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Failure Analysis on High Temperature Reheater Tube of T23 Steel in a 660MW Thermal Power Plant Boiler

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Abstract. The cause of the failure of high temperature reheater tube of T23 Steel in 600MW supercritical unit of a power plant was analysed by visual examination, chemical analysis, microstructural examination, and mechanical property test (at room temperature). The results showed that the cause of reheater tube failure was a long-term overheating over 570 °C (in the furnace), which led to its mechanical properties to decrease, resulting in the tube burst with the longitudinal crack ruptures.

1. Introduction

The burst of the boiler heating tube is the major cause of the force shutdown in the power plant. Due to the serious impact on the safety and economy of the unit, it is highly valued by the power plant. In order to prevent the failure of the boiler heating tube, it is necessary to analyze the cause of the every bust event and find out the causes of failures. Effective measures can be taken to achieve the purpose of metal supervision in this way. In this paper, a comprehensive investigation on failures of high temperature reheater tubes of a 660 MW boiler used for power is presented. The material, designed working and operating parameters of the tube obtained from the power plant are given as follows.

Material of the tube: SA-213 T23.

Designed working temperature and pressure of the tube: 569℃ & 4.20 MPa.

Location of failure: the first U-shape elbow from inside to outside of 19th row from left side to the right side of the high temperature reheater tube. The failure location is shown in figure 1.

Effective operating time: 62750 hours.

Nominal dimension of the tube: 63.5 mm outside diameter × 4 mm thickness.

2. Results and Discussion

2.1 Visual examination

The tube contained two failures, with a tear-shaped one called the first failure (FF) and a blow-out one called the second failure (SF) as shown in figure 2b, c. After the first failure busted, the steam leakage blew the adjacent tube. Therefore, the steam from the first failure led to the second failure that was facing it, which also caused the two failures were on the same tube as shown in figure 2a.

The part (of the tube) at the first failure was incomplete, some of tube flew out during the leakage process, and the first failure edge was not significantly thinned. The oxide scale existed at the internal/external surface of the burst tubes and the oxide scales of the external surface peeled off. The second failure has obvious traces of steam blowing damage, and the thickness of the tube around the burst was obviously reduced, with a minimum of 0.86 mm.

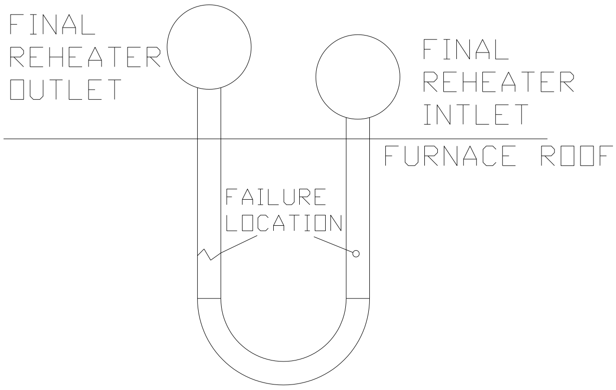

Figure.1 Location of Failures.

The part below the first failure was adjacent to the weld for the elbow and the tube. The tube below the weld within one point five meters, with no bulge, was U-bend shape, of which specification was Φ63.5×6mm. No oxide scales deposits were observed when the U-bend shape elbow was cutting. There was no obvious peeling of the internal oxide scale where the burst was located. Bulges existed above the first failure within one meter, and the maximum diameter of the tube reached 66.8mm, which meant a significant swelling. The internal surface of the first failure edge contained numerous longitudinal cracks, which indicated an abnormal operating condition, as shown in figure 2d.

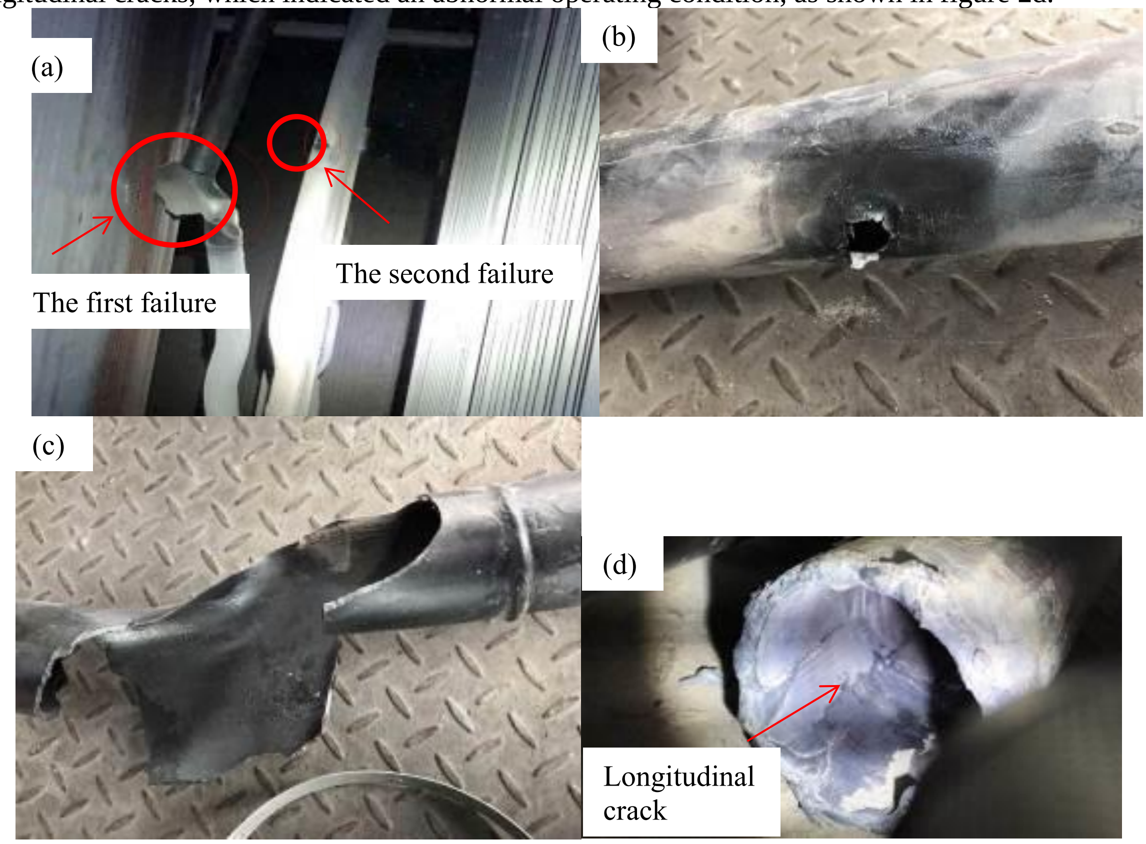

Figure.2 Camera pictures of The failures (a)the position of the two failures in the boiler (b)the first failure (c)the second failure (d)the longitudinal cracks in the internal side of the tube.

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The material used for this analysis was T23 heat resistant steel. The investigated samples were cut from the first failure edge (FF), a second failure edge (SF), and the part of the tube above the first failure (FFA), of which working and operating parameters were given in the introduction.

2.2 Chemical analysis

The chemical analysis of sample FF was performed with the direct reading spectrometer (ARL iSpark 8860). The chemical composition of the tube, compared with the requirements of the ASTM A213/A213M standard for T23 steel are shown in Table 1.

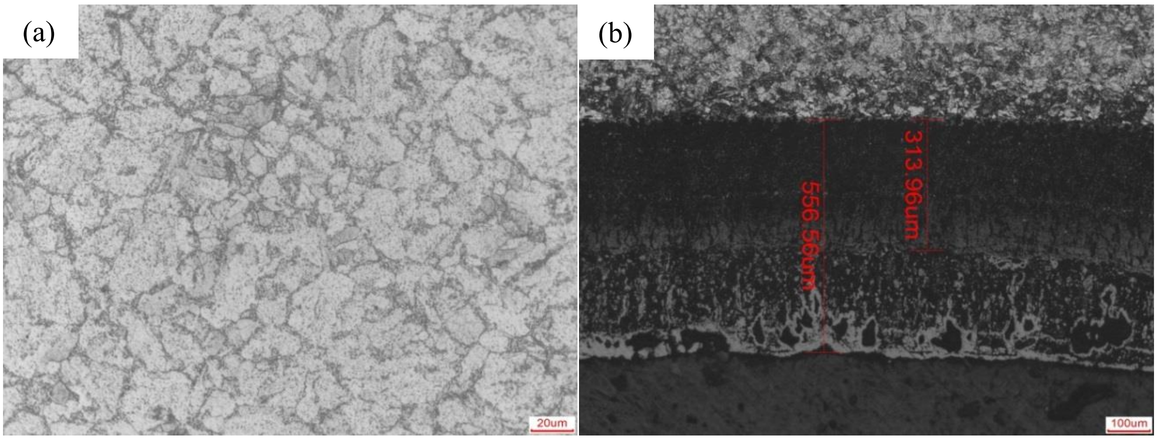
Table 1. Chemical composition of sample FF.

Sample No.	Elements （wt%）										
	C	Si	Mn	S	P	Cr	Mo	V	W	Nb	Fe
FF	0.08	0.32	0.21	0.006	0.017	2.44	0.24	0.23	1.53	0.036	Bal.
ASTM	0.04-0.10	≤0.50	0.10-0.60	≤0.010	≤0.030	1.90-2.60	0.05-0.30	0.20-0.30	1.45-1.75	0.02-0.08	Bal.

2.3 Microstructural examination

Microstructural examination of the failure samples under metallographic microscope (DMI5000M) were prepared by grinding with abrasive papers from No. 100 up to No. 1,500, mechanical polishing by diamond compounds (W1.5) and then chemical etching in a solution composed of 4% nitric acid solution. Based on the optical micrographs of the samples, it was observed that the microstructures of the samples were bainitic–ferritic matrixes with precipitations at grain boundaries and inside grains/laths.

The bainite lath structure of samples was observed. The thickness of internal oxide scale of sample SF was 0.38mm. In the samples FF and FFU, many polygonal ferrites appeared because of the coalescence of bainitic ferrite laths and carbide precipitates aggregated into a chain shape along the grains compared with sample SF. The thickness of oxide scale at the internal surface of sample SF was 0.38mm, and that of the FF and FFU samples were 0.56mm and 0.58mm, respectively, as shown in figure 3.



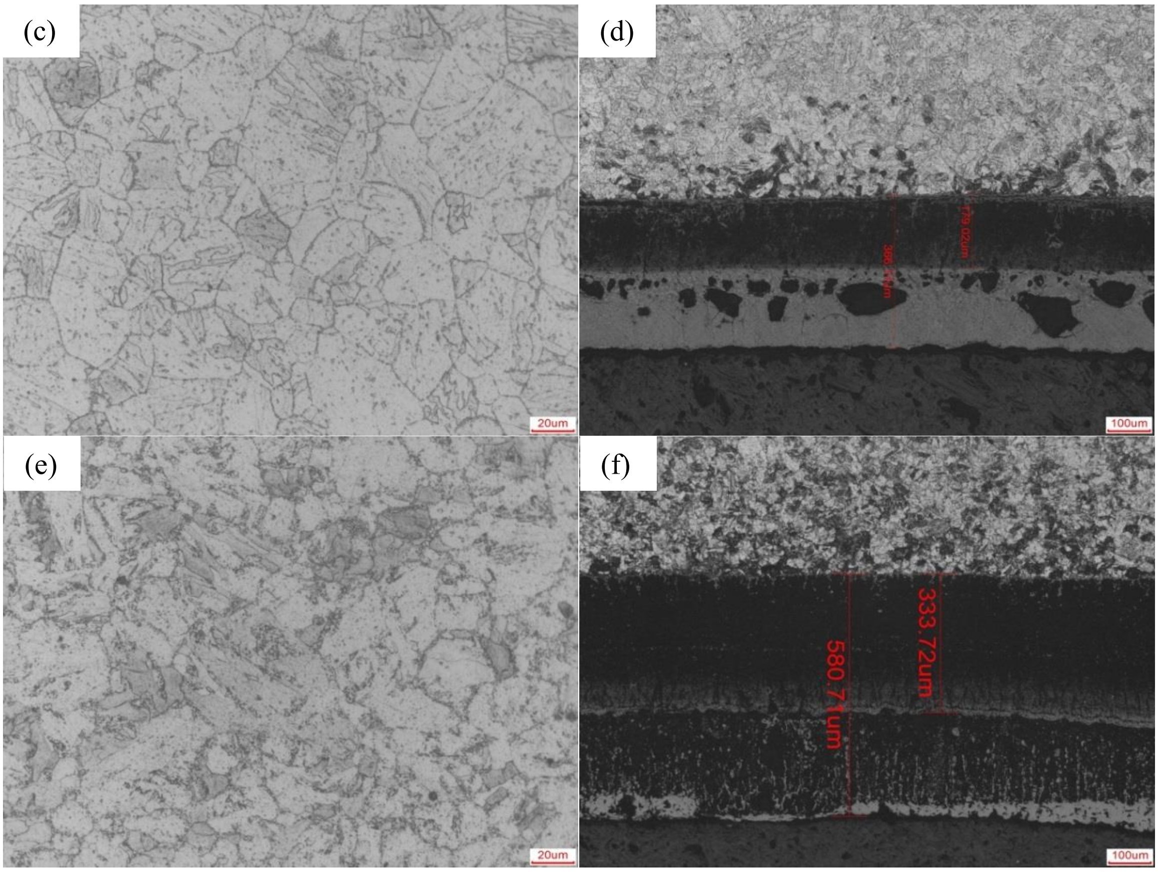


Figure 3. optical micrographs of the first failure tube.
(a) (b)sample FF (c) (d)sample SF (e) (f)sample FFU

2.4 Mechanical properties

Tensile tests were under the the universal mechanical tester (CMT5605). The results were shown in Table 2. The yield strength and tensile strength at the room temperature of the samples were lower than the ASTM A213/A213M standard requirements for T23 steel.

Table 2 Mechanical properties of T23 steel samples

Sample No.	Tensile strength(MPa)	Yield strength(Mpa)
FF	296	438
SF	337	432
FFU	376	495
ASTM	≥400	≥510

3. Discussions

The microstructure and mechanical properties of boiler heating tubes were closely related to the working temperature in the boil. However, the accumulation of oxide scale inside the tubes would cause the flow of steam inside the tubes to decrease, resulting in an increase in their metal temperature. It was well know that the thickness of oxide scales at the internal surface could be used to estimate the metal temperature of the heating tube. For the low alloy ferritic steels containing 1% to 3% chromium, the following formula is more practically applied [1]:

$$\log X(t) = 2.1761 \times 10^{-4} T\ (20 + \log t\ ) - 7.25$$

In this formula X(t), T, t represent the thickness of oxide scales in mils, working temperature (deg.F +460) and operating time in hours, respectively. For Sample FF and FFU, the thickness of the steam-side oxide scale was approximately 550 um and the operating time was 62750 hours. Its metal temperature could reach approximately 610 °C. That of SF sample was 594°C, which was consistent with its position (leeward side). However this temperature was close to the limit of the T23 material, whose allowable operating temperature was 593°C. What's more, the thermocouple data showed the maximum temperature of the unheated tubes in the penthouse had been over 570 °C. The data indicated the temperature of tubes in the furnace would be much higher than 570°C, which was in agreement with the calculation of the formula. It was shown that the metal temperature of the heating boil tubes of T23 in the supercritical boiler should be controlled within 570 °C. [2] Therefore, the high temperature reheater tube was overheating [3-4] for a long time. Overheating would lead to reduction of heat-transfer capability internal surface oxide scales and microstructural degradation which was mainly related to the recovery of matrix, disintegration of bainitic microstructure, an increase in the size of carbides and precipitation of M6C carbides. [5] Eventually, the mechanical properties of the material were increased, which in return led to the explosion of the tubes. In the on-site inspection, longitudinal cracks appeared in the inner wall of the tube within 2 meters above the explosion, and the tube showed obvious swelling. The metallographic structure of the windward surface tube was completely aging, and the carbide precipitates in the grain boundary. The tensile strength and yield strength were lower than the standard requirements, indicating that the tube has long-term overheating characteristics.

4. Conclusion

The cause of high temperature reheater tube failure was a long-term overheating over 570 °C (metal temperature), which led to its yield strength and tensile strength at the room temperature to decrease, resulting in the tube burst with the longitudinal crack rupture.

It is recommended that T23 steel tubes of the high temperature reheater should be tested such as visual examination and wall thickness measurement, diameter measurement and accumulation oxide scale detection. These steps should be taken to find the defects of the tubes and to make sure that the problem tubes will be replaced by new in time.

References

[1] Dehnavi F, Eslami A and Ashrafizadeh F 2017 A case study on failure of superheater tubes in an industrial power plant *Engineering Failure Analysis* **80** 368-377
[2] Huichuan Z, Biao S, Hongquan Y and Chengwu Y 2013 Current service situation and retrofitting advice for tubes on final superheater in supercritical boilers *Thermal Power Generation* **42(1)** 1-4
[3] Lee N H, Kim S, Choe B H, Yoon K B and Kwon D 2009 Failure analysis of a boiler tube in USC coal power plant *Engineering Failure Analysis* **16(7)** 2031-2035
[4] Liang Z, Jin X and Zhao Q 2014 Investigation of overheating of the final super-heater in a 660 MW power plant *Engineering Failure Analysis* **45** 59-64
[5] Zieliński A, Golański G, Sroka M and Skupień P 2016 Microstructure and mechanical properties of the T23 steel after long-term ageing at elevated temperature *Materials at High Temperatures* **33(2)** 154-163