The Study of Metallographic Testing of Welding Joint of Welding in High Alloy Steel Installation of Power Station Boiler

Bing Zhang1*, Peng He2#, Jinqing Wang3, Zhangmin Jin1 and Xinmin Pan1

1Wenzhou Special Equipment Inspection and Research Institute, Wenzhou, Zhejiang, 325007, China
2Shanxi Boiler and Pressure Vessel Supervision Inspection Institute, Taiyuan Shanxi, 030012, China
3School of Metrology and Measurement Engineering, China Metrology University, Hangzhou, Zhejiang, 310018, China
*Corresponding author’s e-mail: 326109580@qq.com
#These two authors contribute equally to this work

Abstract. Two disputes about the metallographic testing of welding joints of the high alloy steel on-site installation welding of the current power plant boiler are discussed. This thesis analyzes the reasons for the two dispute. On this basis, the accordance for the detection, detection method, qualification assessment criteria, etc. and the relevant system documents also makes no requirements.

1.Introduction
The author has found in the process of monitoring and inspection of the boiler installation of the power station that the installation organization does not perform metallographic testing on TP347H (equivalent to 07Cr18Ni11Nb in GB5310, Aussyta body heat-resistant steel) material's screen-mounted superheater site-mounted butt welding joints and TP347H and 12Cr1MoV welding joints of installation welding. The reason is that in the past similar boiler installation process no metallographic testing of the TP347H material installation welding joint is required. Metallographic testing is required by no supervision and inspection agency. The installation organization says that they are not familiar with accordance for testing, testing methods, qualification assessment criteria, etc. and the relevant system documents also makes no requirements.

2.The current situation of metallographic testing of welding joints of high alloy steel installation welding
The investigation made by the author shows at present, some of the domestic power plant boiler installation organization performs no metallographic testing in the installation process. Some supervision and inspection agencies also do not require metallographic testing of welded joints for the installation welding of high alloy steel. There are two disputes about the metallographic testing.
2.1 No need for metallographic testing

Main reasons for no need to perform metallographic testing are as follows.

2.1.1 Boiler Safety Technical Supervision Procedure (TSG G0001-2012) article 4.5 stipulates quality inspection of boiler pressurized components and their welding joints includes appearance inspection, ball test, chemical composition analysis, non-destructive test, mechanical performance test, hydraulic test, etc[1]. No metallographic testing is included.

2.1.2 Grade A boiler installation standard Technical Specifications for Electrical Power Construction Part 2: Boiler Unit (DL5190.2). No metallographic testing is included[2].

2.1.3 Welding Technical Regulations of Thermal Power Plants (DL/T869-2012) article 6.5.3 stipulates that the on-site micro metallographic testing of welded joints should be carried out in accordance with the DL/T884 regulations only when required by contract or design documentation or verification[3]. Metallographic testing does not have to be performed when it is not required by contract or design documents or verification.

2.1.4 Boiler Supervision and Inspection Rules (TSG G7001-2015) item 3.2.5 article 10 stipulates that it is necessary to review the metallographic testing report of welding joint of high alloy steel material installation welding whether it meets the requirements of relevant standards[4]. The rules are formulated for inspection institutions in order to standardize the supervision and inspection work of inspection institutions, and the installation organizations are allowed to make no implement of the rules.

2.2 Need for metallographic examination

Main reasons for need to perform metallographic testing are as follows.

2.2.1 Boiler Supervision and Inspection Rules (TSG G7001-2015) item 3.2.5 article 10 stipulates it is necessary to review the metallographic testing report of welding joint of high alloy steel material installation welding whether it meets the requirements of relevant standards[4].

2.2.2 Welding Technical Regulations of Thermal Power Plants (DL/T869-2012) article 6.5.3 stipulates that on-site micro metallographic testing of welded joints should be carried out when required by contract or design requirements or verification[3]. From the point of view of the systematic structure of special equipment laws and regulations in China, Boiler Supervision and Inspection Rules belongs to the safety technical specification. Welding Technical Regulations of Thermal Power Plants belongs to industry recommended standards. When there is a discrepancy between the two, the provisions of the safety technical specifications should be enforced.

2.2.3 Relevant standards set testing requirements on welding joints (tubes) metallographic testing. Regulations on Safety Supervision of Boiler Pressure Vessels in the Power Industry (DL/T612-2017) article 9.5.1 (c) speculates welding quality inspection of pressurized components includes on-site metallographic examination[5]. Metal Technical Supervision Procedure of Thermal Power Plants (DL/T438-2009) article 9.1.1(b) speculates that the inspection items in the pipe quality inspection supervision report include low-fold inspection and metallographic testing organizations. Article 9.3.8 speculates the superheater tube and reheater tube with wall temperature greater than 450 degrees Celsius during the operation of the unit should be sampled for aging and deterioration of the mechanical properties of the metallographic testing organization, and the quality of the pipe wall thickness, pipe diameter, metallographic testing organization, decarbonization layer and mechanical properties should be checked. Article 9.3.9 stipulates that the superheater tube, reheater tube and the heterogeneous steel welding joints connected to the aucotic stainless steel shall be sampled for aging
of the metallographic testing organization and the deterioration of the mechanical properties[6]. Seamless Steel Pipes for High-Pressure Boilers (GB/T5310-2017) table 11 has set the requirements of the inspection items, sampling quantity, sampling methods, test methods, etc. of metallographic testing[7]. Certificates of Acceptance, Packaging, Marking and Quality of Steel Pipes (GB/T2102-2006) article 4.5.2 stimulates that re-examination is not permitted when the low-fold tissue defects have white dot, micro-tissue in the metallographic testing, the grain size, and decarbonization layer are not qualified in the first test[8]. Rules for the Acceptance of Boiler Materials into the Plant (JB/T3375-2002) article 6.1.2.4 (c) states that high-quality carbon structure steel pipes and alloy structural steel pipes supplied according to GB5310 shall be required for the actual grain size determination and microtissue inspection. Article 6.1.2.4 (d) stipulates cold-drawn (rolled) tubes supplied by GB5310 with outer diameter of not more than 76mm should be required for decarbonization layer inspection[9]. Guidelines for the Supervision of Electrical Equipment (DL/T586-2008) table A1 has set requirements for the inspection of the heterogeneous steel joints of superheater and reheater [10]. Guidelines for the Supervision and Inspection of Thermal Surface Tubes in Boilers in Thermal Power Plants (DL/T939-2005) article 6.6.6(n) stipulates after running time reaches 80,000 hours, the heterogeneous steel joints connected to Auschwitz stainless steel should be examined for the metallographic testing if necessary[11].

3. Analysis & understanding

3.1 Analysis and understanding of legal and regulatory standards

Welding Technical Regulations of Thermal Power Plants (DL/T869-2012) standard applicable steel includes carbon steel, low alloy steel and high alloy steel[3]. Welding of carbon steel and low alloy steel is relatively easy. Control welding quality is generally not easy to form cracks, superheated tissue and hardened mastosome tissue. Therefore, if there is no contract or design requirements or verification needs, welding joints of on-site installation welding are not required for testing. High alloy steel (Auschwitz body heat-resistant steel) alloy element content is high, and the selection of welding process is not proper, and it is easy to have defects such as intercrystalline corrosion and thermal crack. Requirements for welding specifications (e.g. low heat input, multi-layer multi-channel welding, strict control of interlayer temperature, the welding torch shall not swing in the transverse direction, etc.) and inspection process are high. Therefore, in order to strictly control the welding quality and prevent the early failure of high alloy steel welding joints, it is necessary to perform metallographic testing.

Boiler Supervision and Inspection Rules (TSG G7001-2015) item 3.2.5 article 10 stipulates it is necessary to review the metallographic testing report of welding joint of high alloy steel material installation welding whether it meets the requirements of relevant standards[4]. This article does not have any premises, such as no contract or the design document, or the need for verification. On the basis of this article, the following three points can be drawn.

(a) Metallographic testing shall be carried out for the installation of welded joints of high alloy steel material at the boiler installation site, the methods of metallographic inspection of installation organization, the proportion and qualification standards shall conform to the regulations of Boiler Safety Technical Supervision Procedure and related standards[12];

(b) Boiler installation supervision and inspection personnel examines metallographic testing report;

(c) The content of the examination is whether the metallographic test report (metallographic testing items and test results) meets the requirements of the relevant standards.

The metallographic testing is a follow-up test. In order to evaluate the aging and aging speed of the components and materials accurately, the microstructure of the on-site welding shall be the source basis, and the later organizational morphology change, metallographic composition change, carbide coarsening and metallographic structure change shall have the reference standard.

As a formal boiler installation organization licensed by the state administration, the quality assurance system documents shall meet the requirements of the special equipment safety technical specification, and shall also implement the requirements of item 3.2.5 article 10 of Boiler Supervision
and Inspection Rules (TSG G7001-2015). The standards mentioned in 2.2.3 of this article have relevant rules for metallographic testing requirements; therefore, it has good reason that the high alloy steel installation welding joint requires that the metallographic examination. There are many metallographic examination techniques and methods applicable for power plant components. The Technical Guide for Metallographic Testing and Evaluation of Thermal Power Plants (DL/T884)[13] specifies the basic requirements and main operating steps for the on-site and laboratory inspection of high temperature components in thermal power plants by metallographic methods. The basic process and evaluation standard of metallographic analysis are also stipulated and metallographic testing can be carried out according to the standards. The specific method of metallographic detection and analysis is selected by the installation organization according to the purpose of the analysis, and it is clearly stipulated in the quality assurance system document.

3.2 Theoretical analysis and understanding

In the welding of the high alloy steel and the low alloy steel, the austenitic stainless steel and the ferritic heat-resistant steel, the failure problem is very easy to occur at the welding joint[14]; Because of the two materials have great differences in the mechanical property, the chemical composition, the metallographic structure and the thermal expansion coefficient, the welding of the austenitic steel and the 12Cr1MoV results in a crack source[15], as shown in figure 1,2; In the hardened fusion zone, there is an engineering example. Before the water pressure test made after the installation of an ultra supercritical unit is completed, it is found that there is a crack parallel to the weld bead in welding joint between the high temperature superheater tube screen SA-213T91 and HR3C high alloy dissimilar steel[16], as shown in figure 3.
It is pointed out in relevant literature that in the process of post-weld heat treatment, carbon will migrate and spread between the welding seam and the base metal in the welded joint of TP347H and 12Cr1MoV dissimilar steel. Because the chromium with high nickel-based weld content is easy to form carbides with carbon, the free carbon concentration in the weld metal near the fusion line decreases, and the carbon in the low alloy base metal diffuses to the weld and further forms carbides in the weld. A certain carbon-poor zone is formed at the base metal near the fusion line, resulting in a great difference in carbon content between the two sides of the fusion line. The low alloy steel side hardness of fusion line decreases (softens), and the weld side hardness of fusion wire increases (hardened), which makes the fusion line become a weak part with large hardness difference, and it is easy to form microcracks at a higher residual stress level, which leads to the early failure of welded joint.

The metallographic examination of welded joints with high alloy steel can obtain the information of carbide precipitation growth and spheroidizing degree, creep porosity and cracking tendency, and eliminate the existence of microcracks, overheated microstructure and hardened martensite structure, which plays a positive role in preventing the early failure of welded joints.

3.3 Other analysis and understanding

3.3.1 Qualification criteria. The conformity standard of metallographic structure of welded joint shall comply with the following regulations: 1. No cracks, no looseness. 2. There is no overheated tissue. 3. There is no hardened martensite structure. 4. δ-Ferrite must not exist in the metallographic structure of single Austenite steel weld metal.

According to the relevant literature [15-19], Table 1 shows the common failure locations of high alloy steel welded joints.

| Serial number | Base metal                  | Welding consumables | Failure position   |
|---------------|-----------------------------|---------------------|-------------------|
| 1             | 12Cr1MoV + ZGCr20Ni14Si2Mn1.5 | ER316L              | Near fusion line  |
| 2             | SA-213 T91 + HR3C           | ERNiCr-3            | Near fusion line  |
| 3             | TP347H + 12Cr1MoV           | Inconel82           | Near fusion line  |
| 4             | TP347H + 06Cr19Ni10         | ER308               | Near fusion line  |

As seen from table 1, the failure of welded joints of high alloy steel mainly occurs near fusion line, so metallographic testing should focus on the metallographic structure near fusion line.

3.3.2 The current relevant standards do not stipulate the proportion of metallographic testing of welded joints in installation welding. Before the introduction of the relevant standards, the installation organization shall define the proportion of metallographic testing in the quality assurance system documents.

4. Conclusion

The material of the high-temperature component of the power station boiler is easily aged and damaged, which is of great importance to the safety operation of the boiler, and the aging damage condition of the welding joint can be effectively checked and tracked by the metallographic examination method. At present, some installation organizations and supervision and inspection organizations do not make requirements for metallographic testing of welded joints for high alloy steel installation of power station boilers, which need to be paid great attention to in all aspects. It is suggested that the newly revised Boiler Safety Technical Supervision Procedure and other safety technical specifications and related standards should clarify the specific requirements for metallographic testing of welded joints installed with high alloy steel for power station boilers, so that
all parties can comply with the implementation and ensure the installation and welding quality and safe operation of high alloy steel for power station boilers.

References

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[8] GB/ T2102-2006 Acceptance, Packaging, Marking and Quality Certificate of Steel Pipe[S].
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