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Failure Analysis on U-Bend Header Tube of Boiler Economizer

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Abstract. A water tube boiler is a type of boiler in which water circulates in tubes heated externally by fire. It was found that the water tube economizers are often subject to the serious damage mainly because of the overheating and corrosion. Thus, the metallurgical investigation procedures starts with the visual inspection, stereomicroscopy, metallography and chemical analysis methods. It was identified that the failure of the u-bend tube was due to the cracking caused by bending forces during the procedures. This cracking causes a leak for the tube. The appearance of corrosion on the shell side is due to the presence of small content of sulphur under the boiler environment. Several welding imperfections were also detected, however, both corrosion and welding imperfections were not the primary caused of the tube failure. From the analysis, the use of SUS304 grade stainless steel was discovered to be the appropriate material selection for the tube boiler.

1 Introduction

In a boiler system, an economizer captures the heat of the flue gas and transfers it to the feed water [1]. As the flue gas exits the boiler, it enters an economizer with finned tubes. The finned tubes absorb the heat and raises the temperature of the boiler feed water, lowering the need energy input. The material for the economizer will depend on the fuel type and may be all steel, all cast iron or cast iron protected steel. All steel would be used for non-corrosive flue gases from burning natural gas, light oil and coal [2-4].

The u-bend header tube of boiler economizer found to be failed after 5-6 years in service (Figure 1(a)-(d)). A sudden pressure drop was recorded by the person in charge. From the observation, the boiler header was found leaked on the u-bend tube area. The materials of header tubes made of SUS 304 grade stainless steel. The objective of this analysis is to investigate the failure evidence presented by the u-bend tube and to examine the primary cause of the failure through the metallurgical analysis method.

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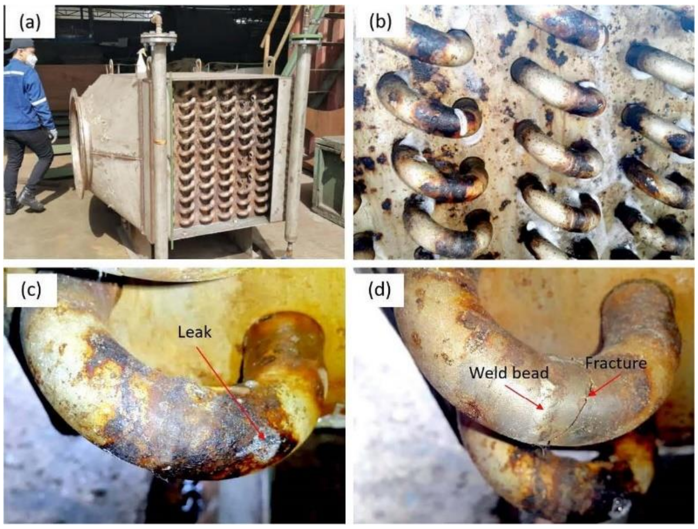

Figure 1:Camera photographs on boiler economizer; (a) header tube, (b) close-up views on defected u-bend tubes, (c) leaked area as indicated by the small white bubbles and (d) transverse crack adjacent to the weld bead.

2 Methodology

Visual inspection of the original condition on as-received u-bend tube was documented by digital DSLR camera (D3100, Nikon). Close-up viewing of crack area was done by stereomicroscope (SZX 10, Olympus). The u-bend tube was then sectioned using a diamond cutter at the slowest speed to ensure no external residual stress exerted onto the u-bend header. The sample once again been examined visually by using camera and stereomicroscope. The sample was cleaned by using stainless steel cleaner to remove all the dirt and rust inside (tube side) and outside (shell side) of the sample. The failed sample then grounded to 180, 240, 320, 440, 800 and 1200 SiC grit paper before polished using 6 and 1μ diamond solutions. The as-polished sample was inspected by metallurgical microscope (BX41, Olympus) to determine the presence of defects such as crack, inclusion, pin holes, void and/or microstructural anomalies. The as-polished samples were etched by 10 ml HNO_3, 10 ml CH_3COOH, 15 ml HCl and 5 ml glycerol to delineate specific microstructural features. Once etched, the microstructure of the material was viewed under metallurgical microscope (BX51M, Olympus). Surface morphology and micro-elemental analysis was conducted by scanning electron microscope, SEM (JSM-6490LA, JOEL) and energy dispersive spectroscopy, EDS (Oxford INCA Energy EDS system).

3 Results and Discussion

Figure 2 (a) - (d) show a camera photographs of as-received u-bend header tubes both on shell and tube sides. The surface of the header tube is found to be covered with brownish rust on both shell and tube side. The shell side surface looks more severe to corrode as compared to the tube side. In as-cleaned samples, there is a residual blackish oxide stain and slightly brownish rust (Figure 2(c)). While the tube side surface is seen to be shiny and rust-free (Figure 2(d)). These observations indicate that the rust is worse on the shell side rather than the tube side where the fluid flowing through in it.

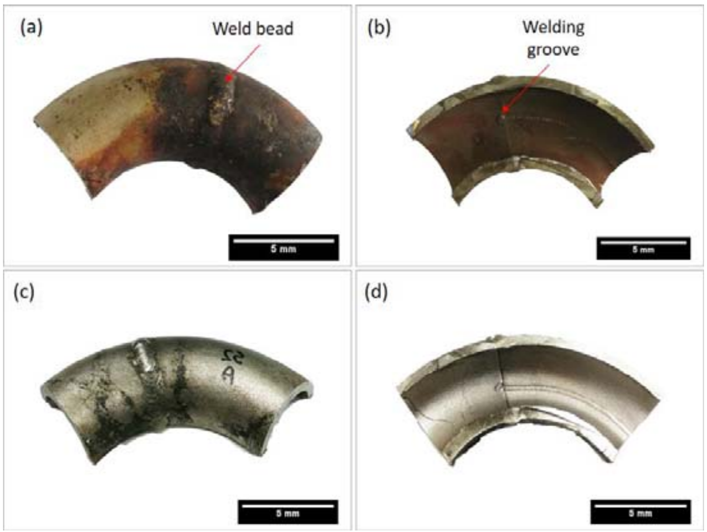

Figure 2:Camera photographs on (a) shell side, (b) tube side of as-received, and (c) shell side and (d) tube side images of as-cleaned of u-bend header tube.

The closed-up camera photographs further reveal the appearance of cracking on the u-bend header tube (Figure 3). At the shell side, there is a crack transversely propagates encircling the tube that occurs adjacent to the weld bead (Figure 3(a)). There are some blackish stains on the crack morphology which indicates that there is a corrosion reaction surrounding the crack area. Figure 3 (b) shows the cracks are found everywhere along the u-bent tube on the tube side. However, there were no signs of cracking on the weld bead. This proves that welding procedures are performed well without any defects. Additionally, no corrosion marks visually detected on the tube side.

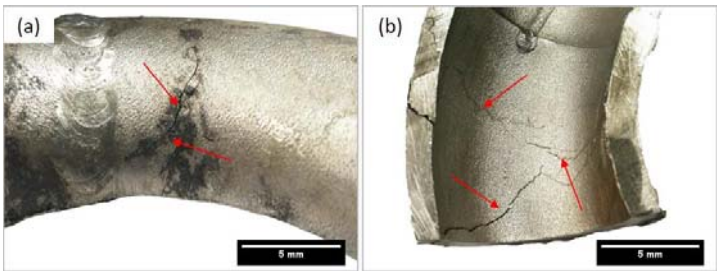

Figure 3:Closed-up camera photograph images on as-cleaned of typical (a) shell side and (b) tube side. Red arrows indicate the cracking morphology.

Observations by stereomicroscope around the weld bead both on shell and tube side found no signs of cracking and corrosion occurred (Figure 4(a) and (b)). Some welding imperfection such as linear misalignment and incomplete penetration (lack of root fusion) spotted on weld join. Generally, this imperfection act as an initiation site of the stress corrosion cracking (SCC) [3]. However, there is no SCC marks detected here. This further strengthens the fact that the welding works to join two semi-bent tubes do not have any problems at all, instead, it was carried out perfectly.

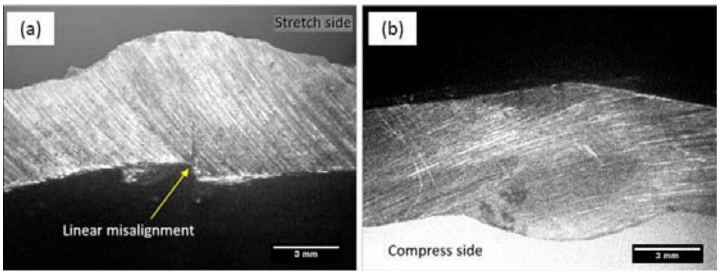

Figure 4: Stereomicroscope images at cross-sectional (parallel to stress direction) of the as-cut weld bead area on (a) stretched and (b) compressed side.

Etched metallographs images on the header tube metal are shown in Figure 5. There are single cracks together with hairline cracks morphology which dominated by transgranular cracking on the cross-sectional tube wall. This crack finally results in the enlargement of crack opening to be more severe. Both hairline and transgranular cracks indicate that the tube metal is under stress due to bending works that occur in a plastic manner beyond the materials yield point. In contrast, there is not a clear intergranular cracking that can be clearly detected. Therefore, the corrosion factor is not the main cause of the failure. Additionally, the absence of a slip band grains is believed due to the optimum heat treatment process performed on the u-bend tube works well and aidful [1-2].

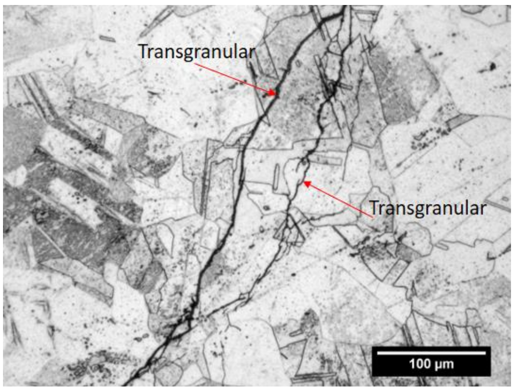

Figure 5: Etched metallographs image on the header tube is dominated by transgranular cracking.

Figure 6 shows the elemental EDS pattern on the shell side surface. The appearance of brownish corroded surface on the shell side was attributed to the oxidation and the presence of slightly sulphur elements which is believed as a result of sulphur content in the condensation of flue gas.

OES Results of the as-received u-bend header tube boiler is shown as in Table 1. This results proved that SUS304 grade stainless steel is the best material selection used for the tube boiler since it is not affecting the tube boiler failure. The material selection factor has been ruled out. The plant technical should perform a periodic NDT inspection for early detection and damage assessment to boiler tubes. Secondly, the application of u-bent header tubes by mechanical bending methods is indeed prone to crack failure, thus it is proposed to replace them with u-bend tubes fabricated by the casting method.

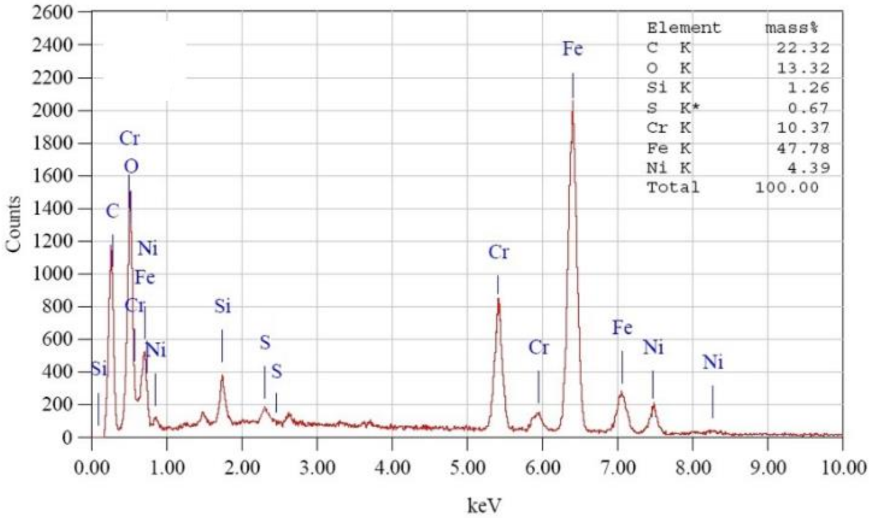

Figure 6: Elemental EDS pattern on u bend header tube at shell-side surface.

Table 1: OES Results of the as-received u-bend header tube boiler

Element	SUS304	Header Tube
C	0.08 max.	0.033
Si	1.00 max.	0.398
Mn	2.00 max.	1.76
P	0.045 max.	0.03
S	0.030 max.	0.008
Ni	8.00 – 10.50	8.499
Cr	18.00 – 20.00	18.586
Others	–	70.689

4 Conclusion

The leakage failure of the u-bend tube is due to a crack caused by stress due the bending procedure that may be performed by the hot or cold work methods. The lack of branching cracks and the absence of slip band grains indicate that the bending and heat treatment (or stress relief treatment) procedure works well, as the inadequacy signs of residual stress in the microstructural analysis observation. However, the cracks are believed to occur earlier that is during the bending procedure. The appearance of brownish rust on the tube surface due to the presence of small content of sulphur elements in the boiler environment. It does not penetrate inward and only affects the surface layer of the metal. However, at the opening cracks, this sulphur penetrates the metal tube through the crack narrow space which eventually speeds up the leakage of the tube. Corrosion is not the main root cause of header tube failure. As well as the welding imperfections. In conclusion, the material (SUS304 grade stainless steel) is found to be the appropriate materials selection for the header tube.

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