Analysis of the causes of the cracking of the tee joint of the header of the utility boiler

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Abstract: The butt joint of the high temperature superheater inlet tee of 330MW Unit Boiler in a thermal power plant cracked. The causes of the weld cracking were analyzed by means of macroscopic morphology observation, fracture SEM inspection, microstructure inspection, mechanical property inspection and chemical composition inspection. The results show that a large number of small thermal cracks are formed in the weld due to improper welding process or operation during boiler installation. At the same time, the improper post weld heat treatment of the joint results in the high hardness of the weld, the insufficient toughness reserve and the decrease of the crack growth resistance. During the long-term operation of the boiler, under the combined action of the primary stress caused by the medium pressure in the pipe and the secondary stress caused by the expansion and contraction of the pipe system, the small crystal cracks in the weld continue to expand, which eventually leads to the macro cracks.

1. Introduction
The superheater is a part of the power plant boiler that further heats the steam from the saturation temperature to the superheat temperature. The high temperature superheater is the last superheater of the superheater system. High temperature superheater is an important device to transfer energy and improve thermal efficiency. The operation condition of the equipment is bad, and it is in the high temperature and high pressure environment for a long time. If the weld of the connecting pipe of the high temperature superheater has crack defects, there may be leakage accidents, which will lead to the shutdown of the unit and cause significant economic losses. Therefore, the reliability of high temperature superheater and its connecting pipe butt joint is of great significance to the safe and stable operation of thermal power units.

During the class A boiler maintenance of 330MW unit in a thermal power plant, through on-site NDT, it was found that there were many cracks on the tee joint of the header at the inlet of the high-temperature superheater, and the direction of the cracks was transverse distribution. Tee material is 12Cr1MoVG, specification is Φ406.4*Φ355.6mm*Φ355.6mm. The boiler is designed and manufactured by Dongfang Boiler Co.Ltd. with the model of DG1065/18.2-II6, subcritical natural circulation drum furnace, one intermediate reheat, tangential combustion at four corners, and balanced ventilation. Single furnace π type arrangement, all steel frame suspension structure, tight sealing, solid slag discharge. The temperature of main steam is 535°C, the pressure of main steam is 12.75mpa, and the butt joint of three-way at the inlet of superheater is cracked, which poses a great threat to the safe and stable continuous operation of the unit.

Combined with the on-site inspection and sampling physical and chemical inspection, this paper analyzes the causes of the cracking of the three-way butt joint at the superheater inlet of the boiler, and
puts forward targeted suggestions to prevent the recurrence of the same type of events and improve the safety and reliability of the boiler operation.

2. Test and analysis on cracking of butt joint of tee at the inlet of high temperature superheater

2.1. Macromorphology analysis

Combined with the field investigation and detection, the macro morphology of the three-way welded joint at the inlet of the header of the cracked high-temperature superheater was observed. The cracking joint is the butt joint of the inlet tee of the high temperature superheater and the connecting pipe of the steam guide. There are many parallel transverse cracks on the joint. Most of the cracks are located in the weld, and some cracks have expanded from the weld to the fusion zone. Each crack is in a straight line shape with a small opening. The longest crack is about 15mm long. All cracks do not penetrate the pipe wall and cause no leakage. No obvious original defects, mechanical damage, oxidation, corrosion and other traces are found on the joint and its adjacent pipes, and no obvious plastic deformation is found, as shown in Figure 1.

Fig.1 Macro morphology of tee weld at the inlet of high temperature superheater

2.2. SEM examination and analysis of fracture

The cracking part of the tee weld of the inlet header of the high temperature superheater was opened, and the micro morphology of the fracture was observed by SEM. The results show that the initial crack on the fracture surface presents a typical intergranular crack morphology of "crystal sugar like", with secondary cracks in some places. There are obvious cleavage facets with river pattern in the local position, and the whole fracture is brittle fracture. As shown in Figure 2. There are obvious cleavage facets with river pattern in the local position, and the whole fracture is brittle fracture. As shown in Figure 2.
2.3. microstructure analysis
The microstructure of the cracked tee weld at the inlet of the high temperature superheater was inspected as shown in Figure 3. It can be seen that the structure of the weld is tempered sorbite with columnar crystal shape, and the structure state is basically normal, no abnormal structure such as overheated structure and hardened martensite is found. In addition to the main crack, there are many microcracks in the weld structure. These microcracks are distributed along the coarse grain boundaries of the original austenite, most of which are tens to hundreds of microns in length with typical intergranular crack morphology characteristics. At the same time, there is oxidation inside the cracks, which indicates that the formation temperature of these microcracks is high. In Figure 3, it is obvious that there are dispersed intergranular pores and grain boundary cracks formed by the cluster of pores. Cracking characteristics with hot cracks.
2.4. Chemical composition detection and analysis

The chemical composition of the three-way weld at the inlet of the high temperature superheater was tested, and the results are shown in Table 1. It can be seen that the chemical composition of the deposited metal of the joint weld conforms to the requirements of DL / T 869—2012 for R317 welding material.

| Items     | C   | Si  | Mn  | Cr  | Mo  | V   | P   | S   |
|-----------|-----|-----|-----|-----|-----|-----|-----|-----|
| Measurements | 0.08 | 0.33 | 0.70 | 1.18 | 0.33 | 0.28 | 0.020 | 0.010 |
| Standard requirements | 0.05~0.12 | ≤0.60 | ≤0.90 | 0.80~1.50 | 0.40~0.65 | 0.10~0.35 | ≤0.035 | ≤0.035 |

2.5. Test and analysis of mechanical properties

The hardness test was carried out for the cracked tee weld at the inlet of high temperature superheater, and the results are shown in Table 2. It can be seen that the measured Brinell hardness of the weld is higher than the requirements of the standard DL / T 869-2012. It shows that the toughness reserve of the weld is insufficient.

| Items                 | Base metal hardness /HBW | Weld hardness /HBW |
|-----------------------|--------------------------|---------------------|
| Standard requirements | 135~195                  | Not higher than base metal hardness plus 100, And the hardness≤270 |
| Measurements         | —                        | 286                 |

3. Comprehensive analysis

According to the analysis of fracture morphology, there are many transverse cracks in the butt joint of the three-way at the inlet of the high-temperature superheater. The cracks are mainly located in the weld and part of them extend to the base metal. The results show that the fracture surface is typical intergranular cracking.

According to the chemical composition analysis, the chemical composition of the deposited metal of the three-way weld at the inlet of the high temperature superheater meets the requirements, eliminating the possibility of misuse of welding materials.

According to the metallographic structure analysis, the structure of the three-way weld at the inlet of the high temperature superheater is basically normal, and no abnormal structure such as overheated structure and hardened martensite is found. There are many microcracks distributed along the coarse grain boundaries of primary austenite in the weld, most of which are tens of microns to hundreds of microns in length. At the same time, there is oxidation in the microcracks, which shows that the microcracks are formed at a relatively high temperature and have the characteristics of crystallization hot cracks formed at a relatively typical high temperature stage of welding.

From the analysis of mechanical properties, the hardness value of the three-way weld at the inlet of the high-temperature superheater is obviously higher than the standard requirements, which indicates that the post weld heat treatment is harmful, which makes the toughness reserve of the weld insufficient and the crack resistance reduced.

From the stress analysis, the three-way pipe system at the inlet of the high-temperature superheater should not only bear the primary stress caused by the internal high-temperature and high-pressure medium, but also bear the secondary stress generated in the pipe system when the unit starts and stops and the load changes. Under the superposition of the above two stresses, the microcracks in the weld will further expand and form macroscopic crack damage.
4. Conclusions and recommendations

Through the test and analysis, it can be judged that the main reason for the cracking of the butt joint of the three-way at the inlet of the high temperature superheater of the boiler is that a large number of small crystal hot cracks are formed in the weld due to the improper welding process or operation during the installation process. At the same time, the improper post weld heat treatment leads to high hardness of the weld, insufficient toughness reserve and resistance to crack propagation. During the long-term operation of the boiler, under the combined action of the primary stress caused by the medium pressure in the pipe and the secondary stress caused by the expansion and contraction of the pipe system, the small crystal cracks in the weld continue to expand, which eventually leads to the macro cracks.

First of all, check whether there are similar cracks in the welding joints of other pipes of the same type, and deal with the problems in time if found, second, strengthen the welding technical supervision of the connecting pipes within the scope of the boiler, strictly control the welding process of pressure equipment, and ensure the welding quality, third, optimize the operation mode to avoid frequent start and stop of the unit and frequent rapid and large value load change, Reduce the relationship stress level to avoid similar cracking failure.

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References:

[1] Li, L., Qin, X. J., Wang, S. T., Chang, D. W. (2019) Failure analysis of girth weld cracking of a pipeline, Hot working process, 3(6): 259-262.
[2] Zhang, C. L. (2009) Analysis and treatment of butt weld crack in high temperature pressure pipe of utility boiler, welding. 01(1): 49-52.
[3] Zheng, F. P., Bao, W. D., Song, S. P., Gao, L. (1981). Analysis on cracking of thick wall steam pipe welding joint of utility boiler, Foundry Technology, 5(1): 1128-1131.
[4] Zou, D. A., Li, M. S. (1999) Study on the fracture mechanism of heterogeneous joint of utility boiler pipe, Power construction, 02(1): 6.
[5] Li, B., Chen, X. J., Wang, J. Q. (2019) Analysis of the causes of the weld cracking of the power plant boiler pipes, Physical and chemical test (physical volume), 01(1): 52-55.
[6] Guo, Y. H. (2017) Discussion on welding quality control of main steam pipe of Ultra Supercritical Boiler, Electromechanical information, 30(2): 88-89.
[7] Cheng, D. Y. (2015) Study on synchronous and constant temperature heat treatment process of two sides of boiler main steam pipe, Hot working process, 16: 206-207.
[8] Li, Q. F., Chen, H. B., Long, P. G., Xiu, F. (2006) Study on temper embrittlement control technique in steel 12Cr1MoV, Journal of Marine Science and Application, 5 (1): 44-47.
[9] National Energy Administration. (2016). DL/T 438 China Electricity Council.
[10] National Energy Administration. (2012). DL/T 869, China Electricity Council.