Effect on properties of HIC resistance vessel steel of quenching and tempering heat treatment

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Abstract. The effect on strength properties, microstructure and HIC of heat treatment of normalizing rolling, normalizing and quenching & tempering was analysed. The following conclusions can be drawn: The strengths of samples of normalizing rolling and normalizing range 459MPa~470MPa. However the strengths of quenching and tempering samples range 539MPa~614MPa. And the strengths of quenching and tempering samples decrease with the tempering temperature rising. The Max. CLR is around 14% of normalizing rolling samples but 4% of normalizing samples. However no cracks was observed on the quenching and tempering samples. The cracks originate on center of samples’ thickness direction and propagate along pearlite bands. However the HICs have a low occurrence rates on the quarter of samples without origination that only exist on thickness center of samples. The quenching and tempering microstructure can prevent the propagation of the originated HIC, which improves the HIC resistance properties of vessel steel.

1. Introduction
The tensile strength of Hydrogen Induced Cracking (HIC) resistance vessel steel is increased by adding of carbon and manganese. But the properties of HIC resistance were influenced by segregation of carbon and manganese, which makes it hard to manufacture carbon-manganese HIC resistance vessel steel [1].

HIC is the cracking induced by hydrogen corrosion, when pipeline steels and pressure vessel plate are exposed to the corrosion environmental of water solution with sulfide. There are three measurements to value the property of resistance to HIC, Crack Length Ratio (CLR), Crack Thickness Ratio (CTR) and Cracking Sensivity Ratio (CSR) [2].

There are many literatures and researches on the mechanism of resistance to HIC [3-8]. The primary measures are: controlling on the impurity in plate and uniform of materials. However for HIC resistance vessel steel, the elements of Nb, V, Cr are not be added intentionally. The tensile strength is only improved by elements carbon and manganese, which deteriorated the segregation of slab contrast pipeline steels for resistance to HIC. Because the central impurities in slab is more such as MnS, Al2O3, which worsens the index of resistance to HIC.

The heat treatment of Quenching and Tempering (QT) is used to acquire tempering martensite structure with good tensile strength properties [9]. There are a little of references about effect of QT on HIC resistance property of carbon and manganese vessel steel, but only based on HIC resistance pipeline steel [10]. The effect on HIC resistance carbon and manganese vessel steel of quenching and tempering was studied on this research, comparing with Normalizing Rolling (NR) samples and Normalizing (N) samples.
2. Experimental
The chemical composition of samples are list in Table 1.

| C   | Si≤ | Mn≤ | P≤  | S≤  | Alt≤ | Nb+V+Ti≤ | Mo≤ | Cu≤ |
|-----|-----|-----|-----|-----|------|----------|-----|-----|
| 0.12%-0.24% | 0.45% | 1.50% | 0.01% | 0.003% | 0.05% | 0.1% | 0.1% | 0.1% |

The process of manufacture of samples is BOF—LF—RH—CC—NR. There are 12 samples taken to research on properties of different heat treatment, as is shown in Table 2. There are 4 normalizing rolling samples. And 4 samples are normalizing after rolling. The normalizing temperature is 880 °C and holding time is 24 min. There are 4 samples after quenching and tempering, 880 °C, the quenching temperature and 24 min holding time. Then the samples are tempered with temperature 550 °C, 580 °C, 620 °C and 650 °C respectively. The plate thickness is 9.53 mm.

3. Results and discuss

3.1. Effect on strength of heat treatment
Effect on tensile strength of heat treatment is shown in Fig. 1.

As shown in figure, the tensile strengths range from 460MPa-470MPa and the yield strengths range from 311MPa-325MPa. There are no obvious differences with two kind of heat treatment samples. After QT, the tensile strengths increase to 539-614MPa and the yield strengths increase to 388-482MPa contrast to NR and N samples. But the tensile strength decrease with the rising of tempering temperature. And the tensile strengths decrease from 614MP to 539MPa with tempering temperature from 550 °C to 650 °C.

3.2. Effect on HIC of heat treatment
Effect on HIC of heat treatment is shown in Table 3. As shown in table, the max CLR of NR samples is about 14%. The HIC resistance of samples improve after normalizing. And the max CLR of N samples is about 4%. After QT, the HIC resistance improve sharply and no obvious cracks are observed on the QT samples.
Table 3 Effect on HIC of heat treatment

| Samples | Heat Treatment | Max% | Ave% |
|---------|----------------|------|------|
|         |                | CLR  | CTR  | CSR  | CLR  | CTR  | CSR  |
| NR-713  | NR             | 5.9  | 8.75 | 0.52 | 2.51 | 3.08 | 0.18 |
| NR-786  | NR             | 5.96 | 8.91 | 0.45 | 4.37 | 3.92 | 0.2  |
| NR-739  | NR             | 13.59| 13.22| 1.68 | 5.65 | 4.99 | 0.57 |
| NR-719  | NR             | 10.07| 3.68 | 0.12 | 6.18 | 1.81 | 0.06 |
| N-724   | N              | 0    | 0    | 0    | 0    | 0    | 0    |
| N-753   | N              | 4.28 | 0.51 | 0.02 | 1.43 | 0.17 | 0.01 |
| N-756   | N              | 0    | 0    | 0    | 0    | 0    | 0    |
| N-761   | N              | 0    | 0    | 0    | 0    | 0    | 0    |
| QT-550  | QT             | 0    | 0    | 0    | 0    | 0    | 0    |
| QT-580  | QT             | 0    | 0    | 0    | 0    | 0    | 0    |
| QT-620  | QT             | 0    | 0    | 0    | 0    | 0    | 0    |
| QT-650  | QT             | 0    | 0    | 0    | 0    | 0    | 0    |

3.3. Effect on structure of heat treatment

The images of microstructure of NR samples are shown in fig. 2. As shown in figure, there are pearlite bands both at center and quarter of plate thickness.

![Images of microstructure of NR samples](image1)

Fig. 2 Images of microstructure of NR samples

Images of a crack of sample are shown in fig. 3 with 100X and 400X multiples respectively. As shown in figure, the crack occurs at the center of thickness of sample and propagates along the pearlite band.

![Images of crack along the pearlite band](image2)

Fig. 3 Images of crack along the pearlite band

Images of microstructure of N samples are shown in fig. 4. As shown in figure, the structures of normalizing samples are made up of pearliters and ferrites. There are both pearlite bands at center and quarter of thickness. The pearlite bands at center are a little worse than that at quarter. But there are no cracks found at the quarter of thickness.

![Images of microstructure of N samples](image3)
Contrast to microstructure of normalizing samples, the microstructures of QT samples are made up of tempering martensites that are more even and fine than microstructure of normalizing samples. The images of QT samples are shown in fig. 5.

Images of crack origination of QT samples are shown in fig. 6. As shown in figure, the crack originates at the center of sample but is prevented to propagate because of even and fine tempering martensites. Then the process of HIC formation is described as two steps: origin and propagation.

The crack originating at the center of QT samples can’t propagate along the even and fine tempering martensites that have the good crack arrest property. Although there are both pearlite bands at center and quarter, the occurrence rates of cracks are very low at the quarter of samples because there are no crack origination at the quarter of samples.

4 Conclusions

The effect on strength properties, microstructure and HIC of heat treatment of normalizing rolling, normalizing and quenching & tempering was analyzed. The following conclusions can be drawn:
1. The strengths of samples of normalizing rolling and normalizing range 459MPa–470MPa. However the strengths of quenching and tempering samples range 539MPa–614MPa. And the strengths of quenching and tempering samples decrease with the tempering temperature rising.

2. The Max. CLR is around 14% of normalizing rolling samples but 4% of normalizing samples. However no cracks was observed on the quenching and tempering samples. The cracks originate on center of samples’ thickness direction and propagate along pearlite bands.

3. There are both pearlite bands on center and quarter of thickness. But the HICs can be found on the center of thickness. Then it’s can be concluded that the HICs have a low occurrence rates on the quarter of samples without origination that only exist on thickness center of samples.

4. The quenching and tempering microstructure can prevent the propagation of the originated HIC because of homogenous structure and fine grain created by quenching and tempering, which improves the HIC resistance properties of vessel steel.

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