Experimental research and manufacturing technology of heavy gauge WPHY-80 pipe fitting plate with uniform microstructure

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Abstract: In order to develop heavy gauge WPHY-80 pipe fitting steel with high strength and low temperature toughness, the experimental research and manufacturing technology have been studied in this paper. The continuous cooling phase transformation behavior of the material under deforming condition was investigated. The microstructure of the steel at different cooling rates was observed by microscope. The temperature gradient rolling process in rough rolling stage was developed, which prompt the deformation penetrated from the surface to the center. It could refine the grain size in the center of the thick plate to enhance uniformity of the microstructure along the thickness direction. By utilizing this process route, the heavy gauge (54mm) WPHY-80 pipe fitting steel with excellent mechanical properties was developed in Shougang steel (SG). The WPHY-80 plates obtained high strength and stable low temperature impact toughness.

1. Introduction

As well known, natural gas is very important energy resource to maintain the development of national economy, in the environment of the global financial crisis, some countries have started to preempt energy resources, strengthen the exploitation of oil and gas fields. In oil and gas pipeline projects, there is a series of steel pipe fittings, such as tee, cross, reducer, cap and elbow. The development of pipeline steel trends toward higher strength, heavier wall thickness and larger diameters¹²³. For example, the pipe fitting used for West to East II pipeline project is WPHY-80 grade, the thickness of the pipe fitting reached to 54mm. Deformation of thick steel plate along the thickness direction was non-uniform during the traditional hot rolling, with which was a small compression ratio in center. The deformation cannot penetrate from the face layer to the center made the defects unbinding. This is the driving force that temperature gradient rolling process was developed by Shougang steel (SG). Stable high strength WPHY-80, heavy gauge (54mm) mechanical properties in the steel plates can be achieved by utilizing this process route.

2. Experimental research of WPHY-80 Steel

Table 1 shows the chemical compositions of 54mm WPHY-80 pipe fitting steel. Low carbon, high manganese, Nb, V and Ti additions were increased, and added some Ni, Cu, Mo etc elements for achieving bainite microstructure.
Table 1. Chemical composition of 54mm WPHY-80 pipe fitting steel (wt%)

| C   | Si  | Mn  | P   | S   | Nb+V+Ti | Ni+Mo+Cu+Cr |
|-----|-----|-----|-----|-----|---------|-------------|
| 0.075 | 0.25 | 1.70 | 0.008 | 0.0015 | ≤0.12 | ≤0.80 |

Table 1 shows chemical composition of the heavy gauge WPHY-80 pipe fitting steels. Low carbon levels (0.075%) contribute to a number of performance improvements, such as low temperature toughness, the weldability. Certain amount of niobium/vanadium solution and diffuse small (Nb, V) (C, N) precipitates can significantly refine the grain. And the molybdenum element can affect CCT curves, to avoid uneven cooling inside and outside the heavy plate, the bainite ferrite can be obtained in a wide range of cooling rate.

The sample was reheated to 1180°C and holding 5 minutes on the Gleeble-2000 thermal simulation machine, then cooled at 15°C/sec to 1050°C, for 20% of compression deformation, the deformation rate was 20S-1, and then cooled to 830°C by 15°C/sec, 30% deformation, then cooled to room temperature, the cooling speed respectively 26°C/s, 22°C/s, 18°C/s, 15°C/s, 10°C/s, 5°C/s, 1°C/s, 0.5°C/s, 0.1°C/s. Figure 1 shows the curve of thermal simulation test.

![Fig 1. The curve of thermal simulation test](image)

The microstructure of at different cooling rates was observed by microscope. From Figure 2, we can conclude that the ferrite(F) and pearlite(P) were obtained at a lower cooling speed range for 0.1~0.5°C/s. Granular bainite (GB) was obtained when the cooling speed increase to the range of 1~5°C/s. With the increase of the cooling speed, the transformation phase were mainly composed of lath bainite (LB) and martensite (M). With the increase of the cooling rate, the bainite microstructure was gradually refined. Figure 3 shows the curve of continuous cooling transformation (CCT). It was shown that the bainite microstructure was obtained in a wider cooling speed range.
Fig 2. The microstructure of WPHY-80 with different cooling rate
(a) 0.1°C/s; (b) 0.5°C/s; (c) 1°C/s; (d) 5°C/s; (e) 10°C/s; (f) 15°C/s; (g) 18°C/s; (h) 22°C/s; (i) 26°C/s

Fig 3. The curve of continuous cooling transformation

3. Manufacturing technology of WPHY-80 Steel
The manufacturing technology starts from the slab reheating which needs to address both dissolution of the main microalloy elements and controlling of the austenite grain coarsening. In the rough rolling stage, temperature gradient rolling method was developed, which was a process that rapid cooling while rolling, and the center of thick plate could not cool down, so that a non-uniform temperature distribution was forming that low temperature on surface and high temperature in center. With this rolling method, the harden layer on the surface could prompt the deformation penetrated from the surface to the center, which could remove the defects in the center of the thick plate to enhance uniformity of the deformation along the thickness direction. Post rolling cooling was controlled to achieve the appropriate cooling stop temperature and cooling rate to obtain the ideal microstructure and plate flatness.

According to the cooling conditions while rolling, the symmetry model was established. The
temperature distribution nephogram of the plate during rough rolling stage was simulated under the temperature gradient rolling process and the process without cooling while rolling, and the temperature contrast between the two processes was shown in Figure 4. Also, the rolling deformation contrast from surface to center of the plate under the two processes was shown in Figure 5.

![Temperature Distribution Nephogram](image1)

**Fig 4.** The temperature contrast form surface to center under the two processes

It can be seen from Figure 4 that the surface temperature under the temperature gradient rolling process is about $42^\circ C$ lower than that of the process without cooling while rolling, and the center temperature of the plate is basically the same under the two processes.

![Rolling Deformation Contrast](image2)

**Fig 5.** The rolling deformation contrast form surface to center under the two processes

It can be seen from Figure 5 that the surface deformation of the plate under the temperature gradient rolling process is smaller than that of the process without cooling while rolling, and the center deformation of the plate under the temperature gradient rolling process is greater than that of the process without cooling while rolling. With this rolling method, the deformation penetrated to the center of the plate, which could remove the defects in the center of the thick plate to enhance uniformity of the microstructure along the thickness direction.

The microstructure on the center of 54mm WPHY-80 pipe fitting plate under the two different processes was observed by optical microscope, as shown in Figure 6.
It can be seen from Figure 6 that the center microstructure of the plate under the process without cooling while rolling is uneven, and there exists some large size grains, while the center microstructure of the plate under temperature gradient rolling process is uniform and small.

4. Mechanical properties of WPHY-80 Steel

According to the continuous cooling phase transformation characteristics and the manufacturing technology, the heavy gauge WPHY-80 pipe fitting steel was produced in Shougang steel (SG).

Table 2 shows the tensile properties on the center of the 54mm WPHY-80 plate under the two processes, Table 3 shows the impact toughness on the center of the 54mm WPHY-80 plate under the two processes.

| Process                                           | Tensile properties on the center | Impact toughness on the center /J |
|---------------------------------------------------|---------------------------------|----------------------------------|
|                                                    | Rt0.5/MPa | Rm/MPa | Rt0.5/Rm | A/%     | 1   | 2   | 3   | Avg |
| Process without cooling while rolling              | 540       | 645    | 0.84     | 39     | 246 | 260 | 178 | 228 |
| Temperature gradient rolling process               | 575       | 695    | 0.83     | 40     | 313 | 332 | 317 | 321 |

Table 3. Impact toughness on the center of the plate under the two processes

| Process                                           | Test temperature /℃ | Impact toughness on the center /J |
|---------------------------------------------------|----------------------|----------------------------------|
| Process without cooling while rolling              | -30                  | 246 260 178 228                   |
| Temperature gradient rolling process               | -40                  | 313 332 317 321                   |
| Process without cooling while rolling              | -60                  | 192 146 178 172                   |
| Temperature gradient rolling process               |                      | 287 254 269 270                   |
| Process without cooling while rolling              |                      | 113 86 127 109                   |
| Temperature gradient rolling process               |                      | 215 203 196 205                   |

From the results of Table 2 and 3, we can see that the plate under the temperature gradient rolling process obtained more stable and excellent performance.

5. Conclusions

According to the experimental research and production practice on 54 mm WPHY-80 pipe fitting plates, the following conclusions can be drawn:

1. For the WPHY-80 pipe fitting steel, bainite microstructure can be obtained in a wider cooling
speed range, and with the increase of the cooling rate, the bainite microstructure was gradually refined.

2. The temperature gradient rolling process was developed and applied to produce low temperature heavy gauge WPHY-80 pipe fitting plates. The plates obtained high strength, low Y/T ratio, and good low temperature toughness.

3. By using the temperature gradient rolling process, a stable control of uniform microstructure can be realized and further more result in the consistent and stable control of mechanical properties of plates.

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