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PERFORMANCE OF THERMAL SPRAYED NICKEL-CHROME COATINGS – A REVIEW

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***Abstract*— *Hot corrosion is a serious problem in various high temperature applications. The thermal spray coatings provides possible solution to counter the problem of hot corrosion in high temperature environment and enhances the life of equipment. Thermal spraying is an effective and low cost method to apply thick coatings to change surface properties of the component. Thermal spraying, a group of coating processes in which finely divided metallic or nonmetallic materials are deposited in a molten or semimolten condition to form a coating. The coating material may be in the form of powder, ceramic-rod, wire, or molten materials. In this review, the performance of Thermal spray Nickel-Crome coatings by different investigators has been presented.*

***Key Words*— Thermal spraying, hvof, nickel-chromium coatings,**

1. INTRODUCTION

Metals and alloys sometimes experience accelerated oxidation when their surfaces are covered with a thin film of fused salt in an oxidizing gas atmosphere at elevated temperatures. This is known as hot corrosion where a porous non-protective oxide scale is formed at the surfaces and sulphides in the substrate [1].Hot corrosion first became known to engineers and researchers with the failure of boiler tubes, and later with the severe attack of gas turbine air- foil materials. One possible way to control hot corrosion is the use of thermal spray protective coatings [2].

Thermal spraying is an effective and low cost method to apply thick coatings to change surface properties of the component. 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, ships [4].Among the commercially available thermal spray coating techniques, Detonation Spray (DS) and High Velocity Oxy Fuel (HVOF) spray are the best choices to get hard, dense and wear resistant coatings as desired [3].The power plants boiler tubes of coal fires boilers suffers big economic losses due to high rate of corrosion, erosion-corrosion of boiler tubes. To overcome this problem the use of thin anti-wear and anti-erosion-corrosion thermal spray coatings is the perfect choice there is an increasing trend in the deposition of Ni based metallic alloy coatings such as Ni-20 wt.% Cr for protection against hot corrosion using thermal spray processes. This is because of high resistance offered by chromium, nickel-chromium alloys against high-temperature oxidation and corrosion. This makes Ni-Cr coatings widely used as welded and thermally sprayed coatings in fossil fuel-fired boilers, waste incineration boilers, and electric furnaces [5].In the present review, the resistance offered by Nickel-Crome coatings against hot corrosion is presented.

2. Thermal Spraying

Thermal spraying is one of the most versatile hard facing techniques available for the application of coating materials used to protect components from abrasive wear, adhesive wear, erosive wear or surface fatigue and corrosion (such as that caused by oxidation or seawater) . Generally, any material which does not decompose, vaporize, sublimate, or dissociate on heating, can be thermally sprayed. Consequently a large class of metallic and nonmetallic materials (metals, alloys, ceramics, cermet's, and polymers) can be deposited by thermal spraying [6].There are many thermal spray coating deposition techniques available, and choosing the best process depends on the functional requirements, adaptability of the coating material to the technique intended, level of adhesion required, (size, shape, and metallurgy of the substrate), and availability and cost of the equipment [7].

Thermal spray processes that have been considered to deposit the coatings are enlisted below:

(1) Flame spraying with a powder or wire, (2) Electric arc wire spraying, (3) Plasma spraying, (4) Spray and fuse, (5) Detonation Gun, (6) High Velocity Oxy-fuel (HVOF) spraying Some general remarks can be expressed in thermal spray coating: [8]

- Different materials require different deposit conditions,

- Specific coating properties (high density or desired porosity) may require specific particle velocity/temperature characteristics,
- The heat fluxes to the substrate depend on the coating method and for some substrate materials they have to be minimized,
- Substrate preheating and temperature control during spraying strongly affect coating properties and in particular residual stresses,
- And frequently a trade-off exists between coating quality and process economics.

The whole process concept of thermal spray coating is given below:

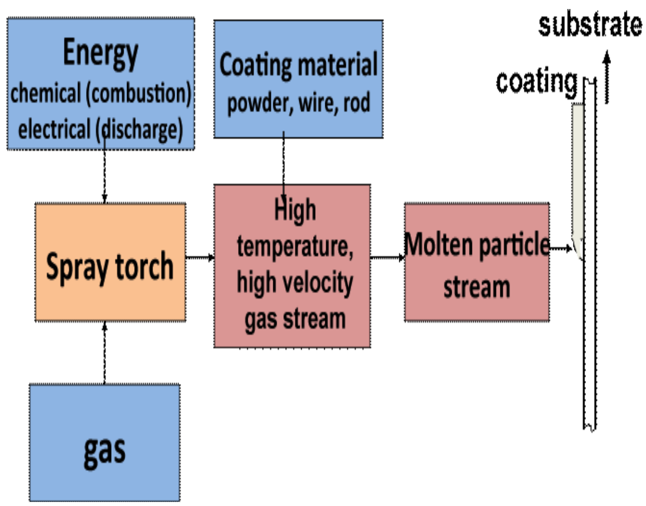

Fig -1: Schematic of the thermal spray concept [8].

High Velocity Oxy-fuel (HVOF) spraying:

HVOF Thermal Spray Process Unlike other flame spraying processes, the HVOF (High Velocity Oxy-Fuel) thermal spray process utilizes only powder as the coating material rather than wire or rod [13].HVOF utilizes confined combustion and an extended nozzle to heat and accelerate the powdered coating material. The HVOF devices operate at hypersonic gas velocities. This high velocity provide kinetic energy which help produce coatings that are very dense and very well adhered in the as-sprayed condition [8].HVOF is a thermal spray system utilizing the combustion of gases, such as Hydrogen or a liquid fuel such as kerosene. Fuel and oxygen mix and atomize within the combustion area under conditions that monitor the correct combustion mode and pressure. The process creates a very high velocity which is used to propel the particles at near supersonic speeds before impact onto the substrate. One of the basic rules of spraying is that high combustion pressure = high gas velocity, high particle velocity and resulting high coating quality. One of the key benefits of this system's high velocity is the extremely high coating density and low oxide content. The low oxides are due partly to the speed of the particles spending less time within the heat source and partly due to the lower flame temperature (around 3,000 °C) of the heat source compared with alternative processes.

During the 1980s, a class of thermal spray processes called high velocity oxy-fuel spraying was developed. A mixture of gaseous or liquid fuel and oxygen is fed into combustion chamber, where they are ignited and combusted continuously. The resultant hot gas at a pressure close to 1 MPa emanates through a converging–diverging nozzle and travels through a straight section. The fuels can be gases (hydrogen, methane, propane, propylene, acetylene, natural gas, etc.) or liquids (kerosene, etc.). The jet velocity at the exit of the barrel (>1000 m/s) exceeds the speed of sound. A powder feed stock is injected into the gas stream, which accelerates the powder up to 800 m/s. The stream of hot gas and powder is directed towards the surface to be coated. The powder partially melts in the stream, and deposits upon the substrate. The resulting coating has low porosity and high bond strength. HVOF coatings may be as thick as 12 mm (1/2").

It is typically used to deposit wear and corrosion resistant coatings on materials, such as ceramic and metallic layers. Common powders include WC-Co, chromium carbide, MCrAlY, and alumina. The process has been most successful for depositing cermet materials (WC–Co, etc.) and other corrosion-resistant alloys (stainless steels, nickel-based alloys, aluminum, hydroxyapatite for medical implants, etc.

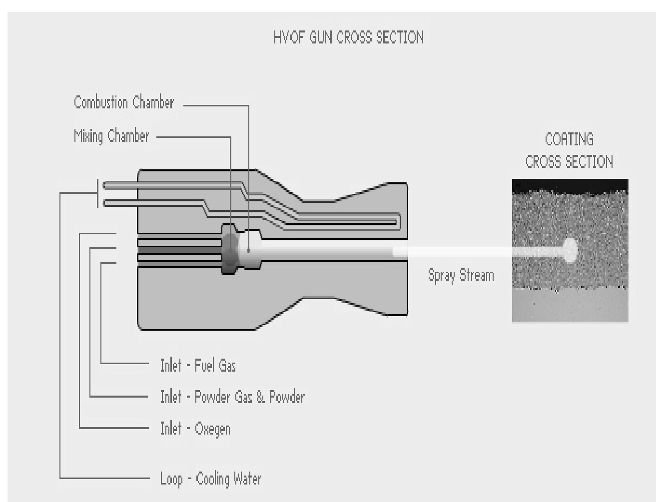

Fig.-2: Schematic diagram of HVOF spraying process [14]

3. STUDIES RELATED TO PERFORMANCE OF THERMAL SPRAYED NICKEL-CHROME COATINGS

The high resistance of high-chromium, nickel-chromium alloys to high-temperature oxidation and corrosion makes them widely used as welded and thermally sprayed coatings in fossil fuel-fired boilers, waste incineration boilers, and electric furnaces . Modern thermal spray processes such as high velocity oxy fuel (HVOF) and plasma spraying are often applied to deposit high-chromium, nickel coatings onto the outer surface of various parts of the boilers, e.g. tubes to prevent the penetration of hot gases, molten ashes, and liquids to the less noble carbon steel boiler tube [11].

J.A.Picas et al. [12] described and compared the mechanical and tribological properties of HVOF CrC75 (NiCr20) 25 coatings sprayed from three different feedstock powders with various powder size distributions. These results have been compared with hard chromium plating. The objective of the present work is applying the HVOF coatings in piston rings and valve stems applications. The coatings in this work are cr_3c_2 75% + NiCr20 25% weight deposited on a steel substrate with a thickness of approximately 150 µm, Three different 2075-NiCr powders were used as feedstock powders in the present investigation are standard, fine 10 µm and fine 5 µm. Although the Fine CrC–NiCr agglomerates, which show a higher decomposition during spraying, produce coatings with lower hardness, the wear behavior of these coatings is up to 50% better than standard CrC–NiCr coating. In Fine coatings the carbide and binder phase seem to be intimately bonded and reduce the pullout of hard particles that involves the abrasive wear mechanism.

Sidhu TS et al. [15] found that the hot corrosion resistance of Ni–20Cr coating was better than cr_3c_2–NiCr coating. The presence of oxides of nickel and chromium and their spinel's $NiCr_2O_4$, and uniform fine grain microstructure of the as sprayed coating might have contributed for better hot corrosion resistance of HVOF sprayed Ni–20Cr wire coating. These oxides might have blocked the pores and splat boundaries, and acted as diffusion barriers to the inward diffusion of oxidizing species.

Souza RC et al. [16] compared the influence of Cr_3C_2–25NiCr and WC–10Ni coatings applied by HVOF process and hard chromium electroplating on the fatigue strength, abrasive wear and corrosion resistance of AISI 4340 steel. S–N curves were obtained in axial fatigue tests for base material, chromium plated and HVOF coated specimens. HVOF coated specimens showed higher axial fatigue resistance and better performance in wear weight loss in comparison to electroplated chromium. Further for Cr_3C_2–25NiCr HVOF coating, results indicate clearly the higher salt spray resistance and higher micro hardness than for chromium electroplated.

Bala et al. [17] studied the high-temperature oxidation behavior of cold-sprayed Ni-20Cr and Ni-50Cr coatings on SAE 213-T22 boiler steel at 900˚C in air under cyclic heating and cooling conditions for 50 cycles. The kinetics of oxidation of coated and bare boiler steel was established with the help of weight change measurements and it was found that all the coated and bare steels obeyed parabolic rate law of oxidation. The uncoated steel suffered corrosion in the form of intense spelling and peeling of its oxide scale, which was perhaps due to the formation of un-protective Fe_2O_3 oxide scale. The trend of protection of coatings against hot corrosion is Ni-50Cr >Ni-20Cr.

The high-velocity air-fuel (HVAF) and HVOF coatings were heat treated for up to 30 days at 900˚C to generate a range of coating microstructures up to a steady state. Erosion was performed under the same conditions. Heat treatment increased the ductility of the NiCr phase, enabling ductile erosion deformation to occur. Inter splat sintering reduced the significance of splat based erosion mechanisms and forced mass loss to become dictated by the phase microstructure. Such developments improved the quantified erosion resistance of both coating systems relative to the as-sprayed conditions. The coating micro hardness was shown to be a poor indicator of erosion response across the range of coating microstructures investigated [18].

G Kaushal et al. [19] Ni-20Cr coatings on boiler steel ASTM A213, 347H using HVOF technique were studied in actual boiler environment at 700˚C and 900˚C under cyclic conditions to ascertain their erosion-corrosion (E-C) behavior. The kinetics of the hot corrosion was studied using mass change and thickness loss data. It was observed that overall mass loss was reduced by 31% and thickness loss by 44% after the application of the coating. During air oxidation exposures, the coating was found to be intact with only marginal spallation of its oxide scales, which is an indicator of good adhesion between the coating and substrate steel. The air oxidation mass change data revealed that the coating enhanced the oxidation resistance of the steel by 85%. Ni-20Cr coatings on ASTM-SAE 213-T22 using HVOF spray and detonation-gun (D-gun) spray techniques were deposited and studied. The salt(Na_2SO_4-60%V_2O_5)studies were carried out at 900˚C for bare and coated samples to access the kinetics of hot corrosion. Specimens were also exposed to the super heater zone of a thermal power plant boiler at an averagetemperatureof700˚Cundercyclicconditionstoascertai ntheir erosion-corrosion (E-C) behavior. The micro structural study revealed HVOF-sprayed coating intact during exposure to both given environments; whereas the D-gun coating showed spallation of its oxide scale during exposure to the molten salt environments. HVOF-sprayed Ni-20Cr coating offered better hot corrosion resistance in comparison to D-gun sprayed coatings in boiler applications. G Kaushal et al. [20].

Bala et al. [21] investigated the deposition of Ni-20Cr powder on T-22 boiler steel using HVOF and cold spray processes. To evaluate the performance of the coatings in actual conditions the bare as well as the coated steels were subjected to cyclic exposures in the super heater zone of a coal fired boiler for 15 cycles. It was found that the HVOF sprayed coating performed better than its cold sprayed counterpart in actual boiler environment.

A.H.G.Rana et al. [22] compared 75CrC25NiCr50 HVOF Coating and Hard Chrome Coating on pistons and valves. The HVOF coatings are applied on maximum weapons area in engine which are piston rings and valve stems applications. So the HVOF coatings are produced with fine powders in order to avoid the blasting and regrinding operations necessary when plasma spray coatings are used. We use three categories of powders which are standard, fine 5 µm and fine 10 µm. The Fine 75CrC25NiCr50 coatings provide superior performance with regard to mechanical and tribological properties. For future applications of 75CrC25NiCr50, HVOF coatings are used as alternative to hard chromium, where many factors like wear resistance, friction coefficient, costs and environmental issues are considered collectively.

Hussain et al. [23] evaluated of coatings for advanced fossil fuel plants and addresses fireside corrosion in coal/biomass-derived flue gases. A selection of four candidate coatings: alloy 625, NiCr, FeCrAl and NiCrAlY were deposited onto super heaters/re heaters alloy (T91) using high-velocity oxy-fuel (HVOF) and plasma spraying. A series of laboratory-based fireside corrosion exposures were carried out on these coated samples in furnaces under controlled atmosphere for 1000 h at 650 C. The tests were carried out using the ''deposit-recoat'' test method to simulate the environment that was anticipated from air-firing 20 wt.% cereal co-product mixed with a UK coal. The exposures were carried out using a deposit containing Na_2SO_4,K_2SO_4, and Fe_2O_3 to produce alkali-iron tri-sulfates, which had been identified as the principal cause of fireside corrosion on super heaters/re heaters in pulverized coal fired power plants.

The exposed samples were examined in an ESEM with EDX analysis to characterize the damage. Pre- and post-exposure dimensional metrologies were used to quantify the metal damage in terms of metal loss distributions. The thermally sprayed coatings suffered significant corrosion attack from a combination of aggressive combustion gases and deposit mixtures. In this study, all the four plasma-sprayed coatings studied performed better than the HVOF-sprayed coatings because of a lower level of porosity. NiCr was found to be the best performing coating material with a median metal loss of ~87 lm (HVOF sprayed) and ~13 lm (plasma sprayed). In general, the median metal damage for coatings had the following ranking (in the descending order: most to the least damage): NiCrAlY > alloy 625 > FeCrAl > NiCr.

4. .CONCLUSION

Hot corrosion poses a serious problem in high temperature applications like power plant boilers, gas turbines, waste incinerations, aircraft, and in other energy conversion and chemical process systems. The only solution to enhance the life of boiler tubes is to use the thermal spray coatings to counter the problem of hot corrosion. It has been concluded after reviewing the literature that nickel-chrome coatings can be successfully deposited on different boiler steels using various thermal spray processes. Further it is observed nickel alloyed with chromium oxidizes to Cr_2O_3, and other protective spinel phases such as $NiCr_2O_4$, which makes it suitable for use up to 950°C to counter hot corrosion in different environments.

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