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To Check the Feasibility of Cr_2O_3 Coating on Boiler Steel Tubes Simulated Coal Fired Boiler Conditions to Prevent the Erosion

Naresh Kumar, Gaurav Prashar** and R.K. Dhawan****

Department of Mechanical Engineering,
**Shiva Institute of Engineering and Technology, Chandpur, (H.P.)*
***Rayat and Bahara College, (P.B.)*
****Ramgarhia Institute of Engineering and Technology, (P.B.)*

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ABSTRACT : Materials are precious resources. Different methods are employed to protect the material from degradation. Thermal spraying is one of the most effective method to protect the material from wear, high temperature corrosion, stresses and erosion, thus increasing the life of material in use. Plasmas spraying is one of the thermal spraying techniques known for providing hard, wear resistant and dense microstructured coatings. This paper shows the results of chromium coating on on ss-304 and ss-310 by plasma spraying technique.

Keyword : Chromium coating (Plasma method), Erosion, Erosion-Corrosion, Angle of attack.

I. INTRODUCTION

Thermal spraying is an effective and low cost method to apply thick coatings to change surface properties of the component. Coatings are used in a wide range of applications including automotive systems, boiler components, and power generation equipment, chemical process equipment, aircraft engines, pulp and paper processing equipment, bridges, rollers and concrete reinforcements, orthopedics and dental, land-based and marine turbines, ships [1]. Among the commercially available thermal spray coating techniques, The objective of the work is to analyzethe role of Chromium coating to enhance the properties of surface of substrate to counter the problems like erosion, residual stress, fretting fatigue, thermal behavior and corrosion etc.

Erosive, high temperatures wear of tubes and other structural materials in coal fired boilers are recognized as being the main cause of downtime which would account for 50-75% of their total arrest time and maintenance costs for replacing broken tubes can be estimated at up to 54% of total production costs. An equally important factor that determines the material loss, which occurs, is the characteristics of the ash particle themselvesFrom above said facts it is clear that erosion is a serious problem in boiler and some preventive measures are required. Plasma sprayed coatings are generally much denser, stronger and cleaner than the other thermal spray processes with the exception of HVOF and detonation processes [8] and [2]. Plasma spray coatings probably account for the widest range of thermal spray coatings and applications. Plasma spraying is reported to be versatile technology that has been successful as a reliable cost-effective solution for many industrial problems. Therefore in the present investigation, the Plasma process has been adopted to deposit the coatings to increase the life of boiler steels.

II. MATERIAL AND METHODS

The substrate material used is: SS-310 and SS-304. This material is used as boiler tube materials in some of the power plants. SS-310 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-310 and SS-304 boiler steel is as reported in the table1 given below:

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

Boiler Steels	*C*	*Mn*	*Si*	*Cr*	*Ni*	*P*	*S*
SS-304	0.08	1.23	0.36	18.57	8.35	0.034	0.013
SS-310	0.16	1.21	0.42	16.31	8.43	0.032	0.02

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.

Plasma spray is the most versatile of the thermal spray processes. Plasma is capable of spraying all materials that are considered sprayable [5]. In plasma spray devices, an arc is formed in between two electrodes in a plasma forming gas, which usually consists of either argon/hydrogen or argon/helium. As the plasma gas is heated by the arc, it expands and is accelerated through a shaped nozzle, creating velocities up to MACH 2. Temperatures in the arc zone approach 36,000°F (20,000°K). Temperatures in the plasma jet are still 18,000°F (10,000°K) several centimeters form the exit of the nozzle. Because plasma-arc spraying is the most versatile of all the thermal spray processes it can be found in the widest range of industries. Plasma spray coatings are used commonly for applications in aerospace, automotive, medical devices, agriculture communication, etc. So chromium coating coating is done with plasma method [3, 5].

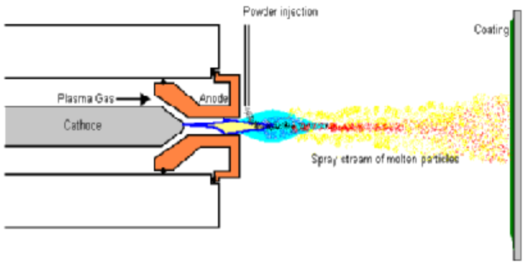

Fig. 1. Schematic Diagram of the Plasma Spray Process.

***(i)* Porosity Measurement :** Porosity of the coatings was measured with an image analyser using Zeiss Axiovert 200 MAT inverted optical microscope, fitted with imaging software Zeiss Axiovision Release, (Germany) software, which was developed based on ASTM B276. The magnification was chosen such that the coating microstructure image covers the screen and allows the resolution of the voids that contributes notably to the total porosity area percentage. The process of selecting the appropriate range of light grey contrast spots was carried out methodically by stereographic imaging to ensure that only voids were selected. The analysis using image processing software determines the pore area size in the view field by converting the pore areas (grey-level areas) into a background color such as red while the rest of the microstructure remains in its original color. The area of one feature is numerically related to the total area of the picture, as the program counts the number of one color type pixels (red) and sets that as a ratio of the total number of pixels in the picture (total area). About twenty (20) separate locations were selected to avoid the overlap between two locations and determine the area percent porosity

***(ii)* Measurement of Surface Roughness :** The surface roughness (Ra) values of the plasma sprayed as coated specimens were measured using Surface Roughness Tester (Mitutoyo SJ-201, Japan). Each reported value of surface roughness (Ra) is the mean of five observations taken at different locations. The centre line average (CLA) method was used to obtain the Ra values.

***(iii)* Measurement of porosity, surface roughness of the sprayed coating :**

Table 2 : Average value of porosity, surface roughness and bond strength of plasma sprayed coating.

Substrate	*Porosity*	*Surface Roughness*
SS-304	2.30-4.25%	10.12-12.12 µm
SS-310	2.12-3.25%	10.38-14.22 µm

***(iv)* 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.

***(v)* 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 and uncoated eroded samples and also used to study the cross-section of as coated mounted specimens to find thickness [4].

III. EXPERIMENTATION

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 3 hrs. 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° and 60°.

A. High temperature erosion

Erosion Studies in an Air Jet Erosion Test Rig

The studies were performed for uncoated as well as coated specimens for the purpose of comparison [4]. 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 1×10^{-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 [7] .In general, Erosion resistance is measured using weight loss technique by measuring the weights before and after the test [4].

Tabel 3 : Erosion conditions.

Erodent Material	***Alumina powder (Irregular Shape)***
Particle size (μm)	50
Particle velocity(m/s)	35m/s
Erodent feed rate(g/min)	2.0
Impact angle (°)	60 and 90
Air Temperature	900°C
Sample Temperature	400°C
Nozzle diameter (mm)	4
Test time (hrs)	3 hrs for one sample

IV. RESULTS AND DISCUSSIONS

Photographs of uncoated and coated Samples shown in Fig. (2), (3), (4), (5), (6), (7) and (8) shows photographs of the samples SS-304 Uncoated, SS-310 Uncoated, SS-304 Cr coated and SS-310 Cr coated.SEM morphologies for the plasma sprayed Cr coatings on SS-304 and SS-310 are shown in Fig. 9. 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. 2.

Fig. 3.

Fig. 4.

Fig. 5.

Fig. 6.

Fig. 7.

Fig. 8.

A. X-Ray diffraction analysis (XRD)

XRD patterns for the plasma sprayed Chromium-oxide coatings on SS-304 and SS-310 in the as sprayed conditions. α(Cr) was the major phase observed in the as sprayed chromium oxide coatings.

X-Ray Diffraction pattern of plasma sprayed Cr_2O_3 as coated steel substrates; (*a*) SS-304 steel, (*b*) SS-310 steel.

Fig. 2 shows Un-coated 304 at 60. Fig. 3 shows is Un-coated 304 at 90 and Fig. 4 shows Cr-coated 304 at 60. Fig. 5 shows Un-coated 310 at 60. Fig. 6 shows Cr-coated 310 at 60. Fig. 7 shows Un-coated 310 at 90. Fig. 8 shows Cr-coated 310 at 90.

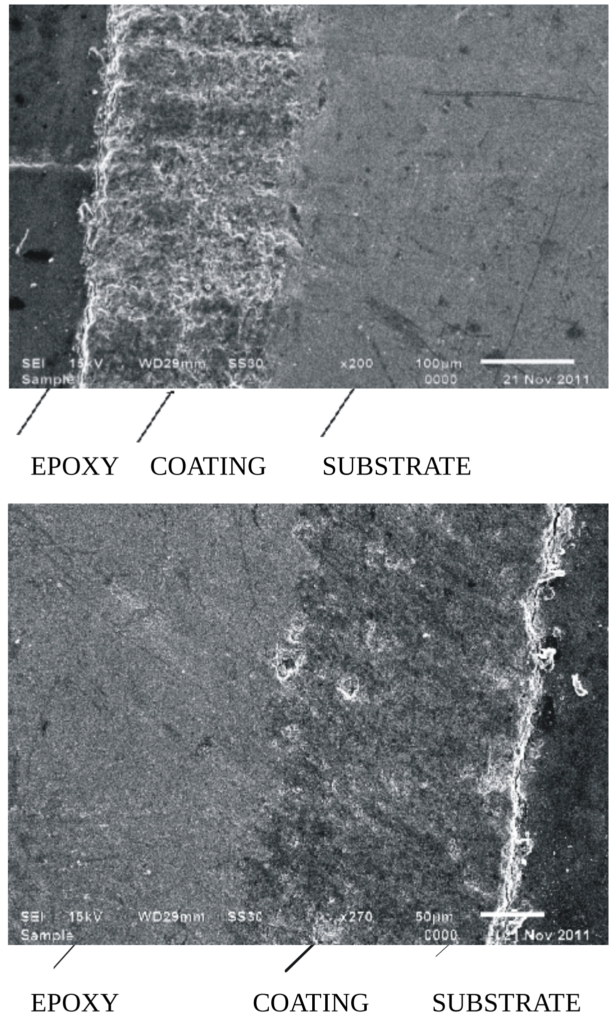

Fig. 9. Composition image of the cross-section of as-coated Cr_2O_3 coating on SS-304 steel (*b*) on SS-310.

B. Macrographs of Eroded Samples

Surface macrographs of the eroded samples are shown on in Figs. 2, 3, 4, shows the surface macrographs of SS-304 coated and uncoated at 90° and 60° [6]. Fig. 5, 6, 7and 8 shows the surface macrographs of SS-310 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 where 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. The SEM observations were made on the eroded surface of SS-304 and SS-310. Both coated and uncoated surfaces were taken into account for different angles.

V. DISCUSSION

The weight loss for un-coated and coated SS-304 and SS-310 boiler steel at an impact velocity of 35 ms-1 and impingement angle of 60° and 90° when substrate temperature was 400°C and surrounding air at 900°C. The weight loss for coated SS-304 at 60° impact is more and weight loss for SS-310 at 60° impact is more. Hence SS-304 gives good erosion resistance at 90° impact angle and SS-310 gives good erosion resistance at 90° impact angle. Same is for uncoated specimens.

VI. CONCLUSION

From the coating thickness it is clear that the sufficient amount of coating is deposited on the substrate to make it erosion- corrosion resistance. Average thickness of both the coatings are above the 200 microns.

Average porosity in the coatings is also under control that means coatings are ready for experiment.

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