The Influence of Tempering Process on Abrasion-resistant Steel Cracking

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Abstract. To the problem of delayed cracking of the high strength low alloy abrasion-resistant steel plate NM360, the tempering temperature and tempering time of abrasion-resistant steel are optimized. The main results are as follows: Through the tempering process optimization, the tempering temperature is 450°C, tempering time of 2.5H for the comprehensive performance of abrasion-resistant is excellent.

Introduction

Low alloy abrasion-resistant steel is a kind of abrasion-resistant materials developed after 1960s. It has good comprehensive mechanical properties, simple production process, widely used working conditions, good economic benefits. Therefore, in recent decades, the research and development of high quality and low alloy abrasion-resistant steel have developed rapidly\cite{1-6}. Take a steel abrasion-resistant steel plate heat treatment process of quenching and low temperature tempering, organized into martensite with high hardness and high strength and good toughness, widely used in machinery manufacturing industries. But some plates in flame cutting, finished standing a few days after the sudden brittle fracture, refined static statistics found that the longer the probability of brittle fracture is small. Analysis of the causes of the cracking abrasion-resistant steel, steel plate hardness along the direction of thickness distribution is not uniform, temper is not sufficient, the internal stress has not been fully released, abrasion-resistant steel tempering temperature in brittle tempering 300~400°C \cite{7}. Therefore, the need to further explore the tempering process, in order to achieve the best balance of performance and performance of mechanical plate, greatly reduce quality objection, realize the stable production.

Test Materials

Table 1. The main chemical composition of converter smelting.

<table>
<thead>
<tr>
<th>Element</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Mo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceptance</td>
<td>(\leq0.17) &amp; (\leq0.50) &amp; (\leq1.50) &amp; (\leq0.025) &amp; (\leq0.015) &amp; (\leq0.70) &amp; (\leq0.40)</td>
<td></td>
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</tr>
<tr>
<td>Range</td>
<td>0.12- &amp; 0.20- &amp; 1.20- &amp; (\leq0.025) &amp; (\leq0.015) &amp; 0.40- &amp; 0.20-</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>0.17 &amp; 0.50 &amp; 1.50 &amp; (\leq0.025) &amp; (\leq0.015) &amp; 0.70 &amp; 0.40</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal control</td>
<td>0.13- &amp; 0.25- &amp; 1.25- &amp; (\leq0.020) &amp; (\leq0.010) &amp; 0.50- &amp; 0.25-</td>
<td></td>
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<tr>
<td>Objective</td>
<td>0.16 &amp; 0.45 &amp; 1.45 &amp; (\leq0.015) &amp; (\leq0.008) &amp; 0.55 &amp; 0.30</td>
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</tbody>
</table>
The test material was taken from the NM360 abrasion-resistant steel plate produced in a steel plant. The main chemical composition of converter smelting was shown in Table 1.

**Test Methods**

Take 900±10°C after quenching and low alloy abrasion-resistant steel plate 6, in the pilot plant research institute of box type resistance furnace under different temperature tempering (250°C, 300°C, 350°C, 400°C, 450°C, 500°C), the sample with the furnace heated to the set temperature, heat released air cooling after 30min. After tempering at different times of 450°C, the abrasion-resistant steel samples are analyzed by impact fracture and metallographic structure. The fracture surface is analyzed by Quanta 400 scanning electron microscope after ultrasonic cleaning.

**Test Results and Analysis**

**Temper Temperature**

The microstructure of the steel plate after tempering at different temperatures is shown in Figure 1. With the increasing of tempering temperature, the morphology of martensite is becoming more and more blurred, and the matrix structure is more and more uniform. Because with the increase of the tempering temperature, the atomic motion frequency is constantly increasing, resulting in martensite carbide in continuous precipitation, aggregation and growth, and ultimately the formation of uniform and stable tissue.

![Figure 1. Microstructure of the tested steel after tempering at different temperatures.](image)

The hardness and the impact energy of -20°C see Figure 2, can be seen from figure 2, the tempering temperature at 250°C and 300°C, the upper limit hardness of abrasion-resistant steel. Different temperature tempering microstructure see Figure 3, can be seen from figure 3, at 470°C, carbide precipitation more, part of the martensite has been broken down into
tempered martensite, resulting in a sharp decline in the hardness of the test steel.

In conclusion, 450°C in the tempering, abrasion-resistant steel mechanical properties are the best.

![Tempering microstructure at 420°C](image1) ![Tempering microstructure at 470°C](image2)

Figure 3. Tempering microstructure.

**Temper Time**

The sample is tempered at 450 degrees centigrade, according to table 2 holding time after tapping air cooling.

<table>
<thead>
<tr>
<th>sample number</th>
<th>temper temperature</th>
<th>tempering time [min]</th>
<th>holding time [min]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>450°C</td>
<td>1.5H</td>
<td>38</td>
</tr>
<tr>
<td>2</td>
<td>450°C</td>
<td>2.0H</td>
<td>63</td>
</tr>
<tr>
<td>3</td>
<td>450°C</td>
<td>2.5H</td>
<td>88</td>
</tr>
<tr>
<td>4</td>
<td>450°C</td>
<td>3.0H</td>
<td>113</td>
</tr>
</tbody>
</table>

Figure 4 shows the tempering temperature is 450 degrees Celsius, the hardness of different heat preservation time test steel and the change of impact power of -20°C. As can be seen from the figure, with the extension of the holding time, the hardness of abrasion-resistant steel is reduced. This is due to the hardened steel with martensite microstructure, microhardness is higher; With the tempering time prolonged, the martensite sub parse out the epsilon epsilon carbides, carbides gradually grow together, at the same time, the density of dislocation decreased and the hardness of steel decreased. The impact power of -20°C is increased with the increase of tempering time.

![Figure 4. Hardness of different tempering time and impact energy of -20°C.](image3)
Figure 5 is the microstructure of abrasion-resistant steel under different tempering time. It can be seen from the figure, the microstructure of 1~4 specimens are mainly lath martensite, the morphology of martensite under different tempering time is similar. In the range of tempering temperature and tempering time, the extension of tempering time has no significant influence on the microstructure of martensite.

![Sample 1 tempering time 1.5H](image1)
![Sample 2 tempering time 1.5H](image2)
![Sample 3 tempering time 2.5H](image3)
![Sample 3 tempering time 3.0H](image4)

Figure 5. Microstructure of different tempering time.

**Impact Fracture Morphology**

The impact fracture surface of different tempering time is shown in figure 6~9. As can be seen from, under different tempering time, 1-4 specimen section is relatively flat, cross-section morphology are characteristic of dimple mixed cleavage feature. After 1.5H after isothermal tempering, can see the river pattern on the fracture surface, which is quasi cleavage fracture and the number of the surrounding dimple is small. After 2.0H isothermal tempering, test steel cleavage planes have short and discontinuous pattern of rivers, compared with the 1.5H isothermal tempering impact specimen, river pattern reduced and the number of dimples increased. After 2.5H isothermal tempering, the fracture surface of the specimen is larger and uniform, which is characteristic of ductile fracture.

A certain amount of second phase particles are precipitated in abrasion-resistant steel. The precipitation and growth of the second phase particles strengthen the pinning effect of the dislocation, and hinder the slip of the dislocation in the impact process, so that the strength of the grain boundary can be improved, also the toughness of the steel can be improved.
Figure 6. Impact fracture morphology of tempering time for 1.5H.

Figure 7. Impact fracture morphology of tempering time for 2.0H.

Figure 8. Impact fracture morphology of tempering time for 2.5H.

Figure 9. Impact fracture morphology of tempering time for 3.0H.
Summary
(1) In different temperature tempering test, when the tempering temperature is increasing, the morphology of martensite plate is becoming more and more blurred, and the microstructure is more and more uniform.
(2) With the extension of tempering time, the hardness of wear resistant steel sample is gradually reduced, the impact toughness is gradually increased, and the fracture of the impact specimen is changed from brittle fracture to ductile fracture. The comprehensive performance is better when the tempering time is 2.5H.
(3) Through the optimization of the tempering process, the final determination tempering temperature is 450°C, the tempering time is 2.5H.

References