Small Diameter Tube Post-Weld Heat Treatment Process with Brinell Hardness and Microstructure Inspection

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Abstract. The local post-weld heat treatment (PWHT) process test of 9Cr-3W-3Co small-diameter pipe welded joints was carried out using rope-type resistance heaters with different parameters, and the Brinell hardness test and microstructure observation were carried out on the welded joints after heat treatment. The results show that when the heating width was 200mm, the constant temperature was 790℃-800℃, and the constant temperature time was 2 hours, the Brinell hardness of the weld was in the range of 246HBW-265HBW, which had good performance. After tempering at 760℃-800℃, the welds all showed a clear tempered lath martensite.

Keywords: Rope-type resistance heaters, Post-weld heat treatment, Brinell hardness, Microstructure.

1. Introduction
In order to improve the environment, all countries are reducing CO₂ gas emissions. For thermal power plants, increasing boiler steam temperature parameters can improve power generation efficiency and reduce CO₂ gas emissions. At present, T/P92 steels are mostly used for the main steam and final superheater of ultra-supercritical units, and the maximum allowable temperature is about 620°C. In recent years, Japan, China and other countries have developed a new steel grade, named 9Cr-3W-3Co steel [1-2]. The maximum allowable temperature of this steel grade can reach 650°C. This steel is a high-alloy steel. The structure after welding is a hardened martensite structure with high residual stress. In order to reduce stress and stabilize the structure, PWHT must be performed [3]. The current research on 9Cr-3W-3Co steel mostly focuses on the base metal, including the influence of heat treatment process on the structure and properties of the base metal [4], and the high-temperature creep properties of the base metal [5]. However, the research on the on-site PWHT process has not been reported in the literature. Unlike the PWHT in the furnace, the post-weld heat treatment on-site is a local heat treatment. The quality of the PWHT is of great significance to the long-term stable operation of the tube [6]. The purpose of this article is to study the PWHT process using resistance heating for the engineering application of 9Cr-3W-3Co small diameter tubes to determine the better PWHT parameters and to guide the engineering application of 9Cr-3W-3Co steel.
2. Experimental methods

2.1. Welding and preheating

The size of the 9Cr-3W-3Co tube used in the test is Ф54*8mm and 500mm length. The chemical composition of the tube is shown in Table 1. The V-shaped groove with blunt edges 1~2mm adopted and the groove angle was 60±5°. The welding method was TIG+SMAW. Welding wire and electrode was 2.4mm and 2.6mm respectively, which were provided by the manufacturer. Welding process parameters included: welding current 90~110A, welding voltage 24-28V, welding speed 65-80mm/min, preheating and interlayer temperature controled between 200-250°C, A rope-type resistance heater adopted for weld preheating, and the heating width was controlled by the number of winding turns. The inner resistance wire of the heater is made of Cr20Ni80 material, and the outer insulation is oxide ceramic beads. The preheating heating width was 100mm on both sides of the groove. The thermocouple type was K-type armored thermocouple. One was tied with iron wire at the middle of the heating width as a temperature control thermocouple, and the other was tied at a position 20mm away from the groove as a monitoring thermocouple. The other end of all thermocouples was connected to the control panel of the instrument. Rock wool on the outside of the heater was used as an insulation layer to reduce heat loss.

Table 1. Chemical composition of 9Cr-3W-3Co tube (wt%).

| C   | Si  | Mn  | Cr  | W   | Co  | Cu  | Ni  | V   | Nb  | N   | B   |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 0.08| 0.15| 0.66| 8.85| 2.76| 2.73| 0.80| 0.03| 0.17| 0.04| 0.02| 0.011|

2.2. Post welding heat treatment (PWHT) of deposited metal

The PWHT was performed after the welding was completed and cooled to room temperature. Two thermocouples also used for temperature measurement and monitoring respectively. The layout diagram of the resistance heater, insulation rock wool and thermocouples is shown in Figure 1. Experiment by changing the heating width of the heater, the insulation width of the rock wool, the heating constant temperature, the constant temperature time, the temperature rise and fall speed and other parameters. The test parameters are shown in Table 2, and the photos of the test process are shown in Figure. 2.

Figure 1. Schematic diagram of local heat treatment layout.
2.3. Hardness Testing
The welded joints under different test conditions were cut by a metallographic cutting machine, and hardness testing was performed on the joints by a Brinell hardness tester in the laboratory according to the standard ISO6506-1: Metallic materials-Brinell hardness test-Part 1: Test method. The diameter of the test cemented carbide ball is 5mm, the test load is 7355N, and the loading time is 15s. Before the test, the surface and root of the welded joint will be ground flat, and the average value of the five points of the test will be taken.

2.4. Microstructure observation
The cut welded joints first ground by pre-grinding machine with sandpapers of 200-800 grid and then polished with diamond polishing agent on the polishing machine for about 20s. Then, etched for about 15s with etching agent (FeCl$_3$: 5g, HCl: 50mL, H$_2$O: 50mL), and observed the microstructure of the welded joints under a metallographic microscope.

3. Experimental results and analysis

3.1. Hardness
Figure 3 shows the test results of the hardness of the welded joint at the heat treatment temperature of 760℃~800℃. It can be seen that the hardness of the weld surface is slightly higher than that of the root of the weld at different heat treatment temperatures, and the deviation is about 2~7HBW. The temperature control thermocouple was located on the surface of the weld, and the heat of the root came from the conduction of surface heat. There was a certain temperature gradient between the surface and the root of the weld, but from the test results, the temperature gradient is not large and the impact on the hardness can be ignored. As the heat treatment temperature increased, the hardness of the weld decreased. According to the literature [7-8], for 9~12% Cr heat-resistant steel, the hardness

![Figure 2. The photos of the PWHT process.](image)

| No. | Heating width /mm | Insulation width /mm | Heating rate /℃/h | Constant temperature /℃ | Soaking time /h |
|-----|-------------------|----------------------|------------------|--------------------------|-----------------|
| 1   | 100               | 300                  | 300              | 760                      | 1.5             |
| 2   | 100               | 300                  | 300              | 780                      | 1.5             |
| 3   | 200               | 350                  | 300              | 790                      | 2               |
| 4   | 200               | 400                  | 200              | 800                      | 2               |

Table 2. Process parameter design of PWHT for 9Cr-3W-3Co tube.
should be controlled at 185~270HB in order to obtain better weld performance, as shown in Figure 2 below the dotted line. Therefore, the PWHT temperature is controlled should be at 790°C-800°C and the soaking time for 2 hours. The weld joint could get hardness between 246HBW-265HBW, which can get good performance. The literature reports that for P92 or P91 steel welded joints, the usual post-weld heat treatment temperature is 760°C, which is lower than the PWHT temperature in this work, so it can be inferred that the 9Cr-3W-3Co material has a higher \( A_{c1} \) point.

![Figure 3. Brinell hardness of welds under different heat treatment temperatures.](image)

3.2. Microstructure analysis

![Figure 4. Tempered martensite structure for PWHT at (a) 760°C, (b) 800°C.](image)

Figure 4 shows the microstructure photos of the welds at different heat treatment temperatures. It can be seen that after tempering at 760°C, 800°C, the welds all shows the characteristics of lath martensite. The difference is not obvious, and no residual austenite and delta ferrite were found in the structure. The reason mainly due to the existence of Co which accelerates the transformation of austenite to martensite. Therefore, it is not appropriate to evaluate the quality of heat treatment by means of on-site metallography.
4. Conclusions
When the heating width is 200mm, the best temperature range for PWHT of 9Cr-3W-3Co small diameter tube is 790℃-800℃. For this, the weld hardness range of PWHT is 248HBW-260HBW, which has better performance.

When the PWHT temperature between 760℃-800℃. The microstructure of the welded joint of 9Cr-3W-3Co small diameter tube is a clear lath tempered martensite structure, and no delta ferrite was found. Therefore, it is not easy to judge the quality of weld after heat treatment.

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