Effect of Heat Treatment Process on Microstructure and Hardness of Ultrafine Grain Steel

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Abstract. Under the heating condition, the grain of ultrafine grain steel will change with the increase of temperature, so that the microstructure and hardness of ultrafine grain steel will change, and even lose the original strength and toughness. In this paper, the grain growth behavior, microstructure and hardness of ultrafine grain steel under different heat treatment conditions were studied experimentally. The results showed that under different cooling methods, the faster the cooling speed was, the more the amount of low-carbon martensite and pearlite was. The hardness obtained by water cooling was the largest. The hardness decreased with the changes of water cooling, oil cooling, air cooling and furnace cooling. The higher the maximum heating temperature was, the coarser the grain became. For ultrafine grain steel, the maximum heating temperature of 1000 ℃ should not be used.

1. Introduction
In industrial production, steel has increasingly become an indispensable part of modern industry. With the development of steel, we have to find and solve some defects of steel itself in order to give full play to its performance in practical application. In the continuous exploration, the predecessors found that refining the grain structure of iron and steel materials is a very effective method to improve the properties of steel. With the unremitting efforts of researchers, the production technical means for iron and steel materials are becoming more and more advanced, more and more in line with the needs of social development, and the grain volume of common steel in life is decreasing, which meets the requirements of high-end applications. This paper mainly studied the effect of heat treatment process on the microstructure and hardness of ultrafine grain steel, so as to provide meaningful experimental basis for the production and application of ultrafine grain steel[1-6].

2. Experimental materials and processes
The steel used in this test was 400MPa ultrafine grain steel, and the grain size of base metal was 4-5 µm. Its chemical composition was shown in Table 1. The metallographic structure of the base metal was shown in Figure 1, which was fine ferrite and pearlite. The base metal hardness was 172.28 vickers hardness. In this paper, the experimental conclusion was obtained by comparing the data before and after heat treatment. Prepare 400MPa ultrafine grain steel test block with uniform size and material.
The experimental scheme was that the heat treatment test was carried out at 850℃, 900℃, 950℃ and 1000℃ without changing the holding time for 10 minutes. After heat treatment, four cooling methods were adopted for cooling, namely water cooling, oil cooling, air cooling and furnace cooling. Four test blocks were used for each temperature, and the four test blocks were water-cooled, oil-cooled, air-cooled and furnace cooled respectively. After the test block was completely cooled, carry out metallographic grinding and metallographic observation, and measure the hardness of the test block obtained under the corresponding conditions of heat treatment. The specific experimental parameters were shown in Table 2. The heating rate of heat treatment test was 8.85℃/min. After the heat treatment test, observe the metallographic structure, measure the hardness of the test block, and record the hardness value.

### Table 2. Experimental parameters under holding time of 10 minutes.

| Temperature(℃) | Cooling mode     |
|----------------|------------------|
| 850℃           | water cooling    |
| 900℃           | water cooling    |
| 950℃           | water cooling    |
| 1000℃          | water cooling    |

3. **Microstructure analysis**

(1) The microstructure obtained from four heating temperatures from low to high under the condition of holding for 10 minutes and water cooling was shown in Figure 2.
Figure 2. Microstructure at different heating temperatures under water cooling.

It can be seen from Figure 2 that under the water cooling condition of 850℃, the microstructure of 400MPa ultrafine grain steel was ferrite and pearlite smaller than the base metal, and pearlite accounted for the majority. Under the condition of water cooling at 900℃, the microstructure of 400MPa ultrafine grain steel was fine low-carbon martensite. When the temperature rose to 950℃, the microstructure of 400MPa ultrafine grain steel was coarse low-carbon martensite and a small amount of ferrite. When the temperature was 1000℃, it was coarse low-carbon martensite and coarse ferrite.

(2) The microstructure obtained from four heating temperatures from low to high under the condition of holding for 10 minutes and oil cooling was shown in Figure 3.

Figure 3. Microstructure at different heating temperatures under oil cooling.

It can be seen from Figure 3 that under the oil cooling condition of 850℃, the microstructure of 400MPa ultrafine grain steel was ferrite and pearlite smaller than the base metal, and the distribution of pearlite and ferrite was relatively uniform and the quantity was the same. Under the oil cooling condition of 900℃, the microstructure of 400MPa ultrafine grain steel was ferrite and pearlite slightly coarser than the base metal. When the temperature rose to 950℃, the microstructure of 400MPa ultrafine grain steel was low-carbon martensite and a small amount of ferrite. When the temperature rose to 1000℃, it was low-carbon martensite, bainite and coarse ferrite.
(3) The microstructure obtained from four heating temperatures from low to high under the condition of holding for 10 minutes and air cooling was shown in Figure 4.

![Microstructure images](a) 850°C air cooling  ![Microstructure images](b) 900°C air cooling  ![Microstructure images](c) 950°C air cooling  ![Microstructure images](d) 1000°C air cooling

Figure 4. Microstructure at different heating temperatures under air cooling.

It can be seen from Figure 4 that under the air cooling condition of 850°C, the microstructure of 400MPa ultrafine grain steel was ferrite and pearlite finer than the base metal. Under the condition of air cooling at 900°C, the microstructure of 400MPa ultrafine grain steel was ferrite and pearlite slightly coarser than the base metal. When the temperature rose to 950°C for air cooling, the microstructure of 400MPa ultrafine grain steel was near equiaxed ferrite and strip ferrite, and the grains were relatively coarse, in which the number of near equiaxed ferrite accounted for the majority. When the temperature rose to 1000°C, the microstructure was near equiaxed ferrite and strip ferrite, and the grains were coarser, in which the number of strip ferrite accounted for the majority.

(4) The microstructure obtained from four heating temperatures from low to high under the condition of holding for 10 minutes and furnace cooling was shown in Figure 5.

It can be seen from Figure 5 that under the furnace cooling condition of 850°C, the microstructure of 400MPa ultrafine grain steel was ferrite and pearlite slightly coarser than the base metal. Under the furnace cooling conditions of 900°C, 950°C and 1000°C, the microstructure of 400MPa ultrafine grain steel was ferrite and pearlite, which was obviously coarser than the base metal, and the grain became coarser and coarser with the increase of heating temperature, and the amount of pearlite decreased with the increase of heating temperature. The higher the temperature was, the clearer the ferrite grain boundary was.
In conclusion, low carbon martensite was formed under the conditions of water cooling and oil cooling. When the temperature increased, the grains will coarsen. Under air cooling and furnace cooling conditions, fine ferrite and pearlite were formed at low temperature. At higher temperature, coarse ferrite and pearlite were formed, and with the increase of temperature, the number of ferrite increased, the number of pearlite decreased, and the grain size of ferrite increased. This phenomenon was caused because the cooling speed of air cooling and furnace cooling was not as fast as that of water cooling and oil cooling.

4. Hardness analysis

The hardness changes of ultrafine grain steel under different heat treatment process parameters were shown in Figure 6, Figure 7, Figure 8 and Figure 9.

Figure 5. Microstructure at different heating temperatures under furnace cooling.

(a) 850℃ furnace cooling  (b) 900℃ furnace cooling

(c) 950℃ furnace cooling  (d) 1000℃ furnace cooling

Figure 6. Hardness changes under different cooling modes after holding at 850℃ for 10 min.

Figure 7. Hardness changes under different cooling modes after holding at 900℃ for 10 min.
It can be seen from Figure 6 that at 850°C the four cooling methods had different effects on hardness, among which the water cooling effect was the best. Compared with the base metal 400MPa ultrafine grain steel, the hardness of water cooling was significantly improved after heat treatment. However, the effect of oil cooling, air cooling and furnace cooling was not ideal, and the hardness after heat treatment was lower than that of the base metal. It can be seen from Figure 7 that at 900°C, the hardness of the samples obtained after water cooling, oil cooling, air cooling and furnace cooling gradually decreased. Among them, water cooling quenching had the best effect, and its hardness was higher than that of the base metal. The hardness of the samples obtained by the remaining three cooling methods was lower than that of the base metal. It can be seen from Figure 8 that the water cooling effect was the best at 950 ℃, and the hardness of the sample was significantly higher than that of the base metal. The hardness of the sample obtained by oil cooling quenching was higher than that of the base metal. It can be seen from Figure 9 that at 1000°C the hardness of the sample obtained by water cooling was significantly higher than that of the base metal. The hardness of the other three cooling methods was less than that of the base metal. To sum up, under different heating temperatures, the hardness decreased with the changes of water cooling, oil cooling, air cooling and furnace cooling.

5. Conclusion
(1) Under different cooling methods, the faster the cooling rate, the more the amount of low-carbon martensite and pearlite, and the hardness obtained by water cooling was the largest. The hardness decreased with the changes of water cooling, oil cooling, air cooling and furnace cooling. During furnace cooling, the grain growth of ultrafine grain steel was serious. For ultrafine grain steel, it was not suitable to cool with the furnace. (2) The higher the maximum heating temperature was, the coarser the grain became. 850°C, 900°C and 950°C can be used for heat treatment of ultrafine grain steel. For ultrafine grain steel, the maximum heating temperature of 1000°C should not be used.

The research of this paper had important practical significance. The effect of holding time on microstructure and hardness of ultrafine grain steel needs to be studied in the future.

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