Effects of Isothermal Temperature on Microstructure and Properties for N80 Oil Pipe Steel

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Abstract: Some key temperature parameters in the process of controlled rolling and controlled cooling of N80 grade oil casing steel were simulated by heat treatment method, and the effects of different isothermal temperatures on the microstructure and mechanical properties of N80 grade oil casing steel were studied. The results show that when the isothermal temperature increases from 500 ℃ to 550 ℃, the influence of different microstructure volume and grain size is not obvious; when the temperature reaches 600 ℃, the ferrite grain coarsens obviously, the volume fraction of ferrite increases obviously, and the volume fraction of pearlite and bainite decreases obviously. In addition, when the isothermal temperature increases from 500 ℃ to 550 ℃, the yield strength and tensile strength of the test steel increase slightly, and the plastic toughness increases obviously; but when the temperature increases to 600 ℃, the yield strength and tensile strength of the test steel decrease obviously, and the plastic toughness continues to increase. The optimum isothermal treatment temperature of test steel is 550 ℃.

1. Introduction

The consumption of oil casing steel accounts for about 30% of the total oil industry steel, and can only be used once, so the demand is enormous [1-3]. According to SY/T 5989-2019 "straight seam resistance welded casing", N80 grade straight seam welded petroleum casing steel is required to have high strength (yield strength not less than 552mpa, tensile strength not less than 689mpa), low yield ratio, good plastic toughness (elongation after fracture not less than 16%, 0 ℃ transverse kV not less than 32J) and weldability [4-6]. In order to obtain good comprehensive mechanical properties, the process of controlled rolling and controlled cooling in the production of oil casing steel is particularly critical.
In this paper, N80 grade oil casing steel was used as experimental steel, and some key temperature parameters in the process of controlled rolling and controlled cooling were simulated by solid solution, austenitizing and isothermal heat treatment methods. The effects of different isothermal temperatures on Microstructure and mechanical properties of N80 grade oil casing steel were studied. Through analysis and discussion, the optimum isothermal treatment temperature parameters are determined, which can provide basis for the formulation of some key temperature parameters in the process of controlled rolling and controlled cooling of N80 grade oil casing steel.

2. Test materials and methods
The test steel was melted in a 500kg medium frequency induction furnace, and then the 200kg ingot was poured, then heated to 1200 ℃ and hot forged into 10 mm thick plate. The specific chemical composition of the test steel is shown in Table 1.

| element | C  | Si  | Mn  | V   | Ti  | Nb  | Mo  | Cu  |
|---------|----|-----|-----|-----|-----|-----|-----|-----|
| content | 0.08 | 0.42 | 1.89 | 0.081 | 0.01 | 0.082 | 0.261 | 0.241 |

Cut the hot forged plate into 300 mm × 200mm ×10mm block specimen, and be engaged in heat treatment. The specific heat treatment process is shown in Figure 1.

The metallographic specimens were prepared, which were photographed it by Zeiss inverted microscope of axiovert.A1, and analyzed it by Image Pro Plus software. Then we prepared the heat-treated samples into TEM samples, and observed the fine structure and particle precipitation of the samples by H-800 Hitachi TEM.

![Fig. 1 Process of heat treatment for steels](image)

The tensile specimens were made from the heat-treated block specimens according to the relevant standards. The mechanical properties were tested on CTM9300 microcomputer controlled electronic universal testing machine (each data point represents the average value of three parallel specimens), and the tensile rate was $1 \times 10^{-3}$ s$^{-1}$.The specimens after heat treatment were made into V-notch specimens according to relevant standards. The low temperature toughness impact test was carried out onJB-W300A microcomputer controlled impact testing machine (each data point represents the average value of three parallel specimens), and the impact temperature was 0 ℃.

3. Test results and analysis

3.1 Microstructure
The microstructure of the test steel after austenitizing at 900 ℃ and different isothermal temperature treatment is shown in Figure 2. The microstructure of the test steel after different isothermal temperature treatment is obviously different. At 500 ℃, the microstructure of the steel is ferrite (f) +
bainite (b) + a little pearlite (P). As shown in Fig. 2a, the white block area is ferrite, the black-and-white strip area is bainite, and the black block area is pearlite. With the increase of isothermal temperature (550 °C), the microstructure of the test steel is ferrite + bainite + a small amount of pearlite, the integral number of ferrite and pearlite increases slightly, the integral number of bainite decreases slightly, and the change of microstructure is not obvious, as shown in Fig. 2b. When the isothermal temperature reaches 600 °C (Fig. 2c), the microstructure of the test steel is ferrite + pearlite + a small amount of bainite, and the volume fraction of ferrite increases obviously, while the volume fraction of pearlite and bainite decreases obviously.

Fig. 2 Microstructures of steels after heat-treatment at different isothermal temperature
(a) 500℃; (b) 550℃; (c) 600℃

Fig. 3 shows the change trend of average grain size and volume fraction of ferrite in test steel after different isothermal temperature treatment. It can be seen from Figure 3 that with the increase of isothermal temperature, the average grain size and volume fraction of ferrite in the tested steel increase. However, when the isothermal temperature increases from 500 °C to 550 °C, the average grain size of ferrite increases from 5.8 μm to 6.2 μm, and the volume fraction increases from 39% to 42%, but the average grain size and volume fraction of ferrite do not change obviously. When the isothermal temperature reaches 600 °C, the average grain size of ferrite reaches 10.1 μm, the volume fraction reaches 72%, and the ferrite grain coarsens obviously and the volume fraction increases obviously. This shows that when the isothermal temperature increases from 500 °C to 550 °C, there is no significant effect of the isothermal temperature on the ferrite in the test steel, but when the temperature increases to 600 °C, the ferrite grain coarsens obviously and the volume fraction increases obviously.
Figure 4 shows the typical microstructure of the test steel after isothermal treatment at 550 °C under TEM. Fig. 4a shows lath bainite, mainly composed of carbon supersaturated lath ferrite and carbide, with high dislocation density and lattice distortion in ferrite [7]. Fig. 4b shows the pearlite and ferrite structure, in which the black-and-white lamellar area is pearlite.

As shown in Figure 5, the second phase particles precipitate in the microstructure of the test steel after austenitizing at 900 °C and different isothermal temperatures. Because microalloyed elements such as Nb, V and Ti are added in the test steel, these microalloyed elements are easy to precipitate carbonitride in the steel, so the second phase particles precipitated in the test steel should be carbonitride of microalloyed elements such as Nb, V and Ti. It can be seen from Fig. 5 that the size of the second phase particles ranges from a few nanometers to 10-20 nanometers. In addition, it can be found that with the increase of isothermal temperature, the number of second phase particles in the test steel also increases significantly, and the number of second phase particles in the test steel is the largest when isothermal treatment is carried out at 600 °C.
3.2 mechanical properties

As shown in Figure 6, the average values of yield strength ($R_{eL}$), tensile strength ($R_m$), elongation after fracture ($\alpha$) and impact toughness ($kV$, $0 \degree C$) of the test steel after austenitizing at 900 $\degree C$ and different isothermal temperatures are compared. It can be seen from Figure 6 that with the increase of isothermal temperature, the strength of test steel decreases gradually, and the most obvious decrease is at 600 temperature. However, the elongation after fracture and impact toughness of the tested steel gradually increase with the increase of isothermal temperature.

It can be seen from Figure 6 that when the isothermal temperature of the test steel increases from 500 $\degree C$ to 550 $\degree C$, the strength increases slightly ($R_{eL}$ increases by 4MPa, $R_m$ increases by 10MPa), but when the isothermal temperature is 600 $\degree C$, the strength decreases significantly ($R_{eL}$ increases by 105MPa, $R_m$ increases by 135MPa). In addition, when the isothermal treatment temperature increases from 500 $\degree C$ to 550 $\degree C$, the increase of elongation and impact toughness after fracture ($\alpha$ increases by 5%, $kV$ increases by 12J) is slightly larger than that when the isothermal treatment temperature increases from 550 $\degree C$ to 600 $\degree C$ ($\alpha$ increases by 2%, $kV$ increases by 10J). In conclusion, after austenitizing at 900 $\degree C$ and isothermal treatment at 550 $\degree C$, the test steel has the best comprehensive mechanical properties. At this time, the test steel has the highest yield strength and tensile strength, as
well as good plasticity (a) and toughness (kJ, 0 °C). At the same time, it can meet the mechanical properties of N80 straight seam welded casing steel specified in SY / T 5989-2019 standard [6].

Combined with the microstructure of the test steel (Fig. 2), there is no difference in microstructure when the isothermal temperature is 500 °C and 550 °C. The volume fraction of bainite, ferrite and pearlite is basically similar, and the average grain size of ferrite (Fig. 3) is also basically similar. Therefore, the mechanical properties of the test steel are basically similar when the isothermal temperature is 500 °C and 550 °C. However, due to the fact that the number of second phase particles precipitated in the test steel at 550 °C is obviously higher than that at 500 °C (as shown in Figure 5), the strengthening of second phase particles is obvious, and the strength of the test steel increases slightly when the isothermal temperature increases from 500 °C to 550 °C. When the isothermal temperature of the test steel reaches 600 °C, although the number of precipitated second phase particles in the test steel further increases, due to the obvious decrease of the volume fraction of bainite and pearlite in the structure, the strength also decreases obviously, and the plastic toughness increases obviously.

4. Conclusion
(1) The effect of isothermal temperature on the microstructure of test steel is as follows: when the temperature rises from 500 °C to 550 °C, the effect of isothermal temperature on different microstructure volume and grain size of test steel is not obvious; However, when the isothermal temperature increases to 600 °C, the ferrite grain coarsens obviously, the volume fraction of ferrite increases obviously, and the volume fraction of pearlite and bainite decreases obviously.

(2) The effect of isothermal temperature on the mechanical properties of test steel is as follows: when the temperature increases from 500 °C to 550 °C, the yield strength and tensile strength of test steel increase slightly, and the plastic toughness increases obviously; However, when the temperature rises to 600 °C, the yield strength and tensile strength of the tested steel decrease obviously, and the plastic toughness continues to increase. The optimum isothermal treatment temperature of the test steel is 550 °C.

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