Investigation on Formation of Delayed Cracks of Abrasion-resistant Steel

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Abstract. To the problem of delayed cracking of the high strength low alloy abrasion-resistant steel plate NM360, the fracture, surface cracks and microstructure were investigated by optical microscopy, electron scanning microscopy and energy spectroscopy, and the residual stress was tested by X ray. The main results were as follows: The fracture source was in the center of the thickness of the steel plate and there were obvious central segregation in the mid-depth of the plate. Microstructure was not uniform in the surface, 1/4 depth and mid-depth of the steel, changed form lath martensite to martensite+granular bainite+ferrite. The steel showed the characteristics of the typical stress crack, there were different degree of resiual stree from edge to center, the impact of various residual stresses generating during heat treatment and the flame cutting on the defective areas was the main reason for the formation of the delayed crack.

Introduction

Low alloy abrasion-resistant steel was a kind of abrasion-resistant materials developed after 1960s. It had 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 had developed rapidly\cite{1-6}. Low levels of NM360 abrasion-resistant steel plate found plate cracking phenomenon in the use of the process, cracking abrasion-resistant steel brought great economic loss to steel mills, also brought potential problems to wear resistant steel equipment safety use. Therefore, it had very important practical significance to analyze the reason of the cracking of abrasion-resistant steel.

Test Materials

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

After corrosion of 4% nitric acid alcohol solution, the microstructure of the sample was observed under the optical microscope. Scanning electron microscope was used to observe the micro morphology of the section. Sampling in the absence of the crack location, the horizontal different position of the plate was taken as the stress test point.
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>≤0.17</td>
<td>≤0.50</td>
<td>≤1.50</td>
<td>≤0.025</td>
<td>≤0.015</td>
<td>≤0.70</td>
<td>≤0.40</td>
</tr>
<tr>
<td>Range</td>
<td>0.12-</td>
<td>0.20-</td>
<td>1.20-</td>
<td>≤0.025</td>
<td>≤0.015</td>
<td>0.40-</td>
<td>0.20-</td>
</tr>
<tr>
<td>Internal</td>
<td>0.17</td>
<td>0.50</td>
<td>1.50</td>
<td>≤0.025</td>
<td>≤0.015</td>
<td>0.70</td>
<td>0.40</td>
</tr>
<tr>
<td>Control</td>
<td>0.13-</td>
<td>0.25-</td>
<td>1.25-</td>
<td>≤0.020</td>
<td>≤0.010</td>
<td>0.50-</td>
<td>0.25-</td>
</tr>
<tr>
<td>Objective</td>
<td>0.15</td>
<td>0.35</td>
<td>1.35</td>
<td>≤0.015</td>
<td>≤0.008</td>
<td>0.55</td>
<td>0.30</td>
</tr>
</tbody>
</table>

Test Results and Analysis

Low Magnification Microstructure

Near surface layer of cracking had a parallel plate and located in the central part of the plate crack, which was straight and shown the characteristics of crack stress[7], shown in Figure 1. After polishing and etching, the crack extended to the center of the plate segregation strip, shown in Figure 2.

Figure 1. Center crack of the sample.  
Figure 2. Center segregation of the sample.

Inclusion

Detection analysis of the cracking specimen found that the cracking surface had a large number of inclusions, which were different sizes and the maximum length were 100μm. EDS results showed that it had the silicate composite inclusion, which contained O, Ca, Al, Mg, Si and other elements, shown in Figure 3. Large granular inclusions would damage the integrity and continuity of the steel[8], which were easy to cause the stress concentration for the formation of cracks.
### Microstructure

Sampling in parallel to the fracture section, the microstructure shown in figure 4 after etching. The cutting edge portion of the fracture source color was deeper than normal parts, accompanied by decarbonizing phenomenon. The microstructure was composed of tempered sorbite+ferrite, while the normal part of the microstructure was tempered martensite in figure 5. The change of this kind of microstructure was similar to that of the heat affected zone[9]. The characteristic of the heat affected zone were formed by the temperature gradient of the heating process and the cooling rate gradient of the cooling process. The ferrite of cutting edge was soft and the strength was low. At the same time, flame cutting edge of grain boundary microstructure was larger and lower plastic, resulting in cutting surface embrittlement and formation of brittle crack source.

![Figure 3. Non-metallic inclusions.](image)

<table>
<thead>
<tr>
<th>Element</th>
<th>Weight%</th>
<th>Atomic%</th>
</tr>
</thead>
<tbody>
<tr>
<td>O K</td>
<td>39.84</td>
<td>56.73</td>
</tr>
<tr>
<td>Mg K</td>
<td>05.86</td>
<td>05.49</td>
</tr>
<tr>
<td>Al K</td>
<td>09.93</td>
<td>08.38</td>
</tr>
<tr>
<td>Si K</td>
<td>17.21</td>
<td>13.96</td>
</tr>
<tr>
<td>Ca K</td>
<td>27.16</td>
<td>15.44</td>
</tr>
</tbody>
</table>

![Figure 4. The surface hardening layer.](image)  
Figure 4. The surface hardening layer.

![Figure 5. Normal microstructure.](image)  
Figure 5. Normal microstructure.

Sampling the fracture near the source, observing the slab surface, 1/4 thickness of the central organization. The results were shown in figure 6.

![Surface](image)  
Surface

![The 1/4 thickness](image)  
The 1/4 thickness

![Center](image)  
Center

![Figure 6. Section microstructure of the sample.](image)  
Figure 6. Section microstructure of the sample.
On the surface of a sample was normal tempered martensite microstructure, the 1/4 thickness for bainite+martensite+ferrite, center segregation with martensite. Thus, the delay sample cracking in the vicinity of crack microstructure were not completely hardenability in the quenching process of center thickness, leading to differences in surface layer and core structure.

**Stress Testing**

The results shown that plate transverse on different positions had certain residual stress and force increased gradually from the edge to the middle, and the residual pressure stress on the plate center was maximal. Its existence had an important influence on the steel plate crack.

**Recommendations**

In order to reduce the generation of wear-resistant steel plate, the following is recommended:

(1) To improve the center segregation in as cast, reducing casting blank center defects and steel center crack in the production process of continuous casting by using electromagnetic stirring and dynamic soft reduction technology.

(2) Refining the microstructure and reduce defect centers by increasing the rolling compression ratio. The steel plate was uniform in structure and full release of the internal stress by using reasonable quenching system and tempering temperature and time. Thus, the delay cracking was reduced in the slab rolling and heat treatment processes.

(3) Preheating treatment before cutting the steel plate, reducing the cutting speed and taking the slow cooling or appropriate heating measures could effectively avoid or reduce the cutting crack and the residual stress.

**Summary**

(1) The fracture source was in the center of the thickness of the steel plate, where were obvious central segregation. The central segregation defects affected the steel plate cracking.

(2) There were a large number of granular inclusions in the crack samples. The large grain structure formed by the cutting edge of abrasion-resistant steel reduced the plasticity of the matrix, and it was easy to form a brittle crack source.

(3) Microstructure was not uniform in the surface, 1/4 depth and mid-depth of the steel, changed form lath martensite to martensite+granular bainite+ferrite. The microstructure near the crack was not completely hardenability in the quenching process.

(4) The steel showed the characteristics of the typical stress crack, there were different degree of resial stree from edge to center, the impact of various residual stresses generating during heat treatment and the flame cutting on the defective areas was the main reason for the formation of the delayed crack.

**References**


