Study on the Influence of Different Tempering Processes on Microstructure and Properties of 40Cr Steel

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Abstract. In this paper, the heat treatment of 40Cr steel is carried out to explore the difference of performance of 40Cr steel under different temperatures and different heat treatment conditions, and the optimal scheme is obtained. The results show that the workpiece is subjected to 850 °C normalizing plus 240 °C low temperature tempering and 860 °C normalizing plus 440 °C medium temperature tempering and 860 °C normalizing plus 520 °C high temperature tempering. It is found that in the process of temperature increase, the infiltration of a large amount of alloying elements such as carbon and chromium contained in the carbon body are incorporated into the austenite. Under the premise of ensuring the normalizing temperature is constant, as the tempering temperature increases, the hardness of the sample decreases, the toughness increases, and the microstructure of the metallographic microstructure is coarse. The samples were compared with 860 °C oil quenching + 240 °C low temperature tempering and 860 °C normalizing + 240 °C low temperature tempering samples. It was found that although the low temperature tempering after oil quenching had the highest strength, the plasticity index decreased significantly, the impact toughness value was the lowest, and the comprehensive performance was poor.

1. Introduction
In recent years, China's industrial development has entered a new stage, and the products produced have been put forward higher requirements in terms of quality and efficiency. 40Cr steel is a kind of metal material with good performance in all aspects, and it has many applications in various fields. 40Cr steel is a medium carbon steel. After a certain heat treatment, it can obtain better toughness, wear resistance and plasticity, and the price is moderate [1-7]. However, the performance of 40Cr steel is currently difficult to meet the growing needs of people, so the development of better and better performance of 40Cr steel is inevitable. We use reasonable heat treatment methods to improve the performance of various aspects without changing the composition of 40Cr steel. In this paper, by changing the metallographic structure of the interior of the model by quenching, normalizing and tempering the small experimental materials of 40Cr steel, the microstructure of the metallographic diagram formed by different heat treatment methods is explored and carried out.

2. Experiments and Materials

2.1. Materials
The selected material is 40Cr Steel. The sample has a length of about 50 mm and a diameter of about 10 mm. A total of 14 blocks, divided into 1, 2, 3, 4 groups, each group of 2 blocks.

2.2. Experimental.
The heat treatment process of quenching and tempering is shown in Table 1.

| number | normalizing temperature | Holding time | tempering temperature | Holding time |
|--------|-------------------------|--------------|-----------------------|--------------|
| SY1    | 860°C                   | 40min        | 240°C                 | 2h           |
| SY2    | 860°C                   | 40min        | 440°C                 | 2h           |
| SY3    | 860°C                   | 40min        | 540°C                 | 2h           |

3. Results and Analysis

3.1. Analysis of hardness test results of the 40Cr steel after different tempering heat treatment
According to the above scheme, the sample was heat-treated, and the treated 40Cr steel samples were respectively tested for mechanical properties and metallographic microstructure. We take 3 points to test the hardness of the specimen and heat the test with the HRC-150 Rockwell hardness tester. The measurement results are shown in Table 2.

| number | The hardness /HRC |
|--------|-------------------|
| SY1    | 59.4              |
| SY2    | 59.3              |
| SY3    | 54.9              |

As we can see from table 2, After 40Cr steel has been treated by different heat treatment processes, the Rockwell hardness has changed significantly, especially the high temperature tempering hardness is more obvious.

3.2. Observe and analyze the microstructure
Fig. 1 is a sample of 40Cr steel held at 860 °C for 40 min and then polished after grinding the metallographic phase, and then magnified 500 times (a) and 1000 times (b) after the Zeiss metallurgical microscope to observe the tissue.

Through the observation of Fig. 1, we can see that the sample 40Cr steel is kept at 860 °C for 40 min, the carbide refining effect is the best, and the carbide particle size is also low. If the heat preservation time is too long, the microstructure is in the tissue. Some deformed large particle carbides and a small amount of flaky pearlite will appear. The reason for this phenomenon is that the austenitizing temperature is too high and the time is too long, causing partial austenite composition to be uniform.

The 40Cr steel was taken out at 860 °C for 40 min in a box heat treatment furnace, and naturally cooled to room temperature, and the cooling medium was air. The sample was then tempered at 240 °C for two hours, and the sample was taken out and placed outside the furnace, waiting for natural cooling to room temperature. The obtained sample was subjected to metallographic experimental grinding and polishing, and then etched, and then cleaned and placed on a Zeiss electron microscope to observe the structure of the structure. The obtained tissue is as shown in Fig.1, which is an image obtained by magnifying 200 times (a) 500 times (b) and 1000 times (c).
Fig. 1. Microstructure of normalizing temperature specimens

It can be seen from Fig. 2 that after the normalized 40Cr steel sample is further subjected to low temperature tempering, its metallographic microstructure is further homogenized and refined, as seen from the magnification of 200 times, the microstructure Basically all are uniform and the same size. We can clearly see from the other two metallographic micrographs that the microstructure of the 40Cr steel pattern after normalizing and low temperature tempering is ferrite and pearlite. And the two are almost evenly distributed and contain each other. The structure inside the sample is made denser due to the generation and diffusion of ferrite. The hardness of the sample of this group was improved.

Fig. 2. Microstructure of tempered SY1 specimens

Fig. 3 shows that the sample 40Cr steel was kept at 860 °C for 40 min, and then placed outside the furnace to cool the sample to room temperature. Then, it was placed in a box type heat treatment furnace heated to 440 °C for 2 hours, and then taken out and then air-cooled to room temperature, and subjected to medium temperature tempering treatment.

Fig. 3 shows the normal temperature tempering at 860 °C for two hours, after cooling the descaling, the metallographic microstructure is observed, and the figure is taken, which is 200 times (a), 500 times (b) and 1000 times (c). Through observation of the metallographic microstructure, it can be found that after tempering at 860 °C for 40 min plus tempering at 440 °C for two hours, as shown in the metallographic microstructure of the figure, metallographic microscopy with low temperature tempering experiments can be seen. The microstructure of the carbide is larger than that of the structure, and the distribution of ferrite and pearlite is more uniform, but the hardness is significantly reduced. Corresponding plastic toughness is enhanced and better machinability is obtained.

Fig. 4 shows the metallographic microstructure of the sample 40Cr steel after tempering at 860 °C for 40 min after tempering at 540°C. The magnifications are 200 times (a), 500 times (b) and 1000 times (c).
It can be seen from Fig. 4 that the 40Cr steel is further tempered after being tempered at 860 °C for 40 minutes and then tempered at 540 °C for two hours, the pearlite is granulated, and the metallographic microstructure is ferrite and granular pearlite. Since the pearlite formed by it is fine, it is black under the microscope of Zeiss electron. The hardness is further reduced, and the toughness and shape are further enhanced.

4. Conclusions
In this paper, several different heat treatment methods are applied to 40Cr steel to refine the undissolved carbides in 40Cr steel. The conclusions obtained are as follows. First, the optimal heat treatment process for 40Cr steel in this experiment is tempering at 850 °C for 40 min and then quenching at 240 °C. The 40Cr steel carbide treated by this method is compared with other gases. It is finer, more uniform, and more diffuse. Hardness and toughness are well matched and have excellent overall performance. Secondly, the 40Cr steel sample treated by the 240°C tempering process after tempering at 850 °C for 40 minutes is normalized and the tempering of the microstructure is fine and uniform. The structure inside the sample is made denser due to the generation and diffusion of ferrite. Finally, the 40Cr steel sample was tempered at 860 °C for 40 min, then rapidly added to the oil for rapid cooling, and then tempered at 240 °C. The metallographic microstructure of the sample was obviously tempered lath martensite structure. Although the hardness is greater than 850 °C + 40 min of heat preservation after the normal temperature and then the 240 °C tempering process after the 40Cr steel sample, but the toughness is obviously insufficient.

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References
[1] Zongde Lin, Wen Chen: Journal of Equipment manufacturing technology Vol. (2014), p.255-256, in Chinese.
[2] Yichao Ding, Hong Yin, Zilian Jiang: Journal of Hot Working Technology Vol. 42(2013), p.30-33, in Chinese.
[3] Chuan Li: Journal of Shandong Industrial Technology Vol.7(2018), p.39-39, in Chinese.
[4] Fuqiang Cai, Fagui Hu, Zhiyong Chao: Journal of World non-ferrous metals Vol. 10(2018), p.240-241, in Chinese.
[5] Huojun Ou, Lixin Dong, Youlong Zhou etc: Journal of Material & Heat Treatment Vol. 41(2012), p.199-201, in Chinese.
[6] Liujun Zhang, Xiaoyang Song, Yuqing Liu etc: Journal of Transactions of Materials and Heat Treatment Vol. 40(2019), p.76-83, in Chinese.
[7] Jianhong Yang, Jianzhong Lei, Jianyi Ye etc: Journal of Bearing Vol.5(2001), p.240-241, in Chinese.