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Performance of cold sprayed Ni based coatings in actual boiler environment

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ABSTRACT

Hot-corrosion combined with erosion-corrosion is a severe problem in boiler tubes of Power Plant Boilers. One possible way to control hot corrosion is the use of thermal spray protective coatings. Cold gas dynamic spraying (CGDS), popularly referred to as cold spray (CS), is a promising technology for depositing protective coatings. Ni based alloys have been used for thermal spraying for various applications. In the current research work three different types of coatings NiCr, NiCrTiC and NiCrTiCRe were deposited by the cold spray technique on SA 516 steel. The performance of the coatings was evaluated in actual boiler conditions wherein the uncoated and coated steels were exposed to the superheater zone of a coal fired boiler for 15 cycles. The change in weight and thickness were noted and used for studying the kinetics of the erosion-corrosion. X-ray diffraction, surface and cross-sectional FE-SEM/EDS and X-ray mapping techniques were used to evaluate the as-coated and eroded-corroded specimens. It was observed that the coated specimens gave better performance than the uncoated steel. The development of oxides and spinels of nickel and chromium might have resulted in better performance of the coatings. The NiCrTiCRe coating established best erosion-corrosion resistance behavior amongst all the investigated specimens.

1. Introduction

Thermal spraying coating technique has been a source of providing protection to large diameter shafts and worn out parts in various applications ranging from turbines, power plants and pumps. This technique represents an important and economical process to apply protective coatings to parts and to repair worn out large diameter shafts in turbines and pumps. Thermal spray processes represent an important and cost-effective technique for improving/enhancing the properties of engineering parts to increase their lifetime and performance under different kinds of working environments. In recent times, cold spray thermal spray coating has been utilized to produce numerous coatings possessing superior qualities [1]. In this process high temperature is replaced by high velocity to produce dense coatings, which ultimately results in a sharp decrease and minimization of deleterious reactions, which usually occur at high temperatures associated with typical thermal sprayed coatings [2]. All this results in formation of dense cold sprayed coatings with minimal amount of oxide impurities and lower porosity, which leads to higher thermal conductivities of cold sprayed coatings in comparison to other thermally sprayed materials. HVOF sprayed TiC based cermet coatings have gained considerable interest for applications requiring resistance to oxidation, erosion and wear [3–5]. Rhenium as a refractory metal is a very attractive material for high temperature structural and energy system applications. In the work done by Lee et al. [6], HVOF sprayed NiCoCrAlYReTa coating was exposed to air oxidisation up to 200 h between 1000 and 1200 °C. Results showed uniform distribution of Re all through the coating and oxide scale, without formation of any free oxides.

In the previous publication by the authors [7] the hot corrosion cyclic behavior of three coatings NiCr, NiCr blended with 24 wt.% TiC (NiCrTiC) and NiCr blended with 24 wt.% TiC and 1 wt.% Re (NiCrTiCRe) in molten salt environment in laboratory was done. The laboratory testing provides useful information and database regarding the behavior of coatings. However, laboratory testing is not able to consider various other factors for example erosion caused due to fly ash particles which is a major degradation mechanisms apart from hot corrosion. Since these coatings were intended for use in the actual boilers, it was essential that the coatings should be studied in the actual boiler environment of thermal power plant.

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Table 1
Chemical composition of SA 516 boiler steel.

Chemical composition (wt.%)	SA 516 (grade 70) steel	
	Nominal composition	Actual composition
C	0.27	0.19
Mn	0.93	1.07
Si	0.1	0.25
S	0.06	0.02
P	0.05	0.01
Fe	Balance	Balance

Table 3
Coal analysis data.

Constituent	wt.% age
Total moisture (inherent + surface)	10.43
Inherent moisture	7.55
Ash	34.74
Ash on fire basis (actual)	33.64
Volatile metal	21.59
GC_v (gross calorific value) in Kcal/kg	4187
GC_v on fire basis in Kcal/kg	4055
Net GC_v in Kcal/kg	3834
Unburnt carbon in fly ash	1.35
Unburnt carbon in bottom ash	5.75

2. Experimental procedure

2.1. Substrate and feedstock powder

In the present work SA 516 (grade 70) steel was chosen as the substrate material. The test material for the current investigation is SA 516 (grade 70). The actual chemical composition measured by Optical Emission Spectroscopy (OES) and that provided by the supplier of the material has been given in Table 1. The specimens in the size of 20 mm × 15 mm × 5 mm, were cut and polished before the deposition of the coating. Cold spraying was used to deposit three different types of coating powder compositions on SA 516 steel namely commercially available Ni-20Cr (NiCr), Ni-20Cr blended with 24 wt.% TiC (NiCrTiC) and Ni-20Cr blended with 24 wt.% TiC and 1 wt.% Re (NiCrTiCRe) powder. The commercially available Ni-20Cr powder was purchased from Sulzer Metco (US) Inc. TiC Powder and Re powder were purchased from Atlantic Equipments Engineers, NJ, USA and Alfa Aesar Johnson Matthey, USA respectively.

2.2. Deposition technique and equipment

All the cold spray coatings under investigation were deposited using Kinetics 3000 cold-spray system (CGT Technologies, GmbH, Ampfing, Germany) at ASB Industries, Inc., Barbeton, Ohio, USA. The parameters used for the cold spraying have been depicted in Table 2 [7,8].

2.3. As-sprayed coating characterization

X-ray diffraction (XRD) of the specimens was done using a Bruker AXS D-8 Advance Diffractometer (Germany) by using CuKα radiation and nickel filter at 20 mA under a voltage of 35 kV. The specimens were scanned with a scanning speed used of 1 kcps in the 2θ range of 10° to 110° and at a chart speed for the intensities was 1 cm/min with 2°/min as Goniometer speed. The diffractometer was interfaced with the Bruker DIFFRAC Plus X-Ray diffraction software which directly provided the 'd' spacings on the diffraction pattern. These 'd' values were used for the recognition of different phases using inorganic ASTM X-ray diffraction data cards. The characterization of the surface morphology of the coatings was done using FE-SEM/EDS analysis (FE-SEM, FEI, Quanta 200F). The electron beam used in this case was of 10 kV energy. For the cross-sectional analysis of the specimens, the samples were sectioned, and then mounted in epoxy powder using hot mounting machine (Bain mount, Chennai Metco Ltd., India). The mounted specimens were then given mirror polish finish by polishing them by using emery papers of 220, 400, 600 grit followed by 1/0, 2/0, 3/0 and 4/0 grades. Further, for fine polishing 0.3 μm diamond paste was used. For the cross-sectional microhardness of the coating Digital Micro Vickers Hardness tester (SHV-1000, Chennai Metco Pvt. Ltd., India) using a load of 2.94 N was used. The cross-sectional morphology and compositions and X-ray mapping by analysis of the various elements were also taken by the same FE-SEM/EDS instrument [7,8].

2.4. Erosion-corrosion (E-C) studies in coal-fired boiler

For erosion-corrosion cyclic studies in the actual boiler environment the uncoated and the coated specimens were hung through soot blower dummy points in the middle zone of the low temperature superheater of the Stage-II Boiler of Guru Gobind Singh Super Thermal Power Plant (GGSSTPP), Punjab (India). The temperature reported in this region was about 700 ± 10 °C with volumetric flow of flue gases around 700 t/h. Flue gases consist of 16% CO_2 and 3% O_2 by volume. The chemical analysis of the coal has been represented in Table 3, and that of ash and flue gas analysis inside the said boiler has been given in Table 4. The studies in the boiler environment consisted of total of 15 cycles; with each cycle of 100 h of exposure to the boiler environment followed by cooling at ambient conditions for 1 h. After the end of each cycle the weight change data were taken along with visual observations to approximate the kinetics of E-C. The change in thickness was also measured using a Sylvac micrometer screw gauge (Swiss make, resolution 0.001) and average of 3 measured values was taken.

Table 2
Process parameters for the cold spray process.

Process gas	Helium
Gun temperature	400 °C
Gun pressure	20.5 bars
Process gas flow rate	150 m^3/h
Powder feed rate	40 g/min
Carrier gas	Nitrogen
Flow rate of gas	4 m^3/h
Coating thickness	250 μm

Table 4
Chemical analysis of ash and flue gases inside the boiler.

Ash		Flue gases (Volumetric flow, 231 m^3/s)	
Constituent	wt.% age		
Silica	54.70	Constituent	Value relative to flue gases
Fe_2O_3	5.18	SO_x	236 mg/m^3
Al_2O_3-Fe_2O_3/Al_2O_3	29.56	NO_x	1004 μg/m^3
Calcium oxide	1.48	CO_2	12%
Magnesium oxide	1.45	O_2	7%
SO_3	0.23	40% excess air was supplied to the boiler for the combustion of coal.	
Na_2O	0.34		
K_2O	1.35		
Ignition loss	4.31		