Cause analysis on tube burst of T23 steel water-wall in a ultra-supercritical unit

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Abstract. During the hydrostatic test of an ultra supercritical unit, the water wall burst occurred. The causes of leakage were analyzed by means of macro observation, chemical composition analysis, metallographic examination and hardness test. The results show that the formation of cracks is related to fatigue, extending from the inner wall to the outer wall, accompanied by corrosion and oxidation. Fatigue is the main cause of transverse crack formation.

1. Introduction

T23 steel is an improved steel developed on the basis of original T22 steel by reducing the carbon content, adding tungsten element and analyzing the trace element of solid solution strengthening agent again\cite{1}. As a new material between T22 steel and T91 steel, T23 steel has good creep resistance and high allowable stress at 550-770\textdegree C\cite{2}, which could be applied to make water wall, superheater and reheater of large power station boiler with metal wall temperature not exceeding 600\textdegree C.

Since the late 1990s, it has been applied in many subcritical, supercritical and even ultra-supercritical lighter resistors in Europe and Japan Currently, T23 steel has been widely used in newly built ultra-supercritical boiler components (including superheater and reheater) in China\cite{3}. However, many properties of T23 steel have not been fully acknowledged by researchers which cause further research should be carried out on the high-temperature properties of T23 steel (such as creep holding strength and high temperature short-term tensile strength).

Regarding the frequent occurrence of tube bursting accidents of T23 steel tube, many literatures at home and abroad have carried out investigation on this, providing a lot of effective suggestions for revealing the essential causes of tube bursting and preventing tube bursting\cite{4-9}.

In this paper, the leakage causes of water wall tubes in thermal power plants are analyzed. The research results can provide reference for the design, use and maintenance of water wall tubes in power plants.

2. Overview of Failed Water Wall Tube

The unit of a power plant leaked during the hydrostatic test. The leakage position is near the fire surface of the water wall tube with an elevation of 74m. The specific location of the leakage position
is shown in Fig. 1(a). The material of failed water wall tube is SA213-T23, and the tube specification is Φ38mm×6.8mm. The wall thickness of the leaking pipe is between 6.5~6.7mm, and no abnormality is found. The lower side away from the leakage, the non penetrating crack tip near the leakage, the penetrating crack and the upper side away from the leakage are marked as a, b, c and d respectively, as shown in Fig. 1(b).

3. Failure Analysis

3.1. Macroscopic morphology analysis
The appearance of the outer wall of the leakage tube is shown in Fig. 2. There is a penetrating transverse crack on the outer wall of the fire facing surface of the tube, with a length of about 15mm. The macro morphology of the inner wall is shown in Fig. 3. At the position corresponding to the outer wall, there is a transverse through crack with a length of about 18mm, the crack trend has a certain bending direction, and multiple fine surface transverse cracks are also found at the upper and lower parts nearby.

Figure 2. Macro morphology of outer wall of leakage tube.
3.2. Chemical composition analysis
Spectral analysis of the leaking tube is carried out, and the results are shown in Table 1. From the results, the chemical composition of the leakage tube meets the composition requirements of SA213-T23 in relevant standard.

| Element        | C  | S  | Si  | Mn  | P  | Cr  | Ni  | Mo  | V   | W   |
|----------------|----|----|-----|-----|----|-----|-----|-----|-----|-----|
| Water-wall tube| 0.08 | 0.01 | 0.25 | 0.35 | 0.02 | 2.34 | 0.02 | 0.11 | 0.26 | 1.44 |
| SA213-T23      | 0.04~ | ≤0.01 | ≤0.50 | 0.10~ | ≤0.03 | 1.90~ | ≤0.40 | 0.05~ | 0.20~ | 1.45~ |
|                | 0.10 | 0.60 | 2.60 | .30 | 1.75 |     |     |     |     |     |

3.3. Metallographic analysis
The metallographic structure of the fire face and back fire face on the lower side away from the leakage (as shown in Fig. 1 (b), a) is tempered bainite, and no abnormality is found, as shown in Fig. 4.

The crack tip is not penetrated near the leakage (as shown in Fig. 1 (b), b), there is a crack with a length of about 4.6mm on the inner wall of the fire surface, and there are several corrosion pits on the inner wall. After etching with 4% nitric acid alcohol solution, the microstructure at the crack tip after etching is shown in Fig. 5. The microstructure is tempered bainite, and no abnormal material defects are found. The crack propagates horizontally along the pipe wall from inside to outside, the crack is full of oxide, the formation and propagation of surface crack have experienced a period of time, and the crack tip presents intergranular corrosion morphology.
The metallographic structure of the fire facing surface at the through crack (as shown in Fig. 1 (b), c) is tempered bainite, and no abnormality is found, as shown in Fig. 6. However, intergranular corrosion or pits were found on the inner and outer walls of the fire surface.

At the upper side away from the leakage (as shown in Fig. 1 (b), d), the microstructure of the fire facing surface and back fire surface are tempered bainite, and there is no abnormality in the microstructure, as shown in Fig. 7.
3.4. Hardness analysis
The hardness of areas a, c and d as shown in Fig. 1 is tested by Brovi bench hardness tester. The parameter is 2.5mm/62.5kgf, and the results are shown in Fig. 8. In DL/T 438-2016 <The technical supervision codes for metal in fossil-fuel power plant>, the hardness range of T23 is HB150~220, and the hardness values at three places meet the standard requirements.

![Figure 8. Brinell hardness.](image)

4. Conclusion
The chemical composition, metallographic structure and hardness of the leakage tube meet the requirements of relevant standards. From the results of macro inspection and metallographic analysis, there are a large number of parallel transverse cracks perpendicular to the axial direction near the leakage area on the inner and outer walls of the leaking water wall pipe towards the fire side. The generation of such cracks is related to fatigue. The expansion from the inner wall to the outer wall is accompanied by oxidation corrosion, and fatigue is the main cause of the generation of transverse cracks.

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