Research Situation of Welding Performance for P92 Heat Resistant Steel

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Abstract. In this paper, the welding performance of P92 ferritic heat resistant steel in recent years was introduced. P92 steel was a ferritic/martensitic steel, which had been brought to commercial maturity during the last decade due to its excellent high temperature performances. However, the welding related problems of P92 steel was gradually exposed with the wide application, causing a serious impact on the production and operation of boiler unit. Therefore, Strengthening research and development of suitable welding process and post weld heat treatment process that can lead P92 heat-resistant steel to being better serve in the power industry for our country will be the focus of metal workers in the next step.

Keywords: P92; Weld; δ-ferrite; Application.

1. Introduction
With the development of ultra supercritical thermal power units in the direction of high power and high parameters, the research on P92 ferritic heat resistant steel has been widely carried out in the United States, Japan, Germany and other industrialized countries [1-2]. Therefore, the welding technology of P92 steel will also be widely used in the construction and repair of thermal power units [3-4]. In the 1990s, the weldability of P92 steel was studied by Electric Power Research Institute (EPRI) and several research institutes. After that, the weldability of this steel was continuously studied in Japan and other developed countries of Europe. The application of P92 ferritic heat-resistant steel in foreign power plant projects is shown in Table 1 [5-8].

At present, there are few researches on welding application of P92 ferritic heat resistant steel in China. Excepting for Huaneng Yuhuan Power Plant, which is the first one million kilowatt ultra supercritical unit project of China, and the designed service temperature of unit is 600 ℃, steam pressure is 26.25 MPa, therefore the performance of service materials required is to be very high. After the research and discussion of the relevant departments in China, P92 steel is finally selected for the construction of the main steam pipeline project of Yuhuan Power Plant, which can not only meet the high temperature durability and oxidation resistance required by the production and operation, but also reduce the project cost. However, the engineering application of P92 heat resistant steel is still blank in China. Therefore, in order to solve the related problems of welding applications, the welding procedure qualification of P92 steel was carried out by Xi'An institute of thermal engineering and several power construction
companies in early 2005s and a lot of instructive data were obtained. After initially solving the problems related to the weldability of P92 steel, seven ultra supercritical units in Huadian Zouxian Power Plant and Guodian Taizhou Power Plant were successively constructed.

Table 1. Application examples of P92 steel in foreign power plant projects

| Country | Project name | Pipe size/mm | Parts       | Steam temperature/℃ | Steam pressure (MPa) | Operation time |
|---------|--------------|--------------|-------------|----------------------|----------------------|----------------|
| Denmark | Vestraft     | 240×39       | Main steam pipe | 560                  | 25                   | 1996s          |
|         | Nordjyliandest | 160×45       | Header      | 582                  | 29                   | 1996s          |
|         | Avedore2     | 400×25       | Main steam pipe | 602                  | 32.9                 | 1999s          |
|         | Elkraft      | 490×30       | Header      | 545                  | 5.3                  | 2001s          |
| Germany | Kiel/Gi      | 480×28       | Header      | 650                  | 1.8                  | 1997s          |
| ST      | Westfailen   | 159×27       | Main steam pipe | 600                  | 25                   | 1998s          |
| Japan   | Orange bay 2 | 635×106      | Main steam pipe | 600                  | 25                   | 1998s          |

2. Weldability of P92 heat resistant steel

P92 ferritic heat-resistant steel is mainly used in boiler superheater, reheater, pipeline and header of ultra supercritical thermal power unit. In such a harsh environment, the heat-affected zones of the joint experiencing a special welding thermal cycle will destroy the good properties of the original base metal and can not be restored [9]. At the same time, it can also result in the segregation of ferrite components and the formation of δ-ferrite in local area. In general, the microstructure of the welded joint is an inhomogeneous body, different thermal processes of weld, heat-affected zone and base metal lead to the difference in grain size of austenite, orientation and size of martensite lath, and distribution, size, type of precipitation phase, and these changes in microstructure will inevitably change the properties of P92 heat resistant steel. Therefore, the analysis and research on the changes of microstructure and properties of P92 heat-resistant steel welded joint is an urgent difficult in the power construction industry [9-10]. By adjusting and improving the composition of P92 ferritic heat resistant steel, a variety of mixed strengthening effects including solution strengthening, precipitation strengthening and grain boundary strengthening are formed [11]. At the same time, micro alloying, controlled rolling and controlled cooling are also used to obtain high density dislocations and fine grains to further improve the strength and toughness of this material. These complex mixing strengthening methods make the weldability of P92 heat-resistant steel more complex, and more problems about welding will be presented.

3. Common problems in welding

3.1. Creep fracture

The creep behavior and microstructure stability of P92 steel were studied by Ennis [12] et al. The results revealed that the influence factors of the creep properties mainly include the change of dislocation density in subgrain, the multilateralization of subgrain, the coarsening of M23C6 phase, the stability of MX phase and the content of W and Mo elements in laves phase. The creep crack of P92 welded joint is a typical IV level, which always occurs in the heat affected zone of the welded joint. Compared with the base metal and weld zone, the creep fracture life of heat-affected zone is shorter and the crack growth rate is faster. The creep fracture position of heat-affected zone always appears in the critical heat affected zones, where there are a lot of creep holes. The results obtained by Wang [13] et al showed that the IV creep fracture occurs at the dimple temperature and low stress condition, and it was located in the fine grain heat affected zone near the critical heat affected zone. And the fine equiaxed grains without lath structure and low hardness would also lead to the instability of microstructure in this region. The density
number of laves phase at the grain boundary of the fine grain heat affected zone is apparently higher than that in other regions, and the creep cavities nucleate preferentially in the coarsened laves phase. Compared with the creep property of base metal, the heat-affected zone of fine grain will be deteriorated. In addition, the formation and growth of the vacancy and crack in the crystal will lead to the increase of creep rate in the thermal affected zone of the fine grains in the welded joint.

3.2. Embrittlement of welded joint
In the welding process, when the welding temperature is too low and the fluidity of weld pool metal is poor due to the unsuitable welding process parameters, the composition segregation will appear in the weld metal [14]. When the weld pool temperature is too high, the grain size of the welded joint will be coarse due to the high heat input, which will lead to the embrittlement of joint. In addition, P92 steel has a high content of alloying elements and a serious tendency of hardening. Therefore, coarse martensites will be formed when it is cooled in air after welding, causing the embrittlement of joint. In the welding joint, a certain amount of $\delta$-ferrites will be formed due to the influence of welding process parameters and base metal composition. The formation of $\delta$-ferrites will significantly reduce the strength of the joint and bring adverse effects. Therefore, in the welding process, it is necessary to select the appropriate welding process parameters, strictly control the heat input and take appropriate post weld heat treatment process, which can effectively reduce the tendency of joint embrittlement [15].

3.3. Reduce of toughness
The reduction of weld toughness is a common problem for high Cr ferritic heat resistant steel after welding [16]. During the welding process, the coarse columnar grains in the weld are often much larger than those in the base metal, so it is difficult to precipitate carbonitrides which play a strengthening role in the base metal in the weld. At the same time, Nb, V and other elements may not precipitate during the post weld heat treatment, and the residual elements will reduce the toughness of the weld, therefore the toughness of the weld will be far less than that of the base metal. When the welding parameters are not suitable and the welding heat input is too high, a large number of tangled dislocations will be produced in the heat affected zone due to the lattice distortion and volume expansion, which will reduce the impact toughness of the joint. At the same time, due to the influence of welding parameters and base metal composition, a certain amount of $\delta$-ferrites will be formed near the fusion line. And the formation of $\delta$-ferrites will significantly reduce the impact toughness of the joint and bring adverse effects on the joint. When the welding parameters are not suitable, coarse martensites will be formed in the weld, and massive ferrites may be formed near the fusion line, which will have a negative impact on the toughness of the joint too [17]. The impact toughness of weld can be improved by controlling heat input line energy, selecting suitable welding process parameters, adjusting weld metal composition and optimizing post weld heat treatment process.

4. Conclusions
As the heat-resistant steel, P92 is very favored by all countries in the world, and preferred for ultra supercritical thermal power units. P92 steel can not only meet the requirements of high temperature endurance and oxidation resistance, but also reduce the wall thickness and engineering cost. At present, P92 steel welding technology is widely used in the construction and repair of ultra supercritical units. However, the welding performance of P92 steel is still very limited in China. Strengthening research and development of suitable welding process and post weld heat treatment process that can lead P92 heat-resistant steel to being better serve in the power industry for our country, which will also be the focus of metal workers in the next step.

Acknowledgments
This research was financially supported by Youth science and technology project of Inner Mongolia Electric Power Research Institute (Grant No. 2020-QK-08).
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