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REVIEW OF EROSION-CORROSION ON PERFORMANCE OF HVOF, COLD AND GUN SPRAYED COATINGS OF DIFFERENT COATING POWDERS ON BOILER TUBE STEEL

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Abstract- It is very important to understand the nature of all types of environmental degradation of metals and alloys so that preventive measures can be done against metal loss and failures. Erosion and corrosion in the boilers and in the related components are responsible for huge losses, both direct and indirect, in power generation. Thus Protective coatings are used to prevent the base material and other losses due to shut down of the plant. Many researchers have studied the different combination of coating powders with HOVF, Cold spray and Detonation gun thermal spraying process technique on boiler steel tube. Researchers have studied erosion behavior, corrosion behavior, hardness, porosity, etc. However, still research can be carried out of combined effect of erosion-corrosion on boiler steel tube by HVOF technique using different coating powders in actual boiler condition or in the more aggressive environment.
Key words:- HVOF technique, boiler tube steel, the combined effect of erosion and corrosion, different coating powders.

1. INTRODUCTION

It is very important to understand the nature of all types of environmental degradation of metals and alloys as possible so that preventive measures can be economically against metal loss and failures to ensure safety and reliability in the use of metallic components [1].

Erosion and corrosion are recognized as serious problems in coal based power plants in India. Erosion and corrosion in boilers and related components are responsible for huge losses, both direct and indirect, in power generation plants. An understanding of these problems and thus to develop suitable protective system is essential for maximizing the utilization of such components. These problems can be prevented by either altering the environment or changing the material or by separating the component from the environment. Erosion and corrosion prevention by the use of coatings for separating the material from the environment is gaining importance in surface engineering [2].

Erosion affects various industries, including those dealing with mining, pneumatic transportation of solids and power generation. The marine, oil and gas, power generation and chemical industries have oxidation and corrosion problems and to a lesser extent, erosion concerns. When considering coal gasification processes, hot corrosion is expected to be a problem because the gas environment generally contains sulphur with low oxygen content and substantial amounts of salts. Erosion and corrosion can be reduced on superheater tubes by metallic coatings spray. Protective coatings are being used on structural alloys in energy conversion and utilization systems to protect their surfaces from oxidation and erosion [3].

Heat transfer pipes and other structural materials in the coal fired boilers are suffering from high temperature corrosion, erosion and oxidation, which may cause of downtime at power generating plants and accounting for 50-70% of the total arrest time. Maintenance costs for replacing broken pipes or damaged pipes in the same installations are also very high and can be estimated at up to 54% of the total production costs. Thus, super alloys have been developed for high temperature applications, but they are not able to meet both the high temperature strength and the high temperature erosion-corrosion resistance simultaneously. These problems can eliminated by applying a thin layer of anti oxidation and anti wear coatings with good thermal conductivity, such as thermal sprayed nickel or iron based alloyed coatings. For higher temperature applications, coating provide a way of extending the limits of use of materials. There are many techniques to deposit metallic coatings on the base material, such as sputtering, electroplating, thermal spraying, diffusion and so on. However, thermal spray techniques are increasingly used for higher temperature application such as flame spraying, arc spraying, plasma spraying, and high velocity oxy fuel spraying [4].

The high velocity oxy fuel processes belongs to the family of thermal spraying techniques and are used in many industries for protection of the components against erosion, corrosion and wear. Several HVOF spraying coatings have been subjected to corrosion erosion testing in sea water including cermets and the anti corrosion alloys. These studies concluded that the HVOF process produced coatings with higher corrosion and erosion resistance when compared with other spraying processes [5].

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2. LITERATURE REVIEW

Many researchers have studied on different materials of boiler tube and also applied different types of coatings on boiler tube by different methods.

Bala et. al. investigated hot corrosion performance of Ni-50Cr powder deposited on two boiler steels SA-213-T22 and SA 516 (Grade 70) by cold spray process. The hot corrosion performance of coated as well as bare boiler steels was evaluated in an aggressive environment of Na_2SO_4-60% V_2O_5 under cyclic conditions at an elevated temperature of 900°C. The cold sprayed Ni-50Cr coating on two different substrates when subjected to hot corrosion in Na_2SO_4-60% V_2O_5 environment at 900°C was found to be successful in maintaining its adherence with the substrate steels. The oxide scales were also found to be intact and there was no indication of spalling in both the cases [6].

Sidhu and Parkash investigated the erosion corrosion (E-C) behavior of plasma as sprayed and laser remelted Stellite-6 coatings on boiler tube steels in the actual coal fired boiler environment. The cyclic experimental studies were performed in the platen super heater zone of a coal fired boiler in which the temperature was 755°C and the study was carried out up to 10 cycles each of 100h duration followed by 1 h cooling at ambient temperature. Coated steels were found to losses higher resistance to Erosion-Corrosion than the uncoated steels. The highest degradation resistance has been indicated by the T11 steels coated and subsequently laser remelted [7].

Mishra et. al. studied the characterization and erosion behavior of a plasma sprayed Ni_3Al coating on a Fe-based super alloy was evaluated. Erosion studies were conducted using an air jet erosion test rig at a velocity of 40 m/s and impingement angle of 30° and 90°, on uncoated as well as plasma spray coated super alloy specimens at room temperature. For Ni_3Al coating, the erosion rate at 30° impact angle was somewhat higher than at a 90° impact angle, thus suggested ductile behavior of the coating [8].

Sidhu et. al. have studied on Ni base super alloys coated with Cr_3C_2-NiCr by using HVOF process for high temperature corrosive environment applications. The hot corrosion behaviors of the bare and Cr_3C_2-NiCr coated super alloys were studied after exposure to aggressive environment of Na_2SO_4-60% V_2O_5 salt mixture at 900°C under cyclic conditions. The Cr_3C_2-NiCr coating has found necessary resistance to hot corrosion, which has been attributed to the formation of oxides of nickel and chromium and spinel of nickel-chromium [9].

Tsaur et. al. studied on high temperature corrosion behavior of 310 stainless steel at 750°C in air with 2 mg cm^{-2} mixtures of various NaCl/Na_2SO_4 ratios. The morphological development and corrosion behavior were investigated by weight gain kinetics, depths of attack, metallographs, metal losses and X-ray analyses. It was found that weight gain kinetics in simple oxidation reveals a steady-state parabolic rate law after 3 h, while the kinetics with salt deposits display multi-stage growth rates. NaCl is the main corrosive specie in high temperature corrosion involving mixtures of Nacl/Na_2SO_4 and is responsible for the formation of internal attack. Mostly the corrosion takes place with the 75% NaCl mixtures. Uniform internal attack is the typical morphology of NaCl induced hot corrosion, while the extent of inter granular attack is more pronounced as the content of Na_2SO_4 in the mixture is increased [10].

Sidhu et. al. evaluate the erosion and corrosion behavior of Ni-based super alloy, Superni-75 in the coal fired boiler of a thermal power plant in the real service environment. The cyclic experimental study was performed for 1000 h in the platen super heater zone of the coal fired boiler where the temperature was around 900°C. The corrosion behavior have been characterized with the help of surface morphology, phase composition and element concentration using the combined techniques of X-ray diffractometry (XRD), scanning electron microscopy/energy-dispersive analysis (SEM/EDAX) and electron probe micro analyzer (EPMA). The performance of superni-75 was better in the coal fired boiler environment, which has been attributed mainly to the formation of a thick band of chromium in scale due to selective oxidation of chromium [11].Sidhu et. al. studied that Cr_3C_2-NiCr, NiCrBSi, Stellite-6 and Ni-20Cr coatings were deposited on a Ni-based super alloy (19.5Cr-3Fe-0.3Ti-0.1C-balance Ni) using an HVOF process. Hot corrosion studies were performed on bare as well as coated super alloy specimens after exposure to a molten salt environment at 900°C under cyclic conditions. Among the coatings studied, the Ni-20Cr coated super alloy imparted maximum hot corrosion resistance, where as the Stellite-6 coated indicated minimum resistance [12].

Kamal et. al. investigated on the cyclic oxidation behavior of detonation gun sprayed Cr_3C_2-NiCr coating on three different super alloys namely Superni75, Superni718 and Superfer 800H at 900°C for 100 cycles in air under cyclic heating and cooling conditions. The kinetic of oxidation of coated and bare super alloys was analyzed, using thermo gravimetric technique. It was observed that all the coated and bare super alloys obey a parabolic rate law of oxidation, X-ray diffraction, FE-SEM/EDAX and x-ray mapping techniques were used to analyze the oxidation products of coated and bare super alloys. The results on the Cr_3C_2-NiCr coated super alloys 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 [13].

Kaur et. al. studied on SAE-347H boiler tube material coated with Cr_3C_2-NiCr by HVOF spray process. The corrosion behavior at high temperature of the bare and coated boiler steels was investigated for 50 cycles in Na_2SO_4-82$Fe_2(SO_4)_3$ molten salt at 700° and also in air environments. Weight change measurements after each cycle were made to establish the kinetics of corrosion. To analyze the oxidation x-ray diffraction, field emission-scanning electron microscopy/energy dispersive spectroscopy and x-ray mapping analyses were performed on the exposed samples. The bare 347H steel suffered accelerated oxidation during exposure at 700°C in the air and in molten salt environment in composition with its respective coated counter parts. The HVOF spray Cr_3C_2-NiCr coating was found to be successful in maintaining its adherence in both the environments [14].

Sidhu et. al. studied to improve hot corrosion resistance of ASTM-SA210 GrA1 steel coated with Cr_2C_3-NiCr –NiCr, WC-Co and satellite-6 with the help of HVOF technique in the presence of Na_2SO_4-V_2O_5 salt deposits. All the coatings showed better result to hot corrosion resistant as compared with bare steels. It was found that NiCr coating be most protective followed by Cr_2C_3-NiCr coatings and WC-Co coating was least effective to protect the substrate steel [15].

Sidhu and Parkash studied on boiler tube steels, namely low carbon steel ASTM-SA210-Grade A1, 1Cr-0.5Mo steel ASTM-SA231-T11 and 2.25Cr-1Mo steel ASTM-SA213-t-22 in boiler environment to enhance degradation resistance. Before applying a 200 µm thick coating of Ni-20Cr, bond coat of 150µm thick Ni-22Cr-10Al-1Y powder was sprayed on the substrate steel. Prior testing of the coating was done in the environment of a coal fire boiler. After that the bare and coated steels were inserted in the actual coal fired boiler at around 755°C for 10 cycles, each 100h. Coated steels showed lower degradation rate as compared to uncoated steels and the lowest rate was observed in the case of Ni-20Cr coated T11 steel [16].

Bhatia et. al. investigated the erosion corrosion behavior of T-91 boiler tubes which was coated by four different compositions of Cr_3C_2-Ni-20Cr powder by HVOF thermal spray technique. The cyclic studies were performed in a coal-fired boiler at 1123 K ± 10 K (850°C ± 10 °C). Various tests like X-ray diffraction, scanning electron microscopy/energy dispersive X-ray analysis and elemental mapping were performed to find out the erosion-corrosion behavior of coated steels. Hot corrosion behavior of all the coatings deposited on T-91 boiler tube steel shows good results as compared to bare one. The authors observed the erosion-corrosion behavior and concluded that coatings provided considerable resistance to thermal erosion and corrosion to the substrate material [17].

Bhatia et. al. investigated the on hot corrosion behavior of T-91 boiler tube steel coated with 75% Cr3C2 -25% (Ni-20Cr) using high velocity oxy fuel-sprayed technique at different operating temperatures i.e. 550,700 and 850 °C. The deposited coatings on T91 boiler tube steel exhibit uniform, adherent and dense microstructure with porosity less than 2%. To study the high temperature hot corrosion behavior of uncoated and coated samples thermo-gravimetric technique was used. Various tests like XRD, SEM, and FE-SEM/EDAX were performed to reveal their microstructural and compositional features for the corrosion mechanisms on coated and uncoated steel. It was evaluated that the coated specimens have minimum weight gain at all the selected temperatures when compared with bare T-91 sample and coating was effective in the given molten salt environment in decreasing the corrosion rate. Oxides and spinels of nickel-chromium also helps for successful resistance against hot corrosion [18].

Somasundaram et. al. prepared a composite powder by blending alloying element Si with Cr_3C_2-35%NiCr powder and deposited the composite powder on SA213-T22, MDN-310, and SUPERFER 800H steels by HVOF process. These coated steels were investigated in 700^0C air under cyclic conditions. The coated steels were found to have higher oxidation corrosion resistance. The Cr_3C_2-35%NiCr + 5% Si coating was found to have better oxidation resistance due to the formation of oxide layer having Cr_2O_3, SiO_2, $NiCr_2O_4$ and $Ni_2(SiO_4)$ phases. Oxygen was not found at substrate and coating interface which indicated that oxidizing elements had not penetrated into the inside of the coatings [19].

Varis et. al. studied the corrosion behavior of NiCr and FeCr coatings under simplified biomass combustion conditions. The coatings were deposited by HVOF thermal spraying process. The authors used KCl-K_2SO_4 mixture as synthetic biomass ash. This ash was placed on coated material and was heat treated for 168 hours at 550^0C and 600^0C in two different gas atmospheres (air and air + 30% H_2O). It was observed that at 550^0C there was neither depletion of chromium from the coatings nor there as penetration of chlorine in the coatings. At 600^0C, it was observed that there was heavy depletion of chromium in ambient and moist environments. Fe-based coatings HVOF CJS Fe25Cr was found to have good corrosion resistance and there was no chlorine penetration through this coating was observed [20].

Oksa et. al. investigated corrosion behavior of two HVOF thermally sprayed Fe–27Cr–11Ni–4Mo and Fe–19Cr–9W–7Nb–4Mo coatings on carbon steel tube (St35.8, DIN 17175-79, size 38 × 5.5 mm). The coatings were exposed to boiler conditions for two years. Coating Fe–19Cr showed minor corrosion in the outer 20 µm layer of the coating. The coating had small amount of porosity and a few perpendicular cracks which allowed corrosion to proceed to the substrate. The authors concluded that Fe–27Cr HVOF coating had shown good corrosion resistance in the conditions [21].

Singh and Singh studied corrosion of Al_2O_3 coated T-91 boiler steel in actual boiler environment. Detonation gun thermal spraying process was used for coating Al_2O_3 powder. The coated and uncoated samples were subjected to cyclic conditions. It was observed that coated T-91 experienced 2.96 % weight loss due to the erosion of the scale formed on the sample. The erosion corrosion rate of Al2O3 coated T-91 was found to be more than that of uncoated T-91 in actual environment. It was found that the resistance to erosion corrosion of uncoated T-91 steel was better than of coated T-91 [22].

Fan et. al. investigated two Co modified aluminide coatings with different Co contents. The coatings were prepared by pack cementation process and above-the-pack process. The hot corrosion tests were performed in mixed salts of 75 wt.% Na_2SO_4+ 25 wt.% K_2SO_4 and 75 wt.% Na_2SO_4+ 25 wt.% NaCl at 700^0C. It was found that the addition of Co improves the hot corrosion resistance of the simple aluminide coating in the mixed sulfate salts. While the coating with medium Co content possessed better corrosion resistance in mixed salt containing chloride. It was because of the nitrides formed in the deposition process deteriorate the corrosion resistance of the coating with highest Co content [23].

Lopez et. al. deposited Ni–50Cr coatings on low alloy ferritic steel (2.25Cr–1Mo) substrates to improve their performance in high temperature steam environments using HVOF technique. The authors found that porosity of the coatings was below 2 vol.% in all cases, regardless of the spraying parameters. Experiments showed that the coated specimen remained practically unaltered. Gray zones were observed in the external part of the coating as well as in zones between layers [24].

Singh et. al. studied the hot corrosive behavior of 80%Ni–20%Cr coating in the waste incinerator environment at 900 °C. The coating was deposited by cold spraying. The porosity of the sprayed specimen was measured with the help of a PMP3 Inverted Metallurgical Microscope. Due to the presence of porosity, the variation in hardness of the coating was reported. It was observed that the strongly bounded scale and dense microstructure of the coating helped for blocking the penetration of corrosive species towards the substrate [25].

Zhu et. al. studied the hot corrosion behavior of Ni-based K438 superalloy deposited NiCrAlYSiN nano-crystalline composite coatings and NiCrAlYSi reference coatings by vacuum arc evaporation on the in a molten salt (75 wt.% Na2SO4 + 25 wt.% NaCl) environment at 900 ◦C. The results were found that both coatings improved the hot corrosion resistance of K438 in the molten salt environment and there was substantial diffusion of N from the coating into the substrate to form internal TiN and AlN. Al_2O_3 scale, internal oxidation and sulphidation was observed in the coating and even in the substrate [26].

Katiki, et. al. deposited Al_2O_3-TiO_2 coatings on Inconel 625 and studied the corrosion behavior in air as well as in molten salt environment of K_2SO_4-60%NaCl at 800˚C under cyclic conditions for 50 cycles. The coated specimens showed low weight gain in both the environments. The high corrosion resistance of coated samples was due to the formation of oxides of chromium and nickel on the samples [27].

Kumar, et. al. studied that erosion-corrosion (E-C) behavior of a cold-spray nano structured Ni-20Cr coating on boiler tube steel SA516 in a coal-fired boiler. The study was carried out for 15 cycles, in which each cycle was 100 h of heating in the boiler environment and 1 h of cooling under ambient air conditions. The erosion and corrosion behavior was evaluated with the help of thickness loss data of the samples and the samples were characterized using XRD, SEM/EDS, and x-ray mapping analyses. It was found that the coated boiler tube material SA516 have good results for erosion-corrosion protection in actual conditions of the boiler. It was also investigated that due to presence of protective NiO and Cr_2O_3 phases in its oxide scale micro hardness was higher in coated steel as compared to bare steel [28].

Singh and Singh have studied on erosion-corrosion behavior of T91 boiler tube steel which was coated by Al2O3 with the help of detonation gun thermal spraying process. The study was performed to achieve high performance and to protect the component from premature failures when used under high temperature and corrosive environment. The coated and bare samples were studied for erosion-corrosion behavior in actual boiler environment for 10 cycles. To analyze the behavior of erosion and corrosion products various tests were performed like SEM/EDAX and gravimetric technique, it was found that Al2O3coating was less effective than the bare T-91 steel[29].

Calderon et. al. evaluated the erosion–corrosion behavior carbon steel coated with pure Ni and Ni–SiC composite in a corrosive environment using in situ potentiondynamic polarization and electrochemical impedance. Coatings were obtained from a Watts classical solution in which SiC nanoparticles were added. The hydrodynamic conditions of the bath and the content of SiC in the electrolyte were varied. The properties of the coatings like morphology and structures were evaluated and it was found that SiC nano-particles produce morphological changes in the deposit. These are responsible for better resistance in erosion corrosion behavior and increases in the microhardness. The increases in SiC nanoparticle content in the coating and the presence of inert particles of SiC in the conductive matrix coating may have blocked the passage of the anodic Faradaic current, results in decreasing the corrosion rate of the coating[30].

Kumar and Sidhu have studied high-temperature erosion behavior and characterization of pulverized coal burner nozzles (PCBN) steel of type AISI 304 coated with Cr3C2-25NiCr and WC-10Co-4Cr with the help of HVOF techniques. It was investigated that the performance of the selected coatings in highly erosive environment is better and it would protect against material degradation. The coatings shows better result in oblique impact erosion at room temperature and depleted fully under all other conditions [31].

Sidhu et. al. studied that to enhance the corrosion resistance, alumina coatings reinforced with various percentages of carbon nano tubes (CNTs) successfully deposited by plasma spray process on T91 boiler tube steel. Before applying CNTs- Al2O3 coatings Ni-20Cr was used as bond coat. Various tests like metallography, XRD, SEM/EDAX and X-ray mapping were performed for analysis of corrosion behavior and decrease in the porosity has been observed in coated steel. The carbon nano tubes were found to be uniformly distributed within the Al2O3 matrix and CNTs were chemically stable during the spray process i.e. at high processing temperature and does not form oxides [32].

Singh et. al. studied that to prevent from corrosion T91 boiler tube steel, the coatings of powder Cr3C2–25 (Ni–20Cr) and Ni-20Cr were deposited by high velocity oxy-fuel (HVOF) process. The bare and coated T-91 steel specimens were tested for hot corrosion studies in molten salt (Na2SO4–60%V2O5) environment at 900°C temperature under cyclic conditions and each cycle consisted 1 h of heating in tube furnace followed by 20 min in air cooling. Using thermo gravimetric technique, the weight change measurements were tested after each cycle in order to establish the kinetics of corrosion. To analyze the corrosion products, x-ray diffraction and scanning electron microscopy/energy dispersive x-ray analysis were used. The uncoated steel has higher weight gain during testing due to the formation of un-protective Fe2O3 dominated oxide scales. The Cr3C2–25(Ni–20Cr) coating was found more protectiveand have better results than the Ni-20Cr coating [33].

Chatha et. al. investigate that $75Cr_3C_2$ -25NiCr coating can be deposited by high velocity oxy-fuel (HVOF) process on T91 boiler tube steel substrate to enhance high-temperature corrosion resistance. In the present investigation high-temperature corrosion behavior of bare as well as coated steels were evaluated. For this study, the experiments were carried out at 900°C temperature for 15 cycles each of 100 h duration and 1 h cooling at ambient temperature. The study of the bare and coated steel specimens were done with the help of metal thickness loss and corresponding to the corrosion scale formation and also with the depth of internal corrosion attacks. The bare boiler tube steel suffered from a catastrophic degradation in the form of internal oxidation attack and thickness loss. The 75Cr C -25NiCr coating shows good result as compare to bare steel and also no tendency for internal oxidation [34].

From the literature it has been concluded that although the work has been done in the field of erosion and corrosion testing of thermal spray coated steels, but more research is needed to evaluate the performance of these coatings in more aggressive environments, whether in the laboratory conditions or in actual boiler conditions. More work is needed to understand the combined effect of erosion corrosion of HVOF sprayed of different coatings on different materials. The proposed investigation will help to establish the science base behind the phenomena of erosion-corrosion with respect to coatings. Moreover, there is great potential in earning some patents in this filed as this field is still open for R & D.

3. FINDINGS AND PROBLEMS

S No	Author Name	Title of Paper	Findings	Causes of failure
1	SB Mishra K Chandra S Parkash B Venkataraman & 2005	Characterisation and erosion behaviour of plasma sprayed Ni_3Al coating on a Fe-based superalloy.	Studied the erosion behavior of Fe based superalloy coated by Ni_3Al with the help of plasma spray process using an air jet erosion test rig at a velocity of 40 m/s and impingement angle of 30° and 90°	erosion rate at 30° impact angle was higher than at a 90° impact angle
2.	Buta Singh Sidhu S. Parkash & 2005	Erosion-corrosion of plasma as sprayed and laser remelted Stellite-6 coatings in a coal fired boiler.	Erosion Corrosion (E-C) behavior of plasma as sprayed and laser remelted Stellite-6 coatings on boiler tube steels in the actual coal fired boiler environment.	Uncoated T-11 steels were found higher losses to E-C than the coated steels.
3.	C C Tsaur J C Rock C J Wang Y H Su & 2005	The hot corrosion of 310 stainless steel with pre coated $NaCl/Na_2SO_4$ mixtures at 750º	Studied on 310 stainless steel at 750°C in air with 2 mg cm^{-2} mixtures of various $NaCl/Na_2SO_4$ ratios. High temperature corrosion behavior was found of the steel.	At high temperature NaCl is the main corrosive in the selected mixtures.
4.	T S Sidhu S Parkash R D Aggerwal & 2006	Characterisations and Hot corrosion resistance of Cr_3C_2-NiCr coating on Ni base superalloys in an aggressive environment	studied on Ni base super alloys coated with Cr_3C_2-NiCr by using HVOF process for high temperature corrosive environment applications.	Formation of oxides of nickel-chromium and spinels were found
5.	H S Sidhu B S Sidhu S Prakash & 2006	The role of HVOF coatings in improving hot corrosion resistance of ASTM-SA210 GrAl steel in the presence of Na_2SO_4-V_2O_5 salt deposits.	Cr_2C_3-NiCr–NiCr, WC-Co and satellite-6 metallic coatings were sprayed by HVOF on ASTM-SA210 GrA1 steel and hot corrosion studies were performed.	Uncoated steel GrA1 shows poor result of hot corrosion as compared to coated steel.
6.	B S Sidhu S Prakash & 2006	Nickel Chromium plasma spray coatings: A way to enhance degradation resistance of boiler tube steels in boiler environment.	Studied on Boiler tube steels, namely low carbon steel GrA1, T11 and T-22 coated by Ni-20Cr powder. Ni-22Cr-10Al-1Y powder was sprayed as a bond coat before applying	Uncoated steel GrA1, T11 and T22 shows poor result of erosion-corrosion as compared to

			coating powder.	coated steel.
7.	T S Sidhu S Parkash R D Aggerwal & 2009	Evaluation of hot corrosion resistance of HVOF coatings on a Ni based super alloy in molten salt environment.	Studied the hot corrosion behavior of a Ni-based super alloy (19.5Cr-3Fe-0.3Ti-0.1C-balance Ni) coated by Cr_3C_2-NiCr, NiCrBSi, Stellite-6 and Ni-20Cr powders using an HVOF process.	Ni-20Cr shows better result of hot corrosion as compared with satellite-6 coating.
8.	S Kamal R Jayaganthan S Parkash & 2009	High temperature oxidation studies of detonation gun sprayed Cr_3C_2-NiCr coating on Fe and Ni based super alloys in air under cyclic condition at 900ºC.	Studied the oxidation behavior of Superni75, Superni718 and Superfer 800H coated by Cr_3C_2-NiCr coating powders using D-gun spray process at 900°C for 100 cycles in air under cyclic heating and cooling conditions.	Weight gain/area is more in uncoated bare superfer 800H as compared to other.
9.	M Kaur H Singh S Prakash & 2009	High temperature corrosion studies of HVOF sprayed Cr_3C_2-NiCr coating on SAE-347H boiler steel.	SAE-347H boiler tube material coated with Cr_3C_2-NiCr by HVOF spray process. Hot corrosion behavior studied	Uncoated steel SAE-347H shows poor result of hot corrosion as compared to coated steel.
10.	T S Sidhu S Parkash R D Aggerwal R Bhagat & 2009	Erosion-corrosion behavior of Ni-based superalloy Superni-75 in the real service environment of the coal fired boiler	Studied the erosion-corrosion performance of Ni-based superalloy Superni-75 in the actual boiler environment of a thermal power plant.	Formation of thick layer of chromium in scale due oxidation.
11.	Niraj Bala Harpreet Singh Satya Parkash & 2010	Accelerated hot corrosion studies of cold spray Ni-50Cr coating on boiler steels.	Studied on two boiler steels SA-213-T22 and SA 516 (Grade 70) coated by Ni-50Cr powder with the help of cold spray process.	Uncoated steels show more weight gain and form oxides scale during hot corrosion study.
12.	K. Katiki S. Yadlapati S. N. S. Chidepudi M. Manikandan M. Arivarasu K D Ramkumar & 2014	Performance of plasma spray coatings on Inconel 625 in air oxidation and molten salt environment at 800˚C	Deposited Al_2O_3-TiO_2 coatings on Inconel 625 and studied the corrosion behavior .	Uncoated steel Inconel 625 shows poor result of hot corrosion as compared to coated steel.
13.	Rakesh Bhatia H. S. Sidhu B. S. Sidhu & 2014	Hot Corrosion Studies of HVOF-Sprayed Coating on T-91 Boiler Tube Steel at Different Operating Temperatures	Studied the usefulness T91 boiler tube steel coated by 75% Cr3C2 -25% (Ni-20Cr) coating powders by HVOF technique to control hot corrosion at different temperatures i.e. 550,700 and 850 °C.	Uncoated steel T91 shows poor result of hot corrosion as compared to coated steel at all operating temperatures.
14.	B. Somasundaram R. Kadoli	Evaluation of Thermocyclic Oxidation Behavior of HVOF Sprayed (Cr_3C_2-35% NiCr)+ 5%	Prepared a composite powder by blending alloying element Si with Cr_3C_2-35%NiCr	Uncoated steel T22, MDN-310 and Superfer

	M. Ramesh & 2014	Si Coatings on Boiler Tube Steels	powder and deposited the composite powder on SA213-T22, MDN-310, and SUPERFER 800H steels by HVOF process. These coated steels were investigated in 700^0C air under cyclic conditions.	800H shows poor result of corrosion as compared to coated steel.
15.	M. Oksa T. Varis K. Ruusuvuori & 2014	Performance testing of iron based thermally sprayed HVOF coatings in a biomass-fired fluidized bed boiler	Investigated the corrosion behavior of carbon steel tube (St35.8, DIN 17175-79, size 38 × 5.5 mm) coated by Fe–27Cr–11Ni–4Mo and Fe–19Cr–9W–7Nb–4Mo powders by HVOF thermally sprayed technique. The coatings were exposed to boiler conditions for two years.	The coating Fe-19Cr showed minor corrosion in outer 20µm layer of coating, small amount of porosity and a few perpendicular cracks.
16.	G. N. Singh T. Singh & 2014	To Study High Temperature Erosion-Corrosion of Detonation Gun Sprayed Al2O3 Coated and Uncoated T-91 Boiler steel in Actual Environment of Boiler	studied corrosion of Al_2O_3 coated T-91 boiler steel in actual boiler environment. Detonation gun thermal spraying process was used for coating Al_2O_3 powder.	Resistance to erosion corrosion of uncoated t91 steel was better than of coated T91.
17.	A.J. López M. Proy V. Utrilla E. Otero J. Rams & 2014	High-temperature corrosion behavior of Ni–50Cr coating deposited by high velocity oxygen–fuel technique on low alloy ferritic steel	Studied on low alloy ferritic steel (2.25Cr–1Mo) substrates coated by Ni–50Cr using HVOF technique to improve their performance in high temperature steam environments.	Gray zones were found in external part of coating as well as in zones between layers.
18	H. Singh T. S. Sidhu J. Karthikeyan S. B. S. Kalsi & 2015	Evaluation of characteristics and behavior of cold sprayed Ni–20Cr coating at elevated temperature in waste incinerator plant	Studied on the Ni-based K438 super alloy coated with NiCrAlYSiN nano-crystalline composite and NiCrAlYSi by vacuum arc evaporation.	Due to porosity, the variation in hardness of the coating was found.
19	Rakesh Bhatia H. S. Sidhu B. S. Sidhu & 2015	High Temperature Behavior of Cr_3C_2-NiCr Coatings in the Actual Coal-Fired Boiler Environment	The erosion corrosion behavior of T-91 boiler tubes which was coated by four different compositions of Cr_3C_2-Ni-20Cr powder by HVOF thermal spray technique.	Uncoated steel T91 shows poor result of hot corrosion as compared to coated steel.
20	P Kumar B S Sidhu & 2016	Characterization and High-Temperature Erosion Behavior of HVOF Thermal Spray Cermet Coatings	Studied the characterization and high-temperature erosion behavior of Cr_3C_2-25NiCr and WC 10Co-4Cr HVOF-sprayed coating on AISI 304 steel.	The erosion behaviour shows better result at oblique impact of erosion at room temperature and depleted in all other conditions.
21	B S Sidhu R Goyal V Chawla &	Characterization of plasma sprayed CNT reinforced alumina coatings on ASME-SA213-T-91 boiler tube steel	Alumina coatings were successfully deposited on ASME-SA213-T91 boiler tube steel using plasma spray	Uncoated steel T91 shows poor result of hot corrosion as

	2016		process to improve corrosion resistance.	compared to coated steel.
22	S Singh K Goyal K Goyal & 2016	Performance of Cr_3C_2–25 (Ni–20Cr) and Ni-20Cr coatings on T-91 boiler tube steel in simulated boiler environment at 900˚C	Studied to prevent T91 boiler tube steel from corrosion, Cr_3C_2–25 (Ni–20Cr) and Ni-20Cr coatings were deposited by high velocity oxy-fuel (HVOF) process.	The uncoated steel showed higher weight gain due to the formation of un-protective Fe2O3 dominated oxide scales.

4. CONCLUSION

In this review paper, erosion-corrosion study is investigated. In previous work boiler tube steel like T-91, AISI 304 steel, T22, MDN-310,SUPERFER 800H, low carbon steel GrA1, T11, SAE-347H, Superni75, Superni718, SA-213-T22 and SA 516 (Grade 70) have studied using different combination of coating powders and different techniques like. And also causes of failure are discussed in tabular form.

5. REFERENCES

[1] Buta Singh Sidhu and S.Parkash, "High-Temperature Oxidation Behavior of NiCrAlY Bond Coats and Stellite-6 Plasma Sprayed Coatings, Oxidation of Metals", Vol. 63, Nos. 314, April 2005.

[2] Vikas Chawla, Amita Chawla, D.Puri, S.Parkash, Prema G.Gurbuxani and Buta Singh Sidhu, "Hot Corrosion and 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.

[3] Buta Singh Sidhu and S. Parkash, "Degradation Behavior of Ni_3Al Plasma-Sprayed Boiler Tube Steels in an Energy Generation System", 356-Volume 14(3) June 2005.

[4] T.S.Sidhu, S.parkash and R.D.Aggarwal, "Characterizations of HVOF sprayed NiCrBSi coatings on Ni and Fe based superalloys and evaluation of cyclic oxidation behaviour of some Ni based superalloys in molten salt environment", Thin solid films 515 (2006) 95-105.

[5] T.S.Sidhu, S.parkash and R.D.Aggarwal, "Studies of the metallurgical and mechanical properties of high velocity oxy-fuel sprayed satellite-6 coatings on Ni and Fe based superalloys", Surface and coating technology 201 (2006) 273-281.

[6] Niraj Bala, Harpreet Singh and S.Parkash, "Accelerated hot corrosion studies of cold spray Ni-50Cr coating on boiler steels", Materials and Design 31 (2010) 244-253.

[7] Buta Singh Sidhu and S. Parkash, "Erosion-corrosion of plasma as sprayed and laser remelted Stellite-6 coatings in a coal fired boiler", Wear (2005).

[8] S.B.Mishra, K.Chandra, S.Parkash and B.Venkataraman, "Characterization and erosion behaviour of a plasma sprayed Ni_3Al coating on a Fe based superalloy", Materials Letters 59 (2005) 3694-3698.

[9] T.S.Sidhu, S.Parkash and R.D.Aggarwal, "Characterization and Hot Corrosion Resistance of Cr_3C_2-NiCr Coating on Ni base Superalloys in an Aggressive Environment", Journal of thermal spray Technology, volume 15(4) December 2006-811.

[10] Charg-Cheng Tsaur, James C.Rock, Chaur-Jeng Wang, Yung-Hua Su, "The hot corrosion of 310 stainless steel with pre-coated NaCl/Na_2SO_4 mixtures at 750° C", Materials Chemistry and Physics 89 (2005) 445-453.

[11] T S Sidhu, S Parkash, R D Aggarwal and Ramesh Bhagat, "Erosion-corrosion behaviour of Ni-Based superalloy Superni-75 in the real service environment of the boiler", Sadhana Vol. 34 Part 2, April 2009, pp.299-307.

[12] T.S.Sidhu, S.Parkash and R.D.Aggarwal, "Evaluation of hot corrosion resistance of HVOF coatings on a Ni-Based superalloy in molten salt environment", Materials science and Engineering A 430 (2006) 64-78.

[13] Subhash Kamal, R.Jayaganthan, S. Parkash, "High temperature oxidation studies of detonation gun sprayed Cr_3C_2-NiCr coating on Fe and Ni based superalloys in air under cyclic condition at 900°C", Journals of Alloys and Compounds 472 (2009) 378-389.

[14] Manpreet Kaur, Harpreet Singh and Satya Parkash, "High Temperature Corrosion Studies of HVOF Sprayed Cr_3C_2-NiCr Coating on SAE-347H Boiler Steel", Journal of thermal spray coating, volume 18(4) December 2009-619.

[15] Hazoor Singh Sidhu, Buta Singh Sidhu, S. Parkash, "The role of HVOF coatings in improving hot corrosion resistance of ASTM-SA210 GrAl steel in the presence of Na_2SO_4- V_2O_5 salt deposits", Surface and Coatings Technology 200 (2006) 5386-5394.

[16] Buta Singh Sidhu and S.Parkash, "Nickel-Chromium Plasma Spray Coatings: A Way to Enhance Degradation Resistance of Boiler Tube Steels in Boiler Environment", Journal of thermal Spray, Volume 15(1) March 2006-131.

[17] R. Bhatia, H. S. Sidhu, and B. S. Sidhu, "High Temperature Behavior of Cr3C2-NiCr Coatings in the Actual Coal-Fired Boiler Environment", Metallurgical and Materials Transactions E, vol. 2, pp. 70-86, 2015.

[18] R. Bhatia, H. Singh, and B. S. Sidhu, "Hot Corrosion Studies of HVOF-Sprayed Coating on T-91 Boiler Tube Steel at Different Operating Temperatures", Journal of materials engineering and performance, vol. 23, pp. 493-505, 2014.

[19] B. Somasundaram, R. Kadoli, and M. Ramesh, "Evaluation of Thermocyclic Oxidation Behavior of HVOF Sprayed (Cr_3C_2-35% NiCr)+ 5% Si Coatings on Boiler Tube Steels", Procedia Materials Science, vol. 5, pp. 398-407, 2014.

[20] T. Varis, D. Bankiewicz, P. Yrjas, M. Oksa, T. Suhonen, S. Tuurna, et al., "High Temperature Corrosion of Thermally Sprayed NiCr and FeCr Coatings Covered with a KCl-K2SO4 Salt Mixture", Surface and Coatings Technology, vol. Article in press, 2014.

[21] M. Oksa, T. Varis, and K. Ruusuvuori, "Performance testing of iron based thermally sprayed HVOF coatings in a biomass-fired fluidised bed boiler", Surface and Coatings Technology, vol. 251, pp. 191-200, 7/25/ 2014.

[22] G. N. Singh and T. Singh, "To Study High Temperature Erosion-Corrosion of Detonation Gun Sprayed Al2O3 Coated and Uncoated T-91 Boiler steel in Actual Environment of Boiler", International Journal, 2014.

[23] Q. X. Fan, S. M. Jiang, H. J. Yu, J. Gong, and C. Sun, "Microstructure and hot corrosion behaviors of two Co modified aluminide coatings on a Ni-based superalloy at 700°C", Applied Surface Science, vol. 311, pp. 214-223, 8/30/ 2014.

[24] A. J. López, M. Proy, V. Utrilla, E. Otero, and J. Rams, "High-temperature corrosion behavior of Ni–50Cr coating deposited by high velocity oxygen–fuel technique on low alloy ferritic steel", Materials & Design, vol. 59, pp. 94-102, 7// 2014.

[25] H. Singh, T. S. Sidhu, J. Karthikeyan, and S. B. S. Kalsi, "Evaluation of characteristics and behavior of cold sprayed Ni–20Cr coating at elevated temperature in waste incinerator plant", Surface and Coatings Technology, vol. 261, pp. 375-384, 1/15/ 2015.

[26] L. Zhu, S. Zhu, and F. Wang, "Hot corrosion behaviour of a NiCrAlYSiN composite coating in Na2SO4–25wt.% NaCl molten salt", Applied Surface Science, vol. 268, pp. 103-110, 3/1/ 2013.

[27] K. Katiki, S. Yadlapati, S. N. S. Chidepudi, M. Manikandan, M. Arivarasu, K. Devendranath Ramkumar, et al., "Performance of plasma spray coatings on Inconel 625 in air oxidation and molten salt environment at 800˚C", International Journal of Chem Tech Research, vol.6,2014.

[28] M. Kumar, H. Singh, N. M. Chavan and S. V. Joshi, " Development of erosion-corrosion resistant cold spray nanostructured Ni-20Cr coating for coal-fired boiler applications", Journal of thermal spray technology, December 2015, volume 24,Issue 8, pp 1441-1449.

[29] G. N. Singh and T. Singh, "To study high temperature erosion-corrosion of detonation gun sprayed Al_2O_3 coated and uncoated T-91 boiler steel in actual environment of boiler", International journal of science and research (IJSR), volume 3, Issue 3, March 2014.

[30] J.A. Calderon, J. E. Henao and M. A. Gomez," Erosion corrosion resistance of Ni composite coatings with embedded SiC nanoparticles", Electrochemica Acta, Volume 124, 1 April 2014, Page 190-198.

[31] Pardeep kumar and Buta Singh Sidhu," Characterization and High-Temperature Erosion Behaviour of HVOF Thermal Spray Cermet Coatings", Journal of Materials Engineering and Performance, Volume 25, Issue 1,pp.250-258, 01/2016.

[32] Buta singh Sidhu, Rakesh Goyal and Vikas Chawala,"Characterization of plasma sprayed CNT reinforced alumina coatings on ASME-SA213-T-91 boiler tube steel", J Material Sci Eng 2016, volume 5, Issue 7.

[33] Sukhjinder Singh, Khushdeep Goyal and Rakesh Goyal,"Performance of Cr3C2–25 (Ni–20Cr) and Ni-20Cr coatings on T-91 boiler tube steel in simulated boiler environment at 900˚C",Chemical and material engineering 4(4): 57-64, 2016.

[34] S. S. Chatha, H. S. Sidhu and B. S. Sidhu,"Performance of $75Cr_3C_2$ -25NiCr coating Produced by HVOF process in coal fired thermal power plant", Advanced material research, vol.1137, pp.88-100, 2016.