BOILER TUBE FAILURE ANALYSIS IN 210MW POWER PLANT STEAM BOILER

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Abstract- *This study is aimed at analyzing the reasons associated with boiler tube failure. Inspection and data collected from MTPS - I serve as the basis for this analysis. Three samples (damaged LTSH tube, failed Economizer tube and failed RH tube) were collected from MTPS. Metallographic investigations were carried out in the samples collected to understand, interpret and substantiate the probable reasons that led to tube failure which occur when the effective strength falls below a critical level. Apart from visual inspection, optical microscopy, micro-hardness tests, SEM investigations, chemical analysis and EDS tests were carried out on various regions of the failed tubes and the results have been elaborately discussed. Upon visual inspection, formation of oxide layers on the inner side of the tube has been noticed which indicated that the inner side of the tube is subjected to corrosion. Formation ofoxide layers has led to inhomogeneous overheating which has thereby affected the homogeneity of the tube. The main reason for rupture (hole formation) in the failed region can be attributed to steam erosion either from an adjacent failed tube or from soot blower. Besides steam erosion, flue gas erosion has also occurred due to unevenvelocity of flue gas which could be catalyzed by the presence of unburnt coal particles. Graphitization leading to formation of elongated as well as spherical graphite nodules and spheroidization over a period of time were identified as the major failure mechanisms involved from a microscopic perspective which could be related with overheating accompanied by creep leading to softening of the tube at the failed region thereby causing ductile fracture from a mechanical perspective. SEM micrographs showed the formation of graphite nodules, micro-cracks and void coalescence. Though occurrences of tube failures in boiler couldn't be completely eradicated, they can be considerably reduced by adopting certain remedial measuressuggested at the end.*

Keywords: Tube failure, metallographic examination, graphitization, spheroidization, overheating, creep, erosion, corrosion, ferrite – pearlite micro structure.

1. INTRODUCTION

As could be observed from the report of Central Electricity Authority, leakage in water wall tubes, super heater tubes, re-heater tubes and economizer tubes accounts for 2.2 % of loss of maximum power generation. While investigating the root cause of these leakages, it transpires that the boiler tubes are subjected to a variety of failures involving one or more of several mechanisms like erosion, corrosion, stress rupture etc. A detailed study is warranted for understanding the various mechanisms leading to failure of boiler tubes.

2. BOILER TUBE FAILURE

The accurate prediction of life of boiler tubes is difficult because of uncertainties associated with operating conditions, material properties, erosion/corrosion rate, geometry of eroded/corroded areas etc. It is very difficult to identify and locate gradual degradation of tubes like thinning, crack formation, deformation till it leads to puncture causing leakages. The only time interval when the tube can be accessed is during the planned maintenance as per the schedule besides forced outages. The symptoms ofleakage in tube are feed water consumption higher than normal leading to more make up water, low water level in the boiler drum, pressure drop in steam, hissing sound emitted by leaking steam, white smoke from chimney, fluctuations in furnace pressure.

2.1 VARIOUS NOMENCLATURES INVOLVED IN TUBE FAILURES

1. Weld failure
2. Secondary tube failure
3. Erosion
4. Corrosion
5. High temperature oxidation
6. Hydrogen attack
7. Caustic corrosion
8. Stress rupture

2. 2 INVESTIGATION WORK

The investigation was carried out on the following scrapped tubes reportedly discarded and disposed as scrap from MTPS.

1. Damaged LTSH tube
2. Failed economizer tube
3. Failed RH tube

Material specifications, design and operating parameters of the LTSH tube as obtained from the thermal power plant are as follows:

	LTSH	Economizer	RH
Material	SA-106 Gr.B	SA-106 Gr.B	SA-106 Gr.B
Outside diameter (mm)	44.5	56.0	56.0
Thickness (mm)	4.5	6.0	6.0
Steam / water inlet temperature (°C)	340	247	332
Steam / water outlet temperature (°C)	420	284	540
Flue gas inlet temperature (°C)	671	476	1020
Flue gas outlet temperature (°C)	476	370	828
Service Exposure (years)	10	15	15

Table 1 - Tube Specifications

To analyze the failure of these tubes, visual examination was performed by naked eye and images have been taken by digital camera. The failed economizer tube and failed RH tube suffered significant damage while LTSH tube has not suffered any kind of significant damage.

In order to investigate the potential causes for failure due to microstructural anomalies or degradations, specimens of economizer and RH tube were cut transversely along the cross section of the tube in the failed region, and randomly chosen region in case of LTSH tube. The small ring is cut longitudinally to make small specimens and marked as detailed below.

The method of optical microscopy has been used for microstructural examinations. Metallographic sample preparation has been carried out using standard procedures. The sectioned samples are mounted using hot mounting process which uses thermosetting plastic compound bakelite to encapsulate the specimen. The mounting undergoes grinding, polishing using series of emery paper containing successively finer abrasive followed by etching. 2% Nital is used as etchant. The mounted samples are investigated using a Leica DMi8 metallurgical microscope.

Micro indentation hardness measurement on the mounted sample was conducted using Vickers digital micro hardness tester (model: MMT – X7 No:MM5250X, Manufacturer MATSUZAWA CO.LTD., Japan).

3. BOILER TUBE FAILURE ANALYSIS

Failure analysis mainly consist of:

- Visual inspection
- Metallographic examination
- Micro hardness test
- Sem investigation

3.1 VISUAL INSPECTION

The failed section of the economizer and RH tube was visually inspected. Figure 3.1 (a) presents an image of as-received sample of the failed economizer tube and Figure (b) presents an image of as-received sample of the failed RH tube. The circularity of the tube cross section is varying.

By observing cross section of the economizer and RH tube, it could be noted thathalf of the cross section of the tube segment was thinner than the other. Figure 3.1 (a) & (b) presents image after making a single cut along transverse plane of failed economizer and RH tube respectively

Figure 3.1 (a): Cross section of LTSHtube

Figure 3.1 (b): Cross section at the failed region of Economizer tube.

Figure 3.1 (c): Cross section at the failed region of RH tube.

The measured thicknesses of tube walls at different segments are as follows:

Table 2 - Thickness of the Economizer tube in mm

A1	B1	C1	D1	E1	F1
1.34	6.48	6.40	5.58	6.10	4.19

Table 3 - Thickness of the RH tube in mm

A2	B2	C2	D2	E2	F2
2.09	6.44	6.53	6.50	5.73	3.07

Upon thinning, the tube could have failed due to following two reasons:

1. The reduced thickness could not withstand the circumferential hoop stressand caused stress rupture.

2. Thinning might have caused over heating which has led the metal temperatures to exceed their creep temperature limit.

3.2 METALLOGRAPHIC EXAMINATION

Long term overheating brings about microstructural changes like grain growth, disintegration of pearlite, spheroidization of carbides, graphitization and decarburization leading to loss of strength of the tube material, eventually resulting in stress rupture or creep rupture through grain boundary void formation. The first stage in the transformation is *in situ* break down of the pearlite colonies remaining intact but the platelets of iron carbide become spheroids. The next stage is the disappearance of pearlite colonies and dispersion of spherical carbide particles throughout the matrix and then finally the formation of graphite particles and their growth.

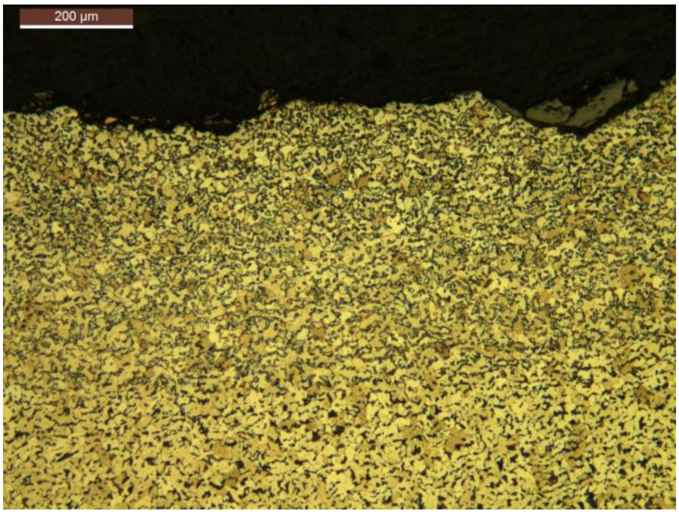

Figure 3.2 (a)

Affected region of LTSH tube

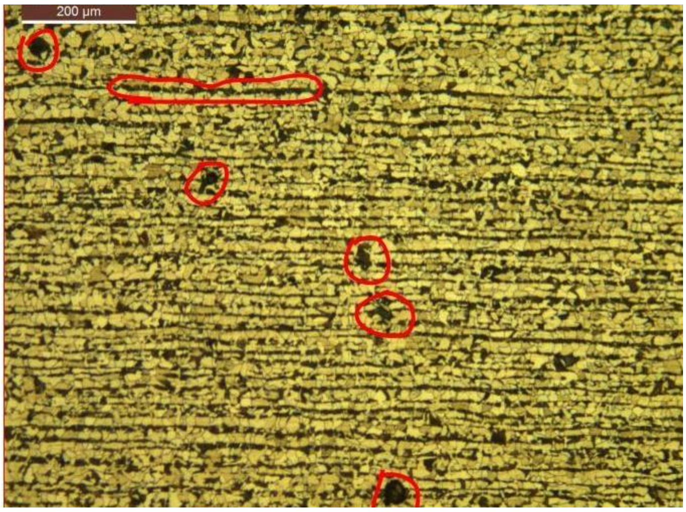

Figure 3.2 (b) More affected region of Economizer tube

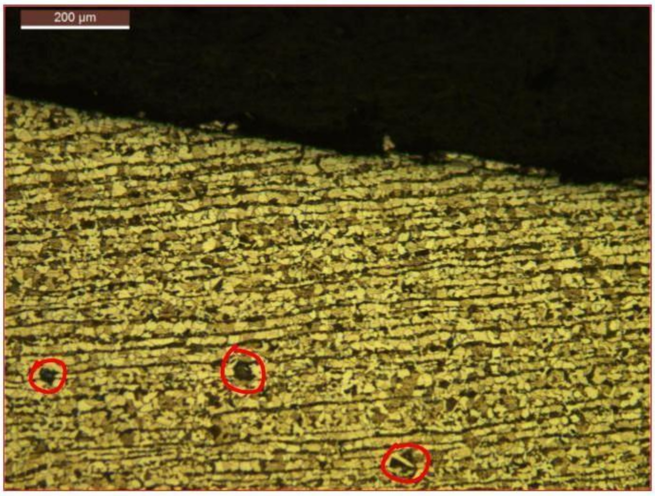

Figure 3.2 (c) More affected region of RH tube with significant graphitization

3.3 MICRO HARDNESS TEST

Specimen	Observed values in HV 300 gm /Dwell time : 15 seconds
B0 – 0.1 mm from OD	145, 140, 141
B0 – 0.1 mm from ID	130, 139, 131
D0 – 0.1 mm from OD	138, 137, 135
D0 – 0.1 mm from ID	156, 151, 155
Economizer tube– Thin region	173, 168, 177
Economizer tube– Medium region	179, 169, 175
Economizer tube – Thick region	183, 190, 195
RH tube – Thin region	190, 184, 188
RH tube – Medium region	182, 189, 184
RH tube – Thick region	193, 200, 198

By referring the above table, it could be noted that the hardness in the thinned portion is lesser than that of the thick portion. Softening has occurred in the thinned portion due to overheating. Since yielding / plastic deformation has occurred in the failed region, the inference that could be drawn is that the fracture mechanism involved here is ductile fracture.

3.4 SEM INVESTIGATION

In order to investigate the fracture mechanisms involved, SEM investigations were conducted through Scanning Electron Microscope Apreo SEM – Thermo Scientific funded by SRM IST and micro-fractographs were taken at various magnifications for un- etched samples.

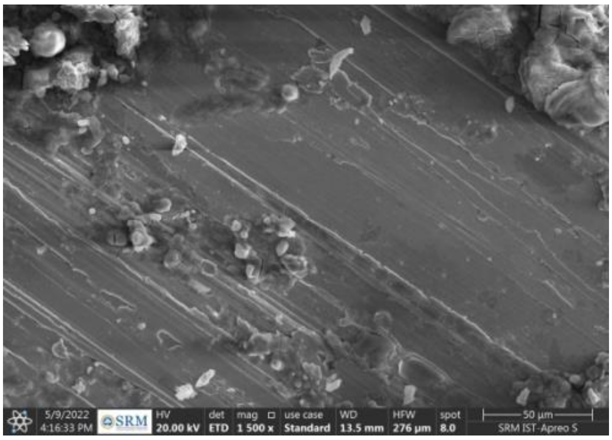

Figure 3.4 (a) SEM micrographs of Economizer tube

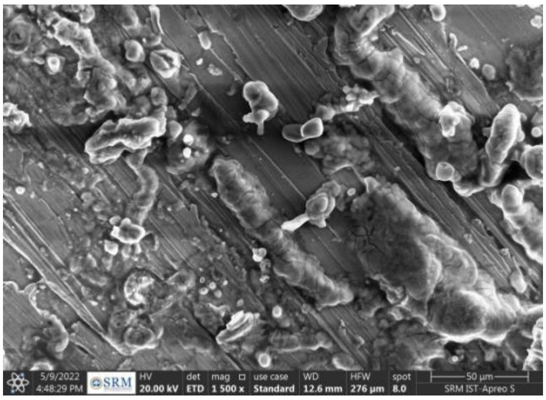

Figure 3.4 (b) SEM micrographs of RH tube

By referring the SEM micrographs, we could observe the formation of graphite nodules which confirms the occurrence of elongated as well as spherical graphitization. We could also observe the formation of micro-voids and void coalescence along with micro-cracks and their growth. Since the main purpose of doing SEM in our project is to ascertain the formation of graphite nodules, micro-cracks and void coalescence which occurs due to diffusion of carbon as a result of overheating accompanied by creep, we have done SEM on un-etched specimens. There is a huge scope for researchers to extend our SEM investigation with specimens after applying various etchants so that the formation of new grains with different microstructures can be observed and appreciated.

Apart from optical microscopy, micro-hardness test and SEM investigation, we have also done chemical analysis and EDS tests on various specimens and the results are attached as annexures.

4 CONCLUSION AND RECOMMENDATIONS

1. When we refer to the standards being followed in industrial thermal power plants mostly in India, we can find that spheroidal graphitization has been taken into consideration while designing the boiler operation but elongated graphitization has not been taken into.

2. Regular thickness measurement consideration since we could rarely find elongated graphitization being discussed in available literatures.

3. Since, "chromium forms more stable carbides than that of iron and molybdenum", usage of boiler tube materials with high chromium content can withstand graphitization which is one of the most predominant failure mechanisms identified via microscopic examination.

4. Since yielding / plastic deformation has occurred in the failed region, the inference that could be drawn from the micro-hardness test is that the fracture mechanism involved here is ductile fracture.

5. Standard operating procedure in maintenance should be adhered to reduce maintenance related failures such as weld failures.

6. The quality of coal should be ensured to reduce failures due to erosion.

7. The quality of water treatment with robust technologies in Demineralization water treatment plant (DM plant) should be ensured to avoid failures due to formationof oxide scales and corrosion.

8. Reduction of fly ash generation which increases erosion related failures in the design phase naturally increases the generation of wet ash which causes detrimental environmental impacts during its disposal in the ash pond via slurry transportation. Hence, a trade off must be given between these two while designing new boilers.

9. By usage of tube materials resistant to high temperature, we can reduce failures due to creep mechanism.

10. By usage of tube materials resistant to high internal pressure (Hoop stress), we can reduce failures due to stress rupture.

11. Usage of supercritical boilers in an emerging technology where we could eliminate the latent heat required for converting water to steam which there by reduces coal consumption. However, this technology is profitable as far as boiler tube failures are concerned only upon usage of tube materials that could withstandhigh temperatures and pressures.

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