INVESTIGATION OF FACTORS CAUSING CRACKS IN PRIMARY AIR TUBE BOILERS (CASE STUDY)

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ABSTRACT

The primary air tube in the boiler is an important component because it has the function of supplying air that will be used in the combustion process. The reliability of the function of the primary air tube contributes to the quality of the combustion results in the boiler. The purpose of this study is to investigate and analyze the causes of cracks that occur in the primary air tube boiler. The method used in conducting the analysis is using SEM (Scanning Electron Microscope) and microstructure. SEM testing will be used to study the morphology of the crack surface in detail, identify the crack propagation mechanism, and see any indications of corrosion or other elements that may be the cause of damage. Meanwhile, microstructure analysis aims to observe the internal composition of the material to ensure whether there is a structural mismatch that affects the strength and resistance of the material to operational conditions. Based on the test results obtained, there are indications of cracks due to square groove welding found in observations with 100x and 400x magnification only on samples 125 and 126. In the microstructure test with the same sample, indications of cracks were also found that occurred from the outside of the stainless compound due to residual stress and changes in atomic structure at the time of its formation and coupled with the corrosive fuel used, but have not spread to the inner carbon steel material.

Keywords *: Tube, Boiler, Cracks, Scanning Electron Microscope, Microstructure*

1 INTRODUCTION

The primary air tube in the boiler is an important component because it has the function of supplying air that will be used in the combustion process(Assefinejad et al., 2020; Bethmont, 1998; Othman et al., 2009; Raghavan & Chowdhury, 2015). The reliability of the primary air tube function contributes to the quality of combustion results in the boiler. (Intang, 2014; Raghavan & Chowdhury, 2015; Septiana et al., 2023). Failure or damage can cause forced shutdowns which can result in major losses for the industry. Component failure that often occurs in the boiler section is the appearance of cracks in the primary air tube (Begum et al., 2013; Haghighat-Shishavan et al., 2019). Cracks can cause several problems such as leaks, reduced efficiency, reduced service life, increased maintenance costs, and increased risk of work accidents (Port & Herro, 1991). Primary air tube in boiler is a quite important problem so that a comprehensive identification and analysis process is needed, so that appropriate and efficient repairs are obtained. Therefore, the durability and reliability of the primary air tube boiler are crucial to ensure optimal system performance and minimize operational downtime (Ahmad et al., 2012; Port & Herro, 1991).

Based on previous studies that have been conducted with the aim of investigating the factors that cause cracks in boiler tubes. Assefinejad et. Al (2020) revealed that the pipe cracks that occur are related to deposits that cause corrosion so that they can accelerate the occurrence of creep (Assefinejad et al., 2020). Meanwhile, research conducted by Kumar (2017) stated that the appearance of cracks was due to the influence of oxidation corrosion on the pipe surface which caused significant thinning (Gupta & Chattopadhyaya, 2017). In addition, Duarte et al (2017) in their research results stated

that cracks or failures in water tube boilers were due to a combination of residual stress and circular stress as well as corrosion in the water, but this case occurred in the bent pipe section (Duarte et al., 2017). Meanwhile, research by Babak Haghighat-Shishavan et al (2019) showed that the material structure affects the reduction in pipe thickness, thereby accelerating corrosion. (Haghighat-Shishavan et al., 2019). Zhao et al. (2021) stated that the low-temperature impact toughness in the HAZ zone of C–Mn steel is influenced by the peak welding temperature, grain size, low-angle boundary, and martensite/austenite (M/A) phase distribution, with the maximum impact energy occurring at 850°C and its fluctuation explained by the fracture mode (Zhao et al., 2021). Based on research by Y.Li et al (2022), the failure of the superheater tube in a waste heat boiler of a cement plant was identified as stress corrosion cracking due to residual stress in the bent area, which was proven through visual, mechanical, metallurgical, and SEM/EDS analysis, even though the material met the standard specifications (Y. Li et al., 2022).

Based on previous studies mentioned above, most of them focus on chemical processes that cause corrosion, but factors such as welding quality and techniques in primary air tube boilers have not been widely studied. Welding is often a weak point in the tube structure because the effect of high heat in the welding area can trigger material distortion and create residual stress. Improper welding techniques or poor welding quality can increase the risk of cracks and accelerate tube degradation under severe operational conditions (Wei & Ling, 2015). This study aims to fill this gap by conducting an in-depth investigation of the effect of welding on cracks in primary air tube boilers. This study will include analysis of welding quality, welding methods used, and the effect of welding techniques on the durability and performance of boiler tubes. By conducting material tests and inspections on the welding area, this study is expected to identify the most effective welding techniques to improve tube durability and provide practical recommendations for improving welding procedures.

Deeper understanding of the influence of welding techniques is essential in developing optimal maintenance and repair strategies for primary air tube boilers. By understanding in detail how welding techniques affect the material's resistance to pressure, extreme temperatures, and other environmental factors, maintenance teams can implement more effective welding methods, thereby extending the tube's service life and minimizing the possibility of recurrent cracks. The results of this study are expected to provide practical guidance for the industry in determining appropriate welding techniques and parameters, as well as improving welding quality standards for boiler tubes. Thus, the application of the results of this study can reduce the risk of system failure due to tube cracks, which in turn can reduce high operational costs due to component replacement or emergency repairs. In addition, the improvement in welding quality resulting from the right maintenance strategy will have a significant impact on the overall operational efficiency of industrial facilities and power plants, which not only supports the stability of energy production but also improves the reliability and safety of the system as a whole.

2. MATERIALS AND METHODS

The samples taken are primary air tube boilers that have been damaged and will be used as the object of investigation in this study. The samples obtained clearly show the physical condition of the primary air tube boiler sample that has been damaged, which will then be used for further analysis purposes (can be seen in Figure 1).



Figure 1. *Samples received from primary air tube boiler Damaged*

In order to support the process of obtaining a comprehensive analysis, the sample will undergo a series of tests, namely Scanning Electron Microscope (SEM) and microstructure. SEM testing will be used to study the morphology of the crack surface in detail, identify the crack propagation mechanism, and see any indications of corrosion or other elements that may be the cause of the damage. Meanwhile, microstructure analysis aims to observe the internal composition of the material to determine whether there is a structural mismatch that affects the strength and resistance of the material to operational conditions. The combination of results from these various tests will help identify the factors that cause damage and provide a strong basis for formulating appropriate repair and prevention measures.

3. RESULTS AND DISCUSSION

3.1 Visual Inspection

Before the damaged Primary Air Port Boiler Tube samples were cut for further analysis, a visual inspection was conducted to record and document various important features and indications of damage that appeared on the surface of the sample. This initial observation aims to identify prominent physical characteristics of the damage, which will later serve as a basis for understanding the process and factors causing component failure. Based on the observations made, several significant findings were found that could be early clues. In Figure 2, the side of the boiler tube is seen to be severely damaged, especially in the part that appears to be severely damaged due to leakage in the tube. This leakage is thought to have occurred due to internal pressure that caused a decrease in structural integrity, which ultimately worsened the condition of the material in that area.

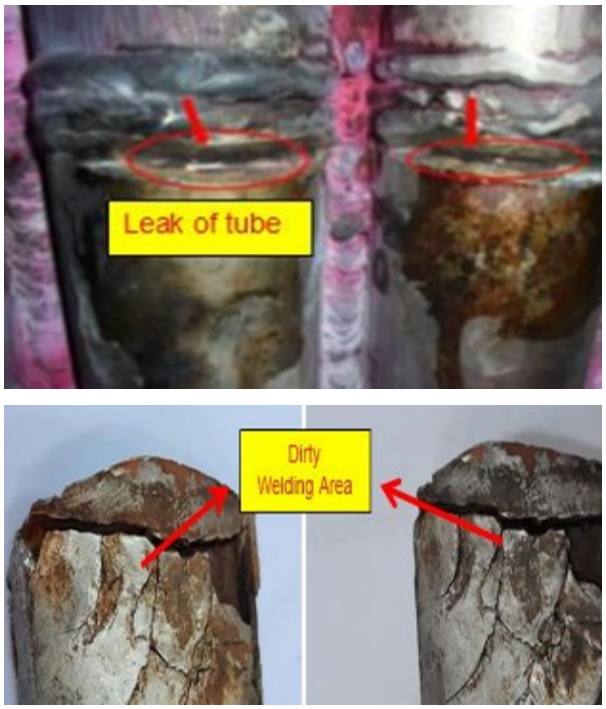


Figure 2. *Visual Inspection of Damaged Primary Air Tube Boiler Failure Materials*

In addition to damage due to leaks, defects were also found in the welded joints used to connect the primary air port pipe to other components. These welded joints use square grooves, but from visual observation, there were defects or imperfections at several points of the welded joints. One of the most striking defects was an indication of unclean welding, often referred to as dirty preparation welding, which can reduce the strength and durability of the joint. This defect usually occurs due to contaminants on the welded surface or suboptimal preparation before the welding process, resulting in joints that are susceptible to stress and corrosion.

The initial findings from these visual observations provide very important information for further analysis, as it allows the investigation team to focus on specific areas that could potentially be the root cause of the failure. By understanding these initial damage patterns, subsequent analyses, such as microstructure testing and SEM, can be more focused in determining the factors that accelerate material failure. The results of the combination of these various analysis methods are expected to provide a deeper understanding of the damage mechanism and become a strong basis in formulating effective repair and prevention measures for Primary Air Port Tube Boilers in the future. This states the research results along with the explanation.

3.2 SEM and Macro Analysis

The fracture surface appearance of Primary Air Port Tube Boilers 126 and 125 was analyzed using Scanning Electron Microscope (SEM). The images were taken from the base metal area, HAZ (Heat Affected Zone) as shown in Figure 3 and Figure 4.

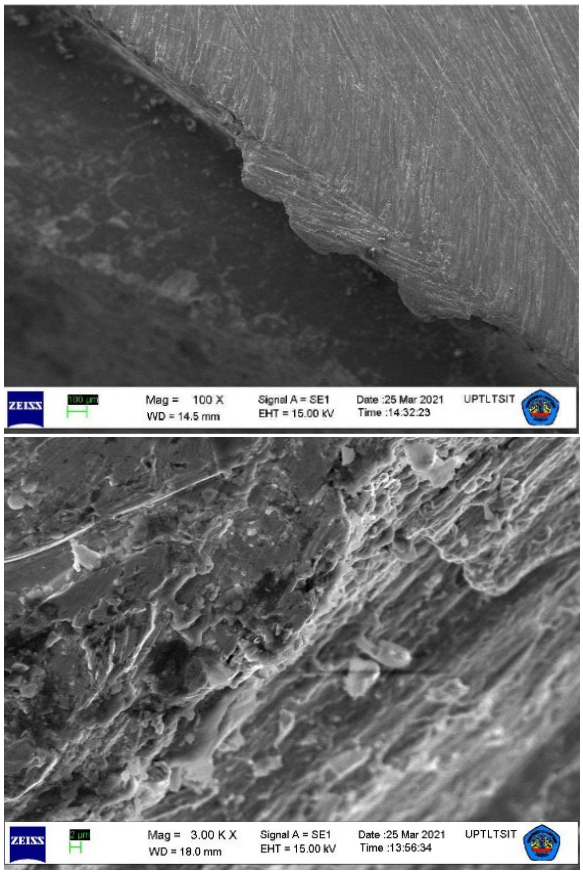


Figure 3. *SEM examination result of the base metal Primary Air Port Tube Boiler 125 and 126 with magnification of 100X and 3000X*

The surface in Figure 3 and Figure 4 is shown by SEM. Small indications were found by observation with 100x and 400x magnification. In Figure 4, information related to crack propagation occurs due to primary air in the weld joint of the port pipe boiler using a square groove. The interaction of the main crack with the microstructure can be observed in the figure. All cracks initiated in the air port tube gap, more precisely it is in the weld metal and weld root. Many cracks initiated in the open tube gap have been found. Small cracks seen at the transition between the weld metal and the HAZ in some air port tubes are oriented perpendicular to the tube.

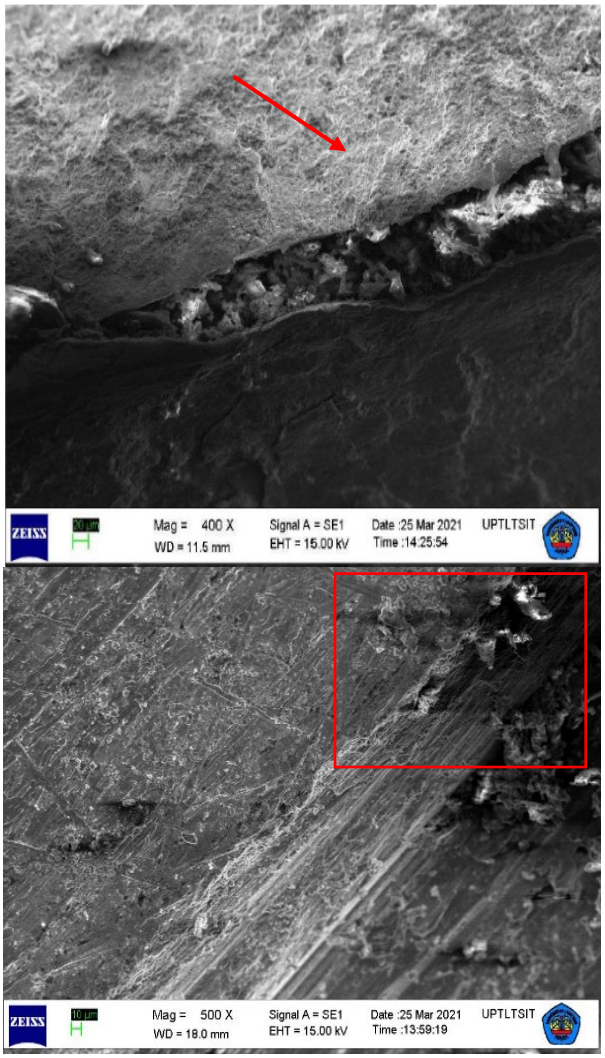


Figure 4. *SEM examination result of the HAZ Primary Air Port Tube Boiler 125 and 126 with magnification of 400X and 500X*

The surface view of Primary Air Port Tube Boilers 120 and 122 was analyzed using a Scanning Electron Microscope (SEM). The area image was drawn, as shown in Figure 5.

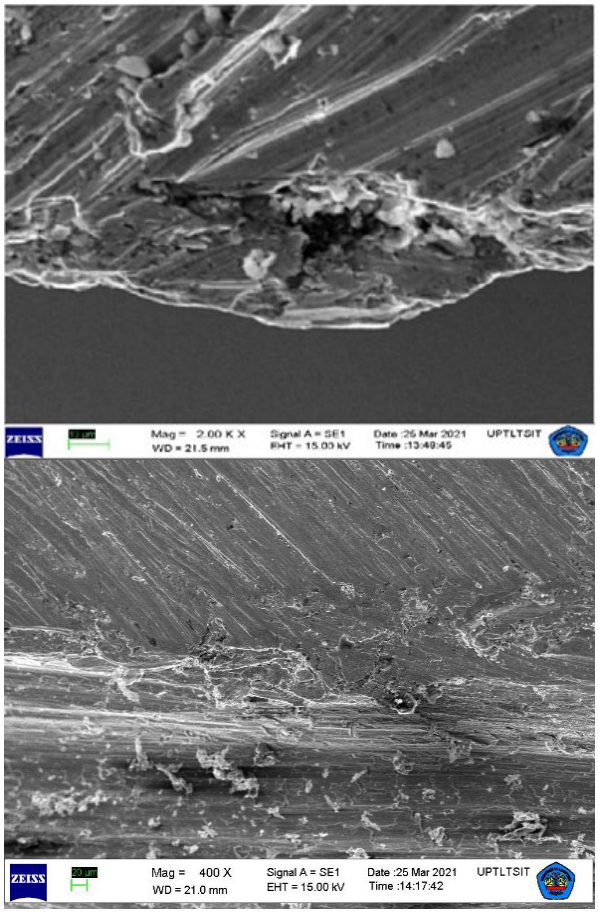


Figure 5. *SEM examination result of the Joint Primary Air Port Tube Boiler 120 and 122 with magnification of 2000X and 400X*

The surfaces in Figures 5 and 6 are shown by SEM and macro. There is no indication of malfunction, but it is found in observations at 1X, 2000X and 400X magnification. In Figure 5, there is no groove on the weld. The surface views of Primary Air Port Tube Boilers 109 and 110 were analyzed using a Scanning Electron Microscope (SEM). Images were taken from the base metal area, as shown in Figure 6.

The surface in Figure 6 is shown by SEM. found in the observation at 400X and 1000X magnification. In Figure 6, there is no indication of failure.

The primary air tube boiler samples were cut and prepared for Metallographic Examination. Preparation for metallographic examination included mounting, grinding, polishing and etching. Etching was performed using Nital solution to reveal the microstructure. The microstructure of the primary air tube of the boiler was examined at the weld joint area. The structure of the weld metal and heat affected zone (HAZ) was normal. No hard microstructure such as martensite was found at the weld joint.

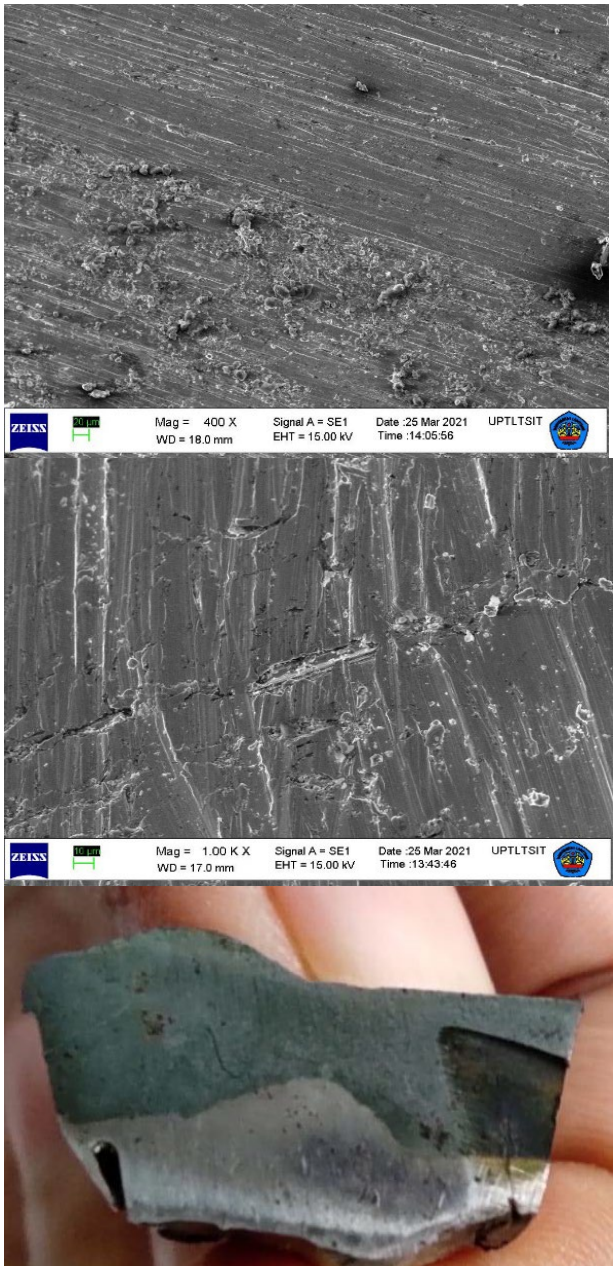


Figure 6. *Macro examination result of the joint area Primary Air Port Tube Boiler*

The microstructure proves that the welded joint on the primary air port tube boiler uses Square Groove. The microstructure of the primary air port tube boiler is examined in the base metal area. There is information related to crack propagation that occurs from the outside of the stainless compound due to residual stress and changes in atomic structure at the time of its formation and coupled with the corrosive fuel used, but has not spread to the inner carbon steel material.

The primary air tube boiler was subjected to laboratory tests to identify the material and root cause of the failure. The chemical composition of the tube material was found to be in accordance with the ASTM A210 G A1 specification. Visual inspection of the damaged airport primary tube boiler found several areas of damage. The damage was mainly found on the outer surface of the primary airport tube weld joint and the dirty weld area (Galvanized Corrosion and became Crevice Corrosion). There was a fracture at the weld joint as seen in Figure 2 and Figure 3, the dirty weld area caused the weld metal and the base metal to not fuse well. In addition, the use of the wrong welding seam greatly affects the onset of cracks in the tube, in this case the condition of the primary air port tube using a square welding seam, it is easier for both metals to break or crack.

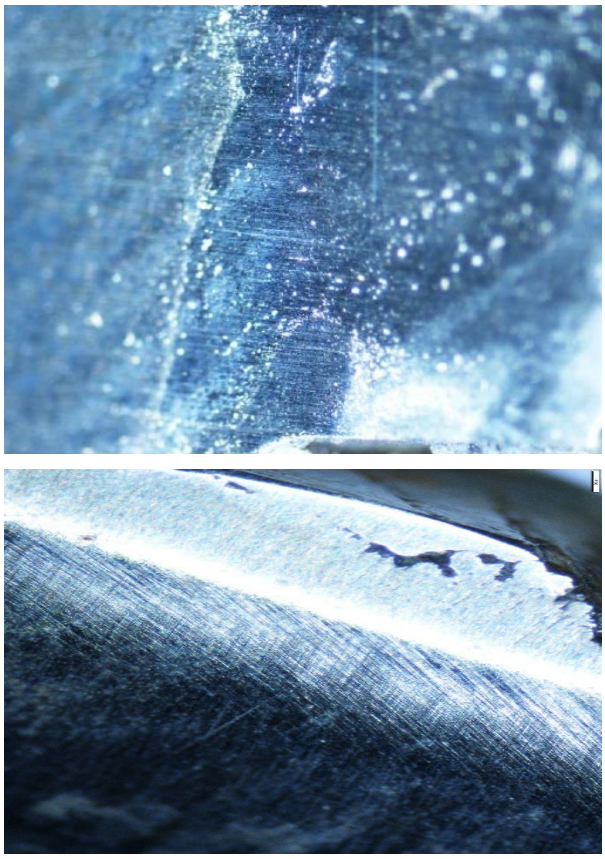


Figure 7. *Microstructure examination result base metal area Primary Air Port Tube Boiler*

The initial crack that occurs at the weld joint at the front of the primary water channel of the port tube boiler is caused by many factors. The weld joint area is a part that is very susceptible to any influence. starting from welding preparation that is not carried out with the procedure and the fuel used by the boiler.

The crack at the front of the primary air tube is also influenced by black liquid used as boiler fuel. Black liquid contains inorganic compounds such as Na_2SO_3, Na_2SO_4, NaOH, and Na_2S, which introduce sulfur elements that significantly contribute to pipe cracking. Sulfur compounds are known to react with water at temperatures above 80 °C, resulting in localized acidification of the corrosion environment. This condition promotes the formation of aggressive corrosion products that

accelerate material degradation. Wang et al. (2022) reported that sulfur-containing inclusions such as MnS and sulfates can trigger pitting and crevice corrosion in stainless steel, particularly under elevated temperature and humid conditions (D. Li et al., 2023).

The bending process in the formation of water port pipe boilers in the factory affects the durability of the material. The strain that occurs in the rolling, bending, and forging processes of the tube material can leave behind residual stress and plastic deformation zones that are not uniformly distributed. These stresses can significantly affect the fatigue resistance and crack initiation behavior of the component. Li et al. (2022) also observed that post-roll bending processes lead to uneven stress distribution and geometric distortion, which can reduce structural integrity and accelerate local failures (Jie Li & Zhao, 2024).

4. CONCLUSION

All failed samples have been tested in the laboratory. The results show that the chemical composition of the primary port water pipe boiler has met the standards. Damage analysis was carried out on the primary air tube with some visible leaks. Damage analysis focused on the weld joints, dirty weld areas on the primary air duct pipe, boiler fuel, and the influence of material formation. Weld joints on the main airport pipe must Use V Grooves instead of Square Grooves to reduce cracks caused by pressure from external factors. In the process of making primary airport tubes, welding is not carried out, pay attention to the cleanliness of the material to be welded and also do not make mistakes in cleaning the crust formed due to welding, which causes galvanic corrosion that spreads into the gap cracks. The use of black liquid which predominantly contains sulfur elements causes the material to be easily corroded and the rolling, forging, and bending processes in the tube making process provide residual stress that affects the strength of the primary air tube boiler.

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