Failure analysis of a water wall tube

Facai Ren, Jinsha Xu and Jun Si
Shanghai Institute of Special Equipment Inspection and Technical Research, Shanghai 200062, PR China
fcren@ssei.cn
Corresponding author e-mail: caifaren@163.com

Abstract. The failure reasons of a boiler water wall tube used in coal-fired power plant were analyzed by the chemical composition, optical microscope and scanning electron microscope analysis. The results of metallographic analysis show that the microstructure is ferrite and pearlite, pearlite has no obvious spheroidization. The comprehensive analysis results show that the abnormal oxidation erosion leads to the leakage failure of the water wall tube at the fire-facing side.

1. Introduction

Water wall is the main heating surface in the furnace. The role of water wall is to absorb the radiation heat of high temperature flame and flue gas in furnace, and change water part into saturated steam. The reliability of boiler water wall tube is directly related to the safe and effective operation of power plant units. Therefore, it is very important to analyze the causes of boiler water wall tube failure for boiler accident prevention.

In the past years, many researchers have analyzed various failure cases of boiler water wall tubes. Xue et al. [1] analyzed the failure reason of water wall tube of a thermal power plant boiler. It was found that excessive sodium hydroxide in boiler water was the main reason for the corrosion of boiler water wall tubes. Prabu et al. [2] studied the failure reason of water wall of circulating fluidized bed coal-fired power plant boiler. Tensile fracture analysis shows that the failure mode of boiler water wall tube is ductile failure. Ahmad et al. [3] studied the failure reason of water wall of circulating fluidized bed coal-fired power plant boiler. Tensile fracture analysis shows that the failure mode of boiler water wall tube is ductile failure. Ray et al. [4] studied the remaining life of in service water wall tubes of steam generators in thermal power plants. The results show that, at 425°C, if there is no local damage in the form of cracks or dents, the remaining life is more than 100000 hours. Dorri et al. [5] studied the cause of corrosion perforation failure of water wall in power plant. The results show that the change of oxygen concentration and decarburization of base metal have influence on corrosion deterioration. Dhua [6] studied the stress fracture specimens of four boiler water wall tubes in coal-fired power plant. The results show that the high temperature leads to the graphitization of the material and the decrease of the strength of the water wall tube. Zhang et al. [7] proposed an on-line leakage location method based on acoustic array. The results show that the time delay estimation and the number of sensors have great influence on the location accuracy of leakage point.

A boiler in coal-fired power plant was shut down due to leakage during operation. Based on the preliminary inspection and analysis on site, it was determined that the failure position was the water wall tube of the boiler. In this paper, the composition, metallography and scanning electron
microscope (SEM) analysis of the water wall tube were carried out, and the cause of leakage failure was discussed.

2. Macroscopic morphology
The macroscopic morphology of the boiler failure water wall tube is shown in Fig. 1. It can be seen that the perforation leakage is mainly distributed on the fire-facing side. There are two depressions on the surface and the small holes are penetrated. The surface of the back-fire surface of the water wall tube is smooth without abnormal macroscopic damage. From the two ends of the cut-off surface, there is no abnormal uneven thinning of the water wall tube at both ends and two facing directions. After measurement, the outer diameter of the water wall tube is about 60 mm and the wall thickness is about 7.2 mm. The material of water wall tube is 20G.

![Figure 1. Macroscopic morphology of the water wall tube.](image1)

The morphology of the damage zone on the fire-facing side of the water wall tube of the boiler is shown in Fig. 2. It can be seen that there are two pits adjacent to each other along the axis on the fire-facing side. The two pits are sand pits under erosion. The length and width of pit A are about 34.5mm and 29mm respectively. The length and width of pit B are about 30mm and 24mm respectively. The thickness of the holes is about 0.22mm at the bottom of the two pits. The edge of the hole protrudes outward, indicating that the bottom of the hole is thinned and finally broken by the water pressure in the tube. The outer surface of the tube is smooth without macro corrosion pit. The surface of the scour like pit is faintly visible.

![Figure 2. Macroscopic morphology of outer surface damage on fire-facing side.](image2)
Longitudinal cutting along both sides of the damage area, the macroscopic morphology of the cavity surface in the pit through hole area is shown in Fig. 3. The length and width of pit A perforation are about 5.4mm and 2.1mm respectively. The length and width of pit B are about 4.7mm and 1.3mm respectively. The inner surface is basically flat and blue gray, and there is no abnormal corrosion around the inner surface hole.

Figure 3. Macroscopic morphology of inner surface damage on fire-facing side.

3. Results and Discussions

3.1. Chemical composition analysis
The chemical composition analysis results of the failure boiler water wall tube are shown in Table 1. According to the chemical analysis results, the material of boiler water wall tube meets the technical requirements of 20G in relevant standard GB/T 5310-2017 < Seamless steel tubes and pipes for high pressure boiler >.

| Element       | C   | S     | Si   | Mn   | P     | Cr   | Ni  | Cu  |
|---------------|-----|-------|------|------|-------|------|-----|-----|
| Water wall tube | 0.21 | 0.005 | 0.20 | 0.40 | 0.017 | 0.079 | 0.009 | 0.005 |
| 20G (GB/T 5310-2017) | 0.17-0.23 | ≤0.015 | 0.17-0.37 | 0.35-0.65 | ≤0.025 | -    | -   | -   |

3.2. Metallographic microstructure analysis
The micromorphology of the surface layer on the fire-facing side on the cross section of the pit B of the water wall tube is shown in Fig. 4. The left side of the figure shows the relatively flat outer surface without depression, and the right side shows the pit surface. It can be seen that the surface subsidence is slightly undulating, and the microstructure tends to strip distribution obliquely. The microstructure is ferrite and pearlite. Part of pearlite has the tendency of spheroidization, and corrosion pits and corrosion products can be seen on the surface.
The micromorphology of the cross section of pit B is shown in Fig. 5. The upper side is the inner surface and the lower side is the outer surface. It can be seen that there are corrosion pits on the inner and outer surface of the hole edge, which may be related to the corrosion caused by the outward curling of the hole edge after perforation. The inner surface is relatively flat, and the two surfaces are covered with oxide layer. The microstructure is ferrite and pearlite. Pearlite did not spheroidize obviously, which indicated that there was no overheating in this area.

3.3. SEM Micromorphology analysis
The SEM morphology at the edge of pit A of water wall tube is shown in Fig. 6 (a). On the left side of the figure is the outer surface of the tube near the pit. It can be seen that the outer surface is relatively flat and some areas are covered with oxide skin. On the right side is the pit area, where the pit is depressed downward, and oxidation products and corrosion pits can be seen. The morphology at high magnification on one side of the pit is shown in Fig. 6 (b). It can be seen that the oxidation corrosion micropores on one side of the pit are associated with the microstructure rheology, which is supposed to be related to erosion corrosion.
The microstructure of the water wall tube pit A is shown in Fig. 7(a). It can be seen that the pit is kidney like along the longitudinal direction, with rough edge and cracking at one end. The high-power morphology of the edge of pit A is shown in Fig. 7(b). It can be seen that there are corrosion pits and erosion rheological traces under the oxidized corrosion products.

4. Conclusion
The results of metallographic analysis show that there is no overheating in the pit area of the water wall tube. The results of SEM, metallographic structure and chemical composition analysis show that the surface depression of the fire-facing side of the water wall tube is caused by the abnormal oxidation erosion in this area. Under the condition of continuous erosion and corrosion, the tube wall becomes thinner gradually, and finally the thinnest part of the tube can not bear the pressure of the water flow in the tube and perforation occurs.

Acknowledgments
The authors are grateful for the support by Shanghai Bureau of Quality and Technical Supervision Research Project (No. 2018-30 and No. 2018-27).

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