

# Failure Analysis on Reheater Tube Boiler Furnace Base on Tensile and Impact Test

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## ABSTRACT

Failure on reheater tube was rupture. Scale latched on the outer surface and progressively thinning thickness with a minimum thickness of tube rupture at the nearest corner. An analysis of this research is to find the cause fracture mechanism and prevent similar failure. The mechanical analysis used tensile and impact test on failure and replacement tubes. Quantitative data analysis used descriptive methods. Characteristic of tube SUS347HTP with tensile strength standard 550N/mm<sup>2</sup>. The yield strength obtained on replacement tube, temperature 30<sup>0</sup> (399.55Mpa), 160<sup>0</sup> (234.09 Mpa), 290<sup>0</sup>C (198.13Mpa), 420<sup>0</sup>C (136.26 MPa), 500<sup>0</sup>C (102.10Mpa), 550<sup>0</sup>C (80.75 Mpa), 580<sup>0</sup>C (67.94Mpa), and 600<sup>0</sup>C (59.40MPa) and on failure tube, temperature 30<sup>0</sup>C (244.45MPa), 160<sup>0</sup>C (206.93MPa), 290<sup>0</sup>C (158.70 MPa), 420<sup>0</sup>C (118.14Mpa), 500<sup>0</sup>C (91.9MPa), 550<sup>0</sup>C (75.5MPa), 580<sup>0</sup>C (65.66MPa), 600<sup>0</sup>C (59.10MPa). Tensile test aimed that pressure of failure tube decreased. Impact test showed that low toughness of failure tube. The Combining tensile and impact data analyzed, the result shows ruptured the reheater tube at this location because it decreased in mechanical strength and hardness value. It shows material (tube) could not hold up the allowable pressure.

**Keywords:** Reheater tube, rupture, scale, tensile test, impact test

## 1. INTRODUCTION

Boiler is a place also referred to as steam generator, it a closed vessel in which water is converted into steam or water and steam above the atmospheric pressure by the application of heat. Two types of boiler are fire tube and water tube [1]. Both are specially designed to change water fluid into steam or steam and water and to control steam outlet temperature. Superheaters and reheaters are part of boiler, divided into multiple parts to optimize heat recovery, to help control steam temperature, and to maximize the heating temperature of the fluid flowing in the tube. The design and location is dependent on the heat absorption, outlet temperature, fuel ash characteristics and cleaning equipment. The main components are manufactured from steel alloys and resistant to high temperatures. Steam boilers must be able to infiltrate heat produced from the combustion process effectively. The thermal from combustion in a boiler is emitted by radiation, convection, and conduction [2].

Failure analysis in boiler tubes have been discussed by Drastiawati and Agustin. As summarized this research emphasizes of failure based on stress and changes in thickness occurred on waterwall tube of boiler furnace. A

protective layer in the form of layers as Fe<sub>3</sub>O<sub>4</sub> on the inner surface tube is exfoliate and on the inner surface there is inherent attachment from failure product with shapes like scratch and flow. Micro visual analysis showed that crystal grains size become larger on the inner surface and smooth crystal grains in the tangential direction. Macro visual observation showed that progressively the tube decreases in thickness here thickness is increasingly showing a minimum when approaching the peak of the tube curvature. The top point of the curvature tube had a thick crust attached to the outer surface [3].

It was shown that the plastic deformation occurred in the material due to the inside of the tube was experiencing tension pressure experienced and a relatively high temperature increase. The combination of stress, changes of thickness dimension, and changes of grains size caused failure of the tube. These factors can cause a decrease in mechanical properties of the tube to hold up pressure although it is in accordance with the operational standard, and fracture occurs before the strength limit is exceeded. Combining all these factors, failure of the tube at waterwall furnace caused the cross-section could not withstand the pressure [3].

Other analysis has been reported investigated on reheater pendent tube due to external scale exfoliation and internal scale formation base on visual inspection, internal oxide scale and tube wall thickness measurements, microscopic examinations, and creep analysis. Investigation of failure focused on reheater pendent type SA213-T22. Analysis showed that it had scale exfoliation on fire-side tube and significant on the steam side. Failure of reheater pendent tube caused the interaction occurrence of significant scale formation on steam side was produced in the higher metal temperature and fire-side peeled of scale as a product of high temperature corrosion [4].

The analysis paper on superheater tubes of coal based reported and summarized about of critical failure mechanism On the inside failure of the tube wall, macro visual observation showed reducing thickness. Micro visual observation indicated spheroidization of alloy carbides, it contains excessive oxidation corrosion and the coarsening of precipitate along grain boundary. Other analysis described intergranular cracking in material through area covered with thick scales. Micro visual showed creep formation along the grain boundary and loss of stiffness. Mechanical properties analysis of the tube showed hardness reduction lower than 200Hb. Macro visual observation from outer surface tube described thin lip fish mouth fracture occurs at both the failed locations, cause failure [5].

Paper research on coal fired power plant analysis of the rear pass tube boiler base on effect of high temperature reported that the presence of higher temperature from economizer, intermediate temperature superheater and temperature at reheater tubes are lower. Heat transfer resulting in temperature changed and metallography observation describes no creep cavities. Mechanical properties observation analysis used the data from hardness test results. Hardness test indicated that strength of the tubes was also maintain as shown by the data. Supporting data used results of LMP parameter and graphitization process could be analyzed by TT (time temperature) diagram for carbon steel to find out the phase change [6]. An increase in inlet steam temperature gives a steady improvement in cycle efficiency and reduces water content as a reheater function and thus increases the turbine internal efficiency. However; operational temperature must be in accordance with material capability standards. The optimum temperature of boilers and tubines materials is limited, maintain 4500 C for steam temperature [7].

Steam superheater tubes stress analysis of a high pressure boiler indicated the hardness results illustrated that the mechanical resistance of the material has been maintained. Dimensional measurements as macro visual observation and Non Destructive Testing (NDT) did not show existence of creep failure. The micro visual analysis of internal layer indicated the presence of deposits stick from water fluid or steam exceed to the first superheater. The thickness of the layer not indicate that the material

has decreased in properties, especially mechanical properties and efficiency on the boiler is not optimal. The micro visual data analysis summarized some spheroidization with phase cementite and pearlite indicating an initial state of high temperature material. Pores or micro cracks were not found in the samples checked. These indicate that twenty-three years' period of service, it showed that the material still had the ability to withstand a pressure. Simulation analysis used ANSYS 5.4 software indicated the sources for deformations observed on the fatigue life related with heating and cooling cycles [8]. Failure of the tube boiler indicated the serious problem, if left uncorrected. Managing of failures tube boiler can help reducing forced outages and increasing availability and reliability. Power Plant which implement an effective tube failure prevention program can minimize the risk of failures. There are certainly many factors that need to be identified in order to implement a successful BTF (Boiler Tbe Failure) prevention program. This paper provides a comprehensive review about the various root causes of boiler tube failure, generating the need for determining the requirement corrective measurement to minimize similar occurrence in the future. The case study presented recognizes the failure area and also emphasis on the factors which increase for type failure mechanism [9].

This analysis of the failure of reheater tube boiler aims on the combining impact of those factors causing the ability to decrease stress received. It limits the material of reheater tube from withstand the stress and furthermore will generate fractures base on tensile and impact test.

## 2. RESEARCH METHOD

### 2.1 Sample Material Tube

Material tube: SUS347 HTP tube no 47

length: 1260mm

replacement tube length: 620mm



Figure 1. Material tube no 47.



Figure 2. Material of replacement tube.

2.2 Step of Research

The mechanical analysis used tensile and impact test on failure and replacement tubes. Quantitative data analysis used descriptive methods. Identification of the problem failure of reheater tube outlet to the PLTU Unit 3. Tube no47. Collecting sample tubes failure and replacement tubes. Sample collection is used to identify failure and data retrieval. Failure investigation and testing. An investigative process needs to be carried out to find out why failure can occur and to categorize problems and cause more specific failures. The test functions to get the data to be analyzed. Formulate the problem and identification of problems. The results of the identification are examined again with the initial hypothesis. Analysis. The analysis is performed after the data obtained that can support the initial hypothesis. The results of the analysis are adjusted to the initial hypothesis, if it is not appropriate to do a review of the initial hypothesis. The review can allow that an error has occurred against the initial hypothesis, so it needs to be re-analyzed until it is in accordance with the initial hypothesis. Conclusion. Based on the data and analysis results obtained, it can be seen the cause of the damage and the mechanism of failure to the tube.

2.3 Testing Method

This research used quantitative descriptive analysis and describe data to analyze the causes of failure tube. The method of the test is:

- a. Tensile Test
  - Tensile test at various temperature near the working temperature of the material (580 °C - 600° C)
  - Tensile test temperature: 30°C, 160°C, 290°C, 420°C, 500°C, 550°C, 580°C, and 600°C.
- b. Impact test
  - dimension of material: 10x2.5mm.

2.4 Chemical Composition of Tube Material

Table 1. Chemical composition tube SUS347

C	0.1-0.4
Si	Max 1.0
Mn	Max 2.0
P	Max 0.030
S	Max 0.030
Ni	9.0-13.0
Cr	17.0-20.0
Mo	-
Others	8xC% -1.0

Table 2. Boiler steam power plant design

Type	IHI FW SR Single Drum Natural Circulation Reheat Type
Evaporator	643.000 kg/hour
Reheat Steam Flow	5233.000 kg/hour
Main Fuel	Residue / Gas
Year of Manufacture	1987
Year of operation	1988
Reheat Steam Temp.	535 °C - 550° C
Metal Temperature	580 °C - 600° C
Reheat Steam Pres.	18 kg/cm <sup>2</sup> - 30 kg/cm <sup>2</sup>
Outside diameter	45mm
Hydrostatic test press	40 kg/cm <sup>2</sup>
Allowable stress at T590°C	9100 psi (62,78 N/mm <sup>2</sup> )
Pressure detected when rupture	
Tensile strength material	28 kg/cm <sup>2</sup> 53 kgf/mm <sup>2</sup> min
Yield strength material	21 kgf/mm <sup>2</sup> min

The table source from PLTU Unit 3.



Figure 3. Tensile test specimen tube no 47 [11]



Figure 4. Tensile test specimen replacement tube [11]



Figure 5. Impact test specimen tube no 47 [11]



Figure 6. Impact test specimen of replacement tube [11]

### 3. RESULTS AND DISCUSSIONS

Strength is the ability of a material to accept stress without causing failure. One of the mechanical properties that can show the strength value of a material is the tensile strength. Tensile strength is obtained by conducting a tensile test on the material.

Table 3. Tensile strength of replacement tube

Location	Material	Tensile strength Kgf/mm <sup>2</sup> (N/mm <sup>2</sup> )	Yield Strength Kgf/mm <sup>2</sup> (N/mm <sup>2</sup> )
Reheater	SUS347	550.193 519.196 498.599 <b>522.663</b>	325.222 285.049 318.391 <b>309.554</b>

Table 4. Tensile strength tube standard

Location	Material	Tensile strength Kgf/mm <sup>2</sup> (N/mm <sup>2</sup> )	Yield strength Kgf/mm <sup>2</sup> (N/mm <sup>2</sup> )
Reheater	SUS347	53 min (520) min	21 min (206) min

The results of these tests indicate that the replacement tube has a value of tensile strength with tube standard thus material can be operated for a period of time in accordance with design standards. The tube is expected to be able to hold up pressure at operating, that the failure rate can be minimized because it is still in the safe category with a value of permission still below the tube yield strength.

Table 5. Tensile test result of replacement tube

Temp. (°C)	Load (kg)	Yield strength (Mpa)	Tensile strength (Mpa)
30	10000	309.55(avg)	522.67
160	6500	234.09(avg)	443.25
290	6500	198.13 (avg)	361.69
420	6500	136.26 (extp)	281.52
500	6500	102.10 (extp)	232
550	6500	80.75 (extp)	201.05
580	6500	67.94 (extp)	182.48
600	6500	59.40 (extp)	170.10

avg=average extp = extrapolation

Table 6. Tensile test result tube no 47

Temp. (°C)	Load (Kg)	Yield strength (Mpa)	Ultim. Strength (Mpa)
30	10000	244.45 (avg)	429
160	6500	206.93 (avg)	383.70
290	6500	158.70 (avg)	256.80
420	6500	118.14(extp)	184.30
500	6500	91.90 (extp)	131.40
550	6500	75.50 (extp)	98.30
580	6500	65.66 (extp)	78.44
600	6500	59.10 (extp)	65.20

Table 7. Impact energy conversion based on thickness [12]

Size of specimens (mm)	Minimum average impact strength for three specimens		Minimum impact strength for one specimens or for set of three specimens	
	J	ft.lbf	J	ft.lbf
10x10 (fullsize)	20.3	15.0	13.6	10.0
10x7.5	16.9	12.5	11.5	8.5
10x5	13.6	10.0	9.5	7.0
10x2.5	6.8	5.0	4.7	3.5

Table 8. Impact test result failure tube no 47

Dimensi on (mm)	Toughness (joule)	Conversion (joule)	Percentage of full size (%)
10x2.5	3.3	0.97	33.5
	3	0.97	33.5
	2.5	0.97	33.5
Avg	<b>2.9</b>	<b>0.97</b>	

**Table 9.** Impact test results of replacement tube

Dimension (mm)	Toughness (joule)	Conversion (joule)	Percentage of full size (%)
10x5	57	37.52	66.70
	56	37.52	66.70
	55	37.52	66.70
<b>Avg</b>	<b>56</b>	<b>37.52</b>	

The failure can be explained as follows break with a tear in the direction of fluid flow. The broken area is located at the bottom with a horizontal position when the tube is in the reheater circuit, where in that part is the path of the combustion process and the path in the water jet cleaning process. The ruptured tube is located at the bottom with the position parallel to the fluid flow.

Failure tube in the reheater tube outlet circuit is in the form of a rupture in the direction of parallel to the fluid flow and thickness changes. On the outer surface there is crust attached. The crust that attaches to the part is very hard and sticks to the material so it is called hard slag. The outer protective layer of the tube has also disappeared. On the inner surface the protective layer is still visible even though there are some peeling parts (there are spots on the surface). Visually the form of failure is shown in Fig. 1. The visual appearance of a failing tube is very different from the replacement tube. On the outer surface area still looks smooth and uniform thickness when viewed from a side view. This shows that in plain view the failure tube has changed in terms of dimensions.

Mechanism of decreasing tensile and impact strength occurred because the tube is used at high temperatures for long periods of time. In the process on power plant, the steam boiler is operated for twenty-four hours a day. Steam boilers experience shut down process when failure or maintenance process. The operation process on tube is the same as the operation process in a steam boiler. During the operation process the tube changes, including changes in dimensions. Changes in these dimensions include, thickness reduction and reduction in outer diameter. Dimension change, in area of the tube becomes increasingly diminished. This is the liner with the tube area in receiving the pressure. This is the liner with the tube area in receiving the pressure as in the following equation:

$$P = F / A \quad [13]$$

With: P is the pressure received by the tube

F is the operating pressure

A is a tube area

Tensile strength decreased is also proportional to the decrease in impact strength. During the operation process the tube changes, including changes in dimensions. Changes in these dimensions include,

thickness reduction and reduction in outer diameter. With the changes in the shape of dimensions, the area of the tube becomes increasingly diminished. Dimensions that are supported by intergranular creep fracture indicate that the impact strength and tensile strength of the tube have decreased. This is comparable to the ability of the tube to accept pressure even though the pressure was below the yield [14].

Compared to previous study and to prevent the failure, the recommendations listed are regular inspections coupled should be implemented on a fundamental of frequent basis and re-inspection plan determined for developing during condition assessment. Initial inspection needs to be carried out on equipment that does not occur failure while inspections carried out on equipment that is often carried out failure. The wide range of causes that failures may occur in the registered the critical components, the categorize and total of inspection will be determined on a unit to unit basis. A comprehensive initial inspection adhered by frequent location and specific inspection should result in increased availability, reliability, safety, and efficiency of the unit [15].

#### 4. CONCLUSIONS

Failure of material reheater tube occurs due to the combination of stress and toughness. Results of tensile and impact testing shown those factors can cause a reduce in the strength of the tube to hold up the stress and fracture occurs before the strength limit is reached. The data results of impact and tensile strength on a failure tube compared to a standard tube due to the tube being unable to withstand loading even though the force applied it is in accordance with the procedure.

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#### REFERENCES

[1] Vinu, V. T., Gowda, J., Sankar, S. Dr., "Design of Reheater for Superheated Steam in Water Tube Boiler," International Journal of Innovative Research in Science, Engineering and Technology, Volume 6 Issue 6, June 2017. pp.11526-11533.

- [2] Zhang, K., Zhang, K., Guan, Y., Zhang, D., "Boiler Design for Ultra-Supercritical Coal Power Plants," *Ultra-Supercritical Coal Power Plants Material Technologies and Optimisation Woodhead Publishing Series in Energy*, 2013. pp. 104-130.
- [3] Drastiawati, N.S., Agustin, HK., "Failure analysis of the left waterwall tube of boiler furnace in the steam power plant based on thickness changes and pressure," *Multidiscipline Modeling in Materials and Structures*, UK, Vol 13 No 4, 2017. pp. 539-549.
- [4] Ahmad, J., Purbolaksono, J., Kadir, A.K., Rahman, M.M., "Failure Investigation on Reheater Pendent Tubes Due to External Scale Exfoliation and Internal Scale Formation," *Journal of Pressure Vessel Technology*, Volume 133 Issue 6, 2011.
- [5] Gupta, G. K., Chattopadhyaya, S., "Critical Failure Analysis of Superheater Tubes of Coal-Based Boiler," *Jornal of Mechanical Engineering*, Volume 63 Issue 5, 2017. pp. 287-299.
- [6] Ahmad, A., Hasan, A., Noor, N.A.W.M., Lim, M.T., Husin, S., "Effect of High Temperature on Rear Pass Boiler Tubein Coal-Fired Power Plant," *American Journal of Material Science*, Volume 5 (3B), 2015. pp. 5-10.
- [7] Viswabharathy, P., Raja, T., Prakash, M., Rahavan, S., Raguvaran, S., "Thermal Stress and Creep Analysis of Failed Tube of Secondary," *International Journal of Emerging Technologies in Engineering Research*, Volume 5 Issue 4, April 2017. pp 212-224.
- [8] Nevesa, Daniel Leite Cypriano., Seixasa, Jansen Renato de Carvalho., Tinocob Ediberto Bastos., Rochac, Adriana da Cunha., Abudc, Ibrahim de Cerqueira., "Stress and Intregity Analysis of Steam Superheater Tubes of a High Pressure Boiler," *Material Research*, Volume 7 No 1, 2004. pp. 155-161.
- [9] Bamrotwar, Suhas ., Deshpande, V.S., "Root Cause Analysis and Economic Implication of Boiler Tube Failures in 210 MW Thermal Power Plant," *IOSR Journal of Mechanical and Civil Engineering*, International Conference on Advances in Engineering & Technology, 2014. pp 6-10.
- [10] ASM Handbook Commite, "Heat Treaters Guide: Standard Practice and Procedures for Steel," American Society for Metals, Metals Park, Ohio 44073, 1984.
- [11] ASTM E Series: E8, "Standard Test Method for Tension Testing of Metallic Materials, American Association State Highway and Transportation Officials Standard," 2002.
- [12] ASM Handbook Comitte, 1998, "Mechanical Testing and Evaluation", 8th edition, American Society for Metals, Volume 8.
- [13] Dieter, G.E, "Mechanical Metallurgy," 2nd edition, Mc Graw Hill Kogakusha Ltd, Tokyo, 1996.
- [14] Boresy, Arthur, and Schmidt, Richard, "Advanced Mechanics of Materials," 6<sup>th</sup> edition, John Will and Sons, New York, 1971
- [15] Hovinga, M.N., Nankoneczny, G.J., "Standard Recommendations for Pressure Part Inspection During a Boiler Life Extension Program," *International Conference on Life Management and Life Extension of Power Plant*, The Babcock & Wilcox Company a Mc Dermott Company, Ohio USA, 2000. pp.1-7.