

# Effect of Optimized Tempering Process on Delayed Fracture of Wear Resistant Steel

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**Abstract**—In order to solve the delayed fracture phenomenon of the wear resistant steel plate, the chamber electric furnace was used to carry out the tempering test; and the influence of tempering temperature and tempering time on the hardness, tensile strength and -20 impact energy of the wear resistant steel is analyzed. The statistical results shows that the comprehensive performance of wear resistant steel is more excellent when the tempering temperature is 450°C and the tempering time is 2.5H.

**Keywords**—tempering temperature; tempering heat preservation time; delayed fracture

## I. INTRODUCTION

The delayed fracture of high strength steel is mainly because the intrusion of the hydrogen in the steel, which is characterized by brittle intergranular fracture, so the starting point of improving the delayed fracture performance is to improve the effectiveness of hydrogen trapping in the steel, reduce the concentration of diffusible hydrogen in the matrix and increase the grain boundary binding strength.[1] The main measures which is used at home and abroad now are refining grain, reducing the grain boundary segregation and high temperature tempering.

High temperature tempering: hydrogen embrittlement susceptibility of martensitic steel decreases with the increase of the tempering temperature. At low temperature, the diffusion of elements is limited, and the microstructure can only be changed in the micro scale. At high temperature, the original austenite grain boundary and the carbide on the martensite lath boundary gather and develop, stress concentration decreases, continuous degree on grain boundary reduces, captured hydrogen on grain boundary decreases, meanwhile, tempering temperature increases, residual stress disappears, dislocation density reduces, carbide in grain interior also can be precipitated in a large amount to capture a portion of the hydrogen in the grain interior, all this above makes the grain boundary binding force increased.

## II. TEMPERING TEMPERATURE TEST

Take 6 block of low alloy wear-resistant steel plate after  $900\pm 10^\circ\text{C}$  quenching, and do tempering test of different temperature ( $250^\circ\text{C}$ ,  $300^\circ\text{C}$ ,  $400^\circ\text{C}$ ,  $450^\circ\text{C}$ ,  $350^\circ\text{C}$ ,  $500^\circ\text{C}$ ) on chamber electric furnace in Research Institute pilot plant, the sample is heated to the set temperature in the furnace, keep it for 30min and then take it out for air cooling.

In the condition of the tempering after the quenching of the heat preservation 30min at  $900\pm 10^\circ\text{C}$ , the relationship between

tempering temperature and hardness, tensile strength and  $-20^\circ\text{C}$  impact energy of test steel, as shown in Figure 1-2.

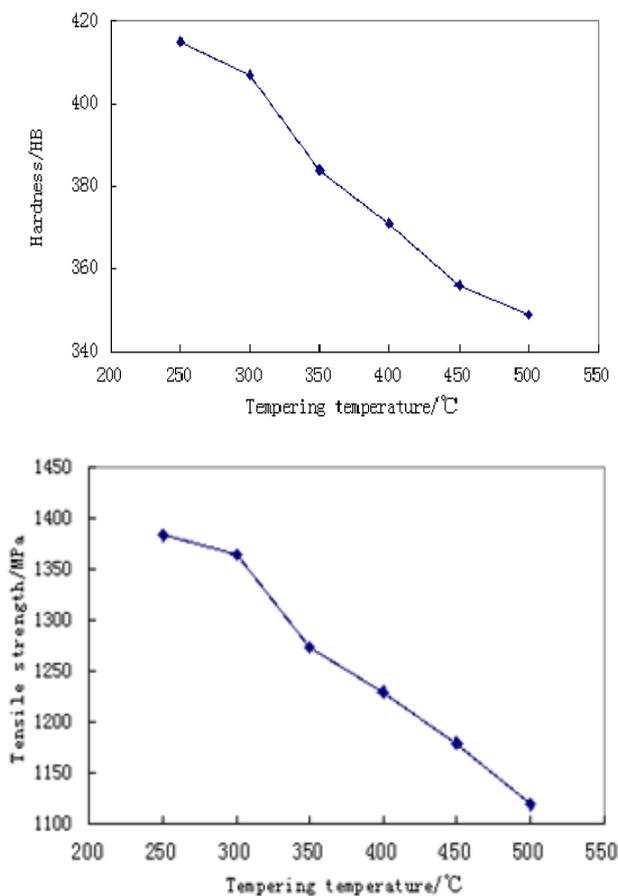


FIGURE 1. THE HARDNESS AND TENSILE STRENGTH AT DIFFERENT TEMPERING TEMPERATURES

From Figure 1, it can be seen that tempering can make the wear resistant steel soften, and the tensile strength and hardness decrease with the increase of the tempering temperature, which is due to the change of the microstructure of the matrix. The content of carbon and the dispersion distribution of carbon nitride are the key factors to influence the strength of low alloy wear-resistant steel. In the process of tempering, the precipitation of the carbide in the martensite and the decrease of carbon content will inevitably lead to the decrease of the strength of the wear

resistant steel[2].

The results of the -20°C impact test are shown in Figure 2.

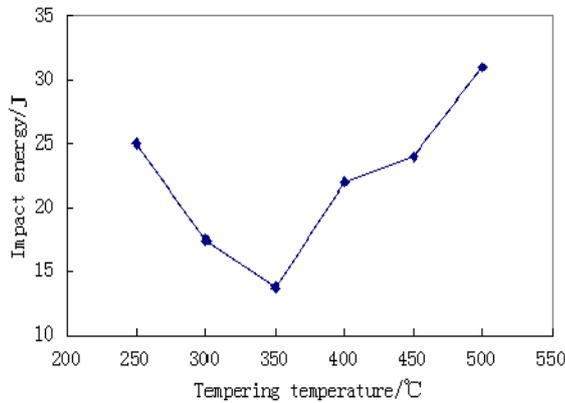


FIGURE II. 20°C IMPACT ENERGY AT DIFFERENT TEMPERING TEMPERATURE

From Figure 2, it can be seen that it is in the temper brittle zone when the tempering temperature is in the vicinity of 350°C. With the increase of the tempering temperature, the carbide precipitated from the matrix gradually gathered coarsening, and the number of carbide particles decreased, the particle size was uniform, and the carbides of the larger particles can hinder the movement of dislocations, and the dislocation slip reduced, therefore, the toughness of the material is obviously improved.

### III. TEMPERING TEMPERATURE OPTIMIZATION TEST

The test procedure is nearly the same with the test above, except the set temperature. The sample is heated to the set temperature (250°C, 300°C, 400°C, 420°C, 450°C, 470°C) in the furnace, keep it for 30min and then take it out for air cooling, in order to avoid the tempering brittle zone (350°C) of wear resistant steel. Hardness and -20°C impact energy of test steel are shown in Figure 3.

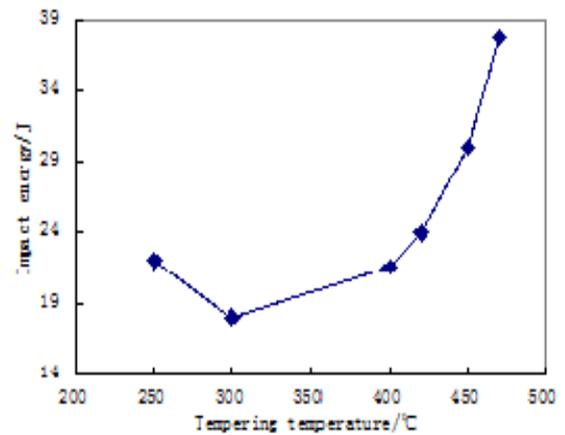
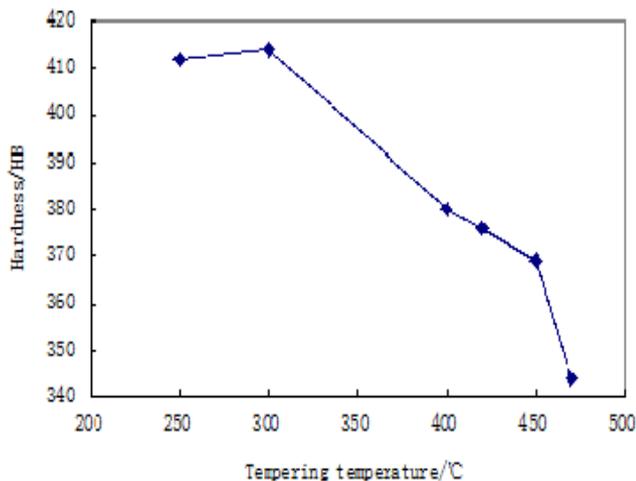


FIGURE III. THE HARDNESS AND -20°C IMPACT ENERGY AT DIFFERENT TEMPERING TEMPERATURES

From Figure 3, it can be seen that the hardness of wear resistant steel is close to the upper limit when the tempering temperature is 250°C and 300°C.

Based on the analysis above the wear resistant steel can obtain the best mechanical properties at 450°C during tempering.

The increase of the tempering temperature can eliminate the residual stress of quenched steel, [3] so as to improve the ability of delay fracture of high strength steel. There must be a role of stress in the hydrogen induced delayed fracture, and austenite transformed to martensite in the quenching process, the phase transition will produce tissue stress because of the big difference of the specific volume existed between austenite and martensite. The superposition of the tissue stress and the heat stress caused by quenching makes the internal stress of the steel increase. On the grain boundary, the carbides gather and develop and the number decreases, so the captured hydrogen content on grain boundary reduces; the dispersion and precipitation of the carbides inside the grains will also decrease the captured hydrogen on the grain boundary, these factors reduce the probability of crack initiation on the grain boundary and the propagation along grain boundary [4]. Therefore, as the tempering temperature increase gradually, the fracture mechanism of notched tensile specimen transfer from the brittle fracture dominated by intergranular fracture at a low tempering temperature into the intergranular quasi-cleavage and a small amount of intergranular mixed fracture at a high tempering temperature. The change of the fracture mechanism is an important performance of the improvement of delayed fracture resistance of the specimen.

### IV. TEMPERING TIME

The conclusion above shows that the wear resistant steel gets better mechanical property when the tempering temperature is 450°C, therefore, the effect of tempering time on the mechanical property was studied. The specimen was tempered at 450°C, kept heat preservation according the time in Table 1 and taken out for air cooling.

TABLE I. TEMPERING TIME TEST SCHEME

Sample number	tempering temperature (°C)	Tempering time in the furnace(min)		Hold time(min)
1	450°C	1.5H	38	11
2	450°C	2.0H	63	19
3	450°C	2.5H	88	26
4	450°C	3.0H	113	34

Figure 4 shows the change of the hardness and -20°C impact energy of the test steel under different heat preservation time when the tempering temperature is 450°C. As can be seen from the picture, with the extension of heat preservation time, the hardness of wear resistant steel is decreased. With the extension of the tempering time, martensite decomposed precipitation epsilon carbide and gradually gather and grow up, meanwhile, the dislocation density and the hardness of the steel decrease.[5] The -20°C impact energy is increased with the extension of tempering time.

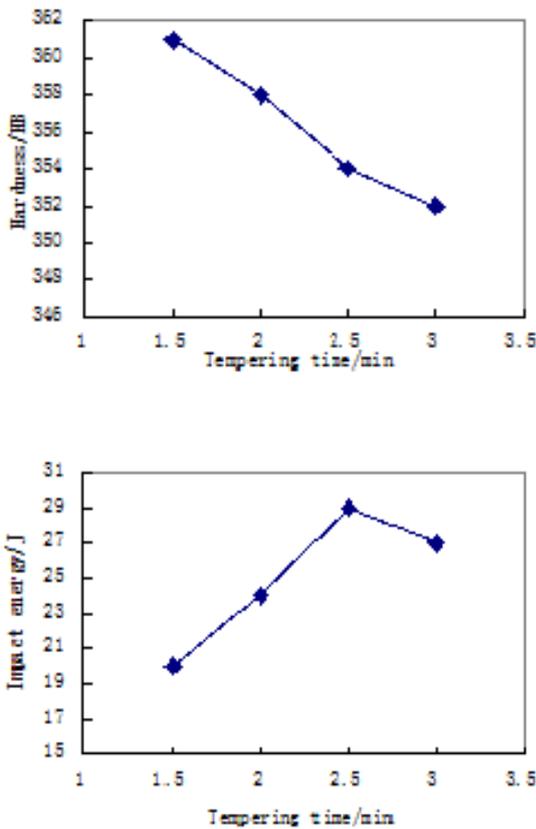


FIGURE IV. THE HARDNESS AND -20°C IMPACT ENERGY AT DIFFERENT TEMPERING TIME

### V. CONCLUSION

(1) With the increase of the tempering temperature, the tensile strength and hardness of the tested steel were decreased, and the impact energy began to decrease, and the impact energy increased rapidly when the temperature was higher than 400.

(2) With the extension of the tempering time, the hardness of the wear resistant steel samples decreased gradually, and the

impact toughness gradually increased, and the fracture surface of the impact specimen changed from brittle fracture to ductile fracture.

(3) Through the optimization of the tempering process, the final determination of the tempering temperature is 450°C and the tempering time is 2.5H.

### ACKNOWLEDGMENT

This work was financially supported by the Key Laboratory for Ferrous Metallurgy and Resources Utilization of Ministry of Education, Wuhan University of Science and Technology (430081) and Wuhan Iron and Steel Corporation (430083).

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