Analysis of the Explosion of Dissimilar Steel Joints in the 1050MW USC Boiler

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Abstract. The leakage of dissimilar steel welded joint near the third superheater occurred in a power plant boiler. Through the analysis of tube cutting sampling, it is considered that the welding quality of dissimilar steel joint is good, the dissimilar steel joint cannot bear the bending load, and the improper arrangement of weld joint position together cause the leakage. It is suggested that the welding joints of dissimilar steel should not be arranged in the position with complex structural stress in the design, and the inspection of anti-abrasion and anti-explosion blind area should be strengthened in the process of maintenance.

1. Introduction
Developing ultra-high parameters and super-supercritical units is a long-term plan for energy saving and emission reduction, increasing power generation efficiency and reducing power generation costs in China's power industry. However, with the development of high parameters and large capacity of boilers, higher requirements are put forward for the metal materials of the hot surface of the boiler. The problem of boiler heat-affected surface burst tube and leakage caused by material problem is becoming more and more prominent. Therefore, it is of great significance to do a good job of failure analysis to ensure the safe and reliable operation of the unit.

2. Overview
Two 1050MW units in a power plant were put into operation in early 2014, and the boiler export steam parameter was 27.56MPa/605/603 ℃, with a maximum continuous evaporation (B-MCR) of 3100t/h. On September 28, 2015, at 14:30, the load of Unit 2 was 780 MW, and the air flow sound at the outlet connecting tube of the three-stage superheater of the boiler increased abnormally. Determine that there has been a leak in the unit and an emergency shutdown to deal with. After pressure relief inspection of the boiler, it is found that the leakage is the first short tube weld fracture of the 11th screen of the third superheater outlet header from west to east, as shown in Figure 1.

It is found that the weld is T92 and TP310HChbN dissimilar steel butt weld, it should be manufactured for the factory according to the requirement, but through appearance analysis, it is judged that the burst tube weld is on-site weld. Refer to relevant installation record, welding record is T92 docking with TP310HChbN, welding material is ENiCrFe-3, which meets the process requirement [1]. The heat treatment report is T92 butt weld of the same kind of steel, and this process can be applied to heat treatment of dissimilar steel weld. The X-ray inspection record is T92 butt weld of the same kind of
steel, which is qualified. In order to further confirm the cause of tube burst, another dissimilar steel welded tube is taken as the sample tube, and the experimental analysis is carried out.

![Figure 1. Location of fracture site.](image)

3. Test analysis Results

3.1. Macro Inspection
Tube break shape shown in Figure 2a and Figure 2b, fracture is located on the edge of the T92 melting zone, the section does not see T92 master metal, the fracture surface is weld ripple, and no crack expansion pattern. There is a tongue like tear on one side of the weld, which should be the last instantaneous fracture area, indicating that the fracture is affected by certain bending stress in the process of formation and propagation. The welding seam is wide, which is multi-layer and multi pass welding, as shown in Figure 2c and Figure 2d.

![Figure 2. The view of failed tube and sampling tube.](image)
3.2. Metallographic Examination
The metallographic sample shown in Figure 3 is prepared at the fracture of the tube sample. The weld is columnar crystal, and no base metal of T92 is found on the section, but a small amount of beak like Peninsula tissue and carbon-enriched zone which due to carbon transfer are found as shown in Figure 3.

![Figure 3](image)

**Figure 3.** Microstructure of weld and carbon migration layer at fracture.

The metallographic sample on T92 side of sampling tube found that the black carbide precipitation zone appeared in the fusion area, as shown in Figure 4a, which should be caused by the base metal melting into the molten pool. The microstructure of the coarse-grained section in the heat affected zone of T92 side is tempered martensite as shown in Figure 4b. There is massive ferrite near the fusion line, which is a decarburized zone. No creep crack or hardened martensite is found.

![Figure 4](image)

**Figure 4.** Microstructure of the fusion line of sampling tube.

3.3. Hardness Testing
The microhardness test is conducted on T92 side of intact tube sample dissimilar steel joint, as shown in Figure 5, and the results are shown in Figure 6. The highest hardness of the weld is more than 300HV. The hardness of the fusion area is relatively low (about 220HV) due to decarburization. The hardness of the coarse-grained area of T92 is about 280HV, which is near the upper limit of the hardness of T92 steel. The weld hardness of the fracture tube sample is between 270 and 300HV.
4. Analysis and Discussion

4.1. Analysis of Structure and Properties
The results of metallography and microhardness show that there is no high hardness martensite transition layer on the weld side of T92 side fusion zone of the fracture and nonfracture tube dissimilar steel joint. And no hardened structure is found in T92 side base metal after PWHT. However, there are a small amount of carbon migration and Peninsula like base metal entrapment on the weld side, and a very narrow decarburization area on the T92 base metal side, which aggravates the inhomogeneity of the structure[2,3]. The carbide precipitated at the edge of the base metal is quite different from the composition and properties of the surrounding [4]. In operation, additional stress and stress concentration are generated here, and microcracks and micropores are caused under certain conditions,
which may lead to joint cracking and early failure. The appearance of carbon migration and carbide precipitation is not serious, the hardness gradient of fusion area is not large, and only the welding quality is not enough to cause the joint cracking. Different from the miscible interface of the same kind of steel or other types of dissimilar steel joints, M-A dissimilar steel joints have heterogeneous interface on the side of ferritic steel, which has poor binding force, especially poor bending resistance. When subjected to large bending load or alternating tensile and compressive stress, it is easy to fracture at the heterogeneous interface.

4.2. Mechanics Analysis
The first and the fourth short tube joints of each 5 tube screens on the header at the outlet of the third stage superheater are dissimilar steel joints. The dissimilar steel joints of other tubes are located on the lower horizontal section, and the first elbow of each screen is equipped with thermal insulation fixing device. As shown in Figure 7, the fracture position is located at the butt weld of T92 short tube and TP310HCbN elbow, which is very close to the header and has a large stress concentration. In the process of boiler start-up, shutdown and operation, with the temperature change, the expansion or contraction of different steel welded joints between the tube panels are inconsistent. In addition, if the upward displacement of header fails to move up freely due to various reasons (limit of heat preservation fixing device or tube clamp suspension device in the figure), a large structural stress will be formed in the tube seat area, and then a large amount of structural stress will be generated in the tube seat area. In the figure, the area of dissimilar steel joint (where is the relative dead point) forms a large bending load, which makes the dissimilar steel joint failure.

![Figure 7. Schematic diagram of fracture part.](image)

5. Preventive Measures

5.1. Analysis of Operation Measures
Based on the analysis of the online operation data of the period before the failure, it is concluded that the boiler operation did not affect the leakage of the header at the outlet of the tertiary superheater. The leakage point is connected with the tube outside the furnace at the outlet of the third stage superheater, so the tube does not overheat. There is no obvious influence on boiler combustion and temperature deviation on both sides, and there is no alarm for online detection of boiler leakage. The calculation of the main steam flow is based on the accumulation of the first superheated steam flow and the desuperheating water flow, so the deviation between the feed water and the main steam flow can only judge the leakage of the economizer and the water wall, and cannot reflect the leakage of the third superheated tube. No abnormality was found by comparing the condensate and feed water flow under the same working condition in different periods. Therefore, it is impossible to detect and avoid the leakage of this part in time through operation measures.
5.2. Analysis of Maintenance Measures
Since the outlet header of the three-stage superheater is arranged outside the furnace, which is an integral structure, and the unit's operation time is not so long, the anti-abrasion and anti-explosion-proof inspection in this area has not been carried out temporarily. And the hidden danger could not be found in advance. Therefore, it is necessary to check the blind area of anti-abrasion and anti-explosion-proof in time to eliminate the hidden danger of leakage of three-stage superheater tube.

5.3. Supervision and Inspection Analysis
Due to the fact that dissimilar steel welds cannot bear bending stress, it is necessary to take metal supervision measures to avoid similar situations at the beginning of equipment design. Or in the process of infrastructure installation, problems and hidden dangers are found and eliminated in time. After the accident, the power plant also checked all similar structures, and timely modified the location of dissimilar steel welded joints.

6. Conclusion and Suggestions
No abnormal structure such as hardened martensite was found in the welded joint of dissimilar steel in the header of three-stage superheater after PWHT. Welding quality is not the main cause of this leakage. The leakage is caused by the structure bearing characteristics of dissimilar steel weld and the improper arrangement of weld position.
In order to avoid similar tube failure, it is suggested that the manufacturer should try to avoid arranging dissimilar steel welds in the parts with complex stress in the design, and strengthen the inspection of "anti-abrasion and anti-explosion inspection" blind area in the maintenance process.

References
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