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Cause Analysis of SA-210 Steel Water-Cooled Wall Leakage

ZHAO Hai*, JIANG Chong, and TIAN Cheng-chuan

Huadian Electric Power Research Institute Co., LTD, Hangzhou 310030, China

Abstract. When the SA-210 steel water-cooled pipes are under high temperature and high pressure, high pressure steam will generate an outward pressure on the inner wall of the pipes, which will cause the pipe to swell outward. If there is a small defect on the inner wall of the water-cooled tube, this defect will become a stress concentration point. The additional pressure acts on the stress concentration point to cause cracks, and after the cracks generated, lead to the cracks to expand at the same time. In the cracks, vapor will diffuse into the matrix along the cracks, occurring corrosion under the action of high temperature, which further accelerates crack growth. Eventually, it leads to water-cooled tube wall leakage.

1 INTRODUCTION

In recent years, the causes of the unit abnormal shutdown caused by the boiler are mainly concentrated on the heating wall leakage. Among them, the condition of the water-cooled wall is the worst, and it also has the highest probability of leakage [1]. A boiler in a thermal power plant has been running for about 20,000 hours in total. During the maintenance, it was found that there was a large area of leakage in the water-cooled wall pipe. The specifications of the water-walled pipe are Φ63.5 × 7mm and the material is SA-210C.

SA-210 is a pearlite hot-strength steel. Its chemical composition is simple, with the exception of high carbon and manganese content, the rest are similar to 20G, and its yield strength is about 20% higher than that of 20G, while its plasticity and toughness are comparable to 20G.

The production process of the steel is simple and the hot and cold workability is good. Using it instead of 20G can reduce the wall thickness, reduce the amount of material used, and also improve the heat transfer status of the boiler. Its use location and temperature are basically the same as 20G, and it is mainly used for water-cooled walls, economizers, low-temperature superheaters and other parts with an operating temperature below 500°C.

In this paper, the internal wall cracks of SA-210 steel water-cooled wall pipes are analyzed and studied from several aspects to find out the causes of cracks and the failure mechanism.

2 TEST AND ANALYSIS

2.1 Macro morphology analysis

The water-cooled tube wall was cut along the longitudinal direction of the tube bundle and observed. There were cracks in the inner wall of the tube. These cracks were distributed linearly along the direction of the tube bundle. The oxide skins of the inner wall cracks were loose and part of them has fallen off (as shown in Figure 1).

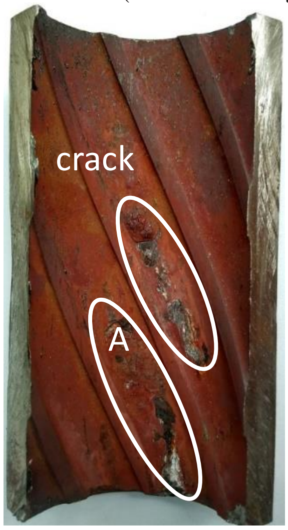


Fig. 1. Macro morphology of cracks on the water-cooled tube wall inner wall

Sampling was performed on the inner wall of the tube where the crack was obvious and the oxide skin did not fall off (point A in Figure 1), which was labeled as Sample 1. Sample 2 is obtain where no crack is found, and the specific sampling location is shown in Figure 2.

* Corresponding author: zhoahai8029@163.com

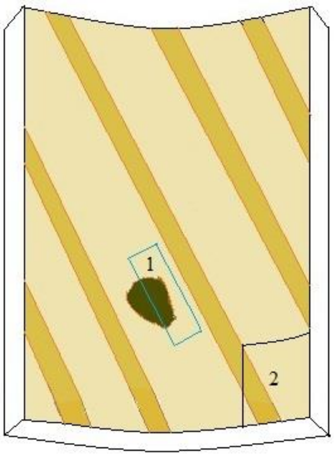


Fig. 2. Sampling position

2.2 Metallographic examination

Metallographic structure reflects the specific morphology of metal, such as martensite, austenite, ferrite, pearlite, etc. Corrosion treatment is required in the analysis of the metallographic structure of the steel. The corrosive of the sample used in this article was 4% nitric acid alcohol solution. The cross sections of Sample 1 and Sample 2 were made into metallographic samples and observed under a metallographic microscope.

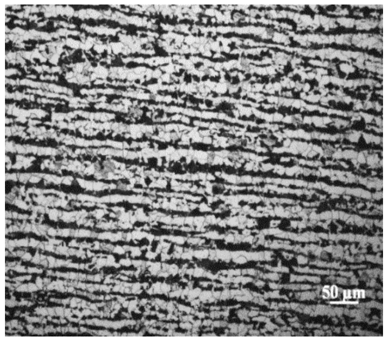
SA-210 steel corresponds to domestic 20G steel, and the metallographic structure of 20G steel is ferrite plus pearlite. Ferrite is an interstitial solid solution in which carbon is dissolved in α-Fe, and has a body-centered cubic lattice, and its carbon dissolving ability is very low. The ferrite grain boundary is smooth, and twins or slip lines are rarely seen in the grain. In steel, ferrite exists as flakes, lumps, needles and nets shape. The ferrite structure has good plasticity and toughness, but the strength and hardness are low, which can enhance the toughness of the matrix.

Pearlite is an interphase structure of ferrite and cementite flakes that are simultaneously precipitated from austenite after eutectoid transformation. The properties of pearlite are between ferrite and cementite, and the toughness is better. The mechanical properties are also between ferrite and cementite, with high strength and moderate hardness, which can enhance the strength of the matrix.

Figure 3 is the metallographic structure of Sample 1 without cracks, and Figure 4 is the metallographic structure of Sample 2. The metallographic structure of both samples is a mixture of ferrite and pearlite. It can be seen from the Figure that the rolling line of water-cooled tube wall structure is relatively obvious.

The existence of rolling streamlines in the metallurgical structure of the material will affect the mechanical properties of the steel and reduce the toughness and strength of the material. At the same time, the chemical composition of ferrite and pearlite is different, which can also cause electrochemical heterogeneity inside the material, and become a potential factor for corrosion.

Through metallographic analysis, it can be seen that there are obvious rolling streamline defects in the metallurgical structure of the water-cooled tube wall, and the chemical composition of pearlite and ferrite is not the same. The heterogeneity of the electrochemical properties inside the steel structure is one of the reasons for cracks in water-cooled tube walls.



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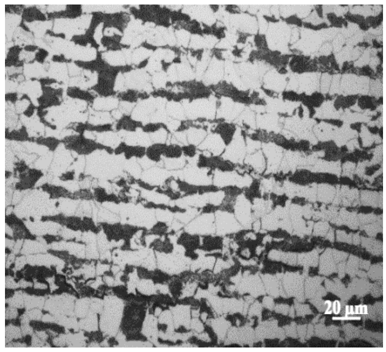

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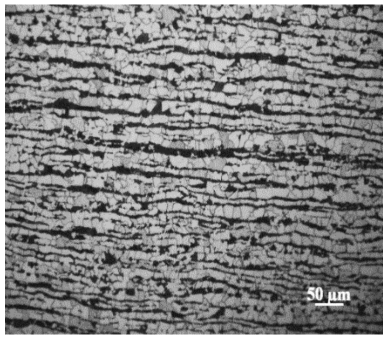
Fig. 3. Metallographic structure of Sample 1



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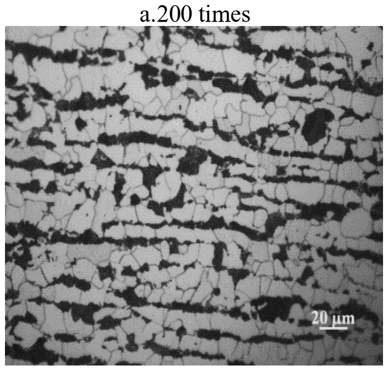

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Fig. 4. Metallographic structure of Sample 2

2.3 Scanning electron microcroscope analysis

Scanning electron microscope (SEM) and the components of energy spectrum analysis (EDS) and electron backscatter diffraction analysis (EBSD) equipped on it can be used to observe the material with high resolution and obtain the distribution information of alloy element content in the material matrix at the same time.

Figure 5 is a 100 times magnification scan of Sample 2. No obvious defects are seen in this figure.

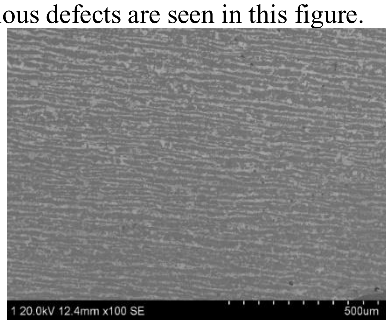
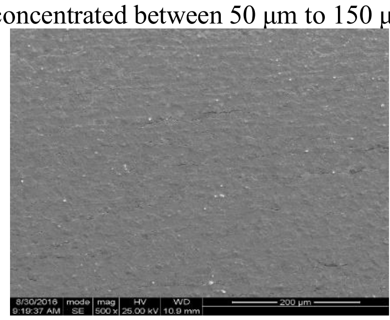


Fig. 5. Scanning image of sample 2

Figure 6 is a scan of the cracked part of Sample 1 at 500 times, 1000 times, and 4000 times magnifications. Obvious cracks can be observed from this figure. The cracks are linear and distributed along the rolling direction of the pipe. It has developed from the inner wall to the outer wall of the pipe, and has cracked through seriously; the crack length is between 10 µm to 200 µm, and most of them are concentrated between 50 µm to 150 µm.



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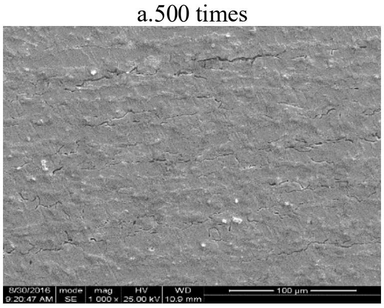

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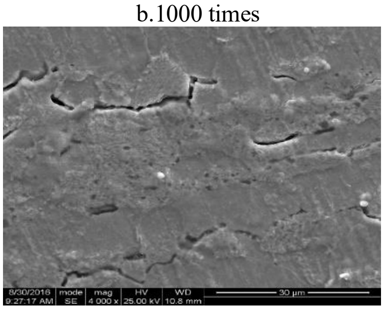


c.4000 times

Fig. 6. Scanning pattern of cracks in sample 1

Through scanning electron microscope analysis, we can see that there are obvious cracks in the metal structure of the water-cooled tube wall. When the pipeline is in working condition, the water vapor in the pipeline will exert pressure on the pipe wall, causing the concentration of stress at the crack, accelerating the expansion of the crack, and also causing the anisotropy of the metal structure, making the metal tissue there highly active, thus accelerating the corrosion of the steel.

The EDS was performed near the cracks of the water-cooled tube wall. The composition is shown in Tables 1 and 2. The results of EDS showed that the tissue composition near the cracks of the water-walled tube is normal, and no other elements are found.

Table 1. Energy spectrum analysis results of water-cooled tube walls (spectrum 1)

element	weight（%）	atom（%）
Mn K	0.97	0.98
Fe K	99.03	99.02
total	100.00	

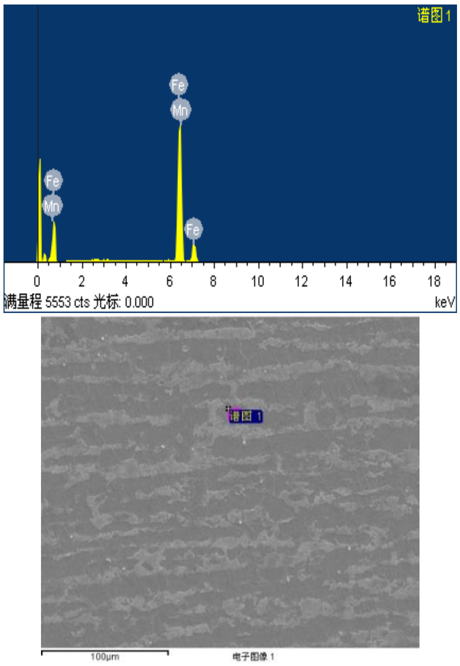
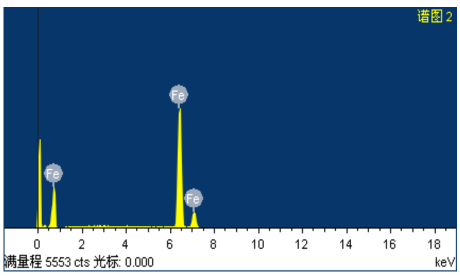


Fig. 7. Scanning matrix of the crack (spectrum 1)

Table 2. Spectrum analysis results of oxide scale on the inner wall of water-cooled tube wall (spectrum 2)

element	weight（%）	atom（%）
Fe K	100.00	100.00
total	100.00	



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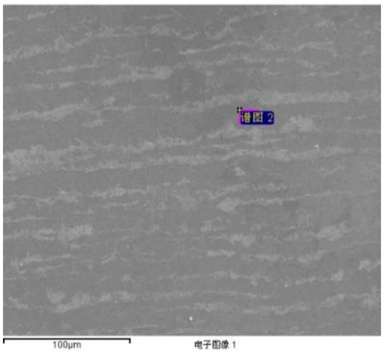

Fig. 8. Scanning matrix of the crack (spectrum 2)

The water-cooled tube walls of power station boilers are often damaged due to the complex and harsh working environment. The failure mechanisms and reasons are various, including acid corrosion, high temperature corrosion, fatigue, wear, hydrogen corrosion, overheating, etc. [2]. The leaking water-cooled pipe runs under high temperature and high pressure. The medium inside the pipe is a vapor-liquid mixture, with a temperature of 366 ° C and a pressure of 20.21 MPa. The smoke temperature of the outer wall of the pipe to the fire side is 797 ° C. During operation, the high-pressure steam will generate an outward pressure on the inner wall of the pipe, which will cause the pipe to swell outward. If there is a small defect in the inner wall of the water-cooled wall pipe, the defect becomes a stress concentration point. This additional pressure on the stress concentration causes the occurrence of cracks, and also causes the cracks to expand after the cracks are generated. In the cracks, water vapor will diffuse along the cracks into the substrate and form corrosion under the action of high temperature, which will further accelerate the cracks to propagate, and eventually cause water-cooled tube walls to leak.

3 CONCLUSION

1. The internal wall defects left over during the manufacture of water-cooled wall pipes are the main reason for the leakage of water-cooled wall pipes.

2. The high temperature and high pressure operating environment of water-cooled tubes and the band structure formed during rolling accelerate the crack propagation are the secondary cause of water-cooled tube wall leakage.

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