



## To Study Erosion Behavior of $\text{Cr}_2\text{O}_3$ Coating on SS-304 Boiler Steel Tubes in Simulated Coal Fired Boiler Conditions

Naresh Kumar\* and Rupinder Kanwar\*

Department of Mechanical Engineering,

\*Shiva Institute of Engineering and Technology, Chandpur, Bilaspur, (HP)

(Received 25 March 2012 Accepted 10 April 2012)

**ABSTRACT :** In the present investigation chromium oxide coatings is deposited on SS-304. Erosion studies are conducted on uncoated as well as plasma sprayed coated samples. The erosion experiments are carried out using an air-jet erosion tester at impingement angles of 60 and 90°. Alumina particles of size 50µm are used as erodent. The coatings have been characterized by X-ray diffract meter (XRD), scanning electron microscope (SEM), equipped with an energy dispersive X-ray analyzer (EDAX) is used to analyze the eroded surfaces. Possible erosion mechanisms are discussed.

**Keywords:** Chromium coating (Plasma method), Erosion rate, Angle of attack, XRD, EDAX and SEM.

### I. INTRODUCTION

Erosion is a process of wear in which material are removed from the solid surface by the action of solid particles impinging on it. This type of wear is common in many industrial devices including boilers. The combustion products of coal contain fly ash particles, which impinge on the boiler tubes and erode them. Erosion is the second most important cause for boiler tube failure. In coal fired power stations, about 20% of the ash produced in the boilers is deposited on the boiler walls, economizers, air-heaters and super-heater tubes. This deposited ash is subsequently discharged as slag and clinker during the soot blowing process. The rest of the ash is entertained in the stream of gas leaving the boiler. These ash particles collide with the boiler steel components and cause extensive surface erosion. Such erosion together with the processes of blocking and

corrosion shortens the service life of boiler components. Once this happens, the power station unit has to be shut down in order to replace the damage components. Due to this production process has to be stopped. However erosion is experienced by two factors: 1. When coal attack upon the surface of the tubes (due to the air feeding), 2. Secondly when the coal fell down along the surface of tubes

### II. MATERIAL AND METHODS

The substrate material used is SS-304. This material is used as boiler tube materials in some of the power plants in India. SS-304 boiler steel has a wide range of applications in boilers, especially where the service conditions are more stringent from the point view of temperature and pressure. The chemical composition of SS-304 boiler steel is as reported in the table 1 given below:

**Table 1: Nominal chemical composition of the substrate materials (wt%).**

Boiler Steels	C	Mn	Si	Cr	Ni	P	S
SS-304	0.08	2.00	1.00	18-20	8-12	0.045	0.030

The specimens with dimensions of 15 × 10 × 5 mm were cut from the flat strip and subsequently grit blasted with alumina powder prior to deposition of coating by Plasma process for better adhesion between substrate and coating.

**Measurement of Coating Thickness.** The coating thickness was measured during spraying with a Minitest-2000 Thin Film.

Thickness Gauge (precision ± 1 µm), to obtain coating of uniform thickness. For verification of thickness of deposited coating, the as sprayed specimen was cut across the cross-section with a diamond cutter.

**2 X-Ray Diffraction (XRD) Analysis.** The XRD analysis was performed on the coated and uncoated specimens to identify the various phases present on their surfaces.

**Scanning Electron Microscopy (SEM)/EDAX.** SEM was used to identify the change in microstructures of coated & uncoated eroded samples and also used to study the cross-section of as coated mounted specimens.

To start with the experiment the physical dimensions of the specimen were measured carefully with digital vernier caliper (resolution 0.01) so that all the dimensions are as per requirements. In this experimentation, erodent powder (alumina) used was first pre-heated at temperature of 900°C

for 1hr so that moisture if any will be removed from the powder and the experiment can be carried out smoothly. The high temperature erosion test was carried out at 900°C (temperature of air) and 400°C temperature of specimen in an air jet erosion tester and the time for one specimen is 3hrs. The weight of the specimen before and after experiment was measured in an electronic balance and noted down. Erosion will be studied at angles of 90° & 60°.

### Deposition of coating

**Table 2: Spray parameters employed for Plasma coating (Coating Formulation).**

Spray method	Plasma
Substrate Preparation	Grit Blasting
Arc Power	700A 30-40V
Powder Flow Rate (rev/min)	3.2
Spraying Distance (mm)	95-110
Plasma Arc Gas (psi)	60
Carrier Gas (psi)	42

### III. EXPERIMENTAL ANALYSIS

The studies were performed for uncoated as well as coated specimens for the purpose of comparison. The erosion test conditions utilized in the present study are listed in Table 3. A standard test procedure was employed for each erosion test. The uncoated as well as the coated specimens were polished down to 1 m alumina wheel cloth polishing to obtain similar condition on all the samples before being subjected to erosion run. The samples were cleaned in acetone, dried, weighed to an accuracy of  $1 \times 10^{-5}$  g using an electronic balance, eroded in the test rig for 3 hours and then weighed again to determine weight loss. In the present study standard alumina 50 micron supplied with

Erosion Test Rig was used as erodent. The two temperatures were taken for the test (Table 3), sample temperature 400°C and air/erodent temperature 900°C simulated to service conditions of boiler tubes in which sample temperature and flow gas temperature correspond to the inner and outer temperature of water wall pipes. In general, Erosion resistance is measured using weight loss technique by measuring the weights before and after the test.

**Table 3: Erosion conditions.**

Erodent Material	Alumina powder(Irregular Shape)
Particle size( $\mu$ m)	50
Particle velocity(m/s)	35m/s
Erodent feed rate(g/min)	2.0
Impact angle( $^{\circ}$ )	60&90
Air Temperature	900°C
Sample Temperature	400°C
Nozzle diameter(mm)	4
Test time(hrs)	3hrs for one sample

All the specimens subjected to erosion wear were analyzed for the characterization of erosion products. The specimens were analyzed using surface SEM, EDAX and measurement of surface profiles using optical profilometer.

### IV. RESULTS AND DISCUSSIONS

Photographs of uncoated and coated Samples Fig. 2, 3, 4 shows photographs of the samples SS-304 Uncoated, SS-304 Cr coated. SEM morphologies for the plasma sprayed Cr coatings on SS-304 shown in Fig. 6. From the micrographs the coating layer can be clearly seen. For the as sprayed plasma coatings the middle one represents the coating layer, left one represents the epoxy and right one represents material. Presence of some open pores as well as oxides has also been noticed in all the coatings.

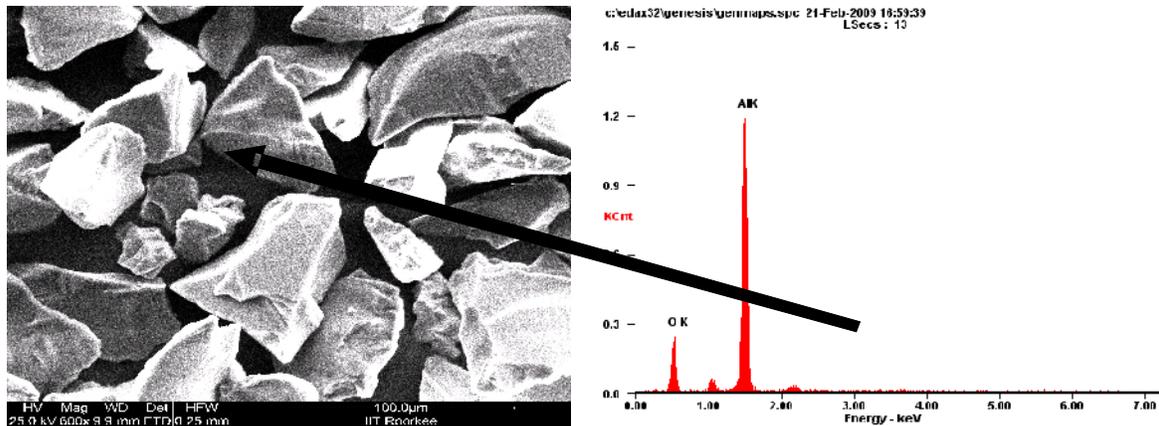


Fig. 1. Analysis of Alumina ( $\text{Al}_2\text{O}_3$ ); (a) SEM morphology and (b) EDAX compositional analysis.

XRD patterns for the plasma sprayed Chromium-oxide coatings on SS-304 in as sprayed conditions.  $\alpha$  (Cr) was the major phase observed in the as sprayed chromium oxide coatings.



Fig. 2. Shows Un-coated 304 at 60°.

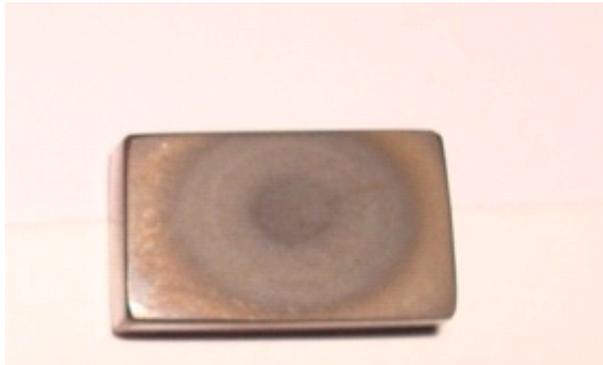


Fig. 3. Shows is Un-coated 304 at 90°.

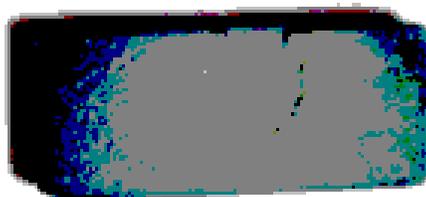


Fig. 4. Shows Cr-coated 304 at 60°.

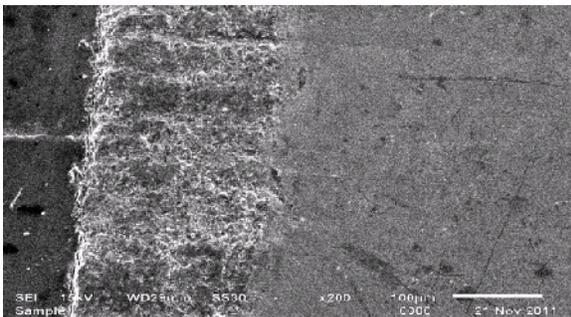


Fig. 5. Composition image of the cross-section of as-coated  $Cr_2O_3$  coating on SS-304 steel.

**Macrographs of eroded samples:** Surface macrographs of the eroded samples are shown on in Fig. 2, 3, and 4 shows the surface macrographs of SS-304 coated and uncoated at 90° and 60°. In all the samples, the erosion starts at the center first, and then proceeds towards the edges of the samples. At a 90° impact angle, material is

eroded forming a circular depression; while at a 60° impact angle, material is eroded creating an elliptical shape depression. The macrographs of eroded samples clearly reveal three zones; a central area from where most of the eroded material has been produced, a second zone of faint color. Somewhat lesser erosion can be seen and a third outside region where a negligible amount of erosion is observed. This can be clearly seen from the macrographs of the eroded samples. Surface morphology of eroded surface. The SEM observations were made on the eroded surface of SS-304. Both coated and uncoated surfaces were taken into account for different angles. The SEM study provides useful information about the mechanism of erosion. Because of the different impingement angles of the alumina particles the eroded surfaces have different lengths and shapes. The microstructure of 304 Un-coated 90°, material is removed by crater formation and crack formation and the erodent is also retained on the substrate. The microstructure of 304 Cr-coated 90°, in this mechanism of erosion is brittle and if EDAX analysis is done it is clear that still Chromium is present which means that coating is still there.

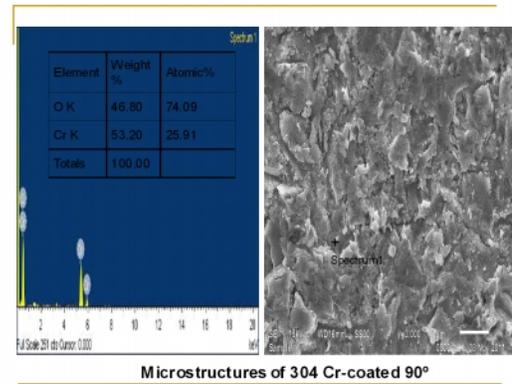
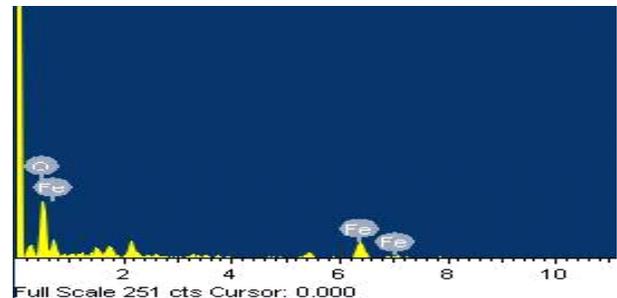


Fig. 6. Microstructures of 304 Cr-coated 90°.

Element	Weight%	Atomic %
O K	46.80	74.09
Cr K	53.20	25.91
Totals	100.00	



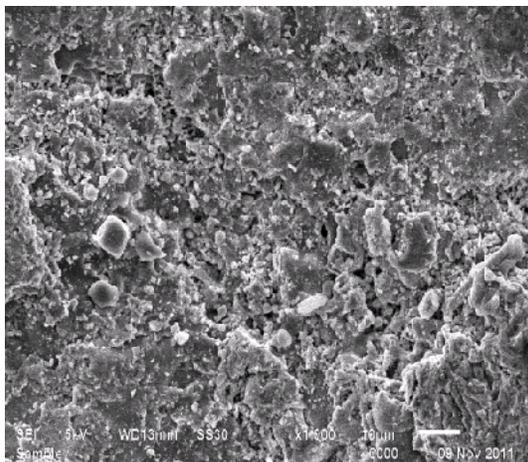


Fig. 7. Microstructure Of 304 Cr.- Coated At 60°.

Element	Weight%	Atomic%
C K	36.29	48.14
O K	40.07	39.91
Al K	16.60	9.80
Cr K	7.04	2.16
Totals	100.00	

Element	Weight %	Atomic %
O K	59.30	83.57
Fe K	40.70	16.43
Totals	100.00	

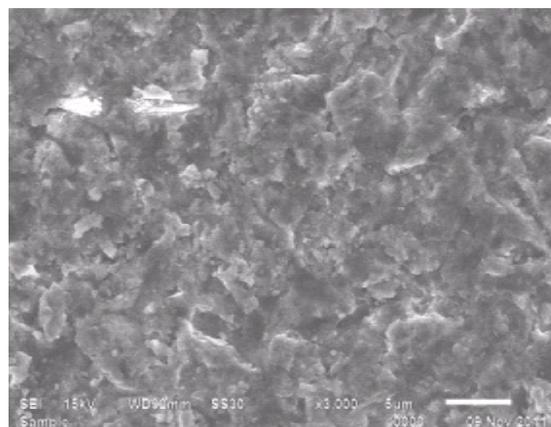
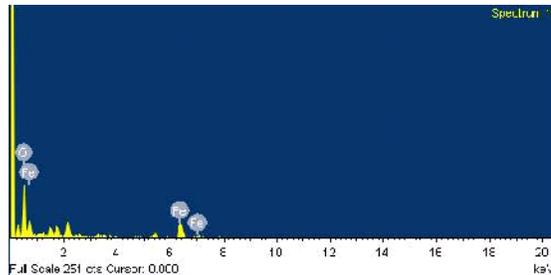


Fig. 9. Microstructure Of 304 Un-Coated At 90°.

Element	Weight%	Atomic%
O K	68.56	88.39
Fe K	31.44	11.61
Totals	100.00	

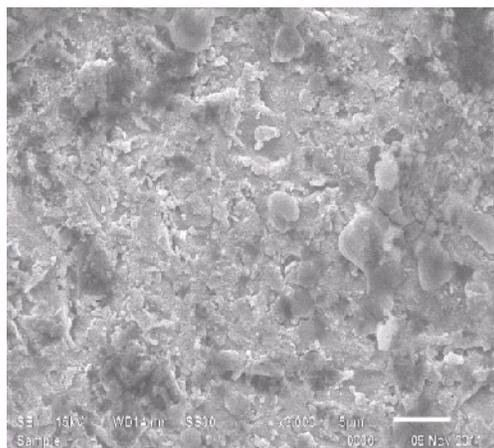
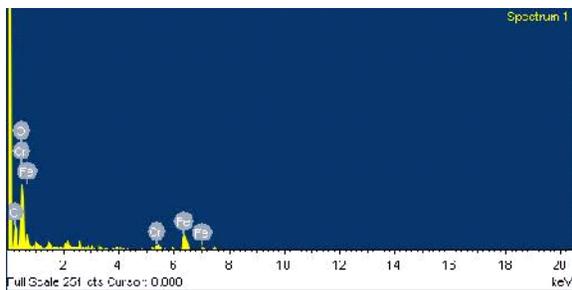


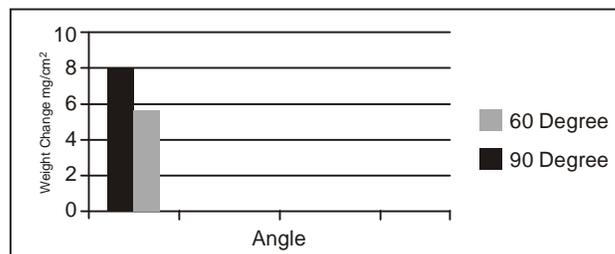
Fig. 8. Microstructure Of 304 Un-Coated At 60°.

SHALLOW IMPACT CRATER

Table 4: Weight loss comparison of uncoated specimens of SS-304 at angles of 60° and 90°.

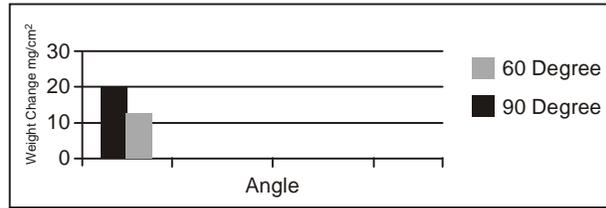
SS-304 Uncoated

Impact Angle	60°	90°
Weight Loss (mg/cm <sup>2</sup> )	8.00 mg/cm <sup>2</sup>	5.73 mg/cm <sup>2</sup>



**Table 5: Weight loss comparison of coated specimens of SS-304 at angles of 60° and 90°.**

Samples	SS-304 coated	
Impact Angle	60°	90°
Weight Loss (mg/cm <sup>2</sup> )	21.00 mg/cm <sup>2</sup>	12.00 mg/cm <sup>2</sup>



## CONCLUSIONS

The uncoated samples (SS-304) give the higher erosions rate at 60° than the 90° impact angles. The coated samples, SS-304 (coating of chromium oxide) gives better results for both 90° than at 60° angle. In the both cases high erosion rate occur at 60°.

## REFERENCES

- [1] Bellman, R. Jr. and Levy, A., "Erosion Mechanism in Ductile Metals", *Wear*, Vol. **70**(1): 1–27(1981).
- [2] Chawla, V., Prakash, S. and Singh, B., "State of art: Applications of Mechanically Alloyed Nanomaterials: A Review", *Materials & Manufacturing Processes, Taylor & Francis Group*, Vol. **22**: pp. 469–473(2007A).
- [3] Chawla, V., Prakash, S., Puri, D. and Singh, B., "Performance of plasma sprayed nanostructured and conventional coatings", *J. Aus. Ceramic Soc.*, Vol. **44**(2): 56–62(2008).
- [4] Chawla, V., Singh, T., "Hot Corrosion and prevention y surface treatment—a review", Proc. of National Conference on "Advances in Manufacturing Technology, organized by National Institute of Technical Teachers' Training & Research, Chandigarh, India, 9–11th November (2005).
- [5] Das, S. K., Godiwalla, K. M., "Analytical model for erosion behavior of impacted fly-ash particles on coal-fired boiler components," *Sadhna*, Vol. **31**: 583–595(2006).
- [6] Fernandez., Garcia, J.R., "Behavior of laser treated Cr,Ni coatings in the oxidative atmosphere of a steam boiler," *Surface And Coatings Technology*, Vol. **195**: 1–7(2005).
- [7] Guessasma, S., Zhang, G., Liao, H., Coddet, C. And Bordes, J.M., "Investigation of Friction and Wear Behavior of SiC-filled Peek Coatings Using Artificial Neural Network," *Surf. Coat. Technol.*, Vol. **200**(8): 2610–2617(2006).
- [8] Hidalgo, V.H., Varela, J.B., Menendez, A.C. and Martinez, S.P., "High Temperature Erosion Wear of Flames and Plasma-sprayed Nickel-chromium Coatings under Coal-fired Boiler Atmospheres," *Wear*, Vol. **247**: 241–222(2001A).
- [9] Hidalgo, V.H., A.C. and Martinez, S.P., "A comparative study of high temperature of erosion wear of plasma sprayed NiCrBSiFe and WC- NiCr BSiFe cpatings under simulated coal fired boiler conditions," *Tribology international*, Vol. **34**: 161–169(2001).
- [10] Hearley, J. A., "The erosion behavior of NiAl intermetallic coatings produced by HVOF thermal spraying" *Wear*, Vol. 233–235, pp. 328–333(1999).
- [11] Hocking, M. G., "Coatings resistant to erosive/corrosive and severe environments," *Surface and Coatings Technology*, Vol. **62**: 460–466(1993).
- [12] Levy, A. V., "The erosion-corrosion of tubing steels in combustion boiler environments," *Corrosion Science*, Vol. **35**: 1035–1043(1993).
- [13] Levy, A. V., Slamovich, E. and Jee, N., "Elevated temperature combined erosion-corrosion of steels", *Wear*, Vol. **110**: 117–149(1986).
- [14] Mann, B.S., " Solid particle erosion and protective layers for steam turbine blading," *Wear*, Vol. **224**: 8–12(1999).
- [15] Mann, B.S., Araya Vivek., "Abrasive and erosive wear of chracterstics of plasma nitriding and HVOF cotings: their application in hydro turbines, *Wear*, Vol. **249**: 354–360(2001).
- [16] Natesan, K., "Applications of coatings in coal-fired energy systems," *Surface an Coating Technology*, Vol. **56**: 185–197(1993).
- [17] Norling, R., Olefjord, I., "Erosion corrosion of Fe and Ni based alloys at 550° C," *Wear*, Vol. **254**: 173–184(2003).
- [18] Poulson, Brayn. "Complexities in predicting erosion corrosion, *Wear*, Vol. 233–235, pp.497–504(1999).
- [19] Puri, D., Prakash, S, "Characterstics of plasma sprayed and laser remelted NiCrAlY bond coats and Ni<sub>3</sub>Al coatings on boiler steel tubes," *Materials Science and Engineering*, Vol. A368, pp. 149–158(2004).
- [20] Qiang, R. U., Shejun, HU, Xiuli, QIU. "Properties of TiAlCrN coating (2008).
- [21] Wong-Moreno, A. and Marchan Salsado, R.I., "Molten Salt Corrosion of Heat Resisting Alloys," *In: Corrosion-95, NACE, Houston, TX* (1995), pp. 465–1–465–16(1995).