Effects of PWHT on Microstructure and Mechanical Properties of A516 Gr.70

Liye Qin¹ᵃ, Yang Zou¹² and Xinyu Zhang¹
¹Shougang Research Institute of Technology, Beijing, China
²Beijing key Laboratory of Green Recyclable Process for Iron & steel Production Technology, Beijing, China
ᵃ Corresponding author: qinliye1986@163.com

Abstract. The article describes the effect of simulated post weld heat treatment (PWHT) on the properties and microstructure of high performance pressure vessel steel plate A516 Gr.70. The research indicates that the strength decreased sharply and the toughness is decreased slightly with increasing simulated PWHT times. And the strength of plate with high carbon content decrease more than which with low carbon content. The main reason of strength decrease is the ferrite degenerated after simulated PWHT. However, the strength can still satisfy the standard requirement with the reasonable composition design.

1. Introduction
In the recent years, the A516 Gr.70 pressure vessel steel plates were more and more used for foreign related projects. In order to improve the weld joint properties and eliminate the adverse effects of weld residual stress, the post weld heat treatment (PWHT) was usually taken in the manufacture of pressure vessel or later. The PWHT technology for A516 Gr.70 may be different for different requirements. The PWHT is a kind of stress relief annealing and a part or component is heated to a special temperature and hold for a fixed time and then cooled in the air. After PWHT the yield strength and tensile strength of the plate will be decreased. An amount of reports had been published about the research on effect on mechanical property of PWHT through simulating method in Lab[1]-[6]. But few specially discuss the reason of strength decrease for A516 Gr.70 after different PWHT technology.
In this article, three kinds component of A516 Gr.70 were simulated PWHT for different time in lab. The mechanical property was measured and microstructure were observed.

2. Experimental procedure
Three kinds of samples were taken in this paper. The chemical composition of samples is given in table1, C content is different from 0.17% to 0.23%. The samples are taken from rolled plates, and then normalize with temperature 900℃. At last, the samples were simulated PWHT with different times in the lab.

Table 1. The chemical composition of samples

| No. | C  | Si  | Mn  | P≤  | S≤  | Nb+V +Ti≤ |
|-----|----|-----|-----|-----|-----|-----------|
| C20 | 0.20 | 0.24 | 1.46 | 0.008 | 0.003 | 0.1       |
The simulated PWHT were taken for normalized plates. The heating rate of simulating PWHT is not larger than 100℃/h and hold for 2 hours, then cooled to room temperature at the speed not larger than 100℃/h. The samples were taken by simulated PWHT for 1, 2 and 3 times respectively. The specimens number and heat treatment technology are given in table 2.

| No. | Normalizing | PWHT temperature | PWHT hold time | cycle times |
|-----|-------------|------------------|----------------|-------------|
| C20 | 900℃        | 620℃             | 2h             | 1 time/2 times/3times |
| C23 | 900℃        | 620℃             | 2h             | 1 time/2 times/3times |
| C25 | 900℃        | 620℃             | 2h             | 1 time/2 times/3times |

After the simulated PWHT, the specimens were tested mechanical properties following standard ASTM test method, and the microstructure were observed by OM and SEM.

3. Results and discussion

Table 3, table 4 and Fig. 1 show the mechanical properties of the samples. The samples have different chemical composition and were heat treated differently. The normalizing samples show higher yield strength and tensile strength. When simulated PWHT were taken, the yield and tensile strength of normalizing samples decreased. The strength decrease is more and more with the increase of PWHT times. For normalizing samples, the C25-1 samples show the highest yield strength and tensile strength, the C20-1 samples show the lowest yield strength and tensile strength. The yield strength and tensile strength for 0.25 C content sample decreased more than the 0.20 and 0.23 C content samples when taken by simulated PWHT. All samples meet standard requirements with the reasonable composition design.

Table 3. Mechanical properties after heat treatment

| No. | Heat treatment | Rp0.2/MPa | Rm/MPa | A% |
|-----|----------------|-----------|--------|----|
| C20-1 | Normalizing | 344 | 537 | 35 |
| C20-2 | Normalizing+ PWHT 1time | 295 | 509 | 30.0 |
| C20-3 | Normalizing+ PWHT 2times | 317 | 500 | 37.5 |
| C20-4 | Normalizing+ PWHT 3times | 311 | 486 | 30.5 |
| C23-1 | Normalizing | 384 | 581 | 35.0 |
| C23-2 | Normalizing+ PWHT 1time | 308 | 531 | 34.5 |
| C23-3 | Normalizing+ PWHT 2times | 293 | 532 | 35.0 |
| C23-4 | Normalizing+ PWHT 3times | 304 | 538 | 36.5 |
| C25-1 | Normalizing | 395 | 602 | 25.0 |
| C25-2 | Normalizing+ PWHT 1time | 314 | 564 | 30.5 |
Table 4. The impact energy after heat treatment

| No.     | -40℃ Ak/J | average |
|---------|-----------|---------|
|         | 1         | 2       | 3       |         |
| C20-1   | 69        | 62      | 49      | 60      |
| C20-2   | 61        | 75      | 62      | 66      |
| C20-3   | 80        | 63      | 57      | 67      |
| C20-4   | 22        | 48      | 103     | 58      |
| C23-1   | 68        | 53      | 48      | 56      |
| C23-2   | 16        | 41      | 40      | 32      |
| C23-3   | 17        | 17      | 30      | 21      |
| C23-4   | 17        | 36      | 16      | 23      |
| C25-1   | 52        | 17      | 51      | 40      |
| C25-2   | 33        | 26      | 37      | 32      |
| C25-3   | 20        | 13      | 27      | 20      |
| C25-4   | 14        | 30      | 28      | 24      |

Fig. 1 shows the charpy impact energy of the samples. The charpy impact energy of the sample with higher C content is lower than the samples with lower C content. After simulated PWHT, the $A_k$ of C20 samples didn’t change notable, while for the C23 and C25 samples, the $A_k$ decreased slightly.
The OM and SEM images are showed in Fig. 2 and Fig. 3 respectively. The normalizing samples microstructural consist of pearlite and ferrite. While taken by simulated PWHT, the pearlite changed to degenerated. the pearlite content increased with the C content increased, so the 0.25% C content samples have the more pearlite than the 0.20% and 0.23% C content samples. The cementite morphology changed obviously according Fig. 4. The cementite is plate shape in the Fig. 4(a). Taken by simulated PWHT, one cementite plate turn to small pieces. And with the simulated PWHT times increased, the size of plate line became shorter and shorter, just like Fig4(d). Otherwise, the granular cementite were found on the ferrite and pearlite grain boundary, which is about 1μm in size. According to more than ten pictures and two hundred cementite plates, the averaged cementite plates distance be measured, and the result showed in table 5. There was no obvious difference among the cementite plates distance for different heat treatment samples. The sketch map was draw to simulate the pearlite degenerated process during the simulated PWHT, as showed in Fig. 4. The cementite plates position did not changed but the plates morphology changed to small pieces, and larger size cementite of about 1μm precipitated on the grain boundary.
Figure 2. Optical microscopy image for the samples

Figure 3. SEM image for the C23 sample

Table 5. The averaged pearlite plates distance

| Normalizing | PWHT 1 time | PWHT 2 times | PWHT 3 times |
|-------------|-------------|-------------|-------------|
| 0.20        | 0.30        | 0.22        | 0.26        |
As we know, pearlite content and morphology is very important to the strength of the specimen, the higher pearlite content, the finer and closer pearlite plates can improve the strength of the specimen. So the C25 specimen show the highest strength, and the C20 specimen show the lowest strength. And the decrease of yield strength and tensile strength after PWHT is because the pearlite degenerated. The decrease of strength for specimen which contain higher C will be bigger than the specimen which contain lower C. That’s because the former contain more pearlite, which will be influenced by simulated PWHT more easily.

The C20 specimens show the higher $A_k$, that’s because which contain more ferrite. The ferrite is the primary microstructure which show the better plasticity and toughness than pearlite. After PWHT, the $A_k$ didn’t show the notable change. For C23 and C25 specimens, the primary microstructure is pearlite. So the $A_k$ is lower than C20 specimens. After the simulated PWHT, the $A_k$ decreased, that’s because the pearlite degenerated. Pearlite plates of normalizing samples are fine and close which can prevent crack propagation. When samples were taken by simulated PWHT, one pearlite plate turned to pieces of small and long plates, which can not prevent crack propagation effectively.

4. Conclusion
The article describes the effect of simulated post weld heat treatment (PWHT) on the properties and microstructure of high performance pressure vessel steel plate A516 Gr.70. the following conclusions could be drawn:

1. After simulated PWHT, the yield and tensile strength for all kinds of samples decreased. For C23 and C25 specimens the $A_k$ decreased. That is all because pearlite degenerated.

2. During the simulated PWHT, the microstructure changed like this: the cementite plates position did not changed but the plates morphology changed to small pieces, and larger size cementite of about 1μm precipitined on the grain boundary.

3. All samples meet standard requirements with the reasonable composition design.

References
[1] J. Wang, H. Lu, H. Murakawa., Trans. JWRI, J, 27(1), 83-88(1998).
[2] G. Z. Zhang, F. Zhao, Ind. Heating. J. 01:66-68(2013).
[3] S. Ravi, V Balasubramanian, S. N. Nasser, Int. J. Fatigue. J. 27(5), 547-553(2005).
[4] D. R. G. Mitchell, C. J. Moss, R. R.O. Griffiths, Int. J. Pres. Pip. J. 76(4), 259-266(1999).
[5] Z. Wang, W. Chen, Petro-Chem. Equip. J. 1, 15(2010).
[6] J, K. Kim, H. J. Park, D. N. Shim, Acta Metall. Sin.(Engl. Lett.), J, 29(12),1107-1118(2016).