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Effect of Cooling Conditions on Metallographic Microstructure of 38MnVTi Non-Quenched and Tempered Steel

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Abstract. The relationship between the cooling end temperature and cooling rate of 38MnVTi non-quenched and tempered steel's microscopic metallographic structure was discussed by means of physical experiment. The experimental results provide effective theoretical guidance for the optimization of process parameters in the actual production process.

1. Introduction

In order to obtain good performance, non-quenched and tempered steel has a great relationship with the recovery and recrystallization in the heating and holding stages, and also has a great connection with the cooling process. By optimizing the non-quenched and tempered steel forging process, refining the austenite grains and matching the cooling rate control after forming, the product can have excellent mechanical properties. Therefore, the microstructure change of the cooling process is a key factor determining the final properties of the hot deformed steel[1-6].

2. Experimental Materials and Methods

The tested material is 38MnVTi non-quenched and tempered steel bar. All the experimental samples are heated to 1250°C for 5 min, then cooled to 1150°C at 5°C/s to start deformation, the deformation amount is 0.6, and the strain rate is 1 s^{-1}. When the thermal deformation is completed and cooled at a cooling rate of 5°C/s, the first group of samples are cooled to 800°C, 700°C, 600°C air cooling to room temperature; The second set of samples were respectively cooled to 800°C, 700°C, and 600°C at the same speed and then water quenched. After the other samples are deformed, they are cooled to 800°C, 700°C, and 600°C at a rate of 0.5°C/s, 2°C/s, and 10°C/s, respectively, and then air-cooled to room temperature. After the single pass hot compression test is completed, the sample is cut in the radial direction, polished and then etched in a 3% nitric acid solution for 6s. The experimental process plan is shown in Figure 1.

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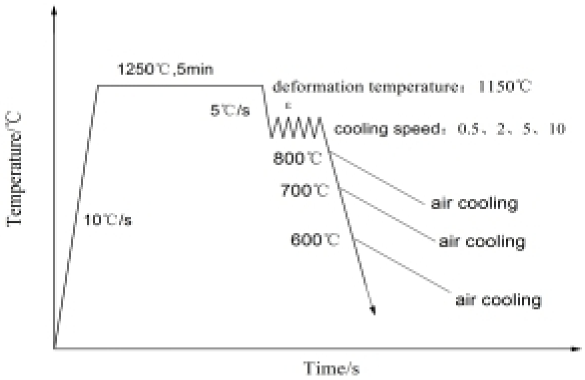
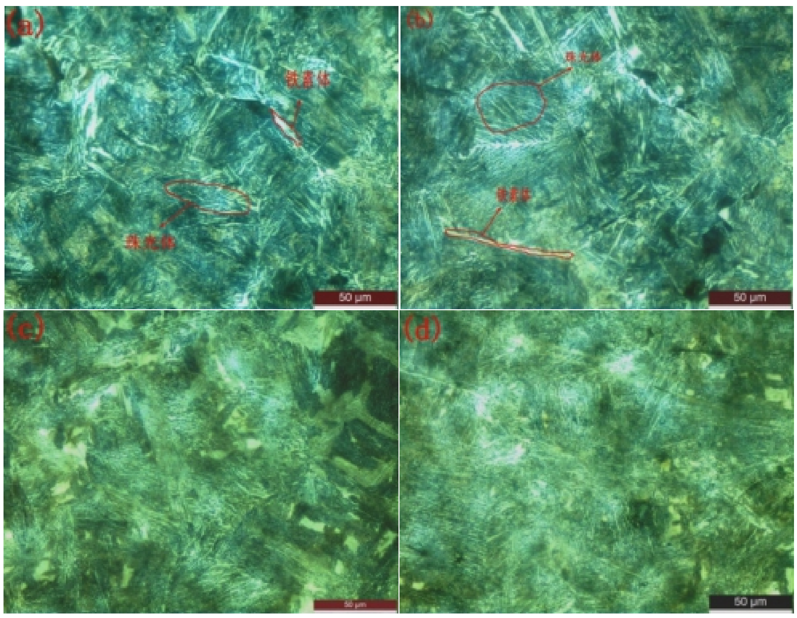


Figure 1. Cooling experimental process plan

3. Metallographic Microstructure under Different Cooling Conditions

3.1. The Effect of Different Cooling Rates on the Microstructure of 38MnVTi Non-quenched and Tempered Steel after Forging

According to the results of the cooling process, the austenite transformation metallographic microstructure when cooled to a temperature of 800 ° C and a cooling rate of 0.5°C/s, 2°C/s, 5°C/s, 10°C/s, respectively, is shown in figure 2. Figure 2 (a) is a microstructure diagram with a cooling rate of 0.5°C/s. It can be seen from the figure that the grain boundary ferrite (white portion of the grain boundary in the figure) and the flaky pearlite structure can be clearly seen when the cooling rate is small, as the cooling rate becomes larger. A slight upper bainite structure appears in figure 2(c) because the cooling rate is large and the degree of supercooling is large, which lowers the actual crystallization temperature. In the upper right part of figure 2(c), not only bainite but also retained austenite appears. The reason is that the alloy contains alloying elements to delay the precipitation of cementite, and the austenite carbon between the ferrite strips is enriched and tends to be stable, forming the upper austenite structure with retained austenite between the strips of ferrite. In figure 2(d),due to the excessive cooling rate, the tissue distribution is not uniform, the phase transformation process is unbalanced, and the ferrite network boundary is almost completely disappeared.



(a) 0.5°C/s (b)2°C/s (c)5°C/s (d)10°C/s

Figure 2. Cooling to 800°C microstructure at different cooling rates

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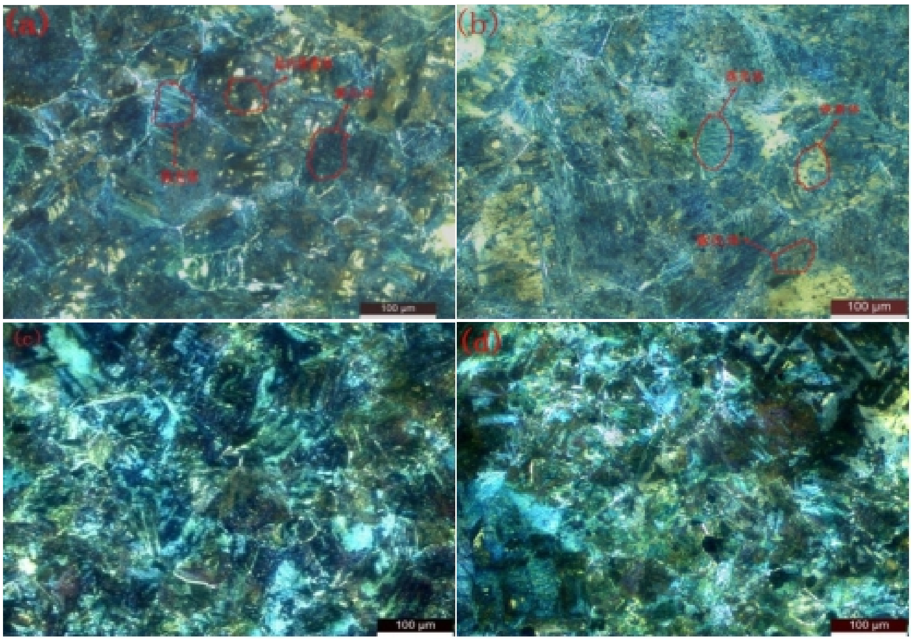
The microstructure of the austenite transformation metallurgy when cooled to 700 °C and the cooling rates of 0.5°C / s, 2 °C / s, 5 °C / s, 10 °C / s, respectively, is shown in figure 3. Figure3(a) shows a small amount of bright white ferrite precipitates along the austenite grain boundary, gray-black sorbite and a little intragranular ferrite appear inside the crystal. It can be seen that intragranular ferrite increases substantially from figure 3(b). The presence of intragranular ferrite is advantageous for steel because intragranular ferrite can cut austenite grains and cause a large amount of equiaxed ferrite inside the grains to improve the toughness of the steel [7]. However, for non-quenched and tempered steel, ferrite is very easy to form reticular ferrite, which deteriorates the performance of steel. Therefore, by controlling the continuous cooling process, a large amount of ferrite nucleation sites are provided in the austenite crystals, and a large amount of intragranular ferrite is obtained. Figure 3(c) shows the ferrite content on the grain boundaries did not change much, the content of gray-black sorbite and light black pearlite increased. Figure 3(d) shows since the cooling rate is too fast, there is almost no intragranular ferrite generation, but a dark black troostite appears in the crystal, and a little upper bainite structure appears in the upper right of the graph d.



(a)0.5°C/s (b)2°C/s (c)5°C/s (d)10°C/s

Figure 3. Cooling to 700 °C microstructure at different cooling rates

The microstructure of the austenite transformation metallurgy when cooled to 600 °C and the cooling rates of 0.5°C / s, 2 °C / s, 5 °C / s, 10 °C / s, respectively, is shown in figure 4. It can be seen from the figures a and b that when the cooling rate is small, the air-cooled structure mainly has pearlite, grain boundary ferrite, sorbite, and troostite structure. The black needle-like morphology seen in figure 4(d) is the lower bainite structure. Which can be formed on the austenite grain boundaries, but more often in the austenite grains along a certain crystal plane or stacked into a needle shape . The lower bainitic ferrite is generally uniform in needle shape, has a high internal dislocation density in the ferrite, and precipitates many small carbides [8]. The lower bainite has high strength and toughness, which can promote the properties of materials.

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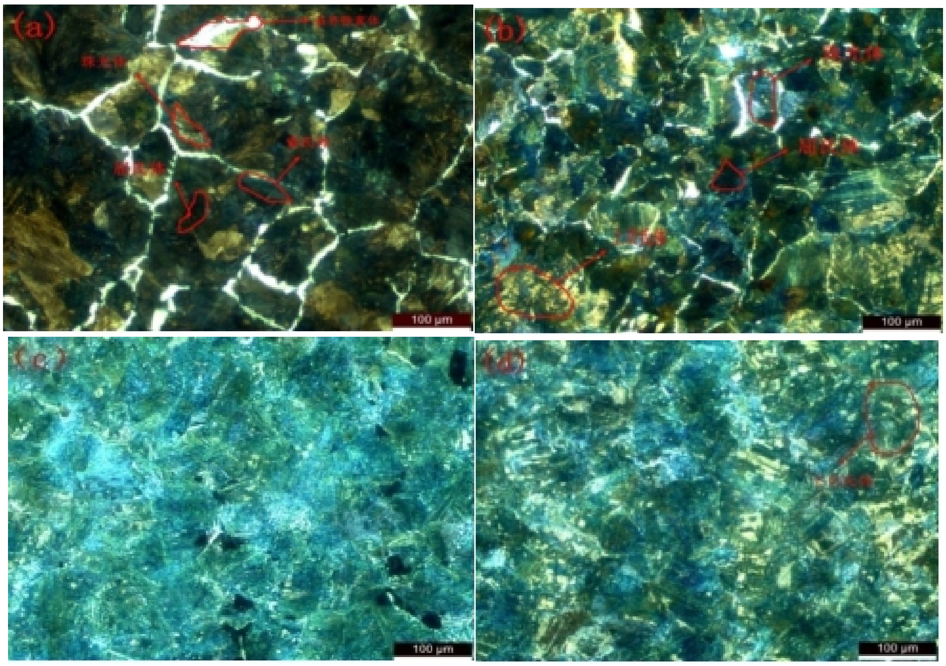
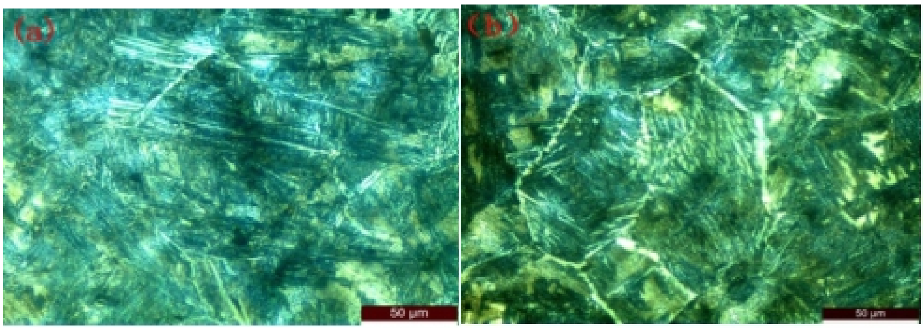


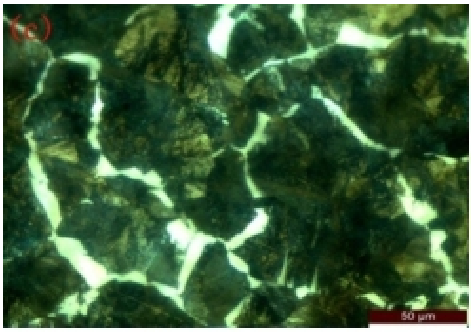
(a)0.5°C/s (b)2°C/s (c)5°C/s (d)10°C/s

Figure 4. Cooling to 600 °C microstructure at different cooling rates

3.2. Effect of Different Cooling Temperatures on Microstructure of 38MnVTi Steel after Forging

Under the process of cooling to 800 ° C, 700 ° C, 600 ° C, the cooling rate is 5 ° C / s, the air-cooled microstructure of 38MnVTi steel is shown in Figure 5. It can be seen from figure a, figure b and figure c that at the same cooling rate, the content of grain boundary ferrite increases with the decrease of cooling temperature. This is because the phase transition process is affected by the degree of subcooling. The lower the temperature, the higher the degree of supercooling, and the grain boundary ferrite does not have time to transform to other structures. But the intragranular ferrite content is slowly decreased as the temperature is lowered. In figure 5 (c), there are obvious grey-black sorbite and dark-black torrentite, which indicates that the original pearlite is transformed into sorbite and torrentite with the decrease of cooling temperature. Thus, it can be seen that the cooling temperature has a great influence on the final microstructure of the material.

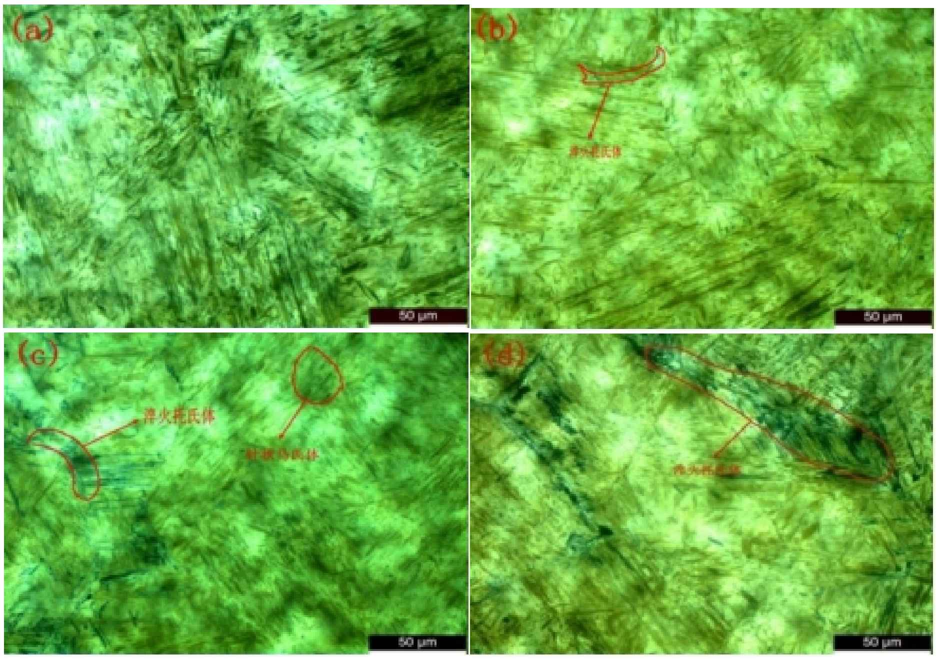




(a)800°C (b)700°C (c)600°C

Figure 5. Air-cooled microstructure cooled to different cooling temperatures at 5°C/s

Under the process of cooling to 800°C, 700°C, 650°C, 600°C, the cooling rate is 5°C / s, the water-cooled microstructure of 38MnVTi steel is shown in figure 6. Figure 6(a) shows a full-needle martensite microstructure at 800°C and a cooling rate of 5°C/s. With the decrease of temperature, the quenched tolsite appears in figure 6(c). The temperature is further reduced, and the content of the quenched torsite is further increased, as shown in figure 6(d). Quenched toughite is a very fine-grained pearlite structure obtained during rapid cooling due to unquenching. The decrease in temperature causes the atomic diffusion capacity to decrease, the structure does not completely change, and the hardenability decreases.



(a)800°C (b)700°C (c)650°C (d)600°C

Figure 6. Water-cooled microstructure cooled to different cooling temperatures at 5°C / s

4. Conclusion

In this paper, the two process parameters of cooling temperature and cooling rate and the micro-phase transition microstructure of 38MnVTi non-quenched and tempered steel were studied. The following conclusions were drawn:

(1)The fundamental reason for lowering the cooling temperature and increasing the cooling rate is to improve the degree of subcooling of 38MnVTi non-quenched and tempered steel. The degree of subcooling is the energy of the phase change provided by the material during the cooling process, which has a great influence on the microscopic phase transition of the material. 38MnVTi

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non-quenched and tempered steel is cooled to 800°C, 700°C, 600°C air cooling conditions at different cooling rates,the phase change structure of the material is mainly composed of pearlite, intragranular ferrite, sorbite, grain boundary ferrite, troostite and bainite. The change in intragranular ferrite content in the microscopic phase transition, as well as the appearance of upper bainite and lower bainite, are strongly related to the cooling rate.

(2)The same cooling rate is cooled to different temperatures and air cooling conditions are mainly composed of grain boundary ferrite, pearlite, sorbite, and troostite. But the structure under water cooling is mainly composed of acicular martensite and quenched torsite. Cooling temperature has a very large effect on the microstructure after forging.

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