

VARIOUS METHODS OF SURFACE COATING OF ENGINEERING MATERIAL: A REVIEW

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The development of new, advanced-performance hard protection coatings is very important for advancement in a number of science and industrial fields. The use of coatings on products in global manufacturing is now common to minimize production costs and increase profitability, both of which are necessary if the industry wants to stay economically competitive. Hard protective coating can significantly improve parts and system performance in many industrial applications, including aerospace, car, manufacturing, and the other industries, enhancing their service life and saving energy. The material's longevity depends on its quality. High quality materials are intrinsically durable. Durability can be improved by choosing products correctly to suggest, position and heal. One way to enhance durability of material is by the application of a coating. The coated materials have a high hardness than those of the uncoated materials. This review paper discusses various techniques of coatings.

1. INTRODUCTION

Hard protective coatings are typically placed on the surfaces of bulk products to secure them from degradation or failure. The development of hard protective coatings is motivated by the demands for improved tribomechanical surface properties of components and parts in various fields of application such as automotive, microelectronics, aerospace, and many others. "Coating" involves a coating applied to other materials to modify surface properties, such as wear resistance, polish, color, permeability or chemical attack without altering the bulk characteristics. A coating is a covering applied to an object's surface, commonly referred to as the layer. There are different coating forms such as Electrochemical Coating, Mechanical Coating, Thermo Coating, Thermo chemical coating, Vapor Deposition coating etc. This term also applies to paints such as enamels or lacquers but also to films that adhere to other materials such as, sealants, varnishes, maskers, inks, adhesives and temporary coatings for the protection purposes. The main challenges of modern industrial processes are the production and manufacture of components with low wear and low friction coefficient for a broad spectrum of working environments. Surface engineering is an emerging area of study, due to the high demand for frictional control and wear resistance combined with a methodology that enables new coatings providing improved tribological and mechanical results. These coatings are used in many tribological fields including aerospace parts or devices, gas turbine rollers, diesel engine piston rings etc. The increased stress and wear contributes to large energy and material losses and lowers mechanical systems' efficiency [3]. The utilisation of coatings to enhance the tribological properties of devices (e.g. for cutting and shaping metals) and system parts (e.g. valves, sliding bearings) is increasingly growing. The number of coating structures, materials, combinations and applications has grown substantially during the last decade. Despite sufficient hard protective coatings, we could not envision high speed machining, rough machining, and dry machining. Most coatings are usually referred to as protective or decorative depending on whether the key reason for their application is to preserve (or change) the appearance or to shield the surface. The two goals are often combined. The coating development over the years is mainly focused on enhancing the coatings for reducing the coating thickness and improving corrosion resistance [1]. To metal coatings, There are two aspects — metals as coatings on any substrates and coatings on metal substrates. The former can be grouped into a single-word "metallizing" type, which is achieved in several ways. On the other hand the latter, coatings applied on metal substrates, are usually called paint-type materials but can include inks, waxes, and other types of coatings. The two subjects will be dealt with separately, starting with metallisation, since these metal surfaces are often coated and painted. The aim of metallisation techniques is to deposit metal on the substrate for protection or appearance purposes. The metallization groups are numerous and diverse, but can

be distinguished by the specifics of their processes. Processes applying metal to surfaces that use metal as individual ions or atoms, as the solid metal or molten metal. We deal separately with each of these [2].

2. SURFACE COATING PROCESSES

The use of surface coatings and plating for the finishing of component surfaces is common in processing. It is applied as thin films and these coatings provide surfaces with longevity, protection and/or decoration to the surface of the parts. The most popular technology used for surface coating and plating include:

- Vapor deposition
- Chemical and electrochemical deposition
- Spraying.

2.1. Vapor Deposition

Vapor deposition refers to any process by means of oxidation, condensation or chemical reactions to form a solid material in a vapor environment. It is a family of processes employed to deposit layers of substance atoms on a solid surface by molecule or atoms. These coating techniques are employed to modify the thermal, corrosion resistance, wear resistance, mechanical, electrical and optical properties of the substrates. These are also used to shape independent bodies, fibers, films and to penetrate fibre to form material composite. There are two types of processes for vapour deposition:

- Physical vapor deposition.
- Chemical vapor deposition.

2.1.1. Physical Vapor Deposition

Physical vapor deposition is basically a vaporization coating process which involves atomic level material transfer. The surface is extracted from a combination of neutral or ionized metal atoms in the vacuum for processes of physical deposition. The material that is incorporated into the substrate is added in a solid form in this process. Except for the raw material, the process is identical to CVD. The substance to be deposited starts in solid form, while the precursor in CVD is in the gaseous state when introduced in the reaction chamber. There are several PVD methods for the deposition of diverse coatings. Among them, the most commonly used techniques for depositing different coatings are, magnetron sputtering cathodic arc vapor and hybrid magnetron and arc processes. Such PVD processes vary in terms of plasma conditions and the form of metallic component evaporation used during the process of deposition. The transition of the metallic part from a solid to a vapor phase can be achieved by a target sputtering (i.e magnetron sputtering) or heating a source of evaporation (as in the cathodic arc). Magnetron sputtering and Cathodic arc techniques allow metals to evaporate from a lloy of Ti–Al cathode / target at different melting points such as Ti and Al. The process of PVD arc evaporation uses more input energy as compared to PVD sputtering technique. For arc evaporation, a small portion of cathodic region with a very high-energy arc is evaporated, which rapidly passes to a point on the surface of the metal to be evaporated and the produced plasma is made of ionized metal vapour. Atoms are sputtered by the action of energy-neutral atoms or ions mechanically expelled from a target. Uniform coating of non-planar substrates is not feasible in most physical vapor deposition methods without specialized rotation/translation of substrates or the use of several, spatially dispersed sources (e.g. cylindrical sputtering of magnetrons). This is because the vapor atoms are formed in a higher vacuum which means that the transfer of vapor to the substratum is almost collisionless. The main downside of the cathodic arc cycle is macro-particulate formation. Such macro-particulated materials are the result of droplets forming low melting materials (e.g. aluminum for (Ti, Al)N covering) during arc evaporation. There is assumption that rapid evaporation during the cathodic arc process

creates excess atoms which are not fully ionized until they reach the substratum surface. These excess neutral atoms become macro particles throughout the flight. The 'enhanced arc' and 'distributed discharge by hot cathode' concepts have been attempted to mitigate this problem. Coll et al's method of spreading arc discharge over a thermally insulated cathode has led to a major reduction in macro particles. Coll et al. subjected the plasma stream with an electric field and excluded other macro particles. Wang et al. used a straight particle filter duct to reduce the particulate matter expelled from the cathode spring. A straight duct particle filter was used by Wang et al. to reduce macro particles expelled from cathode source and increase plasma intensity before cathode surface.[3,4].

2.1.2. Chemical Vapor Deposition

CVD is a process for solid deposition and the creation of a thin film from gaseous phase material. The broadest sense of CVD involves the creation of a thin solid film on a material surface by vapor-phase precursor chemical reaction. This can also be differentiated from processes of physical vapor deposition, such as reactive and evaporation sputtering, involving the adsorption of molecular species and adsorption of atoms on the substrate. The precursor species' chemical reactions occur in the gas and substrate phases. Thermal CVD, plasma-enhanced CVD or higher frequency radiation such as UV (photo-assisted CVD) may stimulate or cause reactions. Deposition of metal-organic chemical vapours is a particular form of chemical vapor deposition utilizing metal-organic precursors. A metal-organic (or organometallic) compound comprises a direct metal-carbon bond (s or p) (e.g. metal carbonyls, metal alkyls) in the strictest sense. Nevertheless, the concept of MOCVD has been extended to include precursors containing metal-nitrogen bonds (e.g. metal alkylamides) or metal-oxygen bonds (e.g. metal-b-diketonates, metal-alkoxides) and also metal hydrides (e.g. alane trimethylamine). Organometallic vapor epitaxy (OMVPE) Metal-organic vapor epitaxy (MOVPE) or is a MOCVD method producing single crystal (i.e., epitaxial) films from metal-organic precursors on single crystal substrates. Gas-phase reactions in MOCVD and MOVPE may often play a significant role in the chemical deposition. Plasma-assisted or plasma-enhanced CVD is a technique used to create homogeneous reaction to generate chemically active ions and radicals that take part in heterogeneous reactions that effectively lead to the formation of substrate layers. A significant benefit of PECVD over thermal CVD processes is that deposition can occur very near to the ambient at very low temperatures, enabling the use of temperature sensitive substrates. Atomic layer deposition (ALD) is the modification of the CVD process in which gaseous precursors are applied sequentially to the surface of the substratum and the reactor is purged or replaced with an inert gas from the precursor pulse, also called atomic layer epitaxy (ALE), alternative CVD pulsed or radioactive layer chemical vapor deposition. The chemical reactions leading to film deposition in ALD only occur on the substratum under the temperature of the metal containing precursor and gas phase reactions are not important. Chemical beam epitaxy (CBE) is a high-speed CVD technique that uses gasses and organic metal precursors, and is closely related to the non-organic molecular beam epitaxy (MOMBE) method, using solid element and volatile organic-metal precursors vapor co-precursors. TCBE and MOMBE chemical reactions occur only in the substratum leading to single crystal-shaped films and thus gas phase reactions do not play an important role in film production. Uniform fibre-shaped coating thicknesses can easily be achieved in CVDs, as the flux is uniformly dispersed onto the fiber surface. However there are extreme difficulties in chemical vapor deposition of the metal alloys needed for metal matrix composites. Uniform coating of the non-planar substrate is not feasible for most PVD based processing approaches, without specialized rotation or translation of substrates or the application of many spatially distributed sources. This is because the vapor atoms form in high vacuum, leading to a decrease in the flow of vapour to the ground almost at a collision. Consequently, the vapor source only coats regions on the line-[5].

2.2. Chemical and Electrochemical Plating

The term electroless metal deposition was coined for the first time by Brenner and Riddell in 1946 and is explained as an autocatalytic method of depositing the material in the absence of an external electrical source. Electroless metal deposition plays a vital role in modern technology, particularly when manufacturing advanced materials for electronics applications, corrosion and wear resistant material, battery technologies, medical applications[6]. The process is autocatalyst and progresses on the newly-formed active catalytic surface. An element (the part to be covered) that is normally the cathode is electrified on an electrode when the electroplating is finished. Metals and alloys shall be deposited in this manner other than aluminum and titanium. Excepting aluminum and titanium, metals and alloys shall be deposited in this manner. The materials produce the anodizing aluminum and its alloys in an aqueous electrolytic solution[7] in which an oxide layer is formed on the surface.

3. THERMAL SPRAYING

Thermal spray is a mechanism in which coating materials are fused and particles on the substratum surface that is filled with kinetic energy are affected. The coating material is pushed to the medium using a gas stream or compressed air, creating a surface structure on a specific substratum on the basis of the thermal spraying procedure used. Molded or half-melted materials with kinetic energy impact the substratum surface and easily solidify and shape splits. A splat is in pancake-like, single-impact particle shape. The splat is less than tens of a micrometer in the case of plasma spray. The alternating break is a region in which it is solidified and secured. The molten or half-molten layer materials affecting the substrate may lead to one or more of these possible bonding mechanisms, i.e. the accumulation of coating. The particles interconnect with the surfaces of the red substratum, ii) Local distribution of the substratum coating material, and iii) Van der Waals force binding mechanism. Process parameters like distribution of droplet size, speed, degree of solidification, substrate material and temperature depend on the physical properties of thermal spraying coatings such as porosity, covering density. Process parameters like the distribution of the droplet size, velocity, solidification degree, substratum material and prototype depend on the physical properties of spraying coatments such as porosity, coating density. The energy source used for heating and melting of the coated particles can be the combustion of fuel gasses, electric arcs and plasma arcs such as flame and arc spray, known as metalization, and (ii) high-energy processes like plasma spraying, detonation arms or high-speed oxygen powder. Coatings under the vacuum system should be done to track deposition of oxides on the covered area. The thickness of the coating will vary from 25 μ m to 2,5 mm depending on the application of the particle portion or unit. The coating is used for the following purposes: increased resistance to corrosion and wear, (ii) electromagnetic protection or electrostatic defense, (iii) protection against radio frequency interference, (iv) surface erosion, and (iv) defense against cosmetic problems. Thermal spray coating can be classified into five most common processes; i) spraying of the flame arc, (ii) spraying of the electric arc, (iii) spraying of the plasma arc, (iv) oxy / fuel (HVOF) and (v) spraying of the gun[8,9].

3.1. High Velocity Oxy-Fuel Flame (HVOF)

High-speed oxide fuel process (HVOF) is an innovative coating process for thermal coating on components used in turbines. HVOF process is a thermal spray coating system and is commonly used to apply wear, degradation and corrosion protective coatings to industrial turbine components. Both systems employ significantly higher upstream pressure than flame spray and a de Laval nozzle; supersonic gas flow rates are distinguished from each other. The combustion of a hydrocarbon molecule (CxHy) as either liquid or gas is accomplished with an oxidizer, either air or oxygen at pressures range of 0.24 - 0.82 MPa or even higher for high-power weapons in a combustion chamber is followed by a convergent-divergent de Laval nozzle hitting very high gas velocities. The final procedure is to inject nitrogen into the chamber of combustion to increase the speed and decrease the temperature of the gas. Usually powders are used that are either pumped radially or axially or both, depending on the configuration of the weapon. Few equipment was developed to use cored wires or wires. For axial injection liquid feedstock injection has been primarily developed recently. Substrate and coating have to be cooled before

spraying. Power rates for HVOF guns that work with gases are about 100-120 kW, while guns that work with liquid can reach 300 kW. Globally, this technique, operating mainly with cermet, metals, alloys and has the efficiency of the disposal of gas fuel guns at powder flow levels up to 7,2kg.h⁻¹, and up to 12kg.h⁻¹ at liquid fuel guns is approximately 70%. The porosity of the coating is very low (between 0.5 and a few%), with strong substrate adherence (approximately 60-80 MPa) and a very low oxygen content. It is very messy, powdery, with huge amounts of explosive gas [9, 10].

4. PLASMA SPRAYING

The powder is injected into a plasma jet during plasma spraying that is produced into the plasma flashing lamp by electric to thermal energies. In the plasma stream, the particles are accelerated and heated, and then impact on the substratum where the sudden deceleration causes the particle-interface to build up pressure, which allows material in liquid form to flow laterally. There is outward spreads of liquid from the point of contact which solidifies and take a form of lamella; piling these lamellae builds up the coating. The size of the injected particles in air plasma spraying (APS) is typically between 10 and 100 µm, and the resultant lamellae are a few micrometers thick and vary from a few tens to hundreds of micrometers in diameter. Therefore, even if the columns or grains which develop within a lamella during a solidification process can vary from few ten to a few hundred nanometers, the main referral scale of the coating microstructures (lamelage size, unmelted particles embedded in a coating, void, cracking etc.) is the micrometer. For the creation of a clear coating, the minimum coating thickness is around 50 µm [11].

5. CONCLUSION

The current analysis presented the different forms of coating technologies. This paper aims to enhance awareness about the use of different coatings whose function is to minimize wear, however it is also true that they have remarkable porosity and corrosion efficiency is improved as the number of layers increases as the film sealing improves. Coatings are commonly used in many industries against corrosion or corrosive wear: land-based generators, aerospace, automobile, glass and ceramic manufacturing, paper and pulp, metal processing, chemical, nuclear, printing industry, waste disposal, cement etc. Nevertheless, these coatings must be removed in almost every case in order to avoid porosity. This is done by the use of self-fluxing alloys that are fused after spraying, heat treatment or annealing, laser glazing, untempering, peening densification, diffusion sealing with organic / inorganic materials or metals. These post-treatment processes raise coating costs. For certain cases, however, the cost of retreated coatings is lower than the use of bulk materials and this is especially true for the repair of parts [9].

REFERENCES

- [1] Corrosion mechanisms of ZnMgAl coated steel in accelerated tests and natural environment by Par Marcelle SALGUEIRO AZEVEDO, April 2015.
- [2] Coatings Materials and Surface Coatings, Metal Coatings by Robert D. Athey, Jr. Athey Technologies.
- [3] Physical vapor deposition on cylindrical substrates D.D. Hassa,*, Y. Marcianob, H.N.G. Wadleya, 2003.
- [4] REVIEW OF PHYSICAL VAPOUR DEPOSITION (PVD) TECHNIQUES FOR HARD COATING by A. Mubarak, E. Hamzah, M. R. M. Toff, December 2005.
- [5] Overview of Chemical Vapour Deposition by ANTHONY C. JONES AND MICHAEL L. HITCHMAN, 2009.
- [6] Chemical and electrochemical depositions of platinum group metals and their applications by Chepuri R.K. Rao, D.C. Trivedi, November 2004.
- [7] Overview of Thermal Spray, Thermal Spray Fundamentals From Powder to Part by Fauchais, P.L.; Heberlein, J.V.R.; Boulos, M. 2014.
- [8] THERMAL SPRAY COATING TECHNOLOGY – A REVIEW by R.J. Talib, S.Saad, M.R.M. Toff, H. Hashim. Solid State Science and Technology, Vol. 11, No.1 (2003) 109-117.

[9] Thermal Sprayed Coatings Used Against Corrosion and Corrosive Wear by P. Fauchais and A. Vardelle, SPCTS, UMR 7315, University of Limoges, France.

[10] Combating Corrosion Degradation of Turbine Materials Using HVOF Sprayed 25% (Cr₃C₂-25(Ni₂₀Cr)) + NiCrAlY Coating by N. Jegadeeswaran,¹ M. R. Ramesh,² and K. Udaya Bhat¹, International Journal of Corrosion, Volume 2013.

[11] Mr. N. Jayakumar, Dr. S. Mohanamurugan, Dr. R. Rajavel and Mr. V. Srinivasan, “Morphological Characterisation of Poly Methyl Methacrylate for Surface Coating of Metals”. International Journal of Mechanical Engineering and Technology (IJMET), 6(8), 2015, pp. 139–143.

[12] A Perspective on Plasma Spray Technology by Armelle Vardelle • Christian Moreau • Nickolas J. Themelis • Christophe Chazelas, Plasma Chem Plasma Process (2015) 35:491–509 OI 10.1007/s11090-014-9600-y

