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Recent Advancements in Thermal Spray Coatings

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Abstract: *Different methods and techniques are employed to protect the materials from degradation. Within most industry segments, significant financial losses may be incurred due to accelerated wear of various components. In order to minimize the effects of mechanical wear and extend product life, thermal spray coating solutions introduced into production and is further developing them to meet even more demanding wear applications. Applying coatings using thermal spray is an established industrial method for resurfacing metal parts. The process is characterized by simultaneously melting and transporting sprayed materials, usually metal or ceramics, onto parts. In this paper some studies on Thermal sprayed wear resistant coatings have been reviewed.*

Keywords: *thermal spraying, detonation gun, grey cast iron.*

I. Introduction

Thermal spraying is a family of processes that use combustion or plasma energy to heat and accelerate the millions of particles, which impact onto the surface of a target/forming remarkable continuous uniform solid layer [1]. Thermal spraying is an effective and low cost method to apply thick coatings to change surface properties of the component [2]. Coatings are used in a wide range of applications including automotive systems, boiler components, and power generation equipment, chemical process equipment, aircraft engines, pulp and paper processing equipment, bridges, rollers and concrete reinforcements, orthopedics and dental, land-based and marine turbines, and ships [2]. For depositing wear resistant thermal spray coatings, the commonly used powders are WC–Co (with Co lying in the range 8–15 wt.). Previous experimental studies have revealed that the hardness and elastic modulus of coatings obtained using the above powders are substantially lower than the hardness and modulus of bulk material of identical composition [3-4]. Indeed, these mechanical properties are dependent not only on the nature and distribution of phases present in the coating (largely determined by powder composition) but also on a host of other properties like coating microstructure (layered structure resulting from splat formation during the coating process), porosity, the nature of residual stress and its magnitude within the coating and finally the coating-substrate adhesion. The purpose of this paper is to present the development status of the Thermal spray wear resistant coating with Detonation gun.

II. Thermal Spray Processes

Thermal spraying can be used to apply coatings to machine or structural parts to satisfy a number of requirements: Repair worn areas on parts damaged in service Restore dimension to mismachined parts Increase a part’s service life by optimizing the physical surface properties The primary advantages of thermal spraying include the range of chemically different materials that can be sprayed, a high coating deposition rate, which allows thick coatings to be applied economically, and spray equipment portability. Heath et al [5] have summarized the thermal spray processes that have been considered to deposit the coatings, are enlisted below:

- Flame spraying with a powder or wire,
- Electric arc wire spraying,
- Plasma Spraying.
- High Velocity Oxy-fuel (HVOF) spraying,
- Spray and fuse.
- Detonation Gun.

Selection of the appropriate thermal spray method typically is determined by:

- Desired coating material
- Coating performance requirements
- Economics
- Part size and portability

III. Detonation Spray Process

Fig. 1, given below represents the detonation spray process in which a precisely measured quantity of the combustion mixture consisting of oxygen and acetylene is fed through a tubular barrel closed at one end. In order to prevent the possible back firing a blanket of nitrogen gas is allowed to cover the gas inlets. Simultaneously, a predetermined quantity of the coating powder is fed into the combustion chamber. The gas mixture inside the chamber is ignited by a simple spark plug.

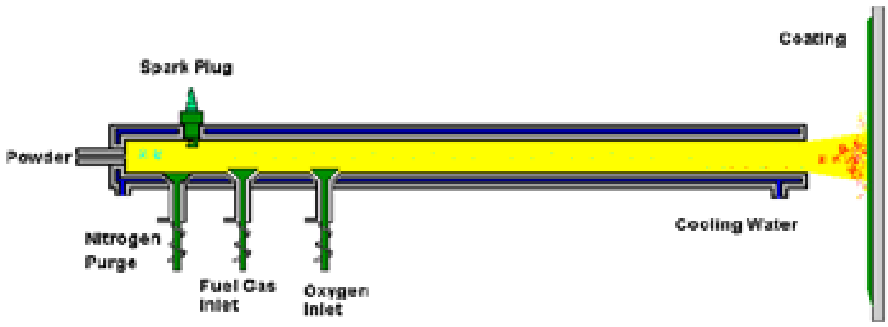

Fig. 1: Schematic Diagram of the Detonation Sprays Process

The combustion of the gas mixture generates high pressure shock waves (detonation wave), which then propagate through the gas stream. Depending upon the ratio of the combustion gases, the temperature of the hot gas stream can go up to 4000 deg C and the velocity of the shock wave can reach 3500 m/sec. The hot gases generated in the detonation chamber travel down the barrel at a high velocity and in the process heat the particles to a plasticizing stage (only skin melting of particle) and also accelerate the particles to a velocity of 1200 m/sec. These particles then come out of the barrel and impact the component held by the manipulator to form a coating. The high kinetic energy of the hot powder particles on impact with the substrate result in a buildup of a very dense and strong coating. The coating thickness developed on the work piece per shot depends on the ratio of combustion gases, powder particle size, carrier gas flow rate, frequency and distance between the barrel end and the substrate. Depending on the required coating thickness and the type of coating material the detonation spraying cycle can be repeated at the rate of 1-10 shots per second. The chamber is finally flushed with nitrogen again to remove all the remaining "hot" powder particles from the chamber as these can otherwise detonate the explosive mixture in an irregular fashion and render the whole process uncontrollable. With this, one detonation cycle is completed above procedure is repeated at a particular frequency until the required thickness of coating is deposited.

IV. Studies Related To Detonation Gun Sprayed Coatings

Sova et al. [6] studied the development of multi material coatings by cold spray and gas detonation spraying. The basic objective was the development of multifunctional multi material protective coatings using cold spraying (CS) and computer controlled detonation spraying (CCDS).As far as CS was concerned, the separate injection of each powder into different zones of the carrier gas stream was applied. Cu–Al, Cu–SiC, Al–Al_2O_3,Cu–Al_2O_3 ,Al-Ti and Ti-SiC coatings were successfully sprayed. As to CCDS, powders were sprayed with a recently developed apparatus that was characterized by a high-precision gas supply system and a fine dosed twin powder feeding system. Computer control provided a flexible programmed readjustment of the detonation gases energy impact on powder thus allowing selecting the optimal for each component spraying parameters to form composite and multilayered coatings. Several powders were sprayed to obtain composite coatings, specifically, among others, WC– Several powders were sprayed to obtain composite coatings, specifically, among others, WC– Co–Cr + Al_2O_3, Cu +Al_2O_3, and Al_2O_3 + ZrO_2.

Estimation of residual stress and its effects on the mechanical properties of detonation gun sprayed WC–Co coatings was done by Wang et al. [7]. Thick coatings seriously affect coatings performance during their service. Authors gave importance to understand the mechanisms by which the stresses arise, to predict and control the stresses for improving coating properties. Because the Stoney formula is commonly used to relate stress to curvature for thin coatings, a new calculation formula was developed to estimate the residual stresses of thick coatings that represent a comprehensive stress state of the coated specimen. Based on the deduced formula and accurate curvature measurements, the residual stresses of detonation gun (D-Gun) sprayed WC–Co coatings with different thickness were obtained. With increasing the coating thickness, the residual stress changed gradually from the tensile nature to a compressive nature. Meanwhile, the coating was in an approximately stress- free state at the thickness of around 365 µm. The analysis results emphasized the significance of penning stress in controlling the final stress state of the coated specimen, due to the high spraying velocity and kinetic energy during the D-Gun spraying process. Finally, the effects of residual stress on the mechanical properties of the coating were understood, namely, the compressive stress could significantly improve the coating properties, whereas the tensile stress impaired the coating properties.

Murthy et al [8] investigating the effect of grinding on the erosion behaviour of a WC–Co–Cr coating. As a part of this work a comparison has also been brought out between two high velocity coating processes namely High Velocity Oxy-Fuel (HVOF) and detonation gun spray process (DS). A WC–10Co–4Cr powder has been sprayed on a medium carbon steel using the above mentioned high velocity sprays processes. The coating in both 'as-coated' and 'as-ground' conditions has been tested for solid particle erosion behaviour. It has been found that surface grinding improved the erosion resistance. This work presents detailed characterization of the WC–Co–Cr coating in both 'as-coated' and 'as-ground' form. A detailed analysis indicates that the increase in residual stress in the ground specimen is a possible cause for the improvement in erosion resistance.

Sundararajan et al. [9] evaluated the tribological performance of 200 µm thick TiMo(CN)–28Co and TiMo(CN)–36NiCo coatings obtained by using the detonation spray coating system. Towards the above purpose, the detonation spray coating conditions were optimized to obtain the best coating properties (low porosity, high wear resistance) by varying two of the important coating process variables, i.e., oxygen to fuel ratio and gas volume. In both the coatings it was observed that the best tribological performance and also the lowest porosity were obtained. However, the coatings with the highest hardness did not exhibit the best tribological performance. A comparison of the tribological performance of the optimized TiMo(CN) type coatings with that of optimized WC–Co coatings revealed that the abrasion resistance of TiMo (CN) type coatings is comparable to that of WC–Co coatings. However, the erosion and sliding wear resistance of TiMo (CN) type coatings were considerably lower than that of WC–Co coatings.

Kamal et al. [10] investigated the microstructure and mechanical properties of detonation gun sprayed NiCrAlY+CeO_2 alloy coatings deposited on superalloys. The morphologies of the coatings were characterized by using the techniques such as optical microscopy, X-ray diffraction and field emission scanning electron microscopy/energy-dispersive analysis. The coating depicted the formation of dendritic structure and the micro structural refinement in the coating was due to ceria. Average porosity on three substrates was less than 0.58% and surface roughness of the coatings was in the range of 6.17–6.94 µm. Average bond strength and micro hardness of the coatings were found to be 58 MPa and 697–920Hv, respectively.

Microstructure characterization of D-gun sprayed Fe–Al intermetallic coatings was done by Senderowsk et al. [11] Intermetallic Fe–Al type coatings about 100 µm thick were deposited on a plain carbon steel substrate by D-gun spraying technique. The 40–75 µm size fraction of the feedstock powder was obtained by self-propagating high-temperature synthesis and sieved prior to D-gun spraying. This powder contained a mixture of Fe–Al type intermetallic phases conventionally appointed FexAly. The Fe–Al coatings were analyzed by transmission electron microscopy, selected area electron diffraction, and semi-quantitative energy-dispersive X-ray analysis in micro-areas. Particular attention was paid to the substructure of the individual grains in the coating zone abutting the steel substrate. The Fe–Al coatings have a multi-layer composite structure. The results explain the formation mechanism of the coating microstructure. The powder particles, which were heterogeneous in chemical composition and structure, were heated, highly softened or even partially melted and oxidized while flying from the gun barrel to the substrate. After impacting the substrate or previously deposited material and being shot peened by the following powder particles, they were rapidly cooled and plastically deformed, creating overlapping splats. In the zone adjacent to the substrate, alternating FeAl and Fe_2Al_5 intermetallic phases for med columnar crystals. The columnar crystal areas were separated by elongated amorphous oxide layers. Areas of mixed equiaxed sub grains of FeAl and Fe_3al phases, fine grains of Fe-rich Fe(Al) solid solution, and micro- and nano-pores were also present.

Wang et al. [12] designed the separation device for detonation gun spraying system and studied its effects on the performance of WC–Co coatings. The WC–Co coatings were synthesized by the D-gun spraying system with and without using a separation device, respectively. The results showed that the use of the separation device resulted in better properties of the D-gun sprayed WC–Co coatings, e.g., lower the surface roughness, lower the porosity, higher the micro hardness, higher the elastic modulus, and higher the interfacial adhesive strength. Also, the tribological performance of the WC–Co coatings was improved. The relationship of surface roughness, micro hardness, elastic modulus, adhesive strength, and wear resistance of the WC– Co coatings with porosity was discussed. At the same time, there is an inevitable disadvantage for using the separation device, i.e., the relatively lower effective utility rate of the feedstock powder. Therefore, the separation device is suitable to be applied in occasions of high-performance requirements where increased costs are acceptable.

Formation and corrosion behavior of Fe-based amorphous metallic coatings prepared by detonation gun spraying was studied by ZHOU Et al [13]. Amorphous metallic coatings with a composition of $Fe_{48}Cr_{15}MO_{14}C_{15}B_6Y_2$ were prepared by detonation gun spraying process. Microstructural studies show that the coatings present a densely layered structure typical of thermally sprayed deposits with the porosity below 2%. Both crystallization and oxidation occurred obviously during spraying process, so that the amorphous fraction of the coatings decreased to 54% compared with fully amorphous alloy ribbons of the same component. Corrosion behavior of the amorphous coatings was investigated by electrochemical measurement. The results show that the coatings exhibit extremely wide passive region and low passive current density in 3.5% NaCl(mass fraction) and 1 mol/L HCl solutions, which illustrates excellent ability to resist localized corrosion.

Magdy et al [14] Cermet-based coatings are being increasingly used to combat erosion-corrosion in oil and gas industries such that occurring in offshore piping, production systems and machinery involving fluid and/or slurry flowing corrosive media which often contain solid particles such as sand. This leads to material substrate damage caused by the combined surface degradation mechanisms of erosion and corrosion. This review assesses the erosion-corrosion resistance and performance of cermet coatings applied by different thermal spraying methods. Electrochemical measurements, which monitor the erosion-corrosion mechanisms and coating integrity by themselves and when both erosion and corrosion act simultaneously are considered. In addition, surface characterization, and the extent of weight loss that covered through different combinations of cermet were reviewed.

V. Conclusion

Detonation sprayed coatings can play important role in protecting materials and alloys from wear and corrosion phenomena. It is possible to use the Detonation-Gun Spray system for developing protective Thermal spray coatings of almost any material like oxides, carbides, metals, hard alloys and composite material powders onto mild steel, and other EN series. There is no doubt that considerable progress has been made in the Detonation –Gun Spray process by optimizing the process parameters like Fuel Ratio, Carrier gas flow rate, frequency of detonations, and spray distance over the last few years. Applications of detonated sprayed coated components include gas turbine blades, camshafts, wire drawing pulleys, ball and gate valves, valve spindles, brake drums etc. Although Nano-structured coatings have been deposited by various other thermal spray processes like HVOF and plasma spray, however further studies are necessary to study the detonation sprayed nano-structured coatings on carbon nano tubes, Use of Thermally sprayed coatings on boiler steel to increase service life of boiler. Thermal spray coatings apply on grey cast iron to reduce wear and to test microbiological behavior of different Thermal spray coatings. Work has been done by various researchers to investigate the performance of detonation sprayed coatings. However more research is needed to evaluate the performance of detonation sprayed coatings in actual environment. Process parameters of Detonation spraying influence the microstructure, mechanical and other properties of the coatings. Research is needed in optimization of the process parameters of detonation spraying process

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