Effect of Different Tempering Temperature on the Microstructure and Properties of G115 Steel Weld

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Abstract. Evolution of microstructure and room-temperature strength of G115 deposited metal after different tempering at 760°C, 800°C and 820°C have been experimentally investigated using metallographic microscope, field emission scanning electron microscopy (SEM) and tensile test, charpy impact test. The results show that after tempering at 800 °C, the G115 deposited metal has the best mechanical properties and can obtain obvious tempered martensite structure of lath bundle. Tempering at 760-800°C, the M_{23}C_6 precipitates has a tendency to grow up. The main mechanism that produces the above results is the recovery of martensite and the precipitation of carbon during high temperature tempering. Spherical oxide inclusions formed by welding metallurgy were found in the dimples of the impact fracture of the deposited metal and its influence on the high-temperature durability of the deposited metal needs further study.

1. Introduction
Increasing the thermal efficiency of coal-fired power plants can reduce CO_2 gas emissions and improve environmental quality, the improvement of thermal efficiency mainly depends on the steam temperature and steam pressure. At present, most of the main steam pipes of ultra-supercritical power plants use P92 martensitic heat-resistant steel, and its upper-use temperature is about 600 °C. In order to further improve the steam parameters of the USC unit, many countries have researched and developed the third generation of martensitic heat-resistant steel. Such as the MARBN steel (9Cr-3W-3Co-VNbBN) developed by Japan’s National Institute for Material Science (NIMS), the G115 (9Cr-2.8W-3CoCuVNBnBN) steel developed by China Iron and Steel Research Institute [1,2].

Compared to P92 steel, this kind of martensitic heat-resistant steel is added with about 3% Co as a solid solution strengthening element, which can also assure get completely tempered martensite. The coarsening of M_{23}C_6 precipitate can be largely suppressed by adding W, B and N. So the allowable upper temperature limit of the third-generation martensitic heat-resistant steel used in USC power plants can reach 650 °C. A lot of research work has been done on G115 steel, Such as the effect of normalizing temperature on the room temperature strength, the effects of applied stress on creep deformation behavior, the effect of chemical composition on microstructural aspects and creep behavior, the effect of microstructural evolution on high-temperature strength under different aging conditions and so on [3,4,5]. However, the application of 9Cr-3W-3Co steel is inseparable from welding. At present, there are few research reports on the microstructure and properties of G115 welded joints. The present paper studied the effects of different post-weld heat treatment (PWHT) temperatures on the microstructure
and mechanical properties at room temperature of G115 deposited metal and determines the better range of post-weld heat treatment temperature in order to guide the engineering application of G115 steel.

2. Experimental methods

2.1. Welding of deposited metal

The material of the base metal was A283 C and its size was 300×260×20mm. G115 steel electrode used for welding provided by the supplier and the diameter of the welding core is 3.2mm. Tab.1 shows the chemical composition of the G115 electrode deposited metal. In order to prevent the dilution effect of the base metal on the deposited metal, the isolation layers with thickness about 3mm were cladded on both sides of the groove. Before welding, dried the electrode to about 150℃. The welding process parameters include welding current of 90~95A, welding voltage of 24~28V and welding speed of about 65~80mm/min. The temperature between layers was controlled at 200~250℃. Deposited metal total welded 8 layers and 24 passes under above parameters. The welding groove is shown in Fig. 1.

| C   | Si | Mn | Cr  | Mo | W  | Co | Cu | Ni | V  | Nb | N  | B  |
|-----|----|----|-----|----|----|----|----|----|----|----|----|----|
| 0.09| 0.17| 0.69| 8.81| 0.02| 2.77| 2.71| 0.83| 0.03| 0.17| 0.04| 0.02| 0.011 |

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

G115 steel is a martensitic heat-resistant steel. In order to improve the tendency of cold cracking, stress in the weld as well as the properties of the weld, PWHT must be performed on the weld. The PWHT process has an important influence on the long-term stable operation of welded joints. To avoid phase change, the temperature of the PWHT cannot exceed the A<sub>c1</sub> point of the deposited metal. Refer to related literature for the estimation formula of A<sub>c1</sub> point of 9Cr heat-resistant steel [6], the PWHT temperature of the deposited metal in the furnace determined was 760 ℃, 800℃, 820℃ and corresponding holding time was 2h. The temperature rising and falling rate was 150℃/h and the temperature was not controlled under 350 ℃ to room temperature.

2.3. Mechanical properties of deposited metal

Mechanical properties were tested at room temperature for the deposited metal specimens at different heat treatment temperatures. Tensile tests were performed based on standard of GB/T228-2010, which can determine the tensile strength R<sub>m</sub>, yield strength R<sub>p0.2</sub> and elongation A. The specimens used are 6mm in gage diameter and 30mm in gage length. Charpy V shaped impact tests were performed based on standard of GB/T229-2010. The size of the impact specimen was 10×10×55mm. Fig.1 give the location of the tensile and impact specimens in the deposited metal. The microhardness tester was used to measure the microhardness of the deposited metal. The tests were carried out on the impact specimens before V-notch processed. 5 measurements for each specimen from top to bottom and take the average as a test result. The load were 10Kg and and holding time was 10s respectively.

2.4. Investigation on the microstructure and fracture of deposited metal

The microstructure observation specimens of deposited metal at different tempering temperatures were taken from impact specimens. After grinding and polishing, the samples were etched for about 20s with etching agent (FeCl<sub>3</sub>:5g, HCL:50mL, H<sub>2</sub>O:50mL) and then observed by the metallographic microscope. Scanning Electron Microscope (SEM) with energy dispersive X-ray spectroscopy (EDS) were used to characterize the precipitates of the deposited metal and the fracture of impact specimens.
3. Experimental results and analysis

3.1. Mechanical properties of deposited metal

Table 2 shows the mechanical properties of the deposited metal at different tempering temperatures. It can be seen with the increase of the tempering temperature, the tensile strength and the microhardness of the deposited metal both show a trend of decreasing first and then increasing. The corresponding elongation and impact value first increase and then decrease, and the yield strength does not change significantly. The room temperature mechanical properties of the deposited metal have the best value after tempering at 800°C. The results can be analyzed when the tempering temperature is below the $A_c1$ point, with the increase of the tempering temperature, the dislocations recovery will reduce dislocation density. At the same time, the precipitation will weaken the solid solution strengthening effect. So the strength of deposited metal decreased, plasticity and toughness increased. But when the tempering temperature is higher than the $A_c1$ point, a new austenitizing zone formed during the preservation process, and the untempered martensite structure regenerated in the subsequent cooling process, which can cause the increasing of strength and microhardness and decreasing the ductility and toughness of the deposited metal. The below numerical equation based on Mn and Ni contents reported by Santella et al. was used to calculate the $A_c1$ temperature [6]. According to the contents of Mn and Ni in Tab.1, the lowest $A_c1$ point calculated to be about 800°C. Therefore, tempering at 820°C maybe has exceeded the $A_c1$ point of the deposited metal.

$$A_{c1}(^\circ C) = 854.5 \pm 0.6 - 43.9 \pm 1 \times (Mn + Ni) - 9 \pm 0.4(Mn + Ni)^2$$  \hspace{1cm} (1)

| NO. | PWHT/°C | $R_m$/MPa | $R_{p0.2}$/MPa | $\delta$ (%) | $AK$/J | HV10 |
|-----|---------|------------|----------------|-------------|--------|------|
| 1   | 760     | 810        | 593            | 17          | 23     | 264  |
| 2   | 800     | 725        | 590            | 20          | 42     | 222  |
| 3   | 820     | 763        | 589            | 19          | 21     | 240  |
3.2. Microstructure of deposited metal

Fig. 2 shows the microstructure of the deposited metal at different tempering temperatures. All of which are martensite but the shape of martensite is different. Tempered at low temperature (760°C), martensite lath Bundle characteristics are not obvious. With the increase of tempering temperature (800-820°C), martensite gradually shows clear lath group and lath bundle characteristics. The main reason for the change of martensite morphology is that with the increase of tempering temperature, the precipitation of strong carbide forming elements in the deposited metal will cause the carbides to segregate and resulting in corrosion resistance in local areas of the matrix. Under the metallographic microscope which presented a brighter color. In addition, adjacent martensite laths will merge and become wide laths and resulting in obvious characteristics of martensite lath bundles [7]. Fig. 3 shows the SEM pictures of the deposited metal at different tempering temperatures. According to the literature, we know that the white precipitated phase in the figure is M23C6. It can be seen from the figure that the tempering temperature increased from 760°C to 800°C. The M23C6 precipitates has a tendency to grow up. From 800°C to 820°C, the tendency is not obvious. The reason is that with the increase of tempering temperature, the diffusion ability of atoms increased and the supersaturated carbon precipitated from the matrix caused the precipitations of M23C6 to grow up. When the carbon elements were precipitated to a certain extended to balance that the M23C6 precipitations no longer grows up significantly even if the tempering temperature was increased. The size evolution rules of M23C6 precipitations need further experimental study.

Figure 2. Tempered martensite structure for tempering temperature at (a) 760°C, (b) 800°C

3.3. Investigation on the impact fracture surface of deposited metals

Fig 4 (a) shows the impact fracture of the deposited metal after heat treatment. It can be seen that the fracture is divided into a brittle zone and a plastic zone. The higher the impact value, the greater the proportion of the plastic zone. The brittle zone is characterized by the quasi-cleavage fracture of the river pattern (Fig 4(b)) and obvious tearing edges (steps). There are some dimples on the cleavage fracture surface. The plastic zone is characterized by obvious dimple fracture(Fig 4(c)).Spherical second-phase particles can be seen in the above part of the dimples and its EDS analysis results is shown in Figure 4(d). It can be seen that the second-phase spherical particles contain more elements of Ti, Mn, and O, so the formation of spherical particles can be judged from deoxidation reaction in the welding metallurgy process. It is reported in the literature that Ti can refine the size of grains and precipitates in G115 steel, and can also form fine dispersed phases with N and C to play a role of dispersion strengthening [8]. Too high Ti content in inclusions may adversely affect the long-term creep properties of welded joints.
Figure 3. Distribution of M$_{23}$C$_6$ phase: (a) 760$^\circ$C, (b) 800$^\circ$C, (c) 820$^\circ$C,
Figure 4. Fracture of impact specimens and EDS results of spherical particles

4. Conclusions
G115 steel deposited metal has the best room temperature mechanical properties when tempered at 800°C. Tempered under 760°C, the characteristics of tempered martensite slabs were not obvious. Tempered between 800-820°C, the deposited metal of G115 steel had obvious characteristics of martensite lath. Tempered between 760-800°C, the M$_{23}$C$_6$ precipitates in the deposited metal had a growing trend, which was not obvious when tempered between 800-820°C.

The impact fracture of G115 steel deposited metal at different tempering temperatures can be divided into ductile fracture and cleavage fracture. The higher the impact value, the larger the area of ductile fracture in the fracture area. There were a large number of spherical particles in the dimples which formed during welding metallurgy.

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References
[1] P. Yan, Z.D. Liu, Toughness evolution of 9Cr–3W–3Co martensitic heat resistant steel during long time aging, Mater. Sci. Eng. A 650 (2016) 290-294.
[2] B. Xiao, L.Y. Xu, L. Zhao, H.Y. Jing, Y.D. Han, K. Song, Transient creep behavior of a novel tempered martensite ferritic steel G115, Mater. Sci. Eng. A 716 (2018) 284-295.
[3] B. Xiao, L.Y. Xu, L. Zhao, H.Y. Jing, Y.D. Han, Y. Zhang, Creep properties, creep deformation behavior, and microstructural evolution of 9Cr-3W-3Co-1CuVNbB martensite ferritic steel, Mater. Sci. Eng. A 711 (2018) 434-447.
[4] A. Fedoseeva, N. Dudova, R. Kaibyshev, Creep strength breakdown and microstructure evolution in a 3%Co modified P92 steel, Mater. Sci. Eng. A 654 (2016)1-12.
[5] F. Abe, Precipitate design for creep strengthening of 9% Cr tempered martensitic steel for ultrasupercritical power plants, Sci. Technol. Adv. Mater. 9 (2008) 1-15.
[6] Pandey C, M. M. Mahapatra , P. Kumara, N. Sainia, Some studies on P91 steel and their weldments,J. Alloy Compd. 743 (2018) 332-364.
[7] J. Hald, Microstructure and long-term creep properties of 9 - 12 % Cr steels, Int. J. Pres. Ves. Pip. 85 (2008) 30-37.
[8] F. Abe, Precipitate design for creep strengthening of 9% Cr tempered martensitic steel for ultrasupercritical power plants, Sci. Tech. Adv. Mater. 9 (2008) 1-15.