Research on Mechanism of Internal Cracking of Welds Caused by Carbon Migration of Welding Joints

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Abstract. The dissimilar steel joints of austenitic stainless steel and low alloy steel are commonly used in superheaters and super heaters of the boiler. Carbon migration is an important factor affecting the life of welding joints during service. In this paper, the carbon migration of T23 and TP304h dissimilar steel of welding joints was studied. The results show that carbon-rich zone and carbon-depleted zone are formed near the interface between the T23 bases and weld metal. The carbon-rich zone is located near the weld line in weld metal. On the other hand, the carbon-depleted zone is located at the T23 steel base metal. Significant carbon migration phenomenon can be observed by the optical micrographs of the welding joins. The morphology of the carbon-rich zone along the fusion line can be used as a “feather” for identification and extends toward the center of the welding joints. In the carbon-depleted zone, it is found that the microstructure of the carbon-depleted zone near the fusion line is inhomogeneous and relatively coarser, and the micro hardness of the carbon-rich zone is significantly different from that of the surrounding zone. The carbon-poor zone is becoming a weak link to promote the process of crack propagation.

1. Preface
In the design of high-temperature components of thermal power generator boilers, in order to rationally utilize the performance of different materials for reducing production and manufacturing costs, different materials are selected according to different steam conditions for different parts of the same component. Thereby dissimilar steel welding joints are used commonly. [1].

For example, in a high-temperature superheater tube row of a supercritical unit for a power plant, T23 steel is used at the inlet. While T91 steel is used in the middle section, and TP304h steel is used in the outlet section. In the pipeline installation process, the problem of dissimilar steel welding is inevitable. Therefore, dissimilar steel welding plays a very important role in the high temperature components of thermal power plants.

At the same time, dissimilar steel welding will lead to additional problems. Firstly, the welding is more difficult than conventional steel welding.[2] Because of the different from the microstructure, properties and chemical composition between the two base metals in the dissimilar steel welding, the welding stress field is more complicated, and higher requirements of welding consumables, welding and heat treatment. Secondly, the diffusion and migration of elements mainly composed of carbon migration between the different base part of the welding joints during the welding and service of the dissimilar steel joints become the key factors affecting the performance and service life of the welding joint. The carbon-depleted zone formed by carbon migration near the fusion line is one of the main causes of the decrease of the high temperature creep resistance of the welded joint. [3, 4].
In this paper, the main locations, migration degrees and migration modes of carbon migration were studied by the result of the alloy composition, mechanics and metallographic structure of T23/TP304h welding joints service for 62000 hours. The formation mechanism of cracks and possible cracks were speculated. The result can be referred by the nondestructive testing of T23/TP304h welding joints.

2. Test sample overview
The T23 / TP304H dissimilar steel joint after 62000 h of 600 MW supercritical generator set boiler in a power plant was cut in the boiler inspection and cutting tube sampling. The joint position is located at the third welding joint below the inlet header. Finished joints are supplied by the boiler plant before building step. The specifications of T23 steel pipe and TP304H steel pipe at both ends of the welded joint are all Ф63.5×4mm, and the weld is filled with nickel-based welding wire.

3. Physical and chemical analysis and experiment

3.1. Alloy Composition Comparison
The alloy composition of the sample base material and the weld was analyzed by a Niton DL3T800 hand-held alloy analyzer. The results are shown in Table 1. It can be seen from Table 1 that the alloy composition of the base metal at both ends meets the requirements of ASME SA213 "American Boiler and Pressure Vessel Code" and GB5310-2008 "High Pressure Boiler Seamless Steel Tube".

| Element   | Mn  | Cr  | Mo  | V   | Al  | Nb  | Ni  | W   |
|-----------|-----|-----|-----|-----|-----|-----|-----|-----|
| T23       | 0.35| 2.14| 0.21| 0.25| 0.01| 0.038| 1.64|
| ASME SA213| 0.10~0.60| 1.90~2.60| 0.05~0.30| 0.20~0.30| ≤0.03| 0.02~0.08| 1.45~1.75|
| TP304H    | 1.2 | 18.9|     |     |     |     |     | 11.7|
| GB5310-2008| ≤2 | 17.0~20.0|     |     |     |     |     | 9.0~13.0|

3.2. Hardness Test
The sample was cut along the diameter direction, and the Vickers hardness of the weld of the sample, the heat affected zone at both ends, and the base materials at both ends were respectively tested. The hardness test position is shown in Fig. 1. The load is 0.2452N and the loading time is 15 seconds. The measurement results are shown in Figure 2. The hardness test results show that the hardness of the T23 steel pipe and the decarburized layer are basically the same in the steel pipe joint, and the hardness of the welded joint is closer to the T23 steel pipe side fusion line, and the hardness value is much higher than the base metal hardness value and the weld center hardness value.

Figure 1. Vickers hardness test position
3.3. Metallographic analysis

The metallographic structure of the T23/TP304H dissimilar steel pipe welded joint was analyzed, and the microstructure of the joint weld, heat affected zone and base metal were observed by DMI5000M optical microscope. Figure 3(a) shows the microstructure of the T23 steel pipe. The structure is mainly bainite. On the weld line of T23 steel weld, there is an obvious decarburization layer along the fusion
The effect of carbon migration is on the side of the partial fusion line. The Bainite structure of T23 steel is not obvious, as shown in Figure 3(b). The carbide is dendritic from the weld line at the root of the weld to the center of the weld, as shown in Figure 3(c). Both the weld and the TP304H base metal are austenitic, in which the grain of the weld is very coarse, as shown in Figure 3(d).

4. Analysis and discussion

The results of alloy composition test show that the alloy composition of T23 steel pipe and TP304H steel pipe used in the high temperature reheater T23/TP304H dissimilar steel joints meet the relevant standards. The dissimilar steel joints produced by the boiler plant have been non-destructively tested before shipment. However, after about 62000 h of operation, the metallographic sampling inspection found that the T23/TP304H joint showed obvious carbon in the T23 steel to the weld. Migration phenomenon, the migration path is dendritic. Carbon migration occurs mainly near the root of the weld and migrates from the vicinity of the weld line to the weld surface.

The reason why the hardness of the decarburization layer has not changed significantly is that T23 steel is based on 2.25Cr-Mo steel, W element is added to form W-Mo composite solid solution strengthening, and micro alloying elements V, Nb, B are added. N is subjected to dispersion precipitation strengthening to obtain good high temperature endurance strength and allowable stress [5]. However, in the final analysis, the toughness of the decarburized layer is reduced due to the decrease of carbon content, while the operating temperature of the high temperature reheater is 569°C, which requires the high temperature strength and thermal fatigue strength of the joint. However, the creep due to carbon migration the breaking strength is reduced, and the risk of failure due to cracking due to fatigue is greatly increased.

From the position where carbon migration occurs, it mainly occurs at the root of the weld. Therefore, if fatigue cracking due to decarburization occurs, the probability of initial creep cracking from the root of the weld is greater than that of other parts. According to the requirements of DL/T438-2016 and DL/T 989-2016, dissimilar steel welding joints only require 100% ray inspection during manufacturing, while in service period, 10% non-destructive testing is carried out after the boiler has been running for 50,000 hours. Radiographic inspection is not mandatory, and surface inspection is often used in practice. This test shows that the creep crack caused by carbon migration during operation is more likely to occur at the root than the surface. Therefore, it is recommended to increase the ultrasonic phased array detection method to detect the root and improve the defect detection rate.

5. Conclusion

The T23/TP304H dissimilar steel welding joints on the high temperature reheater tubes of a 600 MW supercritical unit boiler in a power plant were sampled and analyzed after service for about 62000 h. The alloy composition of the base metal at both ends of the dissimilar steel welding joints met the standard requirements, and the hardness of the base metal. It is also in the normal range, but the hardness of the joint weld near the T23 steel side is much higher than that of the T23 steel due to the carbon migration. According to the analysis of the microstructure of the joint, there is obvious decarburization on the side of the T23 steel near the weld. Layer, but because T23 contains elements such as W and Mo to form a solid solution strengthening effect on the grain boundary, the hardness drop is not obvious, but the bainite structure in the structure near the area is not obvious. There is obvious carbon migration phenomenon near the T23 side of the weld. It is feathery under the microscope and mainly occurs at the root of the weld. It can be judged that the welded joint is creep cracked due to insufficient creep resistance of the decarburized layer. The probability of cracking at the root of the weld is greater than that of the weld surface. Therefore, for the dissimilar steel joints of the in-service units, the root of the weld should be non-destructively tested. It is recommended to use ultrasonic phased array technology for testing.

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