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COMBATING HOT CORROSION OF BOILER TUBES WITH DETONATION GUN SPRAYED COATINGS: A REVIEW

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ABSTRACT

The behavior of materials at elevated temperature is gaining increasing technological importance. Understanding the behaviour of metals at elevated temperatures and especially their corrosion behaviour became an object of scientific investigation since long.Hot corrosion is a serious problem in boilers, gas turbines, internal combustion engines, and industrial waste incinerators. It consumes the materials at an unpredictably rapid rate. Alloys used at high temperature should possess good mechanical properties, corrosion and oxidation resistance. Thermal spray technology encompasses a group of coating processes that provide functional surfaces to protect or improve the performance of a substrate or component. Many types and forms of materials can be thermal sprayed, which provide protection from corrosion, wear, and abrasion and for a variety of other applications. Detonation gun spraying is one of the thermal spraying techniques known for providing hard, wear resistant and dense microstructured coatings. This paper summarizes the results of previous research done by various authors on different coatings done by detonation gun spraying technique.

***Keywords:* Hot Corrosion, Thermal spraying, Detonation gun**

I. 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 was first recognized as a serious problem in the 1940s in connection with the degradation of fireside boiler tubes in coal-fired steam generating plants. Since then the problem has been observed in boilers, internal combustion engines, gas turbines, fluidized bed combustion and industrial waste incinerators. Turbine manufacturers and users became aware of hot corrosion in the late 1960s when serious corrosive attacks occurred for helicopters and rescue planes in service overand near sea water during the Vietnam conflict[2]. 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[4].

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 [6].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 [5]. The objective of the work is to analyze the role of detonation gun spray coating to enhance the properties of surface of substrate to counter the problems like erosion, residual stress, fretting fatigue, thermal behavior and corrosion etc.

II. PREVENTIVE MEASURES AGAINST HOT CORROSION

Although corrosion problems cannot be completely remedied, it is estimated that corrosion-related costs can be reduced by more than 30% with development and use of better corrosion control technologies. Corrosion control measures include corrosion inhibitors, cathodic protection, and coatings[8].

III. COATING PROCESSES

Three processes are in current use from a production point of view. They are chemical vapor deposition (CVD) from a pack, physical vapor deposition (PVD) and thermal spraying (metal spraying) [3].

3.1 Classification of coating: [7]

a. **Overlay Coating**: This type of coating is performed by the application of new materials onto the surface of a component. A major issue of overlay coating is the adhesion of the coating to the substrate.

b. **Diffusion Coating**: In this category, chemical interaction of the coating elements with the substrate by diffusion is involved. New element is diffused onto the substrate surface.

c. **Thermal Spray Coating**: It is the process that involves the deposition of the molten or semi-molten droplets of powder onto the surface of a substrate to form a coating. For protective coating to material surfaces, thermal spraying is widely used in theindustrial process. It exhibits a very good wear resistance property but its corrosion resistance is not good as good as its wear resistance.

IV. 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, cermets, and polymers) can be deposited by thermal spraying [9].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 [10].

Thermal spray processes that have been considered to deposit the coatings are enlisted below: [11].

(1) Flame spraying with a powder or wire, (2) Electric arc wire spraying, (3) Plasma spraying (4) Spray and fuse (5) High Velocity Oxy-fuel (HVOF) spraying, (6) Detonation Gun.

VI. DETONATION GUN SPRAYING

D-gun spray process is a thermal spray coating process, which gives an extremely good adhesive strength, low porosity and coating surface with compressive residual stresses[12].. 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. 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 3500m/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 1200m/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. [10].

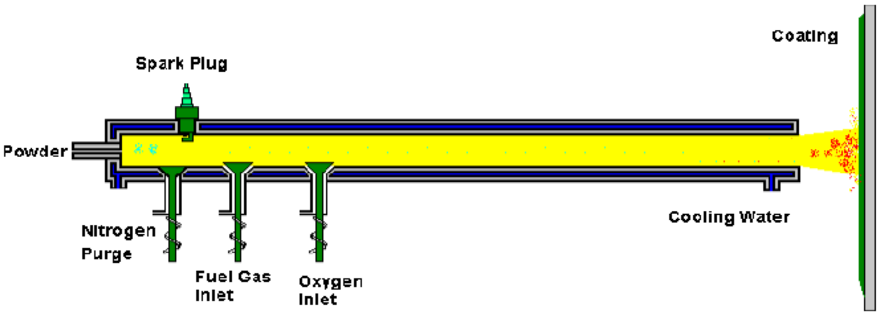

Fig.5.1 Detonation Gun process [7].

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VI. STUDIES RELATED TO DETONATION GUN SPRAYED COATINGS

Kamal et al. [12] 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 microstructural 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 microhardness of the coatings were found to be 58 MPa and 697–920Hv, respectively.

Kamal et al. [13] investigated the hot corrosion resistance of detonation gun sprayed (D-gun) Cr_3C_2–NiCr coatings on Superni 75, Superni 718 and Superfer 800 H superalloys. The deposited coatings on these superalloy substrates exhibit nearly uniform, adherent and dense microstructure with porosity less than 0.8%. Thermogravimetry technique is used to study the high temperature hot corrosion behavior of bare and Cr_3C_2–NiCr coated superalloys in molten salt environment (Na_2SO_4–60% V_2O_5) at high temperature 900 ◦C for 100 cycles. The corrosion products of the detonation gun sprayed Cr_3C_2–NiCr coatings on superalloysare analyzed by using XRD, SEM and FE-SEM/EDAX to reveal their microstructural and compositional features for elucidating the corrosion mechanisms. It is shown that the Cr_3C_2–NiCr coatings on Ni- and Fe-based superalloy substrates are found to be very effective in decreasing the corrosion rate in the given molten salt environment at 900 ◦C. Particularly, the coating deposited on Superfer 800 H showed a better hot corrosion protection as compared to Superni 75 and Superni 718. The coatings serve as an effective diffusion barrier to preclude the diffusion of oxygen from the environment into the substrate superalloys. It is concluded that the hot corrosion resistance of the D-gun sprayed Cr_3C_2–NiCr coating is due to the formation of desirable microstructural features such as very low porosity, uniform fine grains, and the flat splat structures in the coating.

Microstructure characterization of D-gun sprayed Fe–Al intermetallic coatings was done by Senderowski et al. [14]. 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 analysed 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 oxidised 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 Fe2Al5 intermetallic phases formed columnar crystals. The columnar crystal areas were separated by elongated amorphous oxide layers. Areas of mixed equiaxedsubgrains of FeAl and Fe3Al phases, fine grains of Fe-rich Fe(Al) solid solution, and micro- and nano-pores were also present.

Wang et al. [15] 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 microhardness, 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, microhardness, 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 highperformance 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. [16]. Amorphous metallic coatings with a composition of Fe48Cr15Mo14C15B6Y2 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.

Rajasekaran et al. [17] evaluated the effect of grinding on plain fatigue and fretting fatigue behaviour of detonation gun sprayed Cu–Ni–In coating on Al–Mg–Si alloy. Uniaxial plain fatigue and fretting fatigue tests were carried out on detonation gun sprayed Cu–Ni–In coating on Al–Mg–Si alloy samples. The samples in three conditions were considered: uncoated, as-coated and ground after coating. Ground coated specimens exhibited superior plain fatigue and fretting fatigue lives compared with uncoated and as-coated specimens. The life enhancement has been discussed in terms of surface finish and and residual compressive stresses at the surface.

The cyclic oxidation behavior of detonation-gun-sprayed Cr_3C_2–NiCr coating on three different superalloys namely Superni 75, Superni 718 and Superfer 800H at 900 °C for 100 cycles in air under cyclic heating and cooling conditions has been investigated by kamal et al. [18]. The kinetics of oxidation of coated and bare superalloys was analysed, using thermogravimetric technique. It was observed that all the coated and bare superalloys obey a parabolic rate law of oxidation. X-ray diffraction, FE-SEM/EDAX and X-ray mapping techniques were used to analyse the oxidation products of coated and bare superalloys. The results on the Cr_3C_2–NiCrcoatedsuperalloys showed better oxidation resistance due to the formation of a compact and adhesive thin Cr_2O_3 scale on the surface of the coating during oxidation. The scale remained intact and adherent to the partially oxidised coating during cyclic oxidation due to its good compatibility and similar thermal expansion coefficient between Cr_3C_2–NiCr coating and the superalloy substrates. In all the coated superalloys, the chromium, iron, silicon and titanium were oxidised in the inter-splat region, whereas splats which consisted mainly of Ni remained unoxidised. The parabolic rate constants of Cr_3C_2–NiCr-coated alloys were lower than that of the bare superalloys.

Detonation gun-sprayed cermet coatings containing complex ternary transition metal borides as hard particles dispersed in a stainless steel or nickel-based superalloy matrix have beencharacterized by Keranen et al.[19] to ascertain the effects of crystallinity and distribution of hard particles on the wear properties. Optical microscopy, scanning electron microscopy (SEM), X-ray diffraction (XRD) and analytical transmission electron microscopy (AEM) were used for characterization. Moreover, abrasive wear resistance of coatings was evaluated with a rubber wheel abrasion testing system

The wear and friction behaviors of detonation-gun- (D-gun) and plasma-sprayed hard coatings were investigated by Yinglong [20] under dry sliding conditions. The coating materials studied included Cr_2O_3, WC-12%Co, WC-20%Co, Al_2O_3, TiO_2, Al_2O_3-40%TiO_2, TiC-20%Ni and Cr_3C_2-25%NiCr. Sintered WC-6%Co and steel MoCN315M were also investigated as references. Scanning electron microscopy analysis was carried out to study the wear mechanisms. Authors found that D-gun-sprayed hard coatings had higher hardness, density and wear resistance than the corresponding plasma-sprayed coatings. D-gun-sprayed Cr_2O_3 showed the highest wear resistance. The wear resistance of D-gun-sprayed Cr_2O_3 was even higher than that of sintered WC-6%Co.

Ningkang et al. [21] studied the electron beam treatment of detonation-sprayed Stellite coatings. After detailed microstructural and microchemical studies of the coatings authors found that the degree of enhancement of chemical homogeneity in the coatings, the elimination of porosity and impurities, and the development of metallurgical bonding at the coating-substrate interface with consequent improvement in coating adhesion were all dependent on the selection of the electron beam processing parameters.

VII. CONCLUSION

Detonation sprayed coatings can play important role in protecting materials and alloys from wear and corrosion phenomena. 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. Detonation gun separation device designed by researchers resulted in good performance of the detonation gun spraying in high performance requirement. More improvement can be done in the design of detonation gun spraying device. Little work is done in field of using nano structured powder with detonation spraying. More work is needed in using of nanostructured powder for coating by detonation spraying for wear and corrosion resistance.

REFERENCES

[1] Gond Dinesh , Vikas Chawlab, D. Puria, S. Prakasha,‘ ‘ High Temperature Corrosion Behaviour of T-91 and T-22 Bare Steel in 75wt.%Na_2SO_4+25wt.%NaCl Molten Salt Environment at 900°C”, Journal of Minerals & Materials Characterization & Engineering, Vol. 9, No.7, pp.593-606, 2010.

[2] Harpreet Singh1, Devendra Puri2 and Satya Prakash2,‘ ‘ An overview of Na_2SO_4 and/or V_2O_5 induced hot corrosion of Fe- and Ni-based superalloys”,Rev.Adv.Mater.Sci. 16,27-50,2007

[3] H. Singh*, B. S. Sidhu, D. Puri, and S. Prakash,‘ ‘ Use of plasma spray technology for deposition of high temperature oxidation/corrosion resistant coatings – a review”, MATERIALS AND CORROSION ,FEBRUARY 2007

[4] Bala Niraj, Harpreet Singh ,and Satya Prakash, ‘ ‘ Comparative Performance of Cold Sprayed Ni-20cr and Ni-50cr Coatings on T22 Boiler Steel in Different Aggressive Environments”, International Journal of Surface Engineering & Materials Technology, Vol. 1 ,No. 1, 2011, ISSN: 2249-7250.

[5] Goyal Rakesh, Sidhu Buta Singh, Grewal J.S.; “Surface Engineering and Detonation Gun Spray Coating”, International Journal of Engineering Studies”, Volume 2, Number 3 ,351-357,2010.

[6] Chawla Vikas, Sidhu Buta Singh, Puri D. and Prakash S.; “performance of plasma sprayed Nanostructured and Conventional Coatings”, Journal of the Australian Ceramic Society, Volume 44, Number 2, 56-62, 2008,

[7] Bhanu Pratap1, Vijay Bhatt2, Vikas Chaudhary3”, A Review on Thermal Spray Coating”, International Journal of Scientific & Engineering Research, Volume 6, Issue 5, May-2015

[8] 1Amita Rani, 2Niraj Bala, 3C.M. Gupta, 4Vikas Chawla”, Combating Hot Corrosion of Boiler Tubes with Plasma Sprayed Coatings: a Review”, InternatIonal Journal of research In MechanIcal engIneerIng & technology, Vol. 3, IssuE 2, May - ocT 2013.

[9] Chawla Vikas, Amita Chawla, D. Puric, S. Prakashc , Prema G. Gurbuxanid and Buta Singh Sidhu; “Hot Corrosion & Erosion Problems in Coal Based Power Plants in India and Possible Solutions – A Review”, Journal of Minerals & Materials Characterization & Engineering, Vol. 10, No.4, pp.367-385, 2011.

[10] Singh Lakhwinder, Vikas Chawla, J.S. Grewal; “A Review on Detonation Gun Sprayed Coatings”, Journal of Minerals & Materials Characterization & Engineering, Vol. 11, No.3, pp.243-265, 2012.

[11] R.Prabu, J Dineshkumar; “Erosion Resistant Coatings A Review”, InternatIonal Journal of innovation in engIneerIng & technology, Vol. 5, IssuE 2,april 2015.

[12] Subhash Kamala, R. Jayaganthana,∗, S. Prakasha, Sanjay Kumarb”, Hot corrosion behavior of detonation gun sprayed Cr_3C_2–NiCr coatings on Ni and Fe-based superalloys in Na_2SO_4–60% V_2O_5 environment at 900◦C”, Journal of Alloys and Compounds, 463 (2008), 358–372.

[13] Kamal Subash, Jayaganthan R., Prakash Satya; “ Mechanical and microstructural characteristics of detonation gun sprayed NiCrAlY+ 0.4 wt% CeO_2 coatings on superalloys”, Materials chemistry and physics, Volume 122, Number 1, 262-268,2010.

[14] Senderowski C., Bojar Z., Wolczynski W., Pawlowski A.; “Microctructure characterization of D-gun sprayed Fe-Al intermetallic coatings”, Intermetallics, Volume 18, Number 7, 1405-1409.

[15] Wang Tie-Gang, Zhao Sheng-Sheng, Hua Wei-Gang, Gong Jun, Sun Chao; " Design of separation device used in detonation gun spraying system and its effects on the performance of WC-Co coatings", Surface and Coatings Technology, Volume 203, Number 12, 1637-1644,2009.

[16] ZHOU Zheng, WANG Lu, WANG Fu-chi, LIU Yan-bo; "Formation and corrosion behavior of Fe-based amorphous metallic coatings prepared by detonation gun spraying", Transactions of nonferrous metals society of china, Volume 19, Number 3, 634- 638, 2009.

[17] Rajasekaran B., Sundara Raman Ganesh S., Joshi S.V., Sundarajan G.; " Effect of grinding on plain fatigue and fretting behaviour of detonation gun sprayed Cu-Ni-ln coating on Al-Mg-Si alloy", International journal of fatigue, Volume 31, Number 4, 791-796, 2009.

[18] Kamal Subash, Jayaganthan R., Prakash S.; "High temperature oxidation studies of detonation sprayed Cr_3C_2-NiCr coating on Fe- and Ni-based superalloys on air under cyclic condition at 9000 C", Journal of alloys and compounds, Volume 472, Number 1-2,378-389,2009.

[19] Keranen J., Stenberg T., Mantyla T., Lepisto T.; "Microstructural characterization of detonation gun sprayed boride-based cermet coatings", Surface and Coatings Technology, Volume 82, Number 1-2, (1996), 29-37.

[20] Yinglong Wang; "Friction and wear performances of detonation gun and plasma sprayed ceramic and cermet hard coatings under dry friction", Wear, Volume 161, Number 1-2, (1993), 69-78.

[21] Ningkang Huang, Yi Wang, Zhong Zhang Xiao, Pu Wang Xiao; "Electron beam treatment of detonation sprayed satellite coatings", Surface and Coatings Technology, Volume 46, Number 3, (1991), 255-263.