Hot Corrosion Studies on HVOF Sprayed Ni-20Cr Coated ASTM A213 TP347H Boiler Steel AT 700°C

T.S. Bedi[1*], J.S. Gill[2] and G. Kaushal[3]

[1,2]*ME Deptt., RIMT Instiute of Engg. & Tech., Mandi Gobindgarh Punjab–147301, India*

[3]*ME Deptt., Yadavindra College of Engg., Punjabi University, Guru Kashi Campus, Talwandi Sabo, Punjab–501302, India*

E-mail: [1]tbedi87@gmail.com

Abstract—*Ni-20Cr coating was deposited on ASTM A213 TP347H boiler tube steel by High Velocity Oxy Fuel thermal spray process. Hot corrosion studies were conducted to investigate the performance of the coating. The tests were conducted for the uncoated and coated steel in a simulated boiler environment (Na_2SO_4-60%V_2O_5) at 700°C for 50 cycles. Each cycle consisted 1 hour of heating in the silicon carbide tube furnace followed by 20 min of cooling in air. The weight change measurements were recorded after each cycle to establish the kinetics of hot corrosion. The corroded samples were characterized by FE-SEM/EDS and XRD analysis. It was observed that Ni-20Cr coated specimen provided enhanced corrosion resistance than the uncoated specimen. The formation of protective oxides probably provided beneficial results.*

Keywords: *Hot Corrosion, HVOF, Ni-20Cr, Boiler Steel*

INTRODUCTION

Degradation of the materials due to hot corrosion has been consider as a major problem for many of the high temperature aggressive environment applications such as boilers, internal combustion engines etc [1–4]. In the conventional boilers, the various grades of steel are used as a boiler tubes material and the degradation of such a material by high temperature oxidation of hot section components and also accompanied by erosion as well [5–8]. The atmosphere in the power plant has sufficient free oxygen content to account for a combined erosion-corrosion process, consisting of an oxidizing gas at some temperature carrying fly ash particles which impact against metallic surfaces [9]. The combination of high temperature application for better efficiency with contaminates from the environment and low grade fuels such as sodium, sulfur, vanadium and chlorine requires special interest to the phenomenon of high temperature corrosion. This form of corrosion consumes the material at a very rapid rate [10]. Coating provides a way of extending the limits of the use of materials and also increases the life of boiler tubes at the upper end of their concert capabilities [11]. The High Velocity Oxy Fuel process is reported to be a versatile process and has been adopted by many industries due to its flexibility, cost effectiveness and superior quality of coating produced. Due to the high impact velocity of particles the coating shows a high adhesive strength, uniform microstructure, high density and low porosity [12–15].

The objective of this work is to investigate the possibility of deposition of Ni-20Cr coating on ASTM A213 TP347H with the help of HVOF thermal spray process and also to study its high temperature performance in a simulated residual fuel fired boiler environment of molten salt (Na_2SO_4-60%V_2O_5) at 700°C. The selected steel is used extensively for power plant boiler component, mainly in the super heater zone, where it has been observed that it suffers from high temperature erosion-corrosion by fly as particles. Moreover, the high-temperature boiler studies could provide an idea regarding the adhesion between the coatings and the substrate steels under thermal shocks [15]. The information arising out from the investigation will be useful to explore the possibility of the use of HVOF spray coatings on the boiler tubes for increasing the life of the boiler tubes.

EXPERIMENTATION

Substrate Material

The boiler tube steel, ASTM A213 TP347H with the chemical composition as shown in Table 1, had been used as substrate steel. This material is used as boiler tube material in some of power plants in northern India. The steel samples were cut into 20 x 15 x 5 mm^3 sized specimens. The specimens were polished and grit blasted with Al_2O_3 (grit 60) prior to application of HVOF spray coatings.

Table 1: Chemical Composition of ASTM A213 TP347H Steel (in % Age)

C	0.04 - 0.1
Mn	2.0
P	0.04 max
S	0.03 max
Si	0.75
Cr	17 - 19
Ni	9 - 13
Fe	65.08

Deposition of Coating

The Ni-20Cr powder was coated on the substrate material with the help of HVOF thermal spray process (HIPOJET-2700-M) at Metallizing Equipment Corporation Pvt. Ltd Jodhpur (Rajasthan). Samples were grit-blasted before the HVOF spraying. Spray parameters of as-sprayed HVOF Ni-20Cr coating as shown in Table 2. The coating was deposited on all six sides of the each specimen. The size of both the coatings was -45+15μm. (Grain size)

Table 2: Spray Parameters of HVOF As-sprayed Ni-20Cr Coating

Oxygen Flow rate	250 l/m
Air Flow rate	600 l/m
Spray distance	18 cm
Oxygen pressure	9 kg/cm2

Characterization of As-sprayed Coating

The as-sprayed coatings were examined visually. The thickness of as-sprayed coating was measured with the help of Elcometer. The surface roughness of the as-sprayed coated samples was measured with the help of surface roughness tester (Mitutoyo). The each 3 fields on the surface of the coated specimens were used to obtain the value of surface roughness (μm). Porosity of the as-sprayed coatings was measured with the help of metallurgical microscope with image analyzer. The 3 field on the surface of each coated specimens were used to obtain the value of porosity. FE-SEM/EDS (JSM-6610LV and FEI, Quanta 200F) analysis was done for both uncoated and coated specimens to characterize the surface morphology and XRD analysis of the specimens was carried out for both uncoated and coated specimens by using a Bruker AXS D-8 Advance Diffractometer with CuK_α radiation and nickel filter, at 40mA with a voltage of 45kv. The specimens were scanned with a scanning speed of 1kcps in the 2θ range of 1cm/min with 2^o/min as goniometer speed.

Molten Salt Environment

Hot corrosion studies were performed in a molten salt environment (Na_2SO_4-60%V_2O_5) for 50 cycles under the cyclic conditions. Each cycle consisted of 1 hour heating at 700^{o}C in a silicon carbide tube furnace followed by 20 minutes of cooling at room temperature. This cyclic study provides the most severe conditions for testing and represents the actual industrial environment, where breakdown and shutdown occurs frequently. A cyclic study of 50 cycles had been performed as the study of 50 cycles is considered to be adequate for attaining the steady state oxidation for the material [16–17]. The specimens were mirror polished down with 1 mm alumina polishing on cloth wheel before the test. A coating of uniform thickness with 5 mg cm^{-2} of Na_2SO_4-60%V_2O_5 was applied with the help of hairbrush after the preheating of both uncoated and coated specimens at 250^{o}C. The weight change measurements were taken at the end of each cycle with the help of an electronic balance having a sensitivity of 10^{-3} g. The mass change technique was used to formulate the kinetics of corrosion. Visual observations were also made after the end of each cycle with regards to colour, lustre, adherence/ spallation tendency and other physical aspect of the oxide scale/ coatings. After the hot corrosion studies, the corroded samples were then analyzed by SEM/EDS and XRD analysis.

RESULTS

Visual Observation and Thickness

The as-sprayed HVOF Ni-20Cr coating was dark grey in colour. The thickness of as-sprayed HVOF Ni-20Cr coating was found to be within the range of 200-250 μm.

Surface Roughness and Porosity

The surface roughness and porosity of as-sprayed HVOF Ni-20Cr coated 347H steel was measured. The surface roughness of the as-sprayed Ni-20Cr coating was found to be 6.519μm. The porosity value of as sprayed Ni-20Cr coating was found to be 0.40%.

FE-SEM/ EDS Analysis

The surface scale morphology of uncoated 347H steel is shown in Fig. 1. The EDS analysis of the uncoated 347H steel at points 1 revealed 73.37% Fe and 18.16% Cr. Almost a similar composition with 68.22% Fe and 20.33 % Cr was observed at point 2 as shown in Fig. 1. The surface scale morphology of as-sprayed HVOF Ni-20Cr coated 347H steel consists of irregular splats. There is also presence of some superficial void in the microstructure. The EDS analysis of as-sprayed HVOF Ni-20Cr coated 347H steel at point 1 revealed 77.82% Ni and 15.88% Cr. Almost similar composition with 71.42% Ni and 19.8% Cr was observed at point 2 as shown in Fig. 2. As expected, Ni has been found as the main constituent. The marginal presence of O in the composition is also observed. The similar structure of Ni-20Cr coating was also found by Kaushal *et al.*, (2011) [18].

XRD Analysis

The XRD diffraction patterns of as-sprayed HVOF Ni-20Cr coated ASTM A213 TP347H boiler steel is depicted in Fig. 3. The XRD analysis indicates Ni as a main element. The similar results of Ni-20Cr coating was also obtained by Chatha *et al.,* (2012) [19].

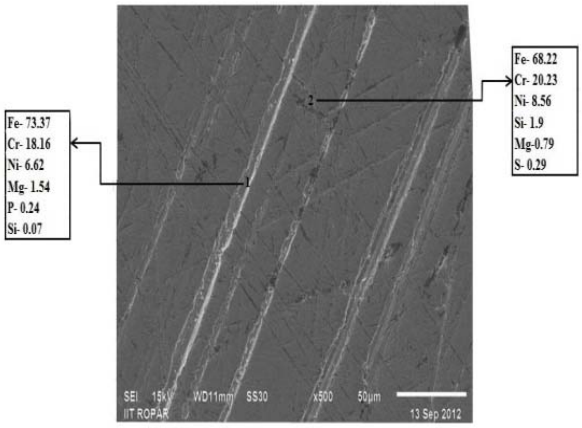

Fig. 1: FE-SEM/EDS Analysis of Uncoated 347H Steel

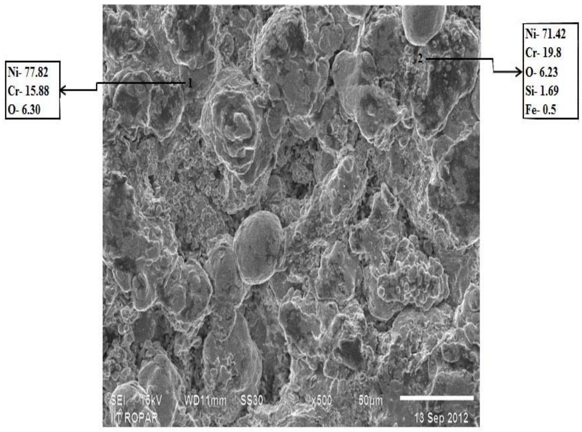

Fig. 2: FE-SEM/EDS Analysis of as-sprayed HVOF Ni- 20Cr Coated 347H Steel

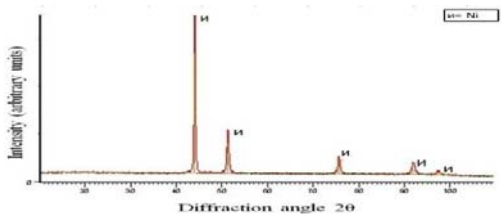

Fig. 3: X-Ray Image of as-sprayed HVOF Ni-20Cr Coated 347H Steel

Corrosion Kinetics

Cumulative weight change (mg/ cm^2) variations as a function of time expressed in number of cycles for the uncoated 347H steel and as-sprayed HVOF Ni-20Cr coated 347H steel was plotted in Fig. 4. The uncoated ASTM A213 TP347H boiler steel showed a rapid decrease in the weight upto 8^{th} cycle and continuous to 12^{th} cycle. After the end of 12^{th} cycle, a gradual decrease in the weight upto 50^{th} cycle was observed. For as-sprayed HVOF Ni-20Cr coated 347H steel showed a rapid decrease in weight upto 2^{nd} cycle and further increase in weight upto 4^{th} cycle was observed. At the end of 28^{th} cycle the weight change was nearly constant. The mass loss is associated with the formation of Na_2CrO_4 within the deposit, as evidenced from the XRD analysis. Na_2CrO_4 gets evaporated as a gas and may be a contributing factor to the mass loss [20]. The results of this HVOF sprayed Ni-20Cr coated 347H steel had also been published by Bedi *et al*., [21]. Amongst the investigation case HVOF as-sprayed Ni-20Cr coated 347H steel has provided the maximum resistance to corrosion as compared to uncoated 347H steel.

FE-SEM/EDS Analysis after Exposure

The surface scale morphology of uncoated 347H boiler steel shows some needle like formation was observed on the surface of specimen, this is probably ferric oxide. The EDS image of corroded uncoated steel at point 1 revealed 44.6% Fe, 43.24% O followed by minor percentage of C, Cr, Ni and Mg. Almost similar composition with 66.27% Fe, 21.17% O followed by Cr, Ni, C and Si were observed at point 2 as shown in Fig. 5. The similar observation of uncoated 374H steel was also found by Kaushal *et al.* (2011) [18]. The surface scale morphology of as-sprayed HVOF Ni-20Cr coated steel coated 347H steel shows at some area, a needle like formation was observed on the surface of specimen. The EDS image of corroded as-sprayed HVOF Ni-20Cr coated 347H steel at point 1 revealed 32.83% Ni, 33.81% O and 16.64% Cr was observed. Almost similar composition with 37.61% O, 25% Cr, and 23.28% Ni was observed at point 2 as shown in Fig. 6. The similar observation of HVOF as-sprayed Ni-20Cr coating was also found by Bala *et al*., (2009) [22].

XRD Analysis after Exposure

XRD image of uncoated ASTM A213 TP347H steel revealed Fe_2O_3 as main phase followed by NiO and Na_2CrO_4 phases as shown in Fig. 7. XRD image of as:

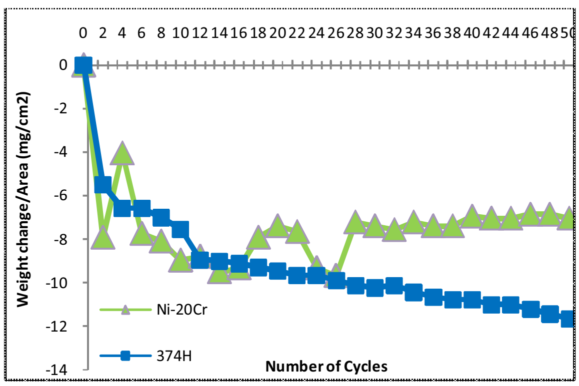

Fig. 4: Weight Change/ Area (mg/cm²) *vs.* Number of Cycles for Uncoated 347H Steel and As-sprayed HVOF Ni-20Cr Coated 347H Steel

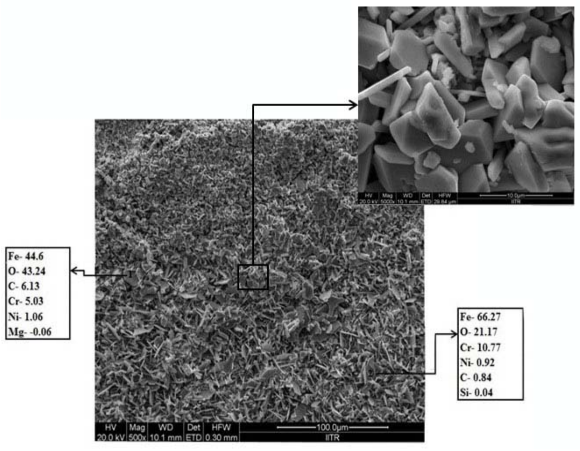

Fig. 5: FE-SEM/EDS Image of Uncoated 347H Steel after Exposure

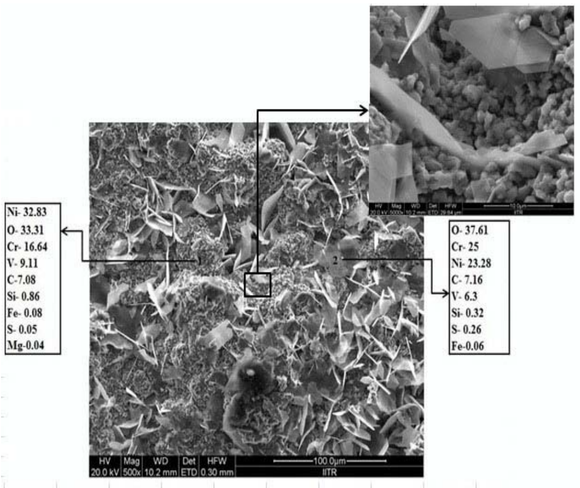

Fig. 6: FE-SEM/EDS Image of As-sprayed HVOF Ni-20Cr Coated 347H Steel after Exposure

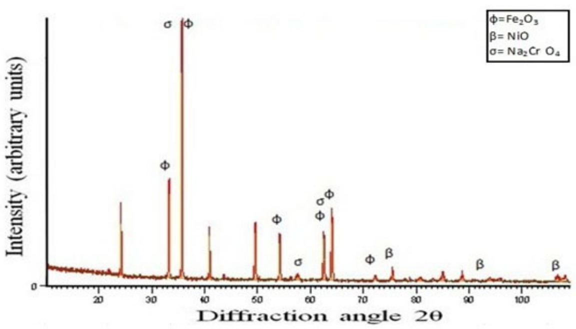

Fig. 7: XRD Image of Uncoated 347H Steel after Exposure

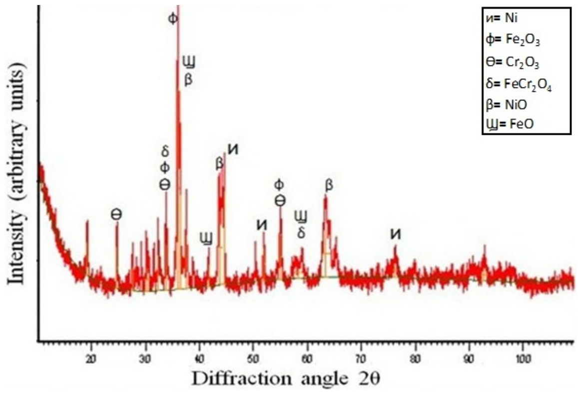

Fig. 8: XRD Image of As-sprayed HVOF Ni-20Cr Coated 347H Steel after Exposure

Sprayed HVOF Ni-20Cr coated ASTM A213 TP347H steel revealed Cr_2O_3, Ni, $FeCr_2O_4$, and Fe_2O_3 as main phases followed by FeO phase as shown in Fig. 8: Almost a similar protective phase was also found by Kaushal *et al.,* (2011) [18].

DISCUSSIONS

The High Velocity Oxy Fuel spray process provides the possibility of the deposition of Ni-20Cr coatings on the selected boiler steel. A coating of about 200–250µm was obtained. The surface roughness of as-sprayed HVOF Ni-20Cr coated 347H boiler steel was found to be 6.519µm. The apparent surface porosity of as-sprayed HVOF Ni-20Cr coated 347H boiler steel was fond to be 0.40%. The average value of porosity of HVOF coating has been found to be marginal with a porosity value of less than 1%. Cumulative weight change (mg/cm^2) variations as a function of time expressed in number of cycles for the uncoated and as-sprayed HVOF Ni-20Cr coated 347H steel was plotted in Fig. 4. It can be inferred from the plot that the as-sprayed HVOF Ni-20Cr coated 347H steel has provided the maximum resistance to the corrosion. The overall results revealed that the formation of protective oxides probably provides the better results.

CONCLUSION

- The HVOF process was found to be suitable to deposit Ni-20Cr coating on 347H boiler steel in the range of 200-250μm.
- The value of surface roughness of as-sprayed HVOF Ni-20Cr coated 347H boiler steel was found to be 6.519μm.
- The apparent value of porosity of as-sprayed HVOF Ni-20Cr coated 347H boiler steel was found to be 0.40%.
- The Ni-20Cr coating was found to be successful in reducing the corrosion rate of the 347H boiler steel.
- The formation of Ni, Cr_2O_3 and $FeCr_2O_4$ phase along with FeO and Fe_2O_3 might have imparted a better corrosion resistance to the coating.

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