, erosion, corrosion and wear resistance, functional coating may be used. Whereas, decorative coating such as artists paints are applied to make the product/material more attractive. Now days, number of coating methods are applied to achieve the desired functional or decorative properties. Thermal spray coating process is one of the effective and attractive methods to preserve/protect the new machine components from wear, hot corrosion, and erosion. This paper briefly explains various spray processes, their basic principles, advantages, and applications. In addition to this features, characteristics of coating methods and various corrosion prevention methods are briefly described.

Keywords: Thermal Spray; Detonation Gun Spray, Flame Spray, High Velocity Oxy-Fuel Spray, Plasma Spray, Wire Arc Spray, Cold Spray.

I. INTRODUCTION

Thermal spray is a collective term for a set of processes in which coating material is heated rapidly in a hot gaseous medium, and simultaneously projected at a high velocity onto a prepared substrate surface, where it deposits to produce the desired thickness of coating. [1] The coating materials (metallic, ceramic, cermet, and some polymeric) in the form of powder, wire, or rod fed to a heating zone to become molten, and is propelled from there to the surface of substrate material. [2].The production rate and adhesion strength of the thermal spray coating process is very high as compared to other coating process. Due to its several advantages such as low cost, versatility, high processing speed it is most widely used in aircraft engines, thermal power plant, bridge, photo chemical industry, automotives system, chemical process equipment, dies, marine turbines, power generation equipments. It is mainly used to apply coating to a numerous range of materials and machine parts to impart resistance to erosion, corrosion, wear, and cavitation. Except this it provide lubricity, sacrificial wear, electrical conductivity, low or high friction and chemical resistance. The first thermal spray process (flame spraying) was invented in 1911 at Swit- zerland by of the M.U. Schoop. Whereas, the wire spraying, D-Gun spraying process (invented by R.M. Poorman, H.B. Sargent, and H. Lamprey and patented in 1955) [3], HVOF (invented by G.H. Smith, J.E Pelton, and R.C. Eschenbach and patented in 1958) [4], and plasma spray (invented by R.M. Gage, O.H. Nestor, and D.M. Yenni and patented in 1962) [5].In simple words, thermal spray coating is a process in which , coating material is heated rapidly in a hot gaseous medium, and simultaneously projected at a high velocity onto a prepared substrate surface, where it deposits to produce the desired thickness of coating.

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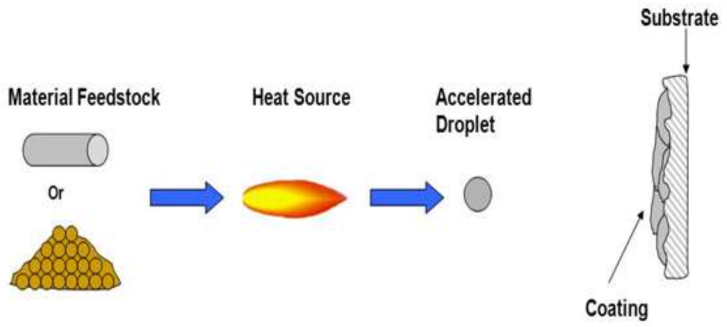

Fig. 1 General thermal spray process

II. LITERATURE SURVEY

Based on the heat source, the thermal spray coating process may be classified as shown in following flow chart, fig. 2. [6].

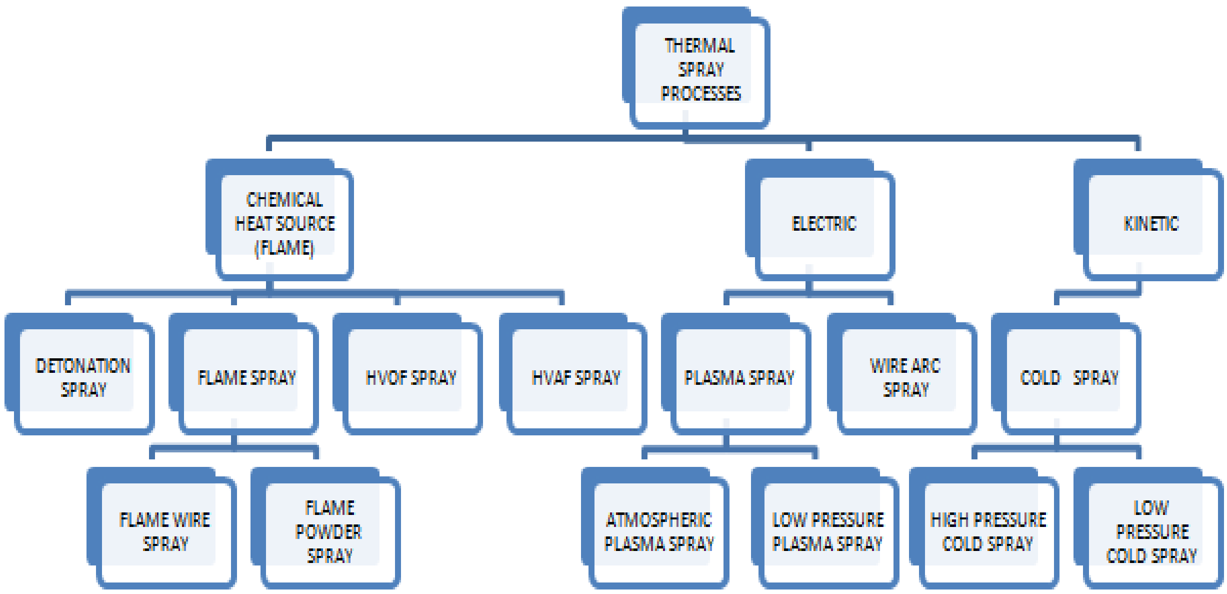

Fig. 2 Classification of thermal spray processes.

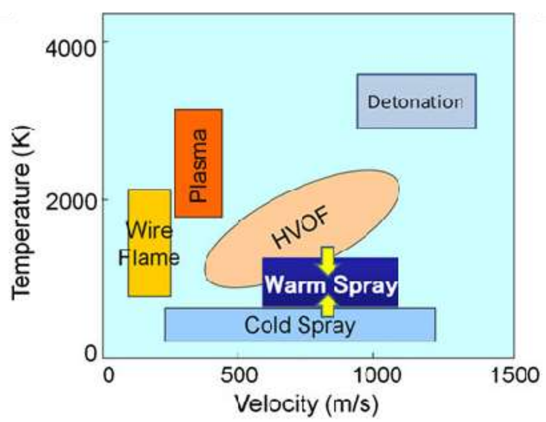

Fig. 3 Schematics classification of thermal spray processes.

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On the basis of chemical heat source, thermal spray processes may be classified as:

1. Detonation- Gun Spray (D-Gun spray)

D-gun spray process is thermal spray process which has remarkably good adhesive strength. In this process a coating powder and mixture of oxygen (O_2) and acetylene gas (C_2H_2) is fed through a tubular barrel whose one end is closed while other end is open. The spark plug is used to ignite the gas mixture. In order to prevent the back firing, nitrogen gas (N_2) is used to cover the gas inlets. Due to the burning of the gas mixture, it creates high pressure shock waves (detonation wave), which propagates through the gas stream. The hot gases speed up the particles to the supersonic velocity. These particles then come out of the barrel and strike on the substrate held by the manipulator to form a coating. [7].

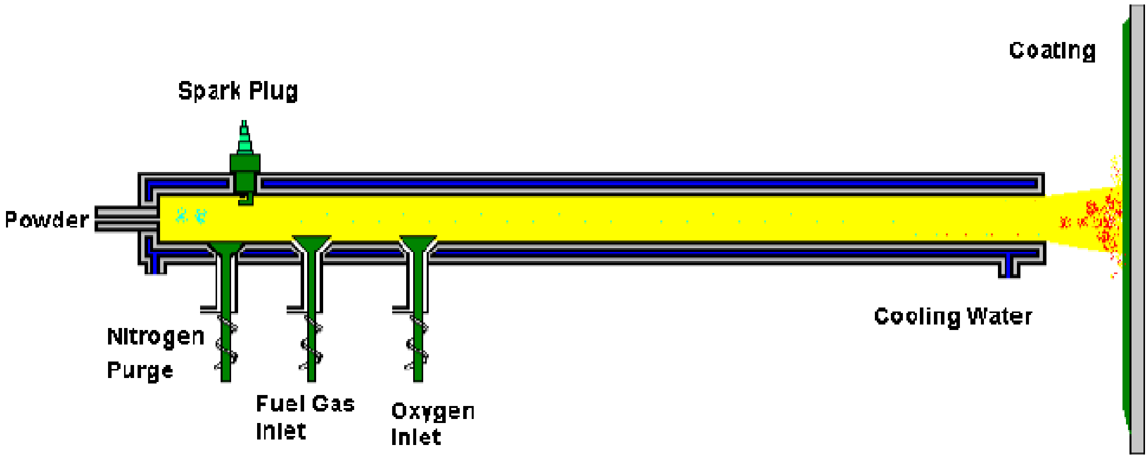

Fig. 4 Schematic diagram of Detonation Gun process [8]

The Detonation -Gun process produces higher density, improved corrosion resistance, higher hardness, better wear resistance, higher bonding and cohesive strength, almost no oxidation, thicker coatings, and smoother as-sprayed surfaces. It is widely used in steel industries (squeeze rollers, tension rolls), textile industries (thread guides coated with alumina titanium layer), aeronautic industries (advance coating on the vanes and driving shaft of a helicopter) and in automobile industries.

2. Flame Spraying

Flame spraying is the oldest of the thermal spraying processes, characterized by low capital investment, high efficiency and deposition rates, 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. The schematics diagram of flame spray process is shown in Fig. 5.

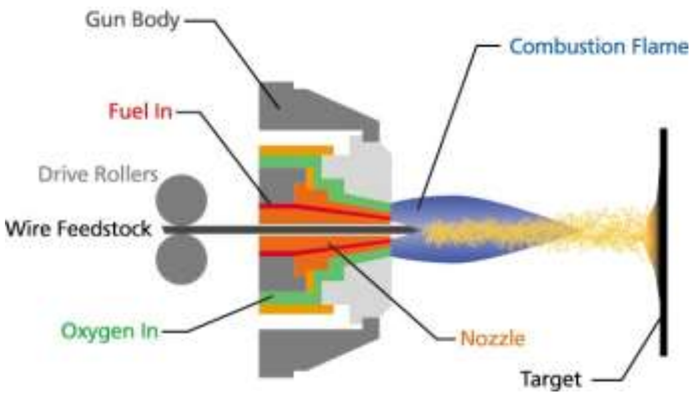

Fig. 5 Schematic diagram of Flame spray process.

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This process has many advantages such as low cost, easy to operate, simple in design, and dust and fumes levels are lower. It is widely used for Corrosion protection of structures and machine parts (e.g. bridges, offshore platforms, LPG bottles). It is used where a cost effective thermal spray coating is desired and a lower quality can be tolerated. For corrosion protection of structures and machine components and reclamation worn shafts flame spray process is mainly used.

3. High Velocity Oxy-Fuel Spray (HVOF)

HVOF process is a relatively recent thermal spray processes invented in the early 1980s by Browning and Witfield, while using rocket engine technologies. The process uses a combination of oxygen (O_2) with one of the fuel gases including hydrogen (H_2), propane (C_3H_8), propylene (C_3H_6), and even kerosene.

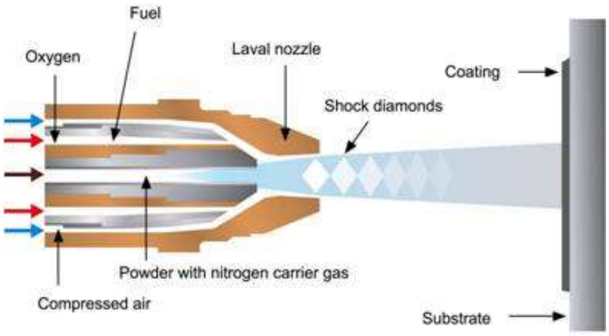

Fig. 6 Schematic diagram of HVOF process

In this process, the fuel and oxygen (O_2) are introduced to the combustion chamber simultaneously with the spray powder. The high temperature and pressure produced in the chamber due to the combustion of the gases, which causes the very high velocity flow of the gases through the nozzle. The flame temperature changes from 2500 °C to 3200 °C, depending on the fuel, the fuel gas/ oxygen ratio and the gas pressure. In the HVOF process the powder particles melt entirely or only partially, depending on the flame temperature, particle dwell time, melting point and thermal conductivity of the material. [9]. It is mostly used in key industries such as oil and gas, power, water, mining, petrochemicals, aerospace, chemicals, paper, engineering and manufacturing. The main advantages of this process is lower porosity because of higher particle impact velocities, smoother spray surface due to more impact velocities and smaller powder sizes , higher wear resistance because of tougher, harder coatings and thick coating due to less residual stresses.

On the basis of electrical heat source, thermal spray process may be classified as:

1. Plasma Spray

It is one of the most mature and versatile thermal spray methods. In this process a DC electric arc is used to generate a stream of high temperature ionized plasma gas, which acts as the spraying heat source [10-11]. The schematics diagram of plasma spray process and plasma theory is shown in Fig.7

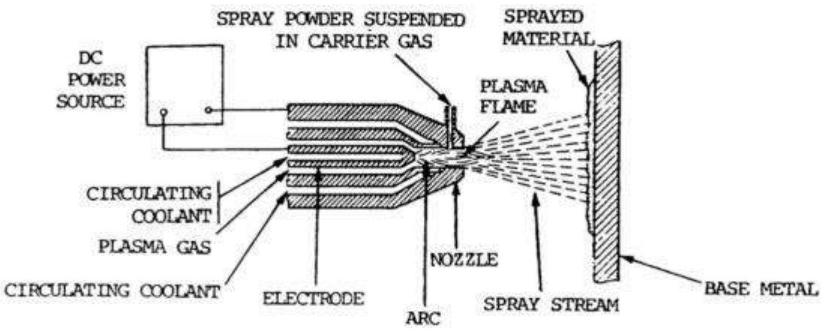

Fig.7 Schematic diagram of plasma arc process

The major advantage of plasma spray is that refectory material can be sprayed on different types of substrate material (metals, plastics, ceramics, glass, and composite materials.[12]. It is widely used to apply hydroxyapatite to dental implants and orthopedic prostheses.

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2. **Wire arc spray**

Wire arc spray is a coating process in which where two consumable metal wires are fed independently into the spray gun. These wires are then charged and an arc is generated between them. The heat from this arc melts the incoming wire, which is then entrained in an air jet from the gun. This entrained molten feedstock is then deposited onto a substrate with the help of compressed air. The schematic diagrams of electric arc spray system is shown in Fig.8 (a, b &c).

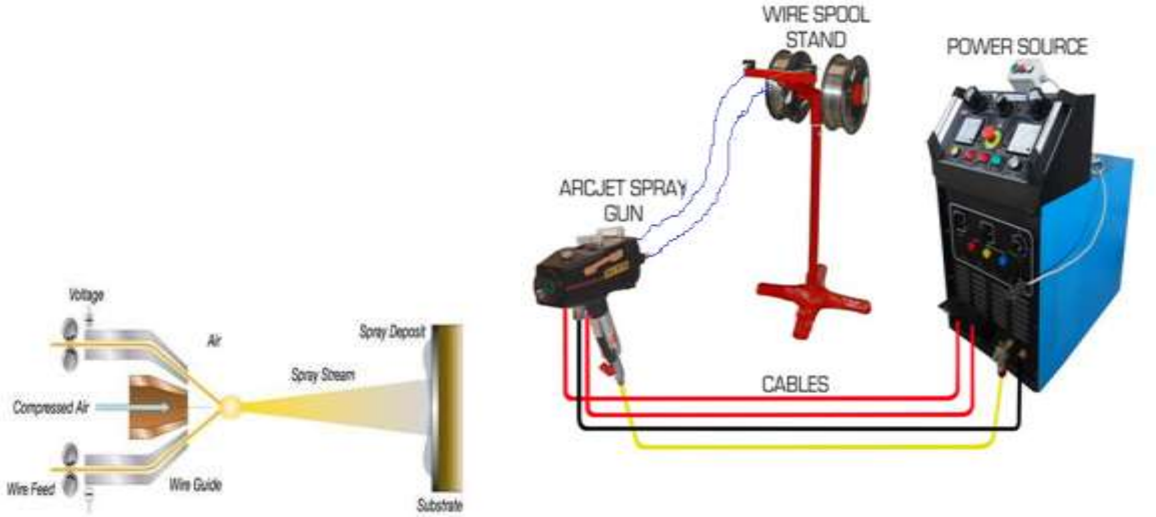

Fig. 8 (a&b): Schematic views of electric arc spray system

Fig. 8 (c) Schematic view of electric arc wire spray process gun

Wire Arc Spray coatings is gaining the potential due to lower operating costs, higher material output per hour, and production of a more coarse coating than the Plasma or HVOF methods. Wire Arc coatings are exceptionally suited for dimensional restoration of both mis-machined, worn parts and also provides on-site soultion. Hence offers versatility and high reliability [13]

On the basis of kinetic energy, thermal spray process is classified as:

1. **Cold spray**

Cold gas dynamic spray is a comparatively recent spray method which relates to a broad group of thermal spray processes in which solid powder particles usually metals, ceramics, composites, and polymers etc are accelerated in a converging- diverging de Laval nozzle in the direction of substrate. The dense solid powder particles are deposited on the substrate by supersonic speed impact at a temperature less than the melting point of the powder material. If the impact velocities go beyond a critical limit, powder particles undergo permanent deformation and stick to the material surface. Cold spray can be used for depositing metals, ceramics, polymers, synthesized materials and nanostructure powders. The schematics presentation of cold spray methods is shown in Fig. 9 (a &b).

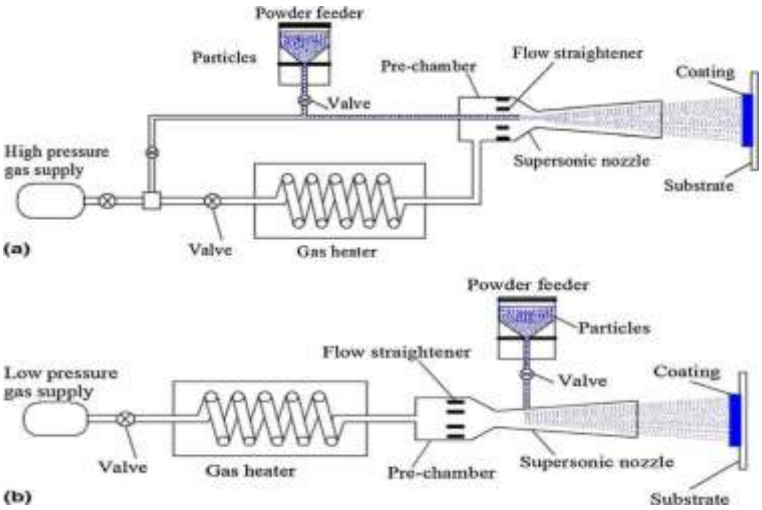

Fig. 9(a&b) Schematic presentation of cold spray methods (a) HPCS (b) LPCS

The main benefits of cold spray as compare to thermal spray methods are the low temperature involved with no heat. Another advantage include no oxide formation, low porosity (below1%), high thermal and electrical conductivity, high density, more hardness of coating, improve wear resistance, heat abrasion, high impact strength, oxidation and high corrosion resistance. In HPCS the powder feeders are commonly big in size and hence costlier. Another drawback of HPCS is linked to nozzle clogging and wear which is due to high temperature and particle velocity; despite in cold spray the carrier gas (helium) is very expensive unless recycled. Cold spray application includes manufacturing and restoration [14] in the area of aerospace, medical, marine, electronics, machine repair, automotive, and organic compound plants [15]. Cold spray coating are most widely employed to produce packed, thick, pure and well bonded layers of different metals and alloy like Aluminum , Copper, Nickel, Silver, Tantalum, zinc, as well as nickel base alloys, stainless steel and bond coats (MCrAlYs) [16].The main feature of thermal spray coating is summarized in Table 1.

Table 1.Features of thermal spraying coatings [17]

Heat Input/source	**Process**	**Particle velocity (m/s)**	**Heat source temp. (°C)**	**spray materials**	**Adhesive strength (MPa)**	**Porosity (%)**	**Features**
Chemical energy (gas)	Flame spray	200	2000	Metals, oxides	20 to 40	10 - 20	It used a combustible gas flame whose heat sources are oxygen and acetylene to melts the spraying material which is in the form of powder, wire, or rod
	HVOF	700	2000	Metals, cermet	> 70	1 - 5	The thermal spray particles collide with the base material surface at a very high speed and produce dense coating.
	D-Gun	800	3500	Metals	> 70	<1	Used for coating refractory material on any substrate.
Electric energy	Arc spray	300	5000	Metals	20 - 40	10 - 20	Material must have electrical conductive.
	Plasma spray	500	5000-10000	Metals, ceramics, cermet	20 - 70	1 to 20	Any refractory material can be sprayed on any substrate.
Kinetic energy	Cold spray	300-1200	100-500	Metals, ceramics, polymers, composite..	>60	1-5	In this a very less porous coating is achieved with no residual stresses and higher microhardness.

Preventive Measures against Corrosion

Although corrosion problems cannot be completely eliminated, but the application of better corrosion control techniques help to reduce the corrosion related cost. Overall economic loss due to all the types of corrosion accounts to US$ 6500 million annually in India (http://www.financialexpress.com/news/-cost-of-corrosion-in-india-at-rs-36000-cr-/118088/ accessed on 27 October 2012). Coating is the one of the effective a way of extending the limits of the usage of materials at the upper end of their performance capabilities, by allowing the mechanical properties of substrate materials to be maintained while protecting them against the wear or corrosion [18].

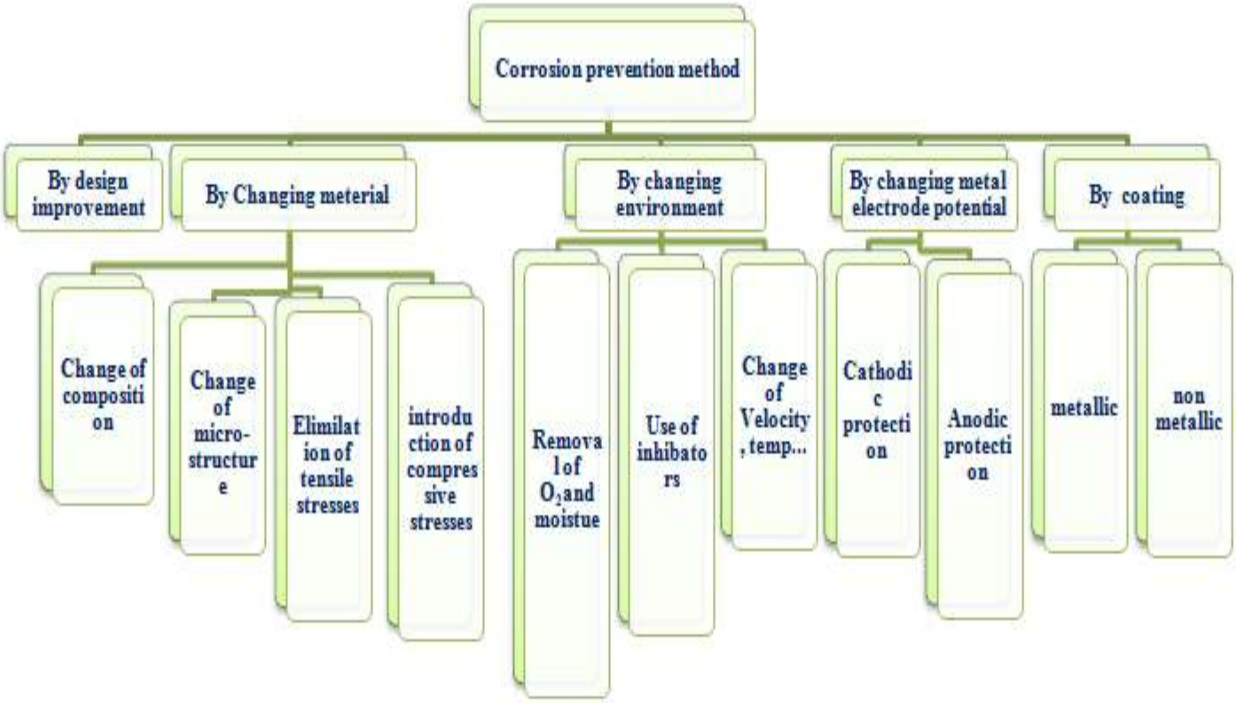

Fig. 10 Classification of Corrosion Prevention Methods [19]

III. DISCUSSION

In the thermal spray coating study, we have concentrate on general introduction of some of the major thermal spray coating processes such as Detonation gun spray, Flame spray, High velocity Oxy-Fuel Spray, Plasma spray, Wire arc Spray, and Cold spray in brief and explain detail only of Wire arc Spray process. All thermal spray processes were used according to properties required, price, fitness of process for particular material etc.

IV. SUMMARY

The major function of surface technology is to produce functionally useful surfaces. Coating improves the life of the part and lowers the price of replacement. An extensive range of coatings can increase the corrosion, wear resistance and erosion of materials. From the study it is found that thermal spray coating is most important techniques of the surface modification. The high hardness, uniform coating thickness and continuous layer of coating can be obtained by using High velocity oxygen fuel spray process. Expect that wire arc spray also gaining importance now a days due to lower cost, high spray rate, and thicker coatings, and overall simplicity and flexibility

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