PERFORMANCE OF NI_3AL AND TIO_2 COATINGS ON T22 BOILER TUBE STEEL IN SIMULATED BOILER ENVIRONMENT IN LABORATORY

Simranjeet Singh[a], Khushdeep Goyal[b*], Rakesh Goyal[c]
[a]Department of Mechanical Engineering, Punjabi University, Patiala
[b]Department of Mechanical Engineering, Punjabi University, Patiala
[c]Chitkara University, Rajpura
[*]Corresponding e-mail: khushgoyal@yahoo.com

Abstract: *The corrosion of boiler steel tube in coal fired boiler is main matter during design and operation of thermal power plant and it leads to both direct and indirect cost and energy lost, including losses due to plant shut down time and inefficiency of operation. One of the feasible solution to solve the problem is providing surface coating on boiler steel tube, which on one hand protect the tube from highly corrosive flue gaseous and on other hand increase their operating life. Ni_3Al and TiO_2 and coatings were sprayed on ASTM SA213-T22 steel by using the HVOF process. Hot corrosion studies were conducted on the uncoated as well as coated sprayed specimens in molten salt environment of Na_2SO_4-60%V_2O_5 at 900ºC for 50 cycles. In the experiment each cycle consist of 1 hr of heating in tube furnace followed by 20 minute of cooling in air. The thermo-gravimetric technique was used in order to establish the kinetics of corrosion. XRD, SEM/EDS testing were used to examine the corrosion specimens. The result shows that both the coated samples are beneficial to corrosion resistance over uncoated samples. TiO_2 coating was found to be most protective followed by the Ni_3Al coating.*

Key Words*: Corrosion, Boiler steel, Degradation, SEM/EDS, XRD technique*

INTRODUCTION

Degradation is mainly occurs in the components of very high temperature or in hot sections i.e. gas turbine, boilers etc. due to very high temperature oxidation, hot corrosion and erosion[1]. Hot corrosion results in failure of precious product and results in increases the cost of product and decreases the surface finish of product. It also reduces the efficiency of product and increases the roughness of product[2]. The corrosion of metals is a spontaneous phenomenon from the view point of chemical Thermodynamics, which esults in function-loss in construction products. Corrosion leads to be the loss or damage of a metal by the action of corrosive agents. Corrosion is the surface wastage that occurs when metals are exposed to reactive environments. In order to prevent the metal from corrosion, coating is applied on the metal surface[1]. A coating is also a covering that is applied to the surface of an object, generally referred to as the substrate or sample. The aim or purpose of applying the coating may be decorative, functional, or both. The coating itself may be an all-over coating, completely covering the substrate, or it may only cover some parts of the substrate[3]. Thermal Spray technique was firstly invented by Dr. Schoop by designed a gun which used O_2 and acetylene as a main source of heating & for projection of molten metal on the substrate he utilised compressed air. This technique was also further used by George & Herb [3]. Many researchers have developed thermal spray coatings to reduce the corrosion of boiler tube steels. **H S Sidhu et al.**[4] studied that by using high velocity oxy fuel (HVOF) technique Cr_3C_2-NiCr, NiCr, WC-Co and stellite 6 alloy coating were sprayed or deposited on ASTM-SA213-T11 steel. The fuel gas used in this process is liquid petroleum gas. Hot corrosion was performed on uncoated as well as coated component by HVOF technique after explosive to the molten salt environment at 900°C under cyclic condition. The various thermo gravimetric techniques, XRD, SEM/EDAX and EPMA technique were used to analysis the corrosion product. The coating showed the good and better resistance to hot corrosion as compared to uncoated steel. The porosity level ranges from less than 1 to 3.5 for each coating. The most protective coating was found to be in NiCr coating followed by Cr_3C_2-NiCr coating. The least protective coating was WC-Co to protect the steel from hot corrosion. It was resulted that Cr_2O_3. NiO, $NiCr_2O_4$ and CoO in the

coating may contribute in the development of a better hot corrosion resistance. The porosity for coating was less than 1 and provides highest resistance to hot corrosion. **T S Sidhu et al.**[5] described that NiCr coating was deposited on the surface of Ni and Fe based alloy by using HVOF process. The coating was approximately 200-250 µm thick and porosity was found to be less than 1% and surface roughness was 5.936 ± 0.32 µm. The structural characteristics of the deposit have been studied with the help of XRD, optical microscopy, SEM/EDAX. The developed coating had dense uniform microstructure with the hardness ranges from 600 to 630 Hv and porosity was found less than 1%. XRD and EDAX showed that main constituent outstanding phase of Ni-20%Cr coating is Ni. The small fraction of Cr_2O_3 phase was formed in the coating. It was found that coating was helpful to provide protection against hot corrosion. **M Kaur et al.**[6] examined that Cr_3C_2-NiCr coating was applied on the surface of SAE-347H boiler steel by using HVOF process in the molten salt environment of Na_2SO_4-$82Fe_2(SO_4)_3$ at a temperature of 700°C for 50 cycles. To establish the kinetic of corrosion weight change measurement after each cycle were made. Then the different XRD, field emission-scanning electron microscopy/energy dispersive spectroscopy and X ray mapping techniques were used to amalysis the corrosion product. It showed that uncoated 347H steel suffered accelerated oxidation at 700°C in the air as well as in the molten salt environment whereas HVOF sprayed Cr_3C_2-NiCr coating was found to be successful in maintaining its adherence in both the environment. The rich oxides of chromium were formed for better hot corrosion resistance in the coated steel. The HVOF sprayed Cr_3C_2-NiCr coating performed well in the molten salt environment than in the air environment. **H.Singh et.al.**[7] reported that metal & alloys suffers from accerlated oxidation when comes in contact with fuse salt. Ni-Cr, NiCr-AlY, Ni_3Al & Stallite-6 were used as substrate material. Plasma spray was used as coating technique. The porosity of coating was less than 2-4%. XRD shows formation of oxides of Fe, Cr, Ni& Al. EDAX shows formation of Cr_2O_3, NiO& M_2O_5. Ni-Cr, stallite-6 shows good corrosion resistance, but NiCr-AlY provides best provides against corrosion. **B.S.Sidhu et. al.**[8] describes that gaseous environment contains Oxygen, sulphur& carbon which cause rapid degradation of metals & alloys. Coating of stallite-6, Ni-Cr-AlY, Ni-Cr & Ni3AlY was done & T22 & T11 were used as substrate material. The plasma spray was used as coating technique.Stallite-6 shows best coating & the Ni_3AlY shows best protection against corrosion. Uncoated T22 shows better corrosion resistance then all other uncoated steels.

The literature review makes us clear that investigation of performance of coated boiler steel samples is crucial research area for the researchers, and there is still a scope to increase the corrosion resistance performance of boiler steel tube in boiler environments. Therefore, the present work has been focused to study the influence of HVOF sprayed Ni_3Al and TiO_2 coatings on hot corrosion behavior of ASTM–SA213-T-22 steel. . XRD, SEM and EDS testing are used to characterize the corrosion samples formed after the experimentations work.

EXPERIMENTATION

Substrate Material

ASTM-SA213-T22 boiler steel has been selected as the substrate material for the current study. This type of carbon steel recently introduced as boiler steel in the super heater zone in northern part of India. The material for the study was available from the CHEEMA BOILER LTD (PB).as shown in Table 1.

Table 1. Nominal Chemical composition (wt %) of ASTM SA213-T22 boiler tube steels

C	Mn	P	Si	S	Cr	Mo	Fe
.05-.15	0.3-0.6	0.025	0.50	0.025	1.9-2.6	0.87-1.13	balance

Preparation of samples of substrate material

Samples each dimensioning 20 mm × 15 mm ×5 mm approximately, were cut from the fresh boiler tubes steel. The sample were polished down with the help of emery papers 180 grit sizes and subsequently on 1/0, 2/0, 3/0 and 4/0 grades and then mirror polished using cloth. The specimens were prepared manually. All the special cares was taken to avoid any structural changes in the specimen and finally the deposition of the coating is done with the help of High velocity oxy fuel process.

Development of coating on material

HVOF process was used to apply coatings on the super alloys at Metallizing Equipment Co. Pvt. Ltd. Jodhpur Rajasthan India. Standard spray parameters were used for depositing the Ni_3Al and TiO_2 coatings on T-22. All the process Parameters including the spray distance, were kept constant throughout the coating Process. The experiment was performed at 900^0C.

Table 2. Specification for tube furnace

MAX TEMPERATURE	POWER	HEATING ELMENT	THERMOCOUPLE	HEATING ZONE
1200 $\pm5^0$C	I KWh	Electric filament	K_TYPE	9 INCHES

RESULTS

The performance of boiler steel T-22 without coating and after coating with Ni_3Al and TiO_2 using High velocity oxy fuel sprayed process is being discussed, under various condition viz. Heating takes place at 900 ℃ in aggressive environment of molten salt Na_2So_4- 60% V_2O_5 at 900°C under cyclic condition[10]. The surface conditions were observed during the process of heating and weight change was analyzed through thermogravimetric data. The corrosion products were analyzed by using SEM, EDS and XRD testing.

3.1 SEM/EDS analysis of Un-Coated T-22 boiler Steel in salt environment

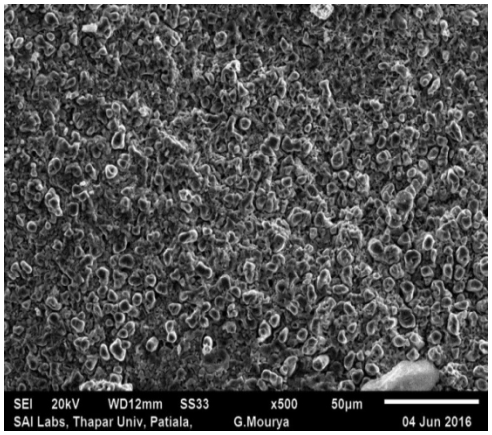
The SEM micrograph showing the surface morphology of Un-Coated T-22 boiler Steel in salt environment of Na_2SO_4-60% V_2O_5 is shown in Figure 1. The Oxide layer for T-22 steel consists of an upper sub layer dispersed in matrix. The further more EDS analysis of these particles corresponding to spectrum indicated. that might have deposited during the exposure. The EDS composition at spectrum indicate that the scale mainly consist of Fe and O, which indicating the formation of Fe_3O_2. There is presence of some globular particles in the scale, the excessive presence of Fe and O elements are shown Fig. 1.

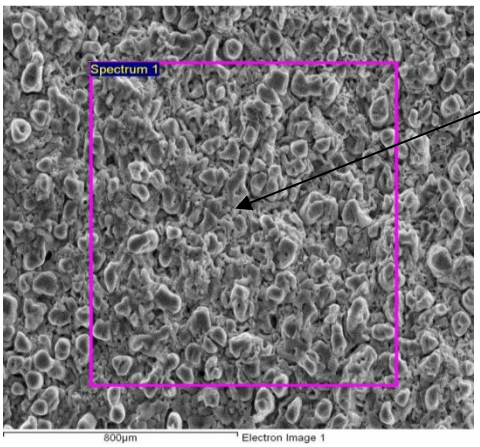
3.2 SEM/EDS analysis of Ni_3Al Coated T-22 boiler Steel in salt environment

The SEM micrograph showing the surface morphology of HVOF-spray Ni_3Al Coated T-22 boiler Steel in molten salt environment in Fig. 2. Furthermore EDS analysis corresponding to spectrum indicates the formation of NiO and NiC on sample. There is presence of some Globular particles in the scale. As could be perceived from the excessive presence of O, Ni and Al.

XRD analysis of uncoated T-22 boiler steel in salt environment

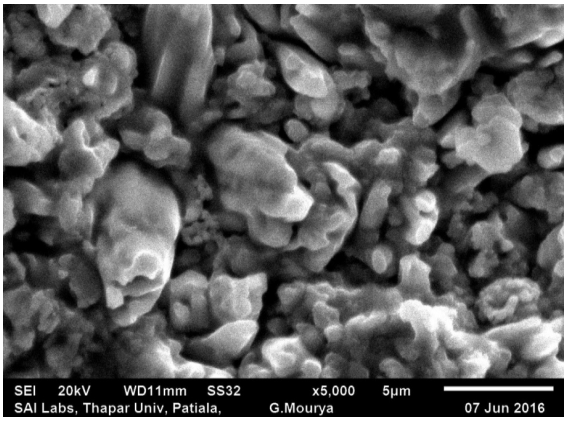
The X-ray diffraction of un-coated specimen of T-22 as shown in fig 5.19.subjected to testing in molten salt enviroment of Na_2SO_4-60%V_2O_5 at 900 ˚C [11] . The oxide scale of uncoated T-22 steel is of Fe_2O_3 and Cr_2O_3 at major peaks while Fe_3O_4 at minor peaks.

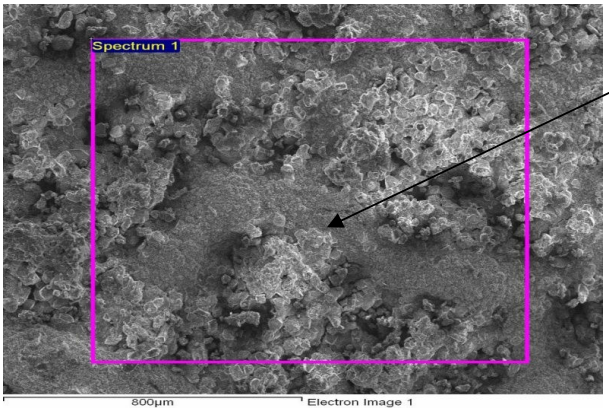




C	4.50
O	36.18
Mn	4.23
Fe	48.23
Ni	0.07
Mo	6.79

Figure 1. Show the Surface scale morphology SEM images and EDS analysis for the Un coated T22 in molten salt environment



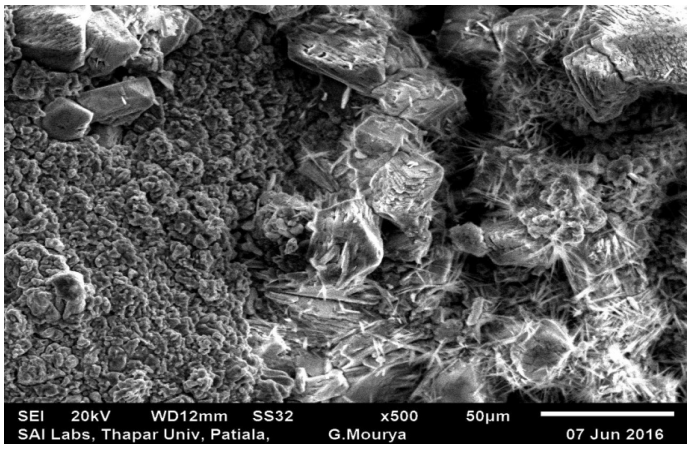


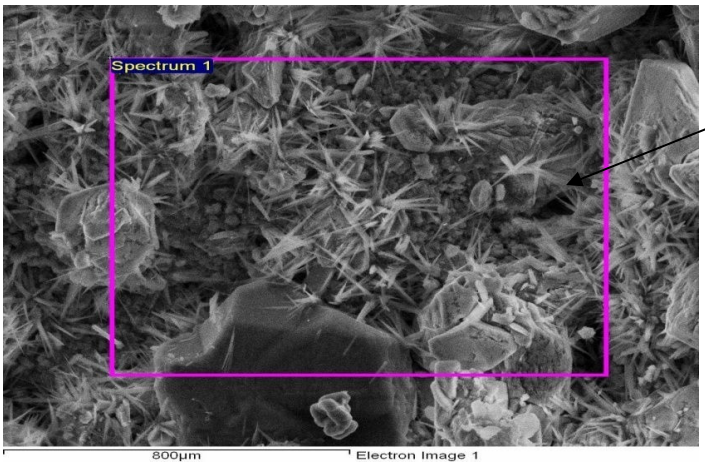
C	1.82
O	32.13
Na	1.69
Al	23.23
Si	0.40
S	0.75
V	0.42
Cr	0.61
Ni	36.71

Figure 2. Surface scale morphology SEM images and EDS analysis for Ni_3Al Coated T-22 boiler Steel in Salt environment

XRD analysis of Ni_3Al coated T-22 boiler steel in salt environment

The X-ray diffraction of Ni_3Al coated specimen of T-22 as shown in fig 5.subjected to molten salt testing in salt enviroment. The oxide scale of coated T-22 steel is found to have of presence of NiO, Al_2O_3 and NiC at major peaks while Fe_2O_3 at minor peaks.





C	0.13
O	49.32
Na	13.37
Ti	20.44
Si	2.99
S	0.97
K	0.51
V	6.93
Cr	0.85
Ni	2.85

Figure 3. Show the Surface scale morphology SEM images and EDS analysis for TiO_2 Coated T-22 boiler Steel in salt environment

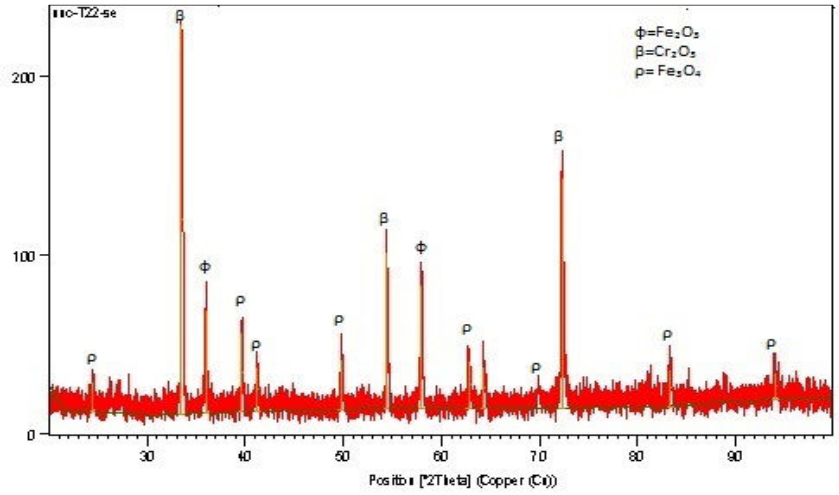


Figure 4. XRD analysis of uncoated T-22 boiler steel in salt environment

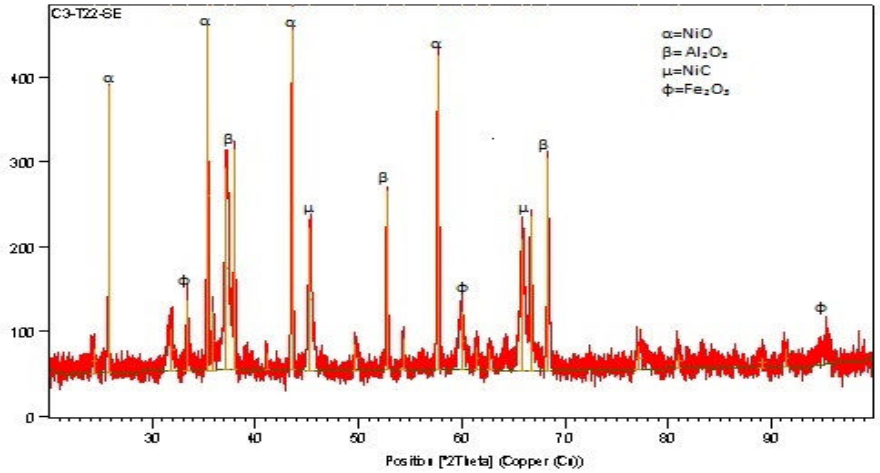


Figure 5. XRD analysis of Ni_3Al coated T-22 boiler steel in salt environment

XRD analysis of TiO_2 coated T-22 boiler steel in salt environment

The X-ray diffraction of TiO_2 coated specimen of T-22 as shown in fig 6.subjected to oxidation testing in oxidation enviroment. The oxide scale of coated T-22 steel is found to have a presence of Ti_2O_3 at major peaks while TiO_2 at minor peaks.

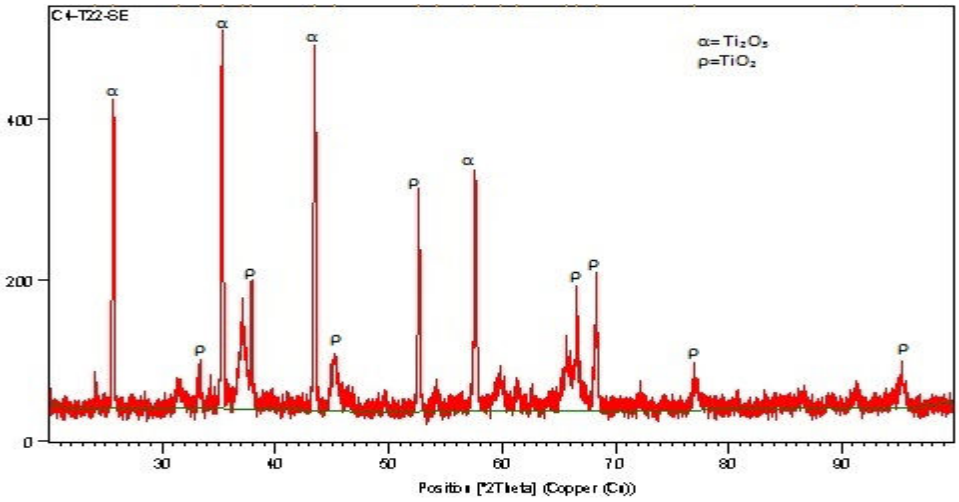


Figure 6. XRD analysis of TiO_2 coated T-22 boiler steel in salt environment

Weight change for T-22 in molten salt environment

The graph is plotted between the weight change and number of cycles for uncoated T-22 , Ni_3Al coated T-22 and TiO_2 coated T-22 in molten salt environment. It can be seen from the graphs that total weight gain in uncoated T-22 is 2.94 gm, 1.97 gm in Ni_3Al coated T-22 and 1.36 gm in TiO_2 coated T-22 in salt environment at temperature of 900℃.

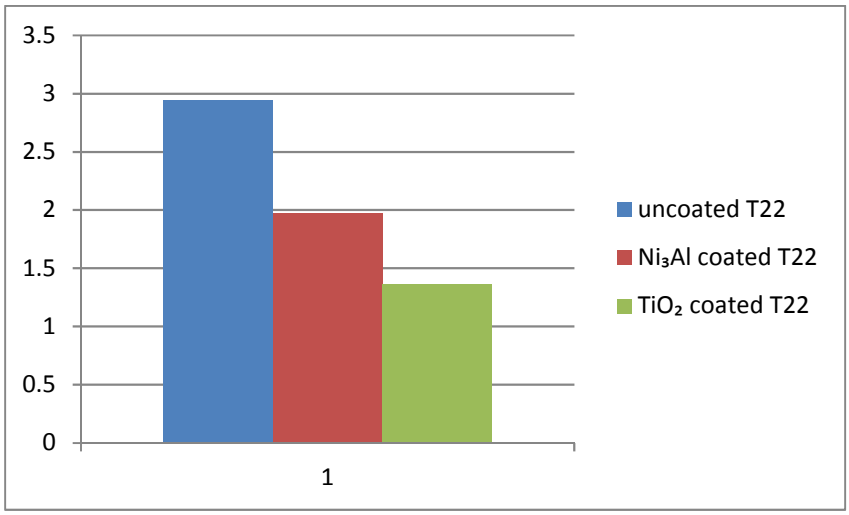


Figure 7. Total weight gain of uncoated T-22, Ni_3Al coated T-22 and TiO_2 coated T-22 in salt environment

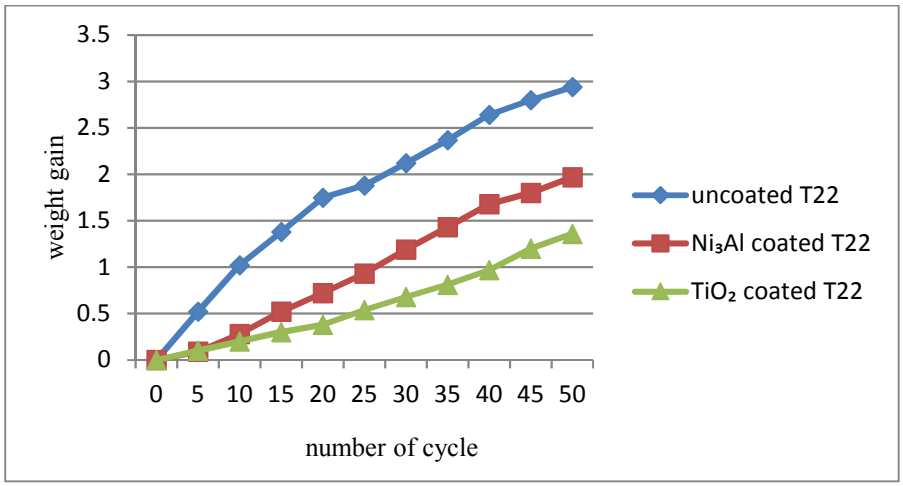


Figure 8. Comparison of uncoated T-22 , Ni_3Al coated T-22 and TiO_2 coated T-22 in salt environment

CONCLUSION

1) Ni_3Al and TiO_2 coating has been successfully deposited by HVOF technique on ASTM-SAE213-T22 boiler steel. The coating thickness has been of range of 250-300 µm.

2) In case of uncoated T-22 boiler steel Fe_2O_3, Cr_2O_3 and Fe_3O_4 were identified as main phase by XRD and SEM/EDS in salt environment.

3) In TiO_2 coated T-22 substrate TiO, Ti_2O_3 and Ti_3O_5 were identified as major phases in salt environment at 900˚C by XRD and SEM/EDS analysis.

4) In Ni_3Al coated T-22 substrate $NiAl_2O_4$, Al_2O_3 and ,NiC were identified as major phases in salt environment at 900 ˚C by XRD and SEM/EDS analysis.

5) The bare T-22 boiler steel suffered high corrosion rate as compared to coated T-22 boiler steel in salt environment. The corrosion loss is more in Ni_3Al coating as compared to TiO_2 coating substrate.

6) Ni_3Al coating may be recommended as a suitable coating process combination for salt environment whereas HVOF sprayed TIO_2 was found to be best among studied coating. The formation of oxide scale might have imparted better corrosion resistance to coating

7) The corrosion rate for uncoated and coated T-22 boiler steel sample in molten salt environment are as follow-

$TiO_2 > Ni_3Al >$ uncoated T-22

REFERENCE

1. Rapp. Robert A. (2002) "Hot corrosion of materials: A fluxing mechanism", Corrosion Science, Vol.44, pp. 209-221.

2. Nelson, H.W., Krause, H. H., Unger, E.W., Putnam, A. A., Slander, C.J., Miller, P.D., Hummel, J.D. and Landry, B.A.(1959) "A Review of Available Information on Corrosion and Deposits in Coal and Oil Fired Boilers and Gas Turbines," Report of ASME Research Pub. Pergamon Press and ASME, New York, pp. 1-197.

3. Chen, K.C, He, J.L, Chen, C.C, Leyland, A and Matthews, A. (2001),"Cyclic Oxidation Resistance of Ni-Al Alloy Coatings Deposited on Steel by a Cathodic Arc Plasma Process" ,Surface Coating Technology, Vol.135, pp.158-165.

4. .Sidhu H S, Sidhu B S, Prakash S (2007) " Hot corrosion behvaiour of HVOF sprayed coating on ASTM-SA213-T11 steel " Journal of thermal spray technology, Vol16, pp 349-354.

5. Sidhu T S, Agrawal R.D (2006) " Characterisation of NiCr wire coating on Ni and Fe based superalloys by the HVOF process" surface coating and technology, Vol 200, pp 5542-5549.

6. Kaur M, Singh H,(2009) " High temperature corrosion studies of HVOF- sprayed Cr_3C_2-NiCr coating on SAE-347H Boiler steel" Journal of thermal spray technology, volume 18, pp 619-632.

7. Puri D, Singh H,(2005) " Some studies of hot corrosion performance of plasma sprayed coating on Fe based superalloys" surface and coating technology, vol 192, pp 27-38

8. Prakash S, Sidhu BS,(2006) " Evaluation of the behavior of shrouded plasma spray coating in the platen superheater of coal fired boilers" Metallurgical and material ransactions, Vol 37A, pp 1927-1936.

9. Bhatia R, Singh H, Sidhu B.S,(2012) " Characteristic parameter and erosion behavior on 65% Cr_3C_2-35% NiCr coating" surface engineering and material technology, Vol 2 No.2, pp 39-47.

10. Jafari M, Nahvi S.M,(2016) " Microstructural and mechanical properties of advanced HVOF sprayed WC-based cermet coating" surface and coating technology Vol 286,pp 95-102.