Study on the continuous cooling transformation behavior of heavy thickness X80 pipeline steel

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Abstract. In this paper, the continuous cooling transformation behavior of heavy thickness X80 pipeline steel after two steps deformation was studied by Gleeble1500 thermal simulator. The continuous cooling transformation (CCT) curve of the sample was set up according to the thermal dilation curve and microstructure. The results show that during the continuous cooling process, ferrite and degenerated pearlite in the X80 are obtained in the high temperature phase transformation region. The bainite in the X80 was obtained in the medium temperature transformation region, and when the cooling rate is less than 20°C/s, the microstructure is granular bainite. When the cooling rate is between 20~30°C/s, the mixed microstructure of granular bainite and lath bainite were obtained. According to the CCT curve, in the production, the start cooling temperature and cooling rate should be controlled properly to get expected microstructure so as to ensure the property requirements of the steel plate.

1. Introduction

With the further advancement of the national sustainable development strategy and the increasing emphasis on environmental protection, the energy consumption structure of our country will also undergo tremendous changes. The proportion of clean energy such as natural gas in the entire energy consumption will increase rapidly. At present, pipeline transportation has developed into the main mode for long-distance transportation of nature gas resources. With the increase of natural gas resources consumption in the future, pipeline transportation will develop towards large-diameter, high-pressure to increase transportation efficiency. In order to adapt to the development of this pipeline transportation trend, pipeline steel also trends to develop in the direction of high strength, high toughness, large wall thickness.

X80 pipeline steel has high strength, high toughness, good crack arrest property and welding performance, so it has been widely used in the long-distance pipeline construction projects. At present, the commonly used and researched thickness specifications of X80 pipeline steel are less than 22mm[1-3]. And the related research and application of pipeline steel above this thickness specification have been rarely reported. For pipeline steel, the increase of thickness of the plate will greatly increase the control difficulty of rolling process and water cooling process after rolling. Therefore it is important to establish CCT curve of steel before formulating controlled rolling and controlled cooling process, especially for the thick gauge pipeline steel, so as to provide theoretical basis for formulating controlled rolling and controlled cooling process.

In this study, the X80 pipeline steel with thickness of 33mm was taken as the research object. And
the continuous cooling transformation behavior of X80 pipeline was studied by Gleeble 1500 thermal simulator in order to lay the foundation for the controlled rolling and controlled cooling process of the plate.

2. Test materials and methods
The material studied in this paper was taken from the X80 pipeline steel plate manufactured by a domestic steel plant. The thickness of the X80 steel plate was 33mm and the steel plate was produced by TMCP process. The specific chemical composition of the plate was shown in table 1.

| C   | Si   | Mn   | P   | S   | Nb+V+Ti | Ni+Cr+Mo |
|-----|------|------|-----|-----|---------|----------|
| 0.041 | 0.19 | 1.73 | 0.009 | 0.001 | ≤0.1 | ≤1 |

The thermal simulation test was carried out on Gleeble 1500 thermal simulator with the sample size of φ8*12mm. Firstly, the samples were heated to 1180℃ at the heating rate of 20℃/s and then the samples were held for 5 minutes to complete the austenization. Then the samples were cooled to 1050℃ from 1180℃ at the cooling rate of 15℃/s and 20% compression deformation was carried out at 1050℃ with the deformation rate 20S⁻¹. After the first step of compression deformation, the samples were cooled at a rate of 15℃/s to 830℃ for 30% compression deformation with a deformation rate of 20S⁻¹. The samples were cooled to room temperature at a certain cooling rate after the second step of compression deformation. The cooling rates were 30℃/s, 25℃/s, 20℃/s, 15℃/s, 10℃/s, 5℃/s, 1℃/s, 0.5℃/s, 0.1℃/s. The test scheme of the thermal simulation test was shown in figure 1. Temperature, time and dilation data during the test were recorded.

3. Results and discussion
3.1 Thermal dilation curve
After the thermal simulation test, the samples were cut along the axis, mechanically ground and polished, and then etched with a 4% nitric acid solution. The microstructure of the samples was observed by a Leica microscope.

The thermal dilation curve of the sample was set up by using the temperature and dilation data recorded during the test. The start temperature and the finish temperature of the phase transformation are determined according to the temperature corresponding to the inflection point on the thermal dilation curve, and the type of phase transformation is determined by combining the microstructure observation results. The temperature-time logarithmic coordinates are plotted according to the phase transformation start temperature and finish temperature of each cooling rate, and the microstructure observation results are combined to get the CCT curve of the test steel.
3.2 Microstructure observation

The microstructure of the samples obtained at different cooling rates was shown in figure 3. The microstructure of the high grade pipeline steel is different from traditional ferrite and pearlite microstructure because of the alloy design and accelerate cooling process, and the microstructure of the high grade pipeline steel is fine ferrite and bainite\cite{4}. Figure 3 shows that when the cooling rate is 0.1℃/s, the microstructure at room temperature is composed of ferrite and a small amount of degenerated pearlite. As for pipeline steel, the degenerated pearlite is formed when the carbon rich austenite is not enriched enough or the cooling rate is not high enough in the cooling process, but the Fe₃C sheet is often incomplete and often fragmented, so it is called degenerated pearlite\cite{5}. When the cooling rate is 0.5℃/s, the microstructure is composed of ferrite, bainite and a small amount of degenerated pearlite, but the microstructure is still mainly ferrite, and with the increase of cooling rate, the ferrite become smaller obviously. When the cooling rate increases to 1℃/s, the ferrite and degenerated pearlite have disappeared, and the microstructure at room temperature has completely transformed into granular bainite. When the cooling rate is between 5~15℃/s, the microstructure is granular bainite and with the increase of cooling rate, the granular bainite becomes smaller and the amount of M/A islands in the matrix gradually increase and the size decrease. This is because the higher the cooling rate, the lower the starting temperature of bainite transformation, the greater the phase transformation driving force, and the carbon atoms are not sufficiently diffused. Therefore the austenite is only rich in carbon in a short distance resulting in a decrease in the size of M/A islands and a corresponding increase in the amount. In addition, with the increase of cooling rate, the defects in austenite increase correspondingly, so that the granular bainite ferrite nucleation zone and the austenite carbon-rich zone increase correspondingly, resulting in an increase in the volume fraction of the M/A island and the size decrease\cite{6}. 

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**Figure 2. Thermal dilation curve of the test steel**
When the cooling rate increases to 20°C/s, except the granular bainite, some lath bainite microstructure appears in the sample. The lath bainite grows from the austenite grain boundary to the inside of grain in parallel with each other, which outlines the prior austenite boundaries, so that the prior austenite boundaries are retained, and the bainite bundles in different orientations divide the prior austenite grains into different regions. Therefore, there are obvious prior austenite grain boundaries in the microstructure when the cooling rate is 20°C/s. Meanwhile, the shape of the M/A island in the matrix changed from the previous granular to short rod or strip, which was the main difference between lath bainite and granular bainite. When the cooling rate was between 20~30°C/s, with the increase of cooling rate, the amount of lath bainite microstructure increase, and the amount of M/A islands with short rod or strip increase further, but there is still some granular bainite. In this cooling rate range, the overall thickness of the mixed microstructure of lath bainite and granular bainite do not change significantly.

3.3 CCT curve of the sample
The CCT curve of the sample was set up based on the temperature of phase transformation determined by dilation curve and the results of microstructure of different cooling rate. Figure 3 showed the CCT curve of the sample. In the CCT curve, bainite ferrite(BF) represent lath bainite mentioned in the microstructure observation.
Figure 4. CCT curve of the sample

It can be seen from the CCT curve of the sample that there are two phase transformation region for the sample during the continuous cooling process, namely, high temperature phase transformation region and medium temperature phase transformation region. The temperature range of the high temperature phase transformation region is 630~770℃ and the microstructure obtained in this region is ferrite and degenerated pearlite, and the start temperature of high temperature phase transformation region decreases with the increase of cooling rate. The temperature range of the medium-temperature phase transformation region is 450~630℃ and the microstructure obtained in this region is mainly bainite microstructure and the start temperature of bainite transformation, which is less affected by cooling rate, is basically stable at around 630℃. In the medium temperature phase transformation region, under the test conditions, when the cooling rate is less than 20℃/s, the microstructure obtained is granular bainite. But when the cooling rate is between 20~30℃/s, the microstructure obtained is a mixture of granular bainite and lath bainite, and the content of lath bainite tends to increase with the increase of cooling rate.

3.4 Discussion

For the thick gauge high strength X80 pipeline steel studied in this paper, in order to get the expected microstructure during the production to ensure its strength and toughness ultimately, it is necessary to properly control the rolling process and water cooling process after rolling.

During the thermal mechanical control process, the steel plate after finish rolling needs to undergo a short air cooling process before it start water cooling. It can be seen from the CCT curve that the phase transformation temperature of austenite to ferrite is about 770℃. Therefore, in order to avoid the formation of ferrite before the water cooling which will affect the strength and toughness of the steel plate, the start cooling temperature of the steel plate should be controlled above 770℃.

On the other hand, according to the specific requirements for strength and toughness of X80 plate, it is necessary to control the water cooling rate reasonably to get expected microstructure. When the strength of the pipeline steel is required to be high, some lath bainite is proposed by increasing the cooling rate, so as to improve the strength. When the comprehensive performance requirements is high, the medium and low cooling rate can be used to reduce the content of lath bainite to make the microstructure mainly composed of granular bainite, so as to ensure the plasticity and toughness, and improve the comprehensive performance of the pipeline steel plate.

4. Conclusions

1. In the continuous cooling process, two types of phase transformation occur in the sample. One is high temperature phase transformation, and ferrite and degenerated pearlite are obtained. The other is medium temperature transformation and bainite is obtained. In the medium temperature phase transformation region, when the cooling rate is less than 20℃/s, the microstructure is granular bainite. When the cooling rate is between 20~30℃/s, the microstructure is composed of granular bainite and lath bainite.

2. In the production process, it is suggested that the start cooling temperature of the steel plate should be controlled above 770℃. And according to the requirement of strength and toughness of
pipeline steel, the cooling rate should be controlled reasonably to get expected microstructure so as to ensure the ultimate strength and toughness of the steel plate.

Reference

[1] Li Si-jun, Zhu Hai-bao, Zhou Ping, et al. (2001) Microstructure and Mechanical Properties of Heavy X80 Pipeline Steel. HOT WORKING TECHNOLOGY, 40(24): 85-88.
[2] Yi Hai-long, Xue Peng, Cui Rong-xin, et al. (2008) Research on continuous cooling transformation of X80 pipeline steel. STEEL ROLLING, 25(2): 10-12.
[3] Liu Wen-bin, Kang Yong-lin, Niu Tao, et al. (2010) Static recrystallization behavior and technological improvement of X80 pipeline steel with heavy thickness produced by hot continuous rolling. Journal of University of Science and Technology Beijing, 32(4): 444-449.
[4] Kong Xiang-lei, Huang Guo-jian, Huang Ming-hao, et al. (2010) Research on continuous cooling transformation of X80 pipeline steel. HEAT TREATMENT OF METALS, 35(9): 66-69.
[5] Li He-lin, Guo Sheng-wu, Feng Yao-rong, et al. (2001) Analysis and identify map of microstructure of high strength microalloy pipeline steel. Petroleum Industry Press, Beijing.
[6] Zhang Hong-mei, Liu Xiang-hua, Wang Guo-dong, et al. (2000) Research on the continuous cooling transformation of deformed austenite of low carbon bainite steel. TRANSACTIONS OF METAL HEAT TREATMENT, 21(4): 35-39.