Effect of Controlled Rolling and Cooling On Microstructure and Mechanical Properties of 30CrMnTi Wire Rod

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Abstract. The effect of controlled rolling and cooling on microstructure and mechanical properties of alloy structure steel 30CrMnTi wire rod with diameter 6.5mm was studied. The results show that the lower finish rolling temperature resulted in a decrease in tensile strength but an increase in elongation and reduction of area. When the finish rolling temperature decreases from 950 °C to 850 °C, the tensile strength value decreases from 750 MPa to 660 MPa, and the elongation increases from 21% to 30%, the reduction of area increases from 64% to 71%. The grain size also refines from 20 μm to 9.9 μm when the finish rolling temperature decreases from 950 °C to 850 °C. The decrease of tensile strength is due to the change of microstructure which evolved from more bainite to ferrite and pearlite.

1. Introduction
30CrMnTi is widely used in the manufacture of high quality pin shaft parts[1-2]. As a kind of medium carbon alloy structural steel, 30CrMnTi has high tensile strength which results in the difficulty of subsequent cold drawing. This steel wire rod is easy to obtain quenched microstructure such as bainite or martensite due to its high alloying elements of chromium and manganese. Based on the study of the continuous cooling transformation behavior of austenite in 30CrMnTi steel, bainite occurs when the cooling rate reaches 1 °C/s[3]. Controlled rolling and controlled cooling, which is often called as Thermo-Mechanical Controlled Processes (TMCP), can improve the quality of wire rod by controlling the recrystallization or grain growth of austenite and subsequent transformations. In this paper, the influence of controlled rolling and controlled cooling process on the microstructure and properties of 30CrMnTi hot rolled wire rod with diameter 6.5mm was studied.

2. Experimental material and procedure
Table 1 shows the main chemical composition of experimental 30CrMnTi steel, which were supplied by Xingtai Iron & Steel Corp., LTD. The experimental steel was first cast into billet with the section size of 160*160mm², and then rolled into wire rod with diameter of 6.5mm by heating, rough rolling, medium rolling and final rolling process.
Table 2 shows the tested controlled rolling and cooling process of 30CrMnTi steel wire rod. The finish rolling temperature of process 1# is 950 °C which is in recrystallization region, and 900 °C of process 2#, and 850 °C of process 3#. The laying head temperature is about 50 °C lower than the finish rolling temperature. All the cooling modes are slow cooling.
Table 1. Chemical composition of experimental 30CrMnTi steel (wt, %)

| Steel grade  | C     | Si    | Mn    | P    | S    | Cr    | Ti    |
|-------------|-------|-------|-------|------|------|-------|-------|
| 30CrMnTi    | 0.24-0.32 | 0.17-0.37 | 0.80-1.10 | ≤0.03 | ≤0.03 | 1.00-1.30 | 0.04-0.10 |

Table 2. The controlled rolling and cooling process of 30CrMnTi wire rod

| Process number | Finish rolling temperature/°C | Laying head temperature/°C | Cooling process   |
|----------------|-------------------------------|---------------------------|------------------|
| 1#             | 950                           | 900                       | Slow cooling     |
| 2#             | 900                           | 850                       | Slow cooling     |
| 3#             | 850                           | 800                       | Slow cooling     |

The mechanical properties of the wire rod were tested by WDW50 universal testing machine, and the microstructure was observed by Leica DM2700M optical microscope (OM).

3. Results and analysis

3.1 Mechanical properties of different processes

Table 3 shows the mechanical properties of experimental 30CrMnTi wire rod with three different processes. The tensile strength decreases with the decrease of finish rolling temperature and the laying head temperature, but the plasticity (such as elongation and reduction of area) increase gradually. When the finish rolling temperature is 950°C, the average tensile strength is 750MPa, the average reduction of area is 64%, the average elongation is 21%; when the finish rolling temperature is 900°C (Process 2#), the average tensile strength decreased to 710MPa, the average reduction of area is 68%, the average elongation is 26%; when perform process 3#, the average tensile strength is further reduced to 660MPa, the average reduction of area is 71%, the average elongation is 30%. Compared with the process 1#, the tensile strength of process 3# was reduced by 90MPa, the reduction of area increased by 7%, the elongation increased by 9%.

Table 3. The mechanical properties of the 30CrMnTi wire rod with diameter 6.5mm

| Process number | Tensile strength / MPa | Reduction of area / % | Elongation / % |
|----------------|------------------------|-----------------------|---------------|
| 1#             | 715-825 (750)          | 60-69 (64)            | 16-28 (21)    |
| 2#             | 677-750 (710)          | 67-70 (68)            | 25-28 (26)    |
| 3#             | 644-705 (660)          | 68-72 (71)            | 27-32 (30)    |

Note: the values in parentheses are average value

3.2 Microstructure of different processes

Figure 1～3 shows the microstructure of experimental 30CrMnTi wire rod with three different processes. The microstructure is quite different with different. With the process 1#, the microstructure of the steel is mainly bainite and a small amount of ferrite and pearlite shown in figure 1.
With the process 2#, when the finish rolling temperature decreases, the bainite was significantly reduced and found only at individual non overlapping locations as shown in figure 2c. The microstructure of tested steel with process 3# is mainly ferrite and pearlite, no bainite can be found.

The grain size and ferrite content in different processes were calculated, as shown in table 4. Obviously, the average grain size decreases with the decrease of finish rolling temperature. The average grain size is 20 μm with process 1#, when the finish rolling temperature become 900°C (Process 2#), the average grain size become 14 μm; when the finish rolling temperature become 850°C, the average grain size become 9.9 μm. The ratio of ferrite content increases from 35-40% with process 1# to 46-50% with process 3#.
Table 4. The average grain size and ferrite content of the 30CrMnTi wire rod

| Process number | Grain size number | Average grain size /μm | Ratio of average ferrite content/% |
|---------------|------------------|------------------------|----------------------------------|
| 1#            | 8                | 20                     | 35-40                            |
| 2#            | 9                | 14                     | 44-48                            |
| 3#            | 10               | 9.9                    | 46-50                            |

3.3 Discussion

In the case of the same chemical composition, the microstructure of the steel is affected by the controlled rolling and controlled cooling process [4-5]. During the traditional process rolling, the recrystallization and grain growth of deformed austenite at high temperature, large grain size is obtained due to the high driving force. During TMCP, with the decrease of deformation temperature, the driving force of grain growth is reduced, and it’s easy to obtain the fine recrystallization grain. When deformation temperature is further reduced, the deformation is in the non-recrystallization zone rolling, recrystallization does not occur during the deformation process, deformed austenite is elongated, and a large amount of energy is stored in the deformed austenite grain boundaries or sub grain boundaries, which will be preferentially nucleated in the subsequent phase transformation process, and the uniform and fine grains can be obtained after the phase transformation.

In this study, the process 1# is traditional process rolling with high deformation temperature, and the grain size is relatively larger after the transformation; The large grain size can improve the hardenability of steel, and because of the high Cr, Mn and other alloying elements, the hardenability of 30CrMnTi can also be improved. For this reason, it is easy to produce bainite structure in the slow cooling process of 30CrMnTi steel. The existence of bainite leads to the increase of tensile strength and the decrease of plasticity for process 1#.

The deformation temperature of process 2# is lower than that of process 1#, the driving force of grain growth is reduced, the grain size decreases after the transformation, and the microstructure is mainly composed of ferrite and pearlite. This kind of microstructure can reduce the tensile strength and increase the plasticity obviously. But in the non-overlapping position of the wire rod, there are also some bainite exists because of the cooling rate is faster than the overlapping position.

The deformation temperature is further reduced by process 3#, and the grain size is smaller after transformation than process 2#. The low deformation temperature makes the CCT curve move to the left[4], which reducing the hardenability of the steel. In the same slow cooling process, the microstructure of process 3# is totally ferrite and pearlite with no bainite. And the tensile strength is further reduced to 660MPa, the elongation and reduction of area were further improved.

The experimental wire rod of Process 3# was drawn directly from 6.5mm to 4.48mm with annealing-free. The properties after drawing can meet customer requirements.

4. Conclusions

Based on the study of the effect of different controlled rolling and controlled cooling processes on the microstructure and properties of 30CrMnTi, the following conclusions can be obtained:

1. The finish rolling temperature decreased from 950°C to 900°C, the tensile strength of 30CrMnTi wire rod with diameter 6.5mm is decreased from 750MPa to 710MPa, the elongation increased from 21% to 26%, the reduction of area increased from 64% to 68%.

2. The finish rolling temperature decreased from 900°C to 850°C, the tensile strength of 30CrMnTi wire rod with diameter 6.5mm is decreased from 710MPa to 660MPa, reduction of area and elongation have been further improved.

3. The CCT curve is shifted to the left by the lower finish rolling temperature, which makes the transformation process of 30CrMnTi steel avoid bainite transformation region, and the uniform ferrite and pearlite structure can be obtained.
5. Reference

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