Failure investigation of Reheat Cross Section and Rear Screen Wall Tubes of 600 MW coal power plant

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Abstract. Tube material that is operated at high temperatures has a higher possibility of failure, due to the addition of temperature and also influenced by the corrosive environment, pressure, and static-dynamic stress. The rupture occurred in the Rear Screen Wall and Reheat Cross Section Tubes that disruptive the performance of the overall Boiler. It was urgently needed to analyze the cause of the rupture. The material tube needs to be prepared to test in the laboratory. The analysis methods were through mechanical tests which are visual observation, fractography, hardness test, metallography or microstructure examination, and deposit analysis. The results showed that the Reheater Cross Section tube leakage caused by the formation of macro cracks that have been spread along the tube, compounded by flue gas erosion on the outer of the tube. On the other hand, Rear Screen Wall tube leakage caused by thinning from the outside of the tube, it occurred as a result of erosion of the flue gas and bursts from the Reheater Cross Section tube that leaked.

1. Introduction
The initial damage of material failure of high temperature component comes from various failure modes, such as high-temperature corrosion with scaling and fouling, excess operating pressure, erosion, overheating, and also the human factor may occur due to improper operation of the procedure [1-6]. Within root caused failure analysis method can be seen which is the most dominant mode that lead to failure. Failure analysis of tube failure has been done by so many researchers, i.e. J. Ahmada, J. Purboaksono, and L.C. Benga [4], showed that the boiler tube failures indicate that rupture can occur due to the cooling process and the influence of foreign material on the tube. In that study showed a tube rupture because of the absence of water flow in the tube due to the deposit thus identified as the root causes of failure. Other analysis by A. Movahedi-Rad, S.S. Plasseyed, M. Attarian [7], showed that the tube failure mainly caused by fireside corrosion of the tube during the service due to low grade of used fuel which caused continuously scale formation and reduction of wall thickness. Root Caused Failure Analysis (RCFA) determines by Ghosh, D., Ray, S. & Roy, H. J Fail. Anal. and Preven on tube [8] through the effect of the deposit on the tube to the rest of the tube. The results showed significantly the influence of the thickness of the deposit to the rise in temperature.

In this research, the initial analysis of the failure of the tube is due to because of macro cracks that have been spread along the tube, compounded by flue gas erosion on the outer of the tube thus also effecting the rear screen wall tube. Reliability of the tubes was decreasing significantly because of the failure. Therefore, failure analysis need to be done immediately so, whenever the boiler is operating these kind of failure can be avoided or prevented.
2. Methods
In order to analyze the tube failure, several methods were conducted. Mechanical analysis, including visual and metallurgical examination and also mechanical property measurement were performed. The detailed experimental method is described below.

2.1. Visual examination
Visual inspection was done to observe unnatural shape or screening material included fractography. Materials that will be investigated is observed using a digital camera and combined with macro camera to determine the likelihood of defects.

2.2. Metallurgical examination
The tests performed using optical microscope within 50-200x magnification. Mechanical tests performed include grinding, polishing, and etching by Nital 5%. The test results can determine the microstructure of material degradation, defects or changes in the microstructure. In addition, the Metallography testing can also identify the presence or absence of an oxide layer or scale on the surface of the material.

2.3. Mechanical property measurement
Hardness measurement were carried out using a Vickers Hardness on surface of the material, the test results are then compared with the ASTM standard to determine the outcome of the measurement is still in the normal range. The other measurement is thickness test in order to seek the thickness tube that has been lost.

2.4. Deposit analysis
Observation of deposit chemical composition inside the tube were inspected using HITACHI TM 3000 which use EDX mechanism.

3. Results and discussion
Location of the failure of Reheat Cross Section and Rear Screen Wall is shown in Figures 1. It shows that most of the tube has experienced flue gas erosion on the outer side of the tube. Both of them has similarity of the failure which is thinning process of the tube in some area. In order to analysis the failure, the tubes were taken to the laboratory for further examination.

Figure 1. Reheat cross section tube and rear screen wall tube location.
Figure 2 shows that the leak occurred in the Reheater Cross Section tube as impact of thinning phenomenon from the outside of the tube. From Figure A as Macro photographic, it can be seen that the failure could happen due to erosion from gas flow during operation. This erosion phenomenon could happen in short or long time period of operation depends on gas flow.

![Figure 2. Reheat cross section tube examination. (1) Visual examination (2) Metallurgical examination.](image)

The results of the microstructure examination in the fracture area can be seen in Figure 2 (B). The Reheat tube microstructure is in the form of ferrite-pearlite with presence of micro and macro cracks that have spread throughout the grain boundary, thus weaken the tube material and cause leakage. The thickness of the deposit is still in normal conditions which is 56.2 μm. The hardness value of the leaked tube as seen in Table 1., has experienced an increase in hardness with the highest value of 438 HV while in the remote part of the leak the hardness value is 231 HV. During operation the tube receives high pressure and high temperature so that it exceeds the stress load and the strength of the tube, finally the tube was weakening and breaks in brittle conditions that is increased hardness or reduced level of tube ductility.

Figure 3 (1). shows that the leak that occurred on the Rear Screen Wall tube is also as impact of thinning from the outside of the tube. In (A) and (B) as macro photography, it can be seen that failure due to thinning process on the outside of the tube. The results of the microstructure examination in the rupture area of Rear Screen wall as seen in Figure 3 (2) is in the form of ferrite-pearlite with presence of micro and macro cracks that have spread at the grain boundary, thus weaken the tube material and cause leakage. The microstructure of the inner diameter tube shown material degradation, characterized by the reduction of the pearlite region i.e. the black or gray area. As a result of material degradation, the hardness value of the leaked tube has decreased with the highest value of 179 HV, while in the remote part of the leak the lowest hardness value is 239 HV. During normal operation the tube receives high pressure and temperature so that it exceeds the stress load and the strength of the tube, finally the tube was breaks.
Figure 3. Rear screen wall tube examination (1) Visual examination, (2) Metallurgical examination.

Table 1. Hardness value of reheat cross section tube.

| No | Hardness in Tube Rupture Area (HV) | Hardness Normal Tube Area (HV) |
|----|-----------------------------------|--------------------------------|
| 1  | 412                               | 231                            |
| 2  | 398                               | 217                            |
| 3  | 407                               | 215                            |
| 4  | 425                               | 226                            |
| 5  | 538                               | 222                            |

Table 2. Hardness value of rear screen wall tube.

| No | Hardness in Tube Rupture Area (HV) | Hardness Normal Tube Area (HV) |
|----|-----------------------------------|--------------------------------|
| 1  | 175                               | 277                            |
| 2  | 156                               | 260                            |
| 3  | 166                               | 265                            |
| 4  | 155                               | 275                            |
| 5  | 179                               | 239                            |
Examination of the thickness and content of deposit elements of Reheat Cross Section using SEM and EDAX as seen in Figure 4 and Table 3 shows that the tube material has a relatively low deposit thickness of 56.2 µm so it would not affect the heat transfer. The chemical composition of the deposit shows the absence of irregularities, the elements detected are those that are still in the normal category.

![Figure 4. Reheat cross section SEM examination.](image)

**Table 3. Reheat Cross Section EDAX Examination**

| Element       | Weight % |
|---------------|----------|
| Carbon        | 24.734   |
| Aluminum      | 0.261    |
| Silicon       | 0.487    |
| Chromium      | 0.454    |
| Iron          | 74.064   |

![Figure 5. Rear screen wall SEM examination.](image)

**Table 4. Rear screen wall EDAX Examination.**

| Element      | Weight % |
|--------------|----------|
| Carbon       | 20.817   |
| Silicon      | 1.279    |
| Manganese    | 0.594    |
| Iron         | 77.311   |
Examination of the thickness and content of deposit elements of Rear Screen Wall using SEM and EDAX as seen in Figure 5 and Table 4 shows that the tube material has a relatively low deposit thickness of 13 µm so it will not affect the heat transfer. The chemical composition of the deposit shows the absence of irregularities, the elements detected are those that are still in the normal category.

4. Conclusion
From the results of visual inspection, macro fractography, hardness testing, and microstructure, tube failure can be concluded that Reheater Cross Section tube leakage is caused by the formation of macro cracks that have spread along the tube, besides that the outer diameter of the tube is thinning due to flue gas erosion. On the other hand, the leakage that happened in Rear Screen Wall tube is also caused by thinning from the outside of the tube, possibly can occur as a result of flue gas erosion and bursts from the Reheater Cross Section tube that leaked as domino effect.

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