FAILURE ANALYSIS OF A REVERSAL CHAMBER PIPELINE IN A FIRE-TUBE BOILER

Danilo Borges Villarino de Castro, danilobvc@yahoo.com.br
Jéferson Aparecido Moreto, jeferson_moreto@yahoo.com.br
Otávio Contart Gamboni, otaviocgamboni@yahoo.com.br
Dirceu Spinelli, dspinell@sc.usp.br
José Ricardo Tarpani, jrpan@sc.usp.br
Department of Materials, Aeronautics and Automotive Engineering, Engineering School of São Carlos / University of São Paulo – Av. Trabalhador Sãocarlense, 400; Parque Arnold Schimidt, São Carlos-SP; Brazil.

Abstract. *This study investigates the possible causes of the reversal chamber pipeline cracking of a fire-tube boiler. The secondary pipe of the reversal chamber showed extensive cracking at the joint with the mirror that seals the water chamber used in the boiler cooling system. The tube-mirror joint is welded on one side of the mirror in the outer surface of the water chamber, where a fluid leakage was detected. Samples were removed from the failed pipe and subjected to visual and metallographic analyses. It has been concluded that cracks nucleated in voids introduced during the tube-mirror welding process. A crack propagation was induced by the thermal cycles imposed during the operation of the equipment, and the mechanism of sub-critical crack growth was recognized as thermal fatigue.*

Keywords*: failure analysis, fire-tube boiler, thermal fatigue.*

1. INTRODUCTION

The increasing global demand for energy has forced more and more industrial units to adopt measures to recover energy or make it available for other system areas and reduce the amount of plants.

According to Aviles (Aviles, 2008), heat exchangers are often employed for this purpose, therefore the thermo-hydraulic design is crucial to operational success and economy.

Boiler is the popular name given to the steam-generating equipment, which has been widely used in industrial and electricity power plants. It is an essential component that requires abundance of water steam for activities of energy generation.

Another way of approaching boilers (steam generators) defines them as equipment designed to transform water into steam. The energy required for operation, i.e., the supply of specific sensible heat to the water until it reaches the boiling temperature, the latent heat to vaporize the water and also the heat to overheat it to turn it into superheated steam are given by means of burning a fuel.

In a fire-tube boiler or pipeline chamber, the hot gases pass inside the tubes, while the water around them is heated and evaporates. The tubes are mounted as bundles of heat exchangers, with one or more steps from the hot gases that pass through them. Figure 1 shows a sectional boiler of this type. Fire-tube boilers are used for small-capacity and low pressure saturated steam (Leite, 2008).

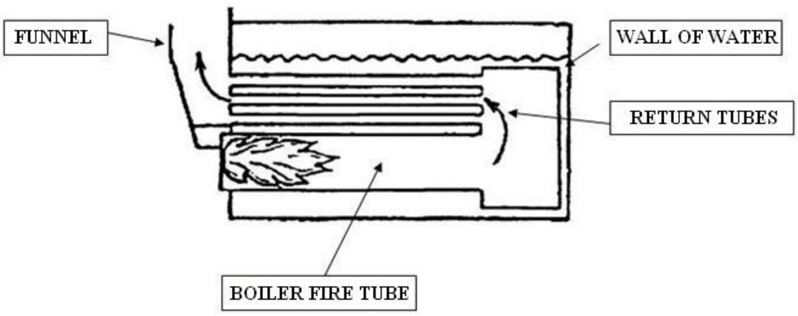


Figure 1. Fire-tube boiler with two passes for oil and gas. (Leite, 2008)

The main parts of fire-tube boilers are body, mirrors, beam tube or tubes of fire and fume box. The body of the boiler, also called shell or carcass, is constructed from calendered carbon steel plates and welded. Its diameter and length are related to the ability to produce steam. The pressures of work are limited (usually up to 20 kgf/cm^2) by the boilers' diameter. The mirrors are flat sheets cut in a circular shape, so they fit both ends of the boiler's body and are fixed by welding. The beam tube or fire tube is responsible for the absorption of heat contained in the exhaust gas used for heating water. The connection between the front mirror and the posterior one is made by one, two or there passes.

The fume box is the place where the route of the combustion gases is reversed, causing them to pass through the boiler again (fire tubes). Figure 2 shows a part of the fire boilers (Leite, 2008).

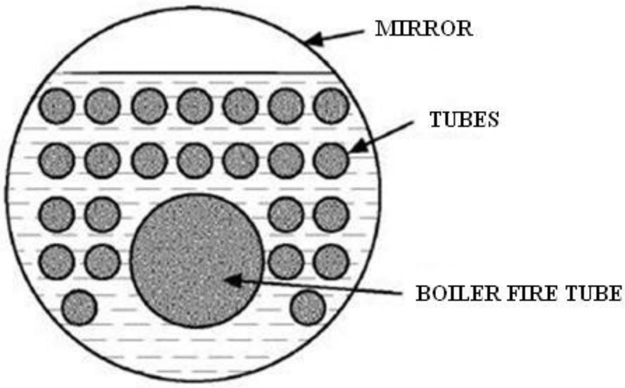


Figure 2. Parts of fire boilers (Leite, 2008).

A boiler may fail due to overheating, causing catastrophic failure (explosion). The main causes of overheating are inadequate selection of steel in the boiler design, use of defective steel, excessive prolongation of the tubes, misplacement of burners, fouling operation in a forced march, water shortages in the regions of heat transfer, poor circulation of water, thermal shock and operational failure (Neves, 2002).

Thermal shocks occur due to frequent downtime and replacement of burners on the march. Boilers susceptible to these conditions will be those with excessive power burners or on-off burners, or those which do not modulate the flame. Another situation of thermal shock occurrence is that in which the boiler is fed with cold water (temperature below 80ºC) or hot water flows in cold regions. Problems with thermal shocks occur more frequently in fire-tube boilers, especially those with a dry rear reversing camera (Altafini, 2002).

Boilers and pressure vessels must undergo initial, periodic and extraordinary security checks, and the non-compliance deadlines of NR-13 are considered serious and imminent risks. The initial safety inspection should be made in a new boiler before the starting operations, comprehending internal and external examinations, as well as hydrostatic tests (Assunção, 2008).

This study investigates the possible causes of a reversal chamber pipeline cracking of a fire-tube boiler.

2. MATERIALS AND METHODS

The pipe of the secondary chamber showed extensive cracking at the mirror seals with water chamber junction. The tubes and mirror junction are made by a welding process on only one side of the face, more exactly on the external surface of the water chamber, where a fluid leakage was detected.

Figure 3 shows a sketch of the boiler, indicating the problem area that was removed for failure analysis and subjected to detailed inspection. Figure 4 shows the cracks developed at the mirror/pipe junction, as revealed during testing with penetrating liquid (PL).

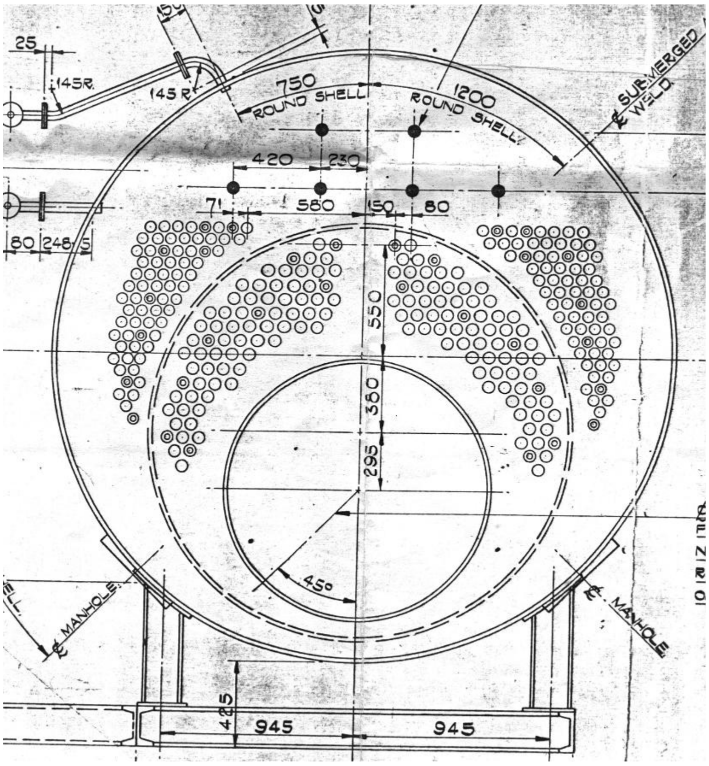
In determining the causes of the equipment failure, metallographic plans were analyzed by welding process in the selected region of the joint.

Figure 5 shows the metallographic plans observed, considering the cross-section AA in the second tube and mirror pattern shown in Figure 4(b), which permits the observation of the longitudinal section welded (dashed line in Figure 4 (b)).

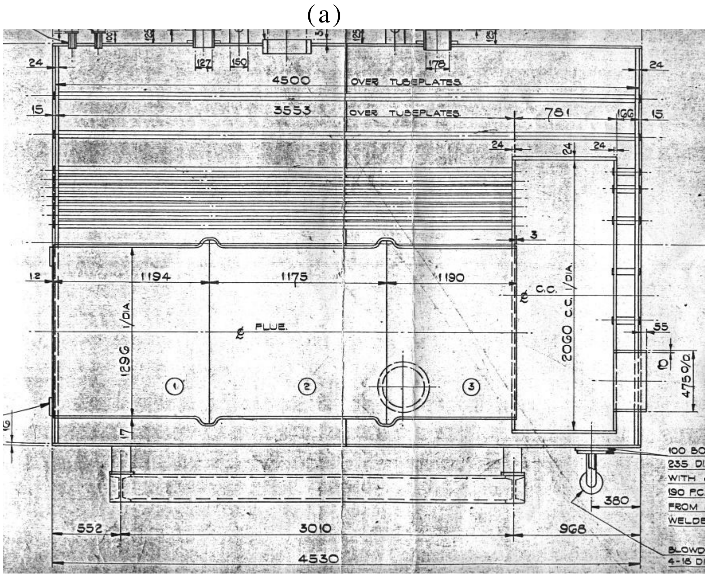
The samples were cupped and sanded with sandpaper water with particle sizes of #80, 120, 220, 400, 800, 1200 and 2000. The sanded surfaces were then polished in three stages: the first with chromium dioxide, the second using alumina solution (0.3 μm) and the last with alumina solution (0.05 μm).

After a previous sequence the surface was finished with chemical attack performed with Nital reagent 2%, which consists of a solution of hydrochloric acid in ethanol 2%. The average duration of the etching immersion was 10 to 20 seconds.

The microstructural observations and data acquisitions were performed with a BX60M Olympus microscope coupled to a digital camera (Sony Cyber – Shot 5.1 megapixels).

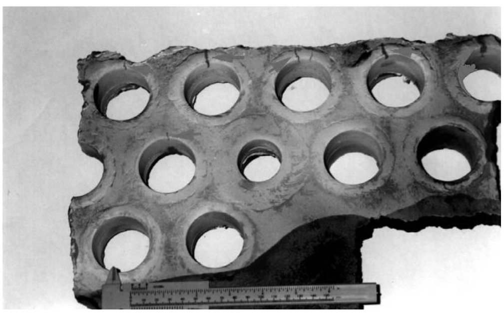


(a)

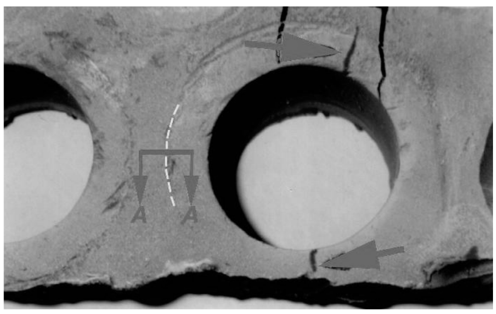


(b)

Figure 3. (a) View of the boiler containing the furnace and secondary pipe circulating hot gas by combustion and (b) View of the combustion chambers and water.



(a)



(b)

Figure 4. (a) Mirror seal of the water chamber welded showing extensive cracking that propagates in the pipe thickness and (b) detail of (a).

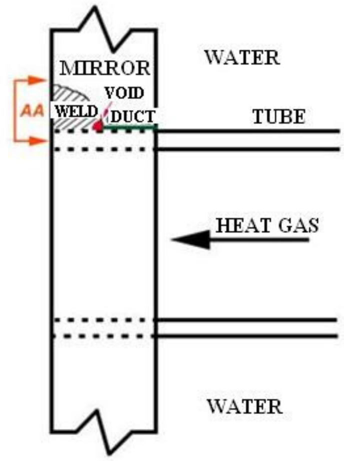
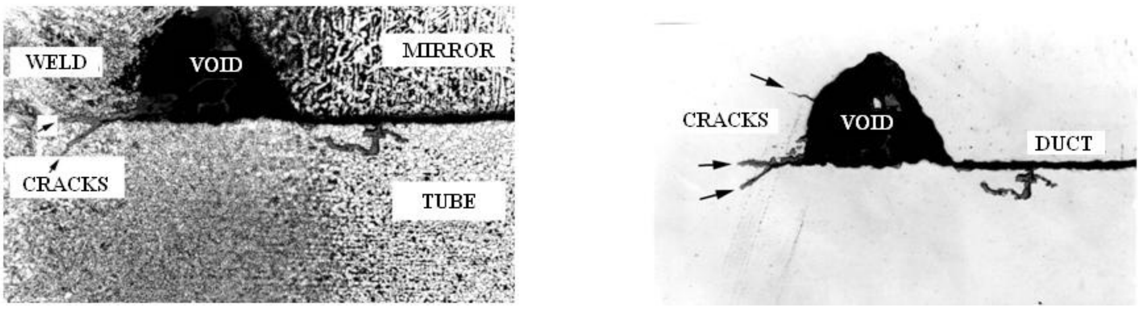


Figure 5. Outline for metallographic cutting observation of the joint.

3. RESULTS AND DISCUSSIONS

Figure 6 shows some views, with and without chemical attack, of the mirror and combustion pipes joint, following the pattern shown in Figure 5, which reflects the presence of a defect (void) typical of the welding process, called lack of weld penetration. This defect is a potential enhancer and stress concentrator, causing cracks (Figure 6) emanating from the defect in the weld metal region and directed toward the outer surface of the mirror, where the leak liquid was detected.

Figure 6 also shows a separation channel between the mirror seal and the water chamber. This channel permits the direct passage of water from inside the refrigerated space to the welding defect. In the presence of this defect, the liquid can leak freely out of that chamber of the boiler water, thus creating the leaks in question.



(a) (b)

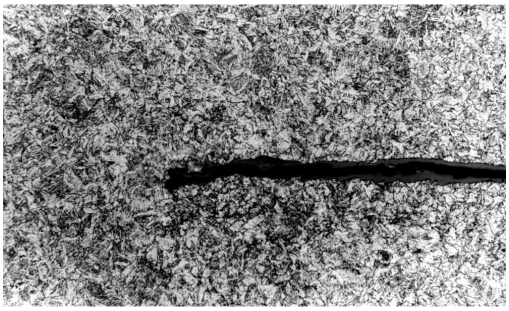
Figure 6. Metallographic sections showing the presence of empty-type defects and cracks emanating from the same sample: (a) with etching (Nital 2%) and (b) without chemical attack.

The cracks shown in Figure 6 are orthogonal to those revealed by the penetrant liquid and illustrated in Figure 4, indicating that several cracks originated from the defects introduced by the welding process. Such cracks emanated to the second radial (Fig. 4) and longitudinal (Fig. 6) directions. However they always followed a path and directions dictated by both the metal weld and more particularly the microstructure of the tube thermally affected during the welding process.

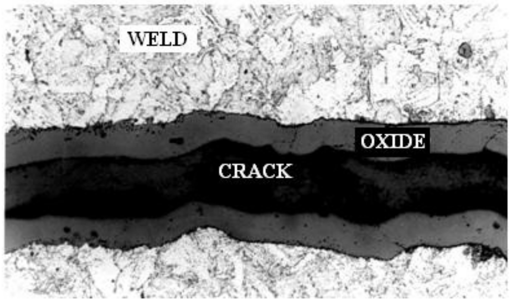
In fact, Figure 4 confirms that, without exception, all cracks detected by the penetrant liquid began at some point along the thickness of the mirror, more exactly in the voids of welding, and invariably propagated towards the outer surface of the mirror along the thickness of the tube, i.e., regions heat-affected during the welding of the joint.

Fig 7 shows the surfaces of cracks originating in the defect-type void, where we observe the oxidation of their inner walls as a result of contact with the water coming from the camera's cooling system.

We can assume that the voids provided some cracks through the welding process, which are powerful enhancers of stress concentrators and, very probably, have spread due to thermal cycles typically developed in the equipment in question. The thermal cycles, including events to disconnect/re-link the plant, as well as any transient power system generate tensile stresses due to thermal expansion/contraction of materials. Such stresses force the opening of cracks, thus inducing their spread subcritical mechanisms under cyclic thermal loading, or thermal fatigue.



(a)



(b)

Figure 7. Internal oxidation of cracks originating in the welding defect of mirror/tube pair. (A) Type and (b) detail of crack.

4. CONCLUSIONS

The crack nucleation occurred in defects (voids) introduced in the mirror/pipe joint during the welding process. These defects are widely recognized as a lack of penetration weld.

Nucleated cracks have spread in various directions, but always toward the weakest fracture path, i.e., microstructures of the weld metal and heat affected the tube during welding.

The propagation of the crack was induced by the thermal cycles imposed during the operation of the equipment, followed by a mechanism of subcritical crack growth, called thermal fatigue.

The inspection of similar components operating under the same conditions and manufactured by the same techniques appraised in this case is mandatory in view of the high probability of occurrence of similar events in service, such as those reported here.

5. ACKNOWLEDGEMENTS

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