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

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Abstract: ***Erosion and corrosion is the commonly experienced causes of failure at a premature stage of component life, when component subjected under high temperature environment. To achieve higher performance and efficiency of components raise the demand of protective surfaces (coatings). In the present work, a boiler steel T-91 was been taken as a sample material for its erosion-corrosion study in actual environment. Detonation gun thermal spraying process was used for coating of Al_2O_3 powder on T-91 boiler steel. The coated and uncoated samples were subjected to cyclic erosion-corrosion in actual environment i.e. in boiler for 10 cycles. The SEM/EDAX and thermo gravimetric techniques were used to analyse the corrosion -erosion products. After the analysis, it was found that Al_2O_3 coating was less effective than the uncoated samples of T-91 steel for providing the protection against erosion-corrosion in actual environment of boiler.***

Keywords: Erosion –corrosion, Detonation-gun, Al_2O_3 coating, T-91 Steel.

1. Introduction

With the advancement in the science and technology, the expectations regard the life of the component in working conditions also increased. Most of the materials used in the modern industrial components and systems often subjected to such environmental conditions which lead them to failure at a premature stage of their life. Erosion and corrosion is the commonly experienced causes of failure at a premature stage of component life, when component subjected under high temperature environment. Many techniques were introduced to provide the resistant from erosion and corrosion failure of material. Among all the techniques, coating is a best technique to resist surface from corrosion as well as erosion by providing the protective layers on the surface.

A coating is a layer of material, formed naturally or synthetically, or deposited artificially on the surface of an object, that is made of another material with the aim of obtaining required technical or decorative properties [1]. During coating various problems encountered by surface engineer that includes substrate compatibility, adhesion, and porosity of repair or recoating systems, inter diffusion, thermal cycling damage, wear and corrosion resistance and cost. So these problems make essential to design the substrate and coatings as an integrated system with all these features in mind [2]. The demand for protective coatings has increased recently for almost all types of alloys, because high temperature attack becomes more significant with increasing operating temperatures. The necessity for higher performance and increased efficiency has resulted in the progressive increase in plant operation temperatures [3].

The erosion and corrosion response, the degeneration of mechanical properties and the micro mechanisms of the surface damage for SiC ceramic materials founded negligible, under high temperature conditions [4].Steels coated with stellite 6 as plasma sprayed were found to possess higher resistance to erosion corrosion than uncoated steels under cyclic conditions in superheated zone of coal fired boiler[5]. The nickel-based superalloy, Superni-75, is resistant to erosion–corrosion mode of degradation in the real service environment of the coal-fired boiler [6].

Detonation gun (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 [7].Detonation gun sprayed of Al_2O_3 powder provides a typical layer structure similar to that of coatings deposited using other thermal spraying processes. However, the high particle velocity results in the formation of a rough surface on the spray splat, which may be effective in enhancing interlocking between flattened particles [8]. Oliker et al. (2006) studied the formation of detonation coatings based on titanium aluminide alloys and aluminium titanate ceramic sprayed from mechanically alloyed powders Ti- Al[9]. Wang et al. (2009) designed the separation device for detonation gun spraying system and studied its effects on the performance of WC-Co coatings. The results showed that the use of the separation device resulted in better properties of the D-gun sprayed WC Co coatings, because of lower the surface roughness, lower the porosity, higher the micro hardness, higher the elastic modulus, and higher the interfacial adhesive strength. Also, the tribological performance of the WC-Co coatings was improved [10].

Many materials such as T-11, T-22, GrA1, SS-347 and T-91 have been employed for the application in boilers. In order to improve the performance of these materials in boilers, the study of behaviour and performance of these materials at high temperature became an important issue. Also it was important to study, if the performance of T-91 could be improved by coating. So it has been planned in the present work, to study the behaviour and performance of T-91 material in uncoated as well as coated condition by examining its surface and sub – surface by heating it at 900 ^{0}C under cyclic conditions and in actual environment that is in boiler. Detonation gun thermal spraying process was used for coating of Al_2O_3 powder on T-91 boiler steel. The coated and uncoated samples were subjected to cyclic erosion-corrosion in actual environment i.e. in boiler for 10 cycles. The SEM/EDAX, XRD and thermo gravimetric techniques were used to analyse the corrosion -erosion products. After the analysis, it was found that $Al_2\,O_3$ coating has failed in providing the protection to base metal against erosion-corrosion in actual environment of boiler.

2. Materials and Methods

2.1. Substrate Material

Boiler steel T-91, recently employed in a thermal power plant which was taken as a sample material. The nominal chemical composition (wt. %) of ASTM-SA213-grade T-91 boiler steel shown in table 1.Specimens with dimensions of 20mm X 15mm X 5mm were cut from the alloy tubes. The specimens were polished using emery papers of 220, 400, 600 grit sizes and subsequently on 1/0, 2/0, 3/0 and 4/0 grades and then mirror polished using cloth polishing wheel machine with 1μm lavigated alumina powder suspension. The specimens were prepared manually and all care was taken to avoid any structural changes in the specimens. Subsequently grit blasted with alumina powder (Al2O3) before spraying of coating. A hole of 1.2 mm diameter was drilled in all the specimens to hang them in the boiler for experimentation.

Table1: Nominal Chemical Composition (wt. %) of ASTM-SA213-grade T-91 boiler steel

Alloy	*C*	*Mn*	*Si*	*S*	*P*	*Cr*	*Mo*	*V*	*Ni*	*Other Elements*	*Fe*
T-91	0.08-0.12	0.30-0.60	0.20-0.50	0.01 Max.	0.02 Max.	8.00-9.50	0.85-1.05	0.18 - 0.25	0.40 Max.	Nb = 0.06 to 0.10 N = 0.03 to 0.07, Al=0.04	Bal.

2.2. Development of coating

Commercially available $Al_2\,O_3$ alloy in the powder form was used as the coating material. Coating was formulated at SVX coating works Pvt. Ltd., Noida (India) by using Detonation gun spray apparatus. The standard spray parameters as mentioned in the manual of Detonation gun spray system were used for the deposition of the coating as shown in table 2.

Table 2: Spray Parameters of D-gun Spraying

Variant	D-gun spraying (Al2O3)
Oxygen flow rate	4800 l/h
Fuel (acetylene) flow rate	1920 l/h
Carrier gas (nitrogen) flow	800 l/h
Spray distance	200 mm
Flame temperature	39000C
Detonation frequency	3 shots/sec

2.3. Studies in coal fired industrial boiler

The T-91 specimens were exposed to the platen super-heater zone of the coal fired boiler of Stage-II at Guru Nanak Dev Thermal Plant, Bathinda, Punjab (India). The coated as well as uncoated specimens were polished down to 1μm alumina on a cloth polishing wheel machine to obtain similar conditions of reaction on the surface of all the specimens. The coated as well as uncoated specimens were hanged with the help of a stainless steel wire through the soot blower dummy points at 27 m height from the base of the boiler. The specimens were exposed to the combustion environment for 10 cycles. Each cycle consisted of 100 hours heating followed by 1 hour cooling at ambient conditions. The temperature was measured at regular intervals during the study and the average temperature was about 900 ^{0}C with variation of ± 100C. After the end of each cycle, the specimens were visually observed for any change in the surface texture, further it has been washed by acetone and weight of the specimens were measured subsequently using an Electronic Balance Model CB-120 (Contech, Mumbai, India, and sensitivity 10-3 g).

3. Results and Discussion

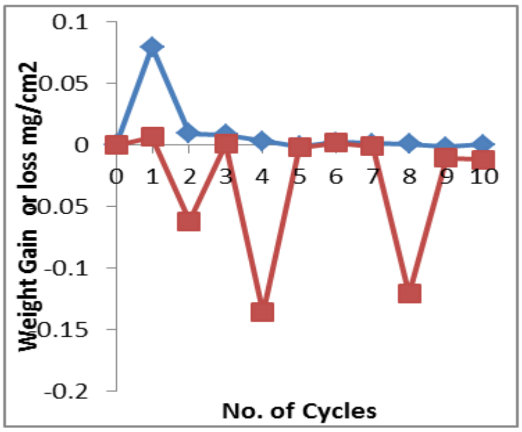
3.1 Visual Examination

After the end of each cycle, the specimens of Uncoated T-91 steel and $Al_2\,O_3$ coated T-91 steel were visually observed for any change in the surface texture and high temperature erosion-corrosion behaviour. The high temperature erosion-corrosion behaviour of uncoated T-91 steel was visually examined for 10 cycles at 900 ^{0}C. Uncoated T-91 steel showed slight erosion-corrosion after finish of 1st cycle and small layer from one side of the substrate was removed up to the 4th cycle. Slight erosion on one side of the substrate was observed after 6th cycle. With the finish of 8th cycle red rusty colour was appeared on the substrate and it was changed to rusty brown colour after the end of 10th cycle.

In case of $Al_2\,O_3$ coated T-91 steel, coating was removed from one corner after 1st cycle and no change was observed with the finish of 3rd cycle. Coating was break down from one side half of the surface after 4th cycle. Same side of the substrate showed cracks in the coating which was not breaked off after 7th cycle. Eroding of coating was increasing with the increase of cycles and one side of coating on substrate was eroded completely with the end of 10th cycle.

3.2 Thermogravimetric Study

The thermogravimetric analysis was done for uncoated and $Al_2\,O_3$ coated T-91steel.Weight gain or loss per unit area (mg/cm2) versus number of cycles plot for boiler steels exposed to super-heater of the coal fired boiler environment at 900 ^{0}C for 1000 hours; is presented and cumulative weight gain or loss is presented in case of uncoated 0.93% weight was gain where as 2.96% weight loss was observed in case of $Al_2\,O_3$ coated T-91 steel. However weight change was quite low which was clear from the graphs shown in figure 1.



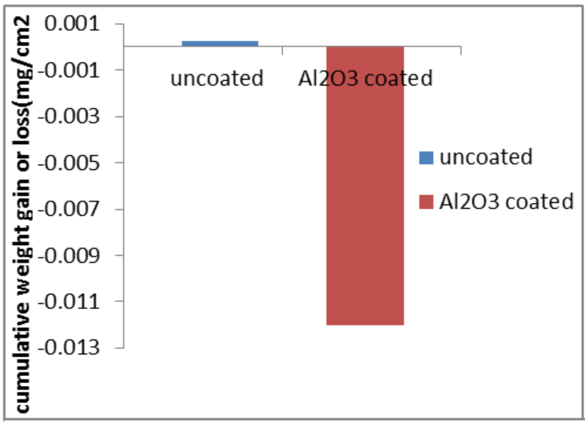


Figure 1: Weight gain or loss/area vs no. of cycles and Cumulative weight gain or loss /unit area for uncoated and coated T-91 steel

3.3 Surface Scale Analysis

SEM micrographs along with EDAX point analysis reveals the surface morphology of the boiler steels exposed to super-heater of the coal fired boiler environment at 900 ^{0}C for 1000 hours; are shown in figure 2 and figure 3respectively. Micrograph for Grade T-91 boiler steel indicates a scale developed dark grey and white regions. EDAX analysis of both uncoated and coated T-91 boiler steel indicates the presence of Al, O, Si, Zr, C elements whereas Fe was present only in uncoated substrate.

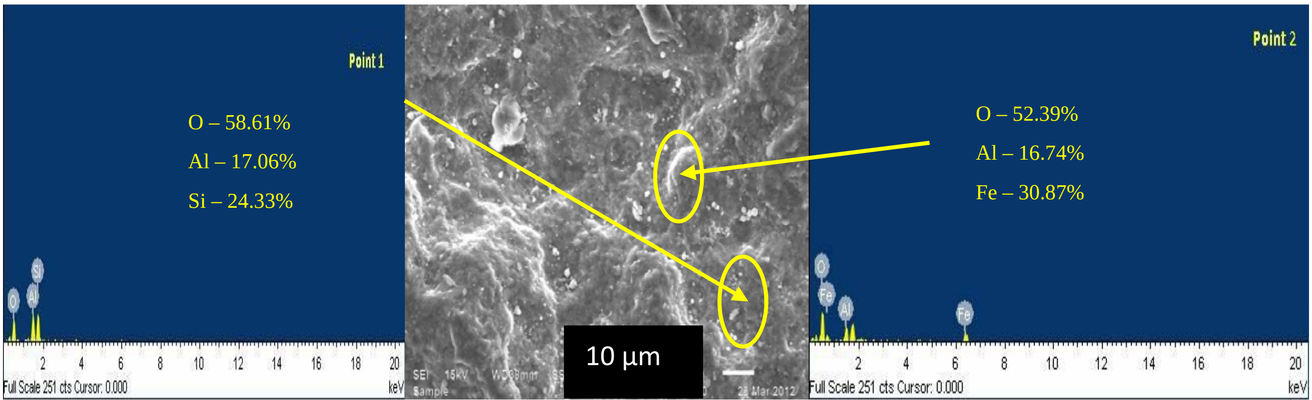


Figure 2: SEM micrograph and EDAX analysis for uncoated T-91 steel after high temperature erosion-corrosion at 900^{0}C for 1000 hours in coal fired boiler environment

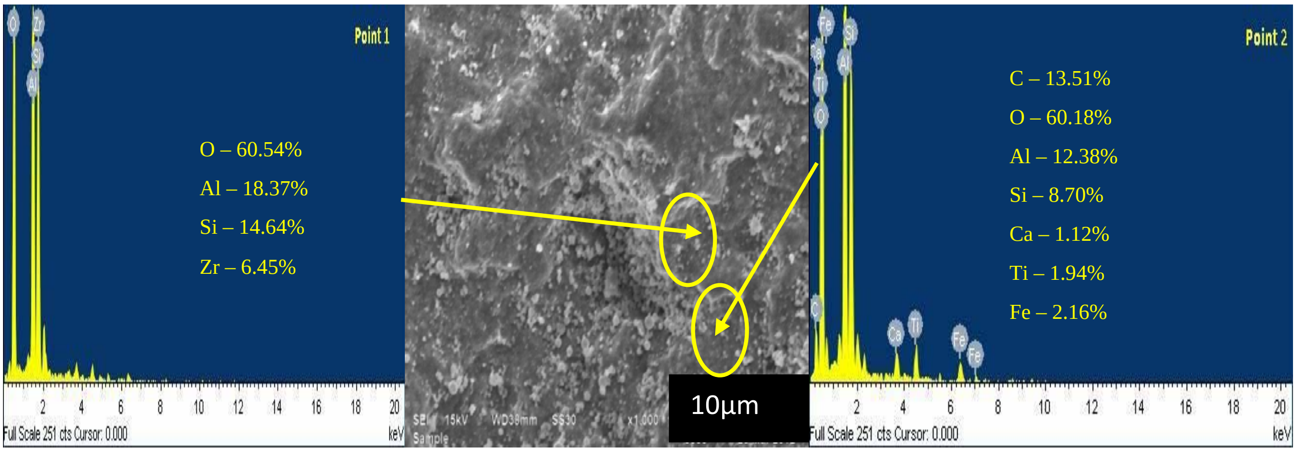


Figure 3: SEM micrograph and EDAX analysis for Al_2O_3 coated T 91 steel after high temperature erosion-corrosion at 900^{0}C for 1000 hours in coal fired boiler environment

3.4 Cross-sectional analysis

Back Scattered Electron Image (BSEI) micrograph and elemental variation across the cross-section for boiler steels exposed to super-heater of the coal fired boiler environment at 900 ^{0}C for 1000 hours of T-91 boiler steel. In analysis Al, O and Fe were present in scale of uncoated and coated samples as shown in figure 4 and figure 5 respectively.

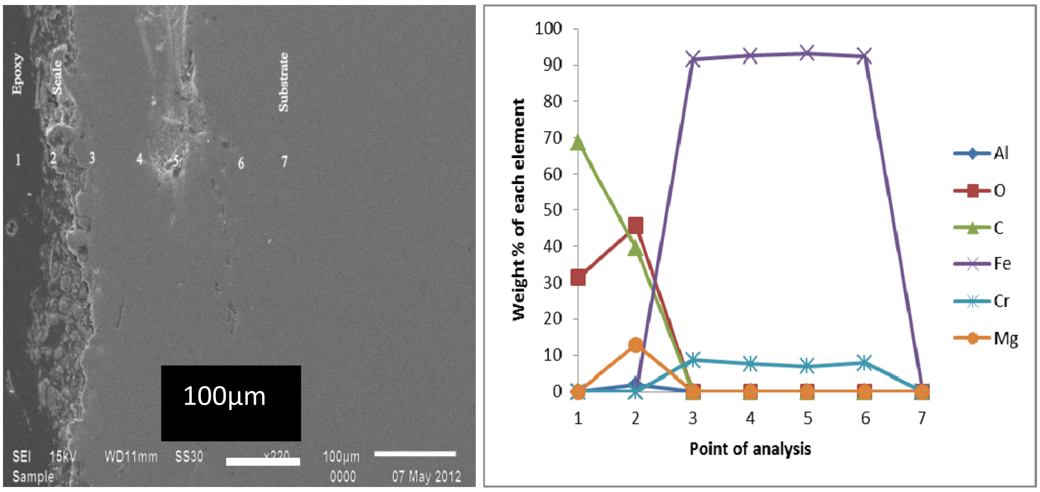


Figure 4: Scale Morphology and Variation of Elemental Composition across the Cross-Section of Uncoated T-91 Steel

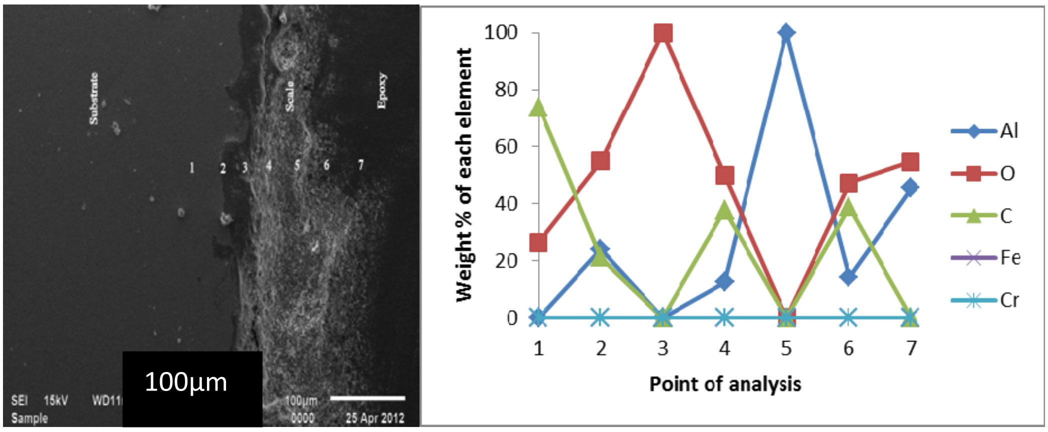


Figure 5: Scale Morphology and Variation of Elemental Composition across the Cross-Section of Coated T-91 Steel

4. Discussion

During erosion-corrosion study of uncoated and coated T-91 steel in actual industrial environment, uncoated specimen gained some weight after 1st cycle, then lost weight after 2nd cycle and remained constant in rest of the cycles where as in case of coated specimen there was great variation in weight and at last there was weight loss from the coated specimen at the end of the cycles. SEM/EDAX showed the presence of same elements which were studied before the samples were studied in actual environment in both the cases bare as well as in coated samples. The erosion-corrosion rate for the uncoated and coated Grade T-91 boiler steel specimens in case of actual environment is: Al_2O_3 coated T-91 >Uncoated Grade T-91.

5. Conclusion

1. Coated T-91 experienced 2.96 % weight loss due to the erosion of the scale formed on the sample whereas uncoated T-91 did not showed weight loss inferring that less erosion was experienced by the uncoated sample.
2. The erosion corrosion rate of Al_2O_3 coated T-91 is more than that of uncoated T-91 in actual environment. Therefore, the resistance to erosion corrosion was better experienced in uncoated T-91 than the coated T-91.

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