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EFFECT OF TEMPERING TEMPERATURE ON MICROSTRUCTURE AND PROPERTIES OF HIGH NITROGEN STAINLESS STEEL SKATES

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The results show that when the tempering temperature is 180 ~ 550 °C, the hardness, tensile strength and yield strength decrease first, then increase and then decrease rapidly. The test steel reduces carbon and increases nitrogen, and there is no coarse eutectic carbide in the structure. When the tempering temperature is 500 °C, the matrix structure is tempered sorbite, carbide $M_{23}C_6$ and nitride Cr_2N are finely dispersed and evenly distributed on the matrix. Secondary hardening occurs when tempering at 500 °C, and the strength and hardness reach the peak, which is related to the dispersion strengthening of carbonitride. The experimental results provide theoretical guidance for high carbon steel in the process of making skates.

Keywords: high nitrogen stainless steel, tempering temperature, skates, microstructure, mechanical properties

INTRODUCTION

Ice skates are steel knives placed under the sole of skates. They melt into water by contacting with the ice surface, which has achieved the effect of reducing friction. As a kind of stainless steel, high nitrogen stainless steel not only takes into account the advantages of stainless steel material, but also increases the hardness and toughness. It is a relatively successful skates material. High nitrogen stainless steel has high hardness and certain corrosion resistance. However, high C and Cr content will lead to the appearance of coarse carbides in the structure, and it is difficult to eliminate or refine these coarse carbides through later heat treatment. The fatigue and corrosion resistance of bearing steel will be damaged [1-3]. In contrast, the addition of N element in steel can reduce the number of coarse eutectic carbides and precipitate a large number of fine nitrides and carbides. N instead of C can not only strengthen the matrix but also improve the corrosion resistance, which can obtain high strength and good corrosion resistance [4-5]. In this paper, high nitrogen stainless bearing steel was used as the test material, and the effects of different tempering temperatures on the microstructure and mechanical properties of the test steel were studied. Through a series of tempering temperature tests and mechanical properties tests, the basic mechanical properties of the experimental steel are given at each temperature point.

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Materials and methods

The medium frequency melting furnace was used for melting, sand casting and preparation of experimental as-cast samples. Its chemical composition (mass fraction): C 0,42 %, Si 0,3 %, Mn 0,93 %, Cr 15,7 %, Mo 1,8 %, V 0,28 %, Ni 0,33 %, N 0,2 %, Fe Bal. The experimental steel was tempered by a box-type resistance furnace. The tempering temperature was 180, 250, 300, 350, 400, 450, 500 and 550 °C, respectively, and the holding time was 1h. The microstructure of the experimental steel was observed on a metallographic microscope. The corrosive agent was 3 % nitric acid alcohol solution. The mechanical properties of experimental steels in different states were tested on 5105 microcomputer controlled electronic universal testing machine.

Experimental results and discussion

Figure 1 shows the typical microstructure of the test steel treated at different tempering temperatures. It can be seen that stable dispersed carbides or nitride particles are uniformly distributed on the tempered martensite matrix, which greatly reduces the presence of coarse eutectic carbides and needle-like eutectic carbides. With the increase of tempering temperature, the number of precipitates in the crystal increases. After tempering at 180 °C and 350 °C, the microstructure is tempered martensite + granular precipitates, as shown in Figure 1 (a, b) ; after tempering at 500 °C, the microstructure is tempered troostite + granular precipitate + secondary dispersed precipitate, as shown in Figure 1 (c); after tempering at 550 °C, the microstructure is tempered sorbite + granular precipitates, as shown in Figure 1 (d).

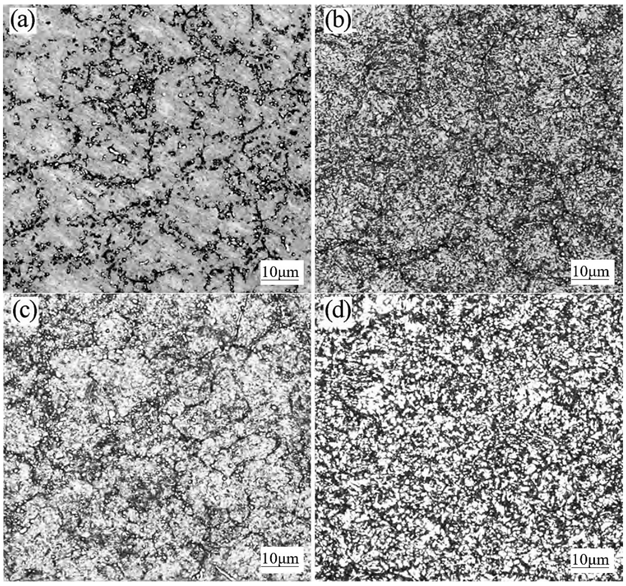

Figure 1 Microstructure of experimental steel at different tempering temperatures

Table 1 **Mechanical properties of experimental steel at different tempering temperatures**

Number	Tempering temperature	Hardness/ HRC	R_v/MPa	R_m/ MPa	Elonga-tion/%	impact work
1	180	58,6	1 961	2 002	35,0	16
2	250	56,5	1 600	1 861	33,7	15,8
3	300	55,0	1 553	1 813	32,8	15,6
4	350	55,2	1 491	1 751	32,0	15,4
5	400	55,4	1 572	1 700	31,1	15,2
6	450	55,9	1 625	1 625	30,7	15
7	500	58,0	1 701	2 021	29,2	14,8
8	550	51,2	1 272	1 757	33,2	20,3

During the tempering process, the tempering time and temperature affect the properties of the material. In general, the best ratio can be obtained by controlling the parameters. The mechanical properties of the experimental steel at different tempering temperatures are as shown in Table 1.

The Rockwell hardness curve of the tested steel at different tempering temperatures is shown in Figure 2. It can be seen that the characteristics of the hardness change in the tempering process are divided into three stages, with the tempering temperature of 300 °C and 500 °C as the demarcation point.

The first stage is the tempering temperature range of 180 ~ 300 °C, and the hardness decreases from the initial 58,6 HRC to the lowest point 55,0 HRC. This is due to the gradual precipitation of carbon in the matrix structure to form carbides, the carbon concentration in martensite decreases, the degree of martensite supersaturation decreases, the lattice distortion decreases, and the hardness decreases.

The second stage is 300 ~ 500 °C, and the hardness increases significantly with the increase of tempering temperature, reaching a peak of 58,0 HRC at 500 °C. During austenitizing, the carbides dissolve into the matrix, and the alloy elements are too late to precipitate

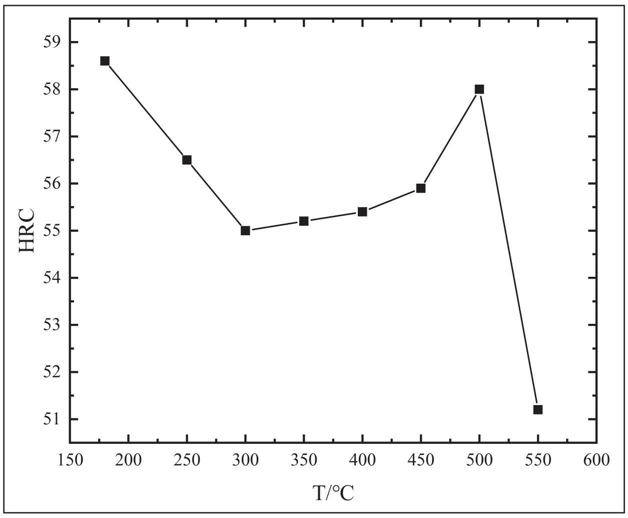

Figure 2 Effect of tempering temperature on hardness of experimental steel

during the quenching process to form a supersaturated solid solution. When the tempering temperature reaches a certain temperature, the alloy elements are precipitated in the form of carbides. Therefore, at this stage, it is related to the dispersion strengthening of $M_{23}C_6$ carbides and Cr_2N nitride phases which are finer and more dispersed by carbide re-dissolution. Because the steel contains Cr, Mo and other strengthening carbide forming elements, fine alloy carbides are formed in the steel, and secondary hardening occurs after tempering at 500 °C and reaches the peak hardness. On the other hand, alloying elements such as Mo and V can also promote the formation of M_2X and increase its stability [6].

The third stage is 500 ~ 550 °C, and the hardness decreases rapidly. When the tempering temperature is above 500 °C, the matrix structure is tempered sorbite, the precipitated carbides and nitrides gradually aggregate and grow up, the content of C and N in the matrix decreases greatly, and the hardness decreases significantly.

Figure 3 and Figure 4 show the relationship between tempering temperature and tensile strength and yield strength. The basic law is as follows : with the increase of tempering temperature, it decreases first and then increases. When the tempering temperature reaches 500 °C, the strength peak appears, and the tensile strength and yield strength are 2 021 MPa and 1 701 MPa, respectively. When tempering temperature exceeds 500 °C, the tensile strength and yield strength decrease obviously. This is consistent with the above hardness change trend.

As shown in Figure 3 and Figure 4, the tensile strength (R_v) and yield strength (R_m) of the test steel after heat treatment decrease first and then increase with the increase of tempering temperature. When the tempering temperature reaches 500 °C, the strength peaks appear, and the tensile strength and yield strength are 2021 MPa and 1 701 MPa, respectively. This is because when tempered below 350 °C, the retained austenite of the soft phase decomposes, and C in the matrix structure gradually precipitates to form carbides, and

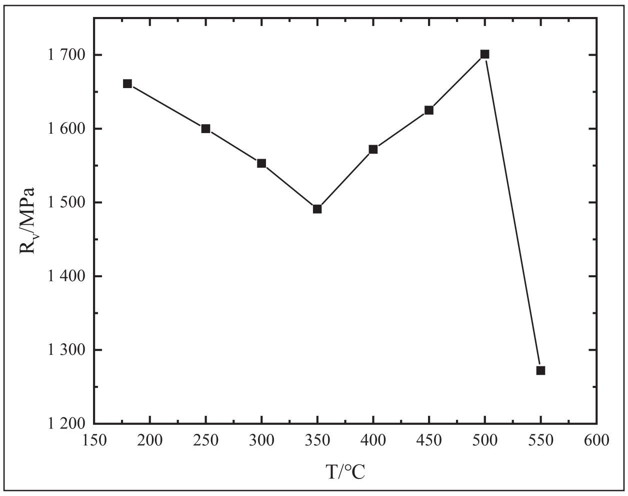

Figure 3 Effect of tempering temperature on tensile strength of experimental steel

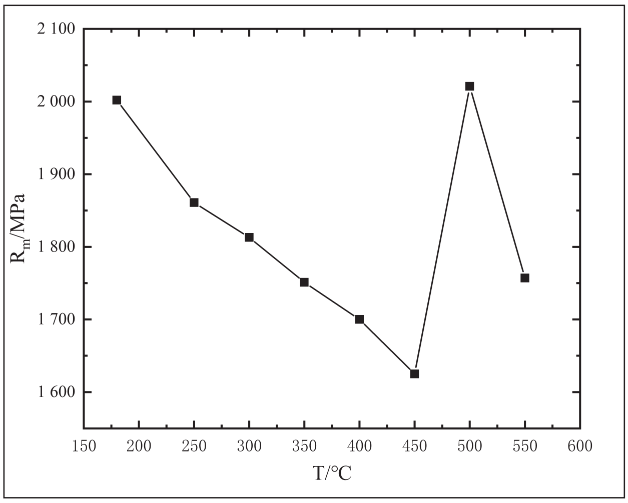

Figure 4 Effect of tempering temperature on yield strength of experimental steel

the C concentration in the martensite decreases, resulting in a continuous decrease in tensile strength and yield strength. When tempering at more than 350 °C, the precipitation of fine carbides and nitrides can increase the yield strength, and the recovery of laths and dislocations reduces the tensile strength. When tempering at 500 °C, the dispersion strengthening effect of $M_{23}C_6$ carbides and Cr_2N nitrides with finer and more dispersed secondary precipitation makes the tensile strength and yield strength reach the peak value. When tempering at more than 500 °C, the precipitated phase is coarse, the dislocation pinning effect is reduced, the strengthening effect is weakened, and the strength is obviously reduced.

The impact energy reflects the ability of the material to resist deformation and failure under impact load, and its size reflects the impact toughness of the material. As shown in Figure 5, the impact toughness decreases first and then increases with the increase of tempering temperature. When the tempering temperature is 500 °C, the impact energy is the lowest, which is 20,3J.

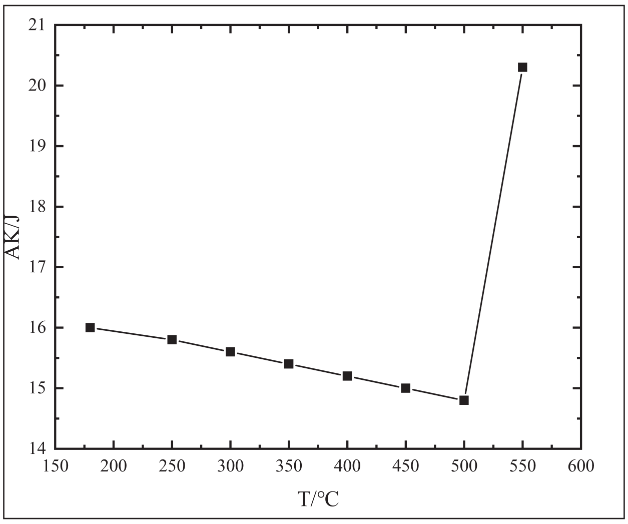

Figure 5 Effect of tempering temperature on impact toughness of experimental steel

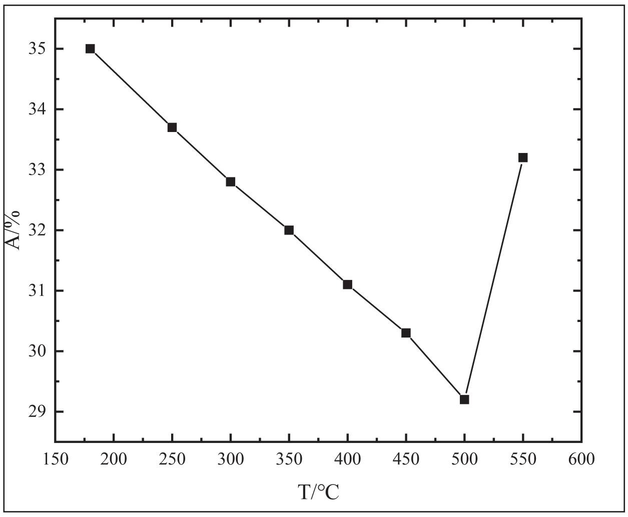

Figure 6 Effect of tempering temperature on elongation of experimental steel

Figure 6 is the effect of tempering temperature on elongation. It can be seen that with the increase of tempering temperature, the elongation decreases first and then increases. The inflection point is at 500 °C, and the elongation is 29,2 %. Compared with the adjacent data, the value decreases, but the change of section shrinkage is more obvious.

It can be seen from the test results that the Rockwell hardness, tensile strength, yield strength, impact toughness and elongation of the tested steel after tempering do not increase monotonously or decrease monotonously with the increase of tempering temperature, but the maximum or minimum values of each performance appear at 500 °C.

CONCLUSION

The tempering temperature has a significant effect on the microstructure of the test steel. After quenching and tempering at different tempering temperatures, the microstructure of the test steel tempered below 550 °C is tempered martensite and tempered troostite. When the tempering temperature is 550 °C, tempered sorbite begins to form. When tempered at 180 ~ 500 °C, with the increase of tempering temperature, the martensite lath becomes more obvious and wider, and the number of precipitated carbonitride increases and is evenly distributed on the matrix. When tempered at more than 500 °C, the precipitated carbonitrides coarsen or spheroidize rapidly and aggregate.

The tempering temperature has a significant effect on the mechanical properties of the test steel. In the tempering temperature range of 180 ~ 550 °C, the hardness, yield strength and tensile strength of the test steel remain high. The change trend of mechanical properties of the tested steel is mainly divided into three stages. With the increase of tempering temperature, it decreases first and then increases slowly, reaching the peak at 500 °C. When the temperature exceeds 500 °C, the mechanical properties decrease rapidly. The impact toughness and elongation of the tested steel decrease first and then increase, reaching the minimum at 500 °C. When the temperature exceeds 500 °C, the impact toughness and elongation increase rapidly. This study has a certain guiding role in the development of skates material.

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Note: The responsible translator for English language is Z. J. Wei - Harbin University, China.