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Failure analysis of water wall tubes in coal fired power plant

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One of power generating utility has reported the failure of boiler water wall tubes after a service life of 10,000 hours against the design life of 30-35 years. The failure of tubes was reported in water wall tubes regions which consist of carbon steel alloy. These boiler tubes were operating under the oxidizing/reducing atmosphere at high temperature and pressure. This paper represents the investigation the failure of water wall tubes used in a coal fired thermal power plant. The failure investigation covers visual inspection, dimensional measurement, hardness mapping, deposit flux measurement and SEM & EDX analysis of the deposited products. This paper is the case study of failure analysis of water wall tubes due to corrosion and ID deposition on the tube. The analysis reveals that the failures were due to inside corrosion and hydrogen damage attack.

Keywords: *Boiler water wall tube, physical observation, grade identification of alloy, dimensional & hardness measurement, corrosion deposit analysis, SEM and EDX analysis, flux deposit, ring test for hydrogen damage*

1.0 INTRODUCTION

In thermal power plant, boilers are used for heating water which is further converted into superheated steam, is used to run the turbine for electricity generation. Boiler components are made of mainly Fe based alloys and high temperature alloy i.e. plain carbon steel, alloy steel (low to high alloy steel), cast iron alloy, stainless steel and other high temperature alloys [1-2].

In boiler water wall tubes are mainly made of plain carbon steel. Water wall tubes are subjected to a very rough and hazardous environment from both inner and outer surface of tubes like burning of coal, oxidising/reducing atmosphere gas flame, un-burnt coal, ash particle to outer surface of tubes and treated water, steam from inner side surface of the tubes, all these interacts with the water wall tubes surface on ID & OD and may lead to degradation of tube material and further failure of the tubes [3-5].

During the planned outages, at the available time of boiler, the boiler's pressure parts components should be thoroughly assessed to monitor the amount of any abnormality in the integrity of the components. Various Non-Destructive Evaluation (NDE) techniques and analysis should be employed for assessing the components.

2.0 LABORATORY INVESTIGATION

The details of laboratory investigations are as follows.

1) Physical observation
2) Dimensional measurements
3) Chemical compositional analysis
4) Hardness measurement

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5) ID side Deposit/scale analysis
6) Ring test for hydrogen damage

The observations in respect of the each of the above tests are given below.

2.1 Physical Observation

The tubes received for the failure analysis are shown in Figure 1:

1) Tube No 1: Tube length - 450 mm
2) Tube No 2: Tube length - 500 mm
3) Tube No 3 : Tube length - 340 mm
4) Tube No 4 : Tube length - 140 mm

FIG. 1 TUBES RECEIVED FOR FAILURE ANALYSIS

A line/ slit type opening were observed in the longitudinal direction on the outer side of the Tube Nos. 1, 2 & 4 while a complete opening like fish mouth opening were observed on the Tube No 3.

ID deposit and gouging were observed on the Tube Nos. 1, 2 & 4. Internal metal losses were also observed on the inner side of the tube at some localized section. Deposited materials were observed mostly along the cracked/slit opening section, which were localized.

The thicknesses of the tubes were within the range of 7 to 8.9 mm except the corroded region where the minimum thicknesses was observed as 5.8 mm.

No bulging was observed on the tubes (outer Diameter from 51 to 53 mm) except the Tube No 3 (fish mouth opening) the outer diameter was noted as 65 mm at the ruptured section.

2.2 Dimensional Measurement

The dimensional measurement were done with the help of equipment's of 38 DL plus (Olympus make) and digital vernier caliper (Mitutoyo make), and are given in Table 1:

TABLE 1
RESULTS OF DIMENSIONAL MEASUREMENT

TUBES NOS.	DIMENSION (MM) [OD-OUTSIDE DIAMETER, T-THICKNESS)		
	ORIGINAL DIMENSION	NEAR THE FAILED (RUPTURE) / SLIT OPENING SECTION	AWAY FROM THE FAILED / SLIT OPENING SECTION
1	OD:51, T: 6 & 7	OD: 50.19 to 50.99, T:5.8 to 7.2	OD: 50.19 to 50.99 T: 7.3 to 8.8
2		OD: 50.91 to 51.25, T:6.08 to 8.84	OD: 50.91 to 51.25,, T:7.76 to 8.9
3		OD: 65.14 to 55.27, T:4.5 to 6.49	OD: 50.68 to 51.05, T:6.0 to 6.19
4		OD: 50.60 to 51.46, T:6.60 to 8.19	OD: 50.60 to 51.46, T:7.72 to 8.8

Dimensional measurement of tubes shows no reduction in its thickness except at the region of corroded section (Tube No. 1, 2 &

4) where it is found minimum of 5.8 mm, no bulging except the rupture section (Tube No. 3) where it is found as OD in the range of 65 to 55 mm and thickness 4.5 to 6.49 mm near the ruptured section.

2.3 Chemical Analysis

The chemical composition of the tube samples has been determined by Optical emission spectrometer Polyspek Neo, Metal Scan Limited (U K) to confirm the grade of the material and the results are given below in Table 2. The chemical composition analysis of all the tubes shows the grade of material as stated ASTM SA 210 grade.

TABLE 2

RESULTS OF CHEMICAL COMPOSITIONAL ANALYSIS

TUBES NOS.	CHEMICAL COMPOSITION (WT %)								
	C	SI	MN	P	S	CR	MO	CU	
1	0.258	0.200	0.850	0.002	0.005	0.109	0.037	0.288	Balanced with Fe
2	0.217	0.232	0.801	0.013	0.007	0.133	0.033	0.332	
3	0.249	0.231	0.863	0.014	0.013	0.110	0.030	0.325	
4	0.235	0.190	0.880	0.003	0.009	0.113	0.027	0.282	

2.4 Hardness Measurement

In order to ascertain the temperature induced physical changes in the tubes, the Brinell hardness was measured using Equotip 3 (Proceq make) and the results are given below in Table 3. The result shows that the hardness near failed section shows relatively less values in comparison to that measured away from failed section or opposite side of the failed section.

TABLE 3

RESULTS OF HARDNESS MEASUREMENT

TUBE NOS.	HARDNESS (BHN)		
	CLOSE TO THE FAILED/ SLIT OPENING SECTION	AWAY FROM THE FAILURE/ SLIT OPENING SECTION	AT 180^0 OF THE FAILED/ SLIT OPENING SECTION
1	115 to 142	178 to 193	189 to 210
2	144 to 167	146 to 190	190 to 216
3	107 to 150	178 to 198	133 to 145
4	133 to 157	-	178 to 190

TABLE 4

RESULTS OF FLUX DEPOSIT CALCULATED

TUBE NOS.	DEPOSITED COLLECTED FROM ID SIDE (GM.)	SURFACE AREA OF THE TUBE (CM^2)	FLUX DEPOSIT (MG/CM^2)
1	5.1585	352.95	14.61
2	6.67404	537.21	12.37
3	0.1041	411.23	0.25
4	6.8101	147.34	46.22

2.5 Internal Deposit Analysis

The inside deposit from the tubes were collected by scrapping from the inner surface of the tubes and it has been assessed for flux deposit and their oxide chemistry by Energy Dispersive X-Ray analysis. The flux deposit is given in Table 4

2.5.1 Energy Dispersive X-Ray (EDX) Analysis

The deposits collected from ID side of the tube were analyzed for the elemental concentration of different elemental oxide present by Energy Dispersive X-Ray analysis and the results are given below in Figure 2.

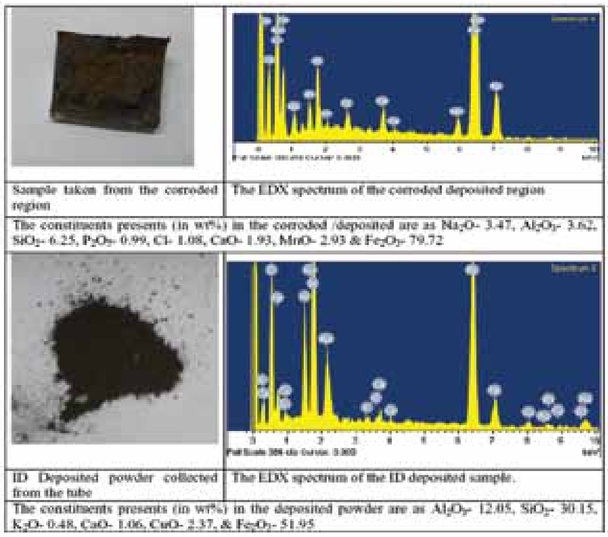

FIG. 2 EDX ANALYSIS OF ID SURFACE OF CORRODED TUBES AND DEPOSITED PRODUCTS

The EDX analysis of the corroded and gouging area reveals the major constituents of iron oxide with small amounts of oxides of sodium, aluminum, silicon, manganese, calcium, potassium, chlorine and phosphorous.

The EDX analysis of ID deposits powder shows as major constituents as iron oxide, silica and oxide of aluminum with small amounts of copper, calcium and potassium.

From the EDX analysis of the corroded section of the tube and ID deposited constituents, it is observed that corrosive constituents (Na, Cl, P, K) are still present that caused the pitting of the tube towards the ID side. These corrosive environments caused the localized pitting to the ID side of the tube.

2.5.2 X-Ray Diffraction (XRD) Analysis

The deposit was analyzed from X-ray diffraction technique (PANalytical, make- X' PertPRO The Netherlands) to analyze the phases present in the powder. The analysis of the deposit powder shows mainly oxides of iron in hematite and magnetite form. The XRD pattern is given below in Figure 3.

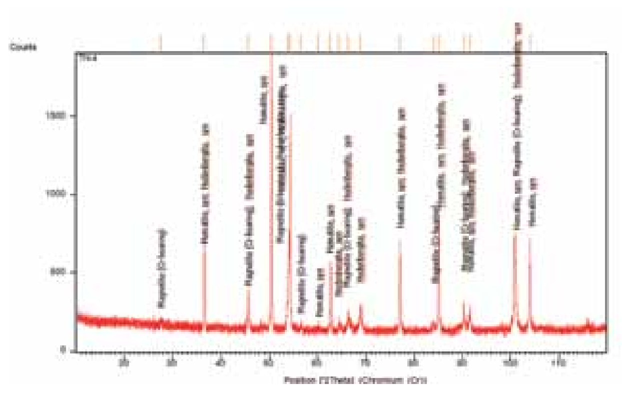

FIG. 3 XRD PATTERNS OF DEPOSIT POWDER

2.6 Ring Test

A ring section type sample was taken from the high flux deposited sample i.e. from Tube No.4. The ring sample was coarse polished with emery paper (silicon carbide) of 220 grit paper followed by 600 grit paper to give the surface a rough shinning surface. After the polishing the ring section was macro etched in a solution of hydrochloric acid for few minutes. The ring sample was taken out and washed it in running tap water for few minutes and dried at room temperature. It is observed that some section of the ring sample turned dark near the corroded area and partially also through the tube wall section, while other section of the ring sample was not dark as shown in Figure 4. The dark section of the ring sample is the indication of attack i.e. hydrogen damage. The tube has failed due to hydrogen damage.

FIG. 4 RING TEST FOR HYDROGEN DAMAGE OF TUBES

3.0 SUMMARY OF OBSERVATIONS

1. Severe corrosion and gouging observed on the ID side of the slit opening tube. The slit opening has been observed on the corroded and gouging section.
2. Localized thinning is observed along the corroded regions.
3. Less hardness are observed near the line crack opening in comparison to away from the line crack opening.
4. Analysis of deposits indicates the presence of corrosive species like, Na, K, P & Cl, which leads to attack the metal surface and results in gouging towards the ID surface of the tube.
5. The ID deposit analysis has shown the presence of sodium, potassium, chlorine and copper which may be entrapped through the water by leaking of condenser tubes and chemical dosing during water treatment etc.
6. The ring test performed on the tube cross-sectional shows the presence of hydrogen attack on the tube.

3.1 Probable causes

1) Poor feed water treatment due to leakage in condenser tubes or due to entrapped of un-treated water.
2) Flow disruptions to cooling media towards ID side due to excessive deposition towards ID side of tube.
3) Prevent ingress of regeneration chemicals.
4) Flame impingement or burnermisalignment, which accelerates ID corrosion.

3.2 Probable Solutions

(1) Proper maintenance of feed water chemistry

(2) Proper maintain the fuel firing pattern

(3) Chemical cleaning of the tubes to remove the ID deposits

(4) Complete scanning of the boiler tubes in the affected regions to find out the corroded/ metal gouged tubes.

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