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Short communication

Failure analysis of the boiler water-wall tube

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ABSTRACT

Failure analysis of the boiler water-wall tube is presented in this work. In order to examine the causes of failure, various techniques including visual inspection, chemical analysis, optical microscopy, scanning electron microscopy and energy dispersive spectroscopy were carried out. Tube wall thickness measurements were performed on the ruptured tube. The fire-facing side of the tube was observed to have experienced significant wall thinning. The composition of the matrix material of the tube meets the requirements of the relevant standards. Microscopic examinations showed that the spheroidization of pearlite is not very obvious. The failure mechanism is identified as a result of the significant localized wall thinning of the boiler water-wall tube due to oxidation.

1. Introduction

Uninterrupted power supply from a power plant mainly depends on the continued functioning of its equipment and components. In fossil fuel-based power plants, proper functioning of boiler tubes, super heater, heat exchanger, turbine, etc., is important for maintaining the power supply. Even a single component failure can lead to the shutdown of the entire power generation system. Failure of boiler tubes is one of the main reasons for the shutdown of power plants, and its occurrence has often been reported in many such power plants [1–3].

Boiler components are mainly made of steels, cast irons, stainless steels and high temperature alloys. Failure of boiler tubes is a very common phenomenon in a power plant. The investigation into the causes of a boiler tube failure is very important to prevent future tube failures. Identifying correct failure mechanism often helps to ensure the integrity of the equipment. There are many reasons for boiler tube failures such as pitting, stress corrosion cracking, stress rupture, creep, erosion, and thermal fatigue [4–8].

The failed boiler tube in this investigation is made from 20G steel. The operating pressure and the operating temperature of the tube are 10.8 MPa and 320 °C, respectively. And the working medium in this tube is deaerated water. After 8 years of service, the boiler tube was found to burst a small hole. The dimensions of the opening burst of the tube are 30 mm in length and 17 mm in width. Through detailed investigation of the failed tube, this study aims to find out the failure mechanism, and put forward the corresponding preventive measures.

2. Experimental procedure

The failure analysis was performed to the failed tube, especially the bursting section of the tube. For examining the inner wall surface morphology of the tube, samples were prepared from different regions of the failed tube. The metallography samples were prepared by using standard metallographic techniques and etched with 4% nital solution. The microstructure was analyzed by optical

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(a) (b)

Fig 1. General view of the failed tube (a) and the enlarged view of the fracture (b).

microscope and scanning electron microscope (SEM) equipped with an energy dispersive X-ray (EDX) analysis facility. In addition, the chemical composition of the failed tube was analyzed by 725ES Agilent spectrometer.

3. Result and discussion

3.1. Visual inspection

During inspection a hole has been found on the fire-facing side of the tube as shown in Fig. 1. The cocked-up metal was around the hole. Close visual inspection also revealed that the wall thickness of the fire-facing side is less than that of the back side (see Fig. 2). It may indicate that the tube has significant localized wall thinning and is eventually followed by a sudden failure. Based on this finding, wall thickness measurements on the failed tube were carried out. The thickness of the thinnest area is about 1.90 mm on the fire-facing side, far less than the wall thickness of the back side (6.08 mm). In addition, scale was observed on the internal and external surface of the failed tube, and no significant bulges were found on the ruptured part of the tube.

In order to analyze the failure reason of the tube, the sampling and analysis on the as-received tube at the rupture part and in some distance away from the rupture region were carried out. Two small pieces of specimens shown as Fig. 3a and b were cut from the fire-facing side and the back side of the tube and labeled as Sample I and Sample II, respectively. The cocked-up slice around the burst hole was also cut down (Fig. 3c), labeled as Sample III. It can be seen that the pits are very obvious on the internal surface of the fire-facing side (Sample I) and the cocked-up slice of the burst hole (Sample III), while they could hardly be found on the inner wall of the back side (Sample II). It reveals that corrosion on the fire-facing side of the failed tube is more serious than the back side.

3.2. Chemical analysis

According to the manufacturer, the failed boiler tube is made of 20G steel. And the chemical composition of the failed tube was shown in Table 1. It can be seen that the composition of the matrix material of the tube meets the requirements of the relevant standards according to GB 5310-2008.

Fig. 2. Cross section of the failed tube.

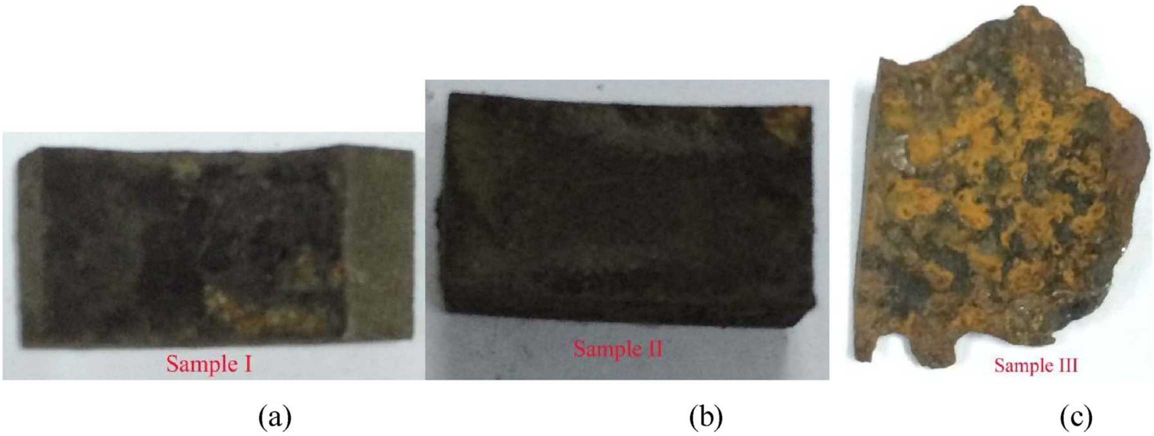

Fig. 3. The inner wall surface of the fire-facing side (a), the back side (b), and the cocked-up slice around the burst hole (c).

Table 1
The chemical composition of the failed tube, (wt. %).

Composition	C	Si	Mn	P	S
GB 5310-2008	0.17–0.24	0.17–0.37	0.35–0.65	≤0.035	≤0.035
Measurements		0.18	0.46	0.01	0.01

3.3. Microstructure analysis

Acetone solution was used to clean the three samples with ultrasonic washer, and then a solvent softened acetate strip was applied to remove the impurities on the surface of the samples. The surface morphology of the three samples was analyzed by scanning electron microscope, as shown in Fig. 4. It can be found that the inner wall surface of the fire-facing side, especially of the thin slice of the rupture part, has a large number of corrosion pits. The inner wall surface of the back side is relatively flat, and the pits are much less. In addition, obvious scales are observed on the inner wall surface of the fire-facing side, some of which have been cracking and peeling off the fouling layer. This is consistent with the macroscopic observation results. EDS results (Table 2) show that the scale layer contains a lot of oxygen, iron, and a small amount of calcium, silicon etc. No chlorine and other abnormal elements were found. It indicates that the boiler tube has severe oxygen corrosion. And the iron-to-oxygen ratio of the fire-facing side is smaller than that of the back side, especially at the cracked part where the ratio reaches the minimum, which shows that the oxidation of tube on the fire-facing side is more serious than that on the back side. The continuous occurrence of oxidation may result in thinning of wall thickness.

In order to investigate the potential cause of the failure due to any microstructural anomaly or degradation, metallography specimens were cut from the Sample I, Sample II and Sample III, respectively. The microstructure of the failed tube was shown in Fig. 5, which is typically ferrite-pearlite structure. Microstructural degradation/anomalies in the form of carbide rounding or grain boundary void generation were not obvious in the base material. Hence, the possibility of creep damage can be ruled out [9].

The pearlite in the specimens on the fire-facing side of tubes and the slice around the burst hole shows a certain degree of spheroidization, the latter of which is more serious. During service, the original lamellar pearlite forms into spherical pearlite due to cementite developing toward spherical driven by the decrease of the surface energy. Previous studies [10] have showed that the tensile strength of 20G is reduced by 6.5% when the testing temperature increases from room temperature to 475 °C though the pearlite spheroidization is different. Therefore, the pearlite spheroidization has little effect on the mechanical properties of 20G when the temperature is lower than 475 °C. In this study, the pearlite spheroidization effect is not very obvious, and then it could be concluded that the mechanical properties of 20G are not degraded significantly.

3.4. Discussion

The chemical composition of tube meets the standard requirements. The ferrite-pearlite structure is found from the microstructure of the failed tube, which shows no obvious microstructural degradation, including no apparent pearlite spheroidization. However, a large number of corrosion pits exist on the inner wall surface of the fire-facing side. That corrosion pits could hardly be found on the inner wall of the back side could be related with the relative low temperature. The similar failures owing to the oxidation thinning have also been observed for the carbon steel grade SA213-T22 [11] and INCONEL alloy 601 [12] used as super-heater tubes and radiant tube, respectively. Oxidation corrosion of steels is easily to happen due to the high affinity of oxygen to react with steel to form oxides. The kinetic of oxidation is higher at high temperatures than that at room temperature. The inner wall surface of the fire-facing side is exposed to both the deaerated water and high temperature, and therefore undergoes oxidation corrosion.

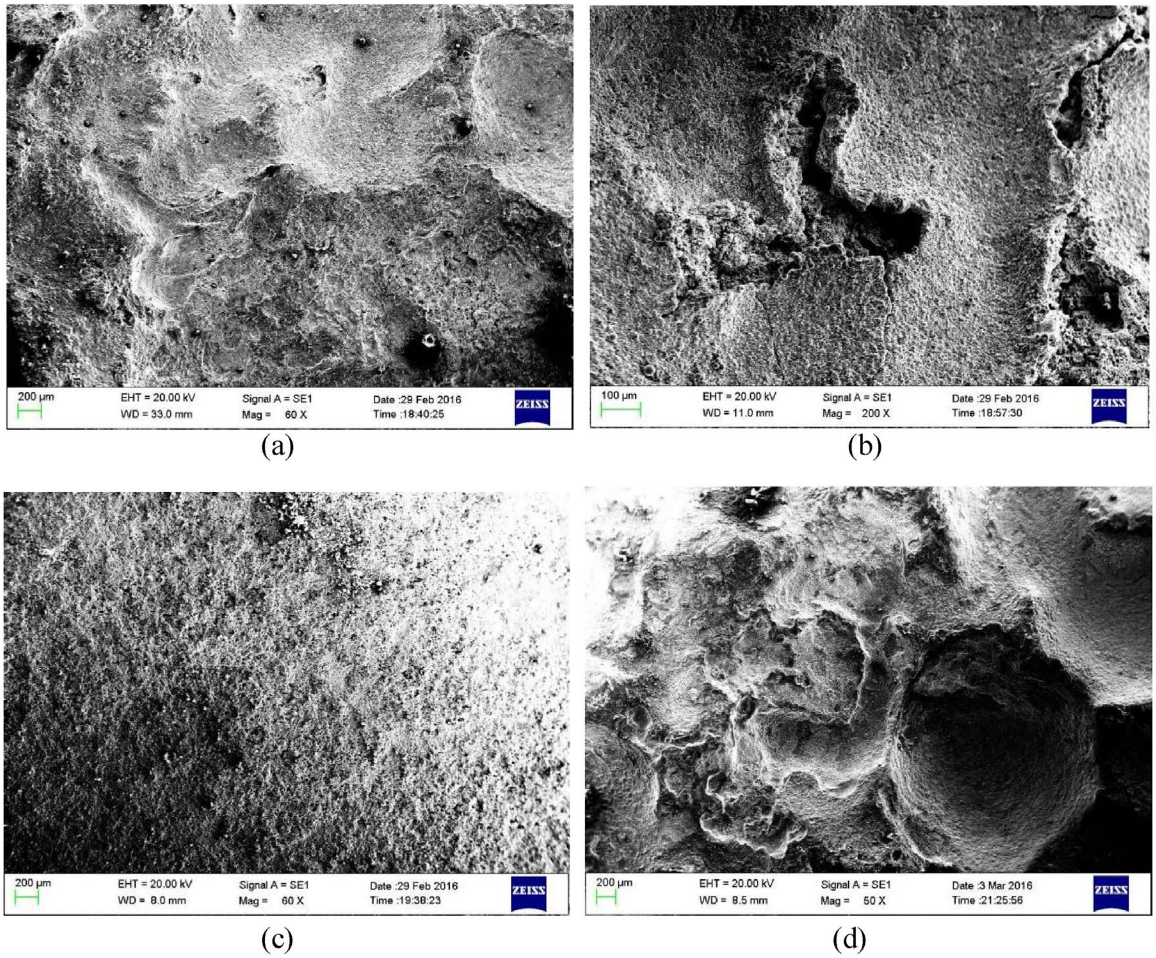

Fig. 4. Surface morphology of the inner wall of Sample I (a, b), Sample II (c) and Sample III (d).

Table 2
EDS results of the inner wall of the failed tube, (wt. %).

Element	C	O	Al	Si	P	Ca	Cr	Fe	Others	iron-to-oxygen ratio
Sample I	1.02	23.44	0.22	0.42	0.36	0.41	0.22	72.64	1.28	3.10
Sample II	1.77	16.04	0.19	0.91	1.21	2.83	0.50	73.12	3.43	4.56
Sample III	1.52	28.52	0.30	0.50	0.42	0.78	0.20	67.19	0.57	2.36

Correspondingly, reducing the oxidation contents in the deaerated water or reducing the maximum temperature would help minimize the fireside oxidation. However, the latter action has a direct impact on the efficiency and output of the boiler so as not to be applied.

4. Conclusions and recommendations

The boiler water-wall tube was found bursting on the fire-face side. Through examination it is found that the composition of the matrix material of the tube meets the requirements of the relevant standards. The microstructure of the tube is composed of ferrite and pearlite. Pearlite shows only a small amount of spheroidization, which has little effect on the mechanical properties of the material. The fire-facing side of the tube was observed to have experienced significant wall thinning. And the corrosion products of the inner wall of the tube are mainly iron oxide. The iron-to-oxygen ratio of the fire-facing side is smaller than that of the back side, and the iron-to-oxygen ratio at the cracked part is the smallest, which indicates the oxidation of tube on the fire-facing side is more serious than that on the back side. The result shows that the failure is caused by the significant localized wall thinning on the fire-facing side of the tube due to oxidation, which leads to the tube pressure exceeds the bearing limit of the thin tube.

Since the oxidation is the root failure cause of the tube, it is recommended that the standards of water quality of the boiler water-wall tube should be implemented strictly in the operation process, in order to improve the operating environment of the boiler tube, especially to control the oxygen content in the water. In addition, preventing the boiler tube from exceeding the working temperature

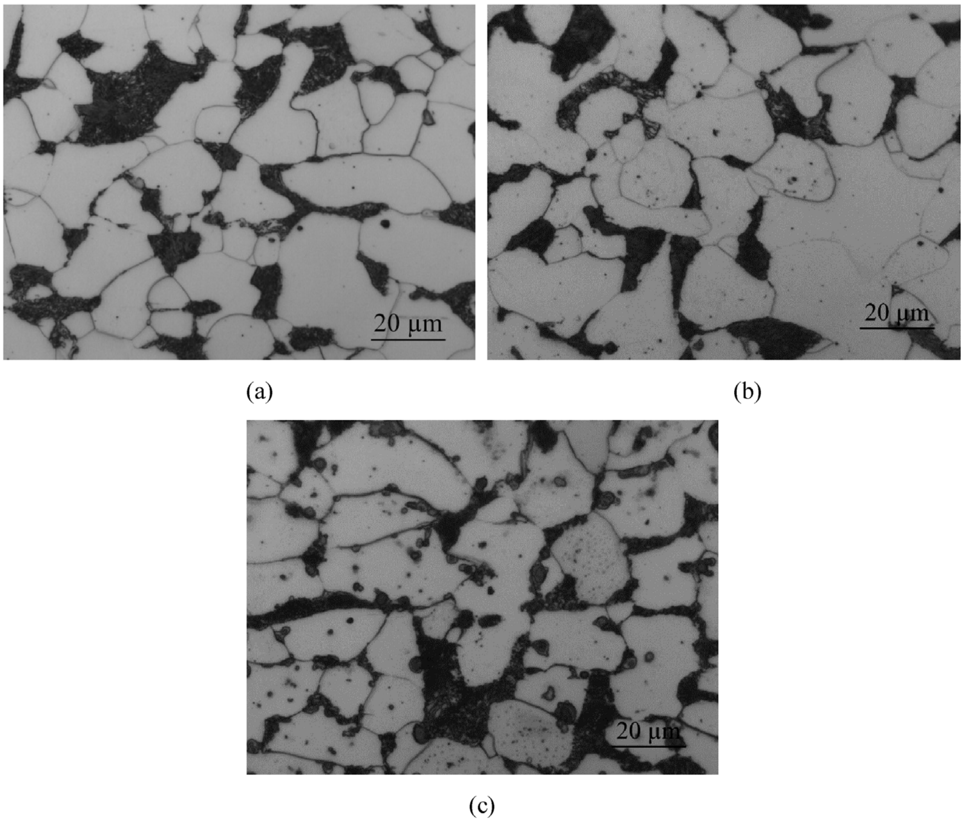

Fig. 5. Optical micrographs of Sample I (a), Sample II (b) and Sample III (c).

and working pressure can also slow down the oxidation corrosion. At the same time, regular cleaning and wall thickness inspection of boiler tubes are also extremely important.

Acknowledgements

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