Rail Damages and its Counter Measures in a Heavy Haul Railway

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Summary: By means of field investigation and laboratory experiments on rail defects in a heavy haul railway, the types and features of rail damages were studied, then the counter measures were presented and put in practice. Valuable practical results were achieved.

Index Terms: heavy haul railway, rail damage, counter measures

Since commencing operations in Dec, 1992, the Datong-Qinhuangdao (Daqin) line has been running heavy-loading trains. This is the first electrified double track line in China that serves as a major conduit for moving coal. The Daqin line is a typical heavy haul railway in China with many characteristics comparable to international Heavy Haul Railroads in the 1980's.

During the first ten years of operation, Daqin line ran mainly heavy-loading trains from 5,000 tons to 10,000 tons. In 2003, it started running 20,000 ton trains. The amount of coal transported by the line is as follows: 2005, 200MGT; 2006, 250MGT; 2007, 340MGT. Now the Daqin line mainly runs 10,000 and 20,000 ton trains, and the axle load is mainly 25 ton.

With the increase in both transport volume and axle load, damage to rail of the Daqin line is increasing greatly. So it is urgent that we research how to prolong the service life of the rail in Daqin line. On the track of Daqin line, the type II and type III concrete sleeper, I-level (i.e. highest quality) ballast and continuously welded 75kg/m rail are used.

In this paper, we summarize our various investigations of rails laid on Daqin line over these years, deduce the main types of rail defects based on analyzing the features of failed rails, then present the countermeasures applied to reduce the rail damages. Some valuable practical results have been achieved on the test section.

1 TYPES OF RAIL DAMAGE ON THE DAQIN HEAVY HAUL RAILWAY LINE

The investigation of rail damages in the Daqin line showed that the lateral wear, spalling, shelling on curve line rails and defects and failures on welded joints are main types of damage and are also the main causes of limited rail service life [1].

1.1 The Lateral Wear and Spalling on Curve line Rail

Lateral wear is the main damage type on curved line rail. In recent years, the lateral wear of rail has been effectively controlled by using full-length head hardened rails. But on heavy haul line, many of the rails are replaced early because of serious lateral wear.

On the Daqin line, the as-rolled rail with an ultimate strength 880MPa was used for the whole line at the beginning of operation. The lateral wear on the rail of a curve with radius 400 - 600m can be up to 18mm within 9 months of service because of the rail's low wear resistance. In the middle to end of the 1990's, U75V full-length off-line heat treated rails were laid on the curve line, and the lateral wear on the curve line rail declined greatly [2]. With the running of 10,000 ton and 20,000 ton trains and the rise of both axle load and traffic volume, rail wear increased severely. Especially on curve line with radius less than 600m, rails had to be replaced early because of severe lateral wearing of rail. Figure 1
shows the lateral wearing of an in-line heat treated rail serving for 1 year on a 600m radius curve.

Lateral wear of the outside rail in curves with radius less than 800m is the rail damage type needing urgent treatment in heavy haul railway.

1. 2 Shelling

The classification and statistics on the severe rail damage types on the Daqin line at K108 - K392 between 2000 and Sept, 2007 are shown in Table 1. We see that the main damage types are shelling, spalling and cracking, which are all due to fatigue. These kinds of fatigue damage, which have increased greatly these years, are the most important factors influencing the service life of rail.

Therefore, decreasing the fatigue defects of rail is one of the most important factors for prolonging the service life of rail.

<table>
<thead>
<tr>
<th>Year</th>
<th>RCF</th>
<th>Spalling</th>
<th>Cracked</th>
<th>Broken</th>
<th>Defects</th>
<th>Others</th>
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</thead>
<tbody>
<tr>
<td>2000</td>
<td>46</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2001</td>
<td>433</td>
<td>1</td>
<td>31</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2002</td>
<td>350</td>
<td>1</td>
<td>22</td>
<td>2</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>2003</td>
<td>455</td>
<td>4</td>
<td>51</td>
<td>4</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>2004</td>
<td>500</td>
<td>12</td>
<td>89</td>
<td>2</td>
<td>112</td>
<td>2</td>
</tr>
<tr>
<td>2005</td>
<td>962</td>
<td>28</td>
<td>129</td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>1362</td>
<td>143</td>
<td>80</td>
<td>29</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td>1845</td>
<td>40</td>
<td>46</td>
<td>1</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>5953</td>
<td>231</td>
<td>448</td>
<td>9</td>
<td>167</td>
<td>27</td>
</tr>
</tbody>
</table>

1. 3 Damage on Rail Welded Joints

Take the rails of B plant’s U75V on Daqin line in 2005 as an example, when the accumulative passing volume up to
754 MGT, the total number of rail damages was up to 16 per kilometer, of which the damages on not welded area was only 3.57 per kilometer. So we can see the damage rate on welded joints is very high.

Based on the rates of damage on welded joints, gas pressure welding is the worst, and next is thermite welding. The damage on welded joints not only increases the maintenance work, but also threatens the passing train's safety.

Our investigation showed that damping of the rail joint is the main reason for welded joint damage. For both gas pressure and flash-but welds, the hardness of the welded joint is lower than the adjacent rails. Dipping of the gas pressure welded joint can reach 2.9mm and half of the flash-but welded joints dip more than 1 mm. It is very effective to prolong the service life of welds by improving the evenness and hardness of the welded joint.

2 COUNTERMEASURES TO PREVENT RAIL DEFECTS

2.1 Lessen the Lateral Wear of Rail

Analysis of rails with severe lateral wear on the Daqin heavy haul line, finds that the reason is that the hardness of in-line heat-treated rail is too low [1], in spite of the super-elevation on the curve being too high. So the steps we adopted to decrease lateral wear of outside rail on curved track are as follows:

(1) Set the lower super-elevation

Research on the relationship of lateral wear on rail to the super-elevation on curves showed that decreasing super elevation reduces lateral wear [1]. This is because the higher the super-elevation the larger the attack angle of passing train, and the lateral wear increases [4]. So when the lateral wear rate is very severe, we should set the super elevation 10% to 15% lower based on the accurately tested balanced super-elevation.

(2) Lubricate scientifically

Reference [5] showed that high strength outside rails on a curve line with 300 - 400 radius had almost no lateral wear and spalling before 50MGT if solid lubricated, then the lateral wear increased at a rate of 0.02mm/MGT, and no evident spalling was observed. But for the case of lubrication by the injecting grease installed on the train, the rail showed almost no lateral wearing but spalled severely before 50MGT.

We can see that solid lubrication, which not only reduces wear greatly but also does not hasten spalling on the rail, greatly prolonging the service life of the outside rail on the curve line.

So we should adopt solid lubrication of the high strength and wear resistant rail on heavy haul lines that wear greatly, which not only controls the wear rate of the rail but also can restrain the initiation and development of spalling

(3) Increase the hardness of rail

The experience in many countries is that the wear resistance of rail improves with higher rail hardness. It is important for prolonging the service life of rail on curved track that we research a rail with strength of 1280MPa and hardness of 370HB on the running surface.

It has been proven that heat treatment on chromium alloyed rail is an effective way of improving the strength and hardness of rail [6].

(4) Lay the rail scientifically

We suggest that heat treated rail with hardness higher than 370HB be laid on curved track with radius lower than 1200m, the as-rolled rail with strength at 980-1100MPa be used on other sections, and heat treated rails be used to replace broken rail.

2.2 Decrease the Spalling on Rail

Spalling on the running surface of rail comes from the rolling contact fatigue (RCF). Research has shown that an effective way of minimizing spalling on rail includes increasing the flexibility of track, improving the track's evenness, minimizing the impact between wheel and rail, improving the contact conditions of wheel and rail, enhancing the rail's RCF resistance, adjusting the reasonable wear rate of rail by using proper strength rail and preventive rail grinding.

2.3 Lessen Shelling

Rail shelling is one of the most common defects and failure mechanisms on heavy haul rails. Research has shown that the toughness and cleanliness of rail are the main factors that influence the rail's fatigue resistance. It is understood that rail will fatigue if the applied stress is higher than its fatigue strength limit, and the fatigue crack originates always at the weakest region such as an inclusion. An effective way to improve the rail's fatigue resistance is to control strictly the purity and low power structure of rail (looseness, segregation, etc.), maintain or improve the elasticity of track, minimize rail forces, etc. Other good ways include adopting premium padding under the rail, timely ballast cleaning and periodic rail grinding.

2.4 Decrease the Defects on Rail Welded Joint

Effective ways of improving the welded joint properties
and decreasing the damage on welded joints include using longer rails to reduce the number of welded joints, adopting the more reliable flash-butt welding, optimizing the gas pressure welding equipment and techniques, and minimizing the use of thermite welding.

Weld dipping can be greatly reduced by improving the evenness and hardness of the welded joint. The welded joint should be treated by air jetting after finish welding to improve the hardness of as-rolled rail on tangent track or the heat treated rail in curves. For the heavy axle load lines, the hardness of the running surface of welded joints should be 95% - 110% that of the connected rails. For as-rolled rail the weld should strive for the upper limit and for heat treated rail the lower end of the range.

3 THE PRACTICAL RESULTS OF PREVENTIVE COUNTERMEASURE

In order to validate the practical results of preventive countermeasure for heavy haul rail, the research team and some related departments developed U77MnCr and PG4 low chromium alloyed 75kg/m rail with the ultimate strength of 980MPa and 1100MPa when as-rolled, and a running surface hardness higher than 370HB when heat treated. In May, 2007, these two kinds of rails were laid on the outside of k388. 674 - k398. 549 and k398. 549 - k410.020 of Daqin line. The heat treated rail are laid on the curve line having a radius lower than 1200m and the as-rolled rail on the straight line. For this testing section, we also took the steps list below:

(1) Lay thermoplastic padding [8].
(2) Clean the ballast of the testing section,
(3) Grind the rails preventively immediately after laying and grind a second time after 400MGT. In order to make up for rail cant and improve the contact condition between rail and wheel, the grinding focused on the gauge corner,
(4) Welded joints are heat treated after finish welding, induction heat treated on flash-butt welds, flame heating and air jet cooling on the head of gas pressure welded joints. Heat treatment on the welded joint not only improves the toughness and plasticity but also the hardness of the running face of welded rail joints.

This countermeasure has proven effective in decreasing the rail defects after one and a half year's traffic over the testing section.

(1) The damages on running face of rail
The damages on the running face of PG4 and U77MnCr rail decreased with preventive grinding and the second grinding after 400MGT. The time to initiate spalls is later than previous rails.

(2) Wear of rail
The average of curve to spiral, curve center and spiral to curve lateral wear of U77MnCr and PG4 heat treated rail (after 1. 5 years, 500MGT) are 6. 8mm and 5. 5mm respectively [7]. The maximal lateral wear is 9. 2mm and 7. 9mm respectively. The service life of U77MnCr and PG4 can be expected to be 1 billion tons, and even more if solid lubricated.

(3) Severe failures on rail
The number of severe failures on rail was 36 between May, 2007 and Nov. 18th, 2008, and the failures on PG4 and U77MnCr are 18 each. The failure rate is thus 1. 8 per km for the total traffic volume of 500MGT. These are lower than the numbers reported in Section 1. 3 for U75V rails. (The severe failures rate on the rails of B plant of 2005 is 11. 1 per km after 550 MGT, and P plant of 2005 is 3. 4 per km after 550 MGT on Daqin heavy line).

The accumulated severe failures rate for PG4 and U77MnCr rail is 0. 4/km and 1. 2/km respectively. The accumulative severe failures rate for PG4 and U77MnCr welded joint is 1. 4/km and O. 6/km respectively. Based on this result, we can expect the total gross tons of PG4 and U77MnCr rail be more than 1. 5 billion ton [3].
(4) Damage on welded joints and dipping
Dipping of the running surface of welded joints was not observed, owing to the post-weld heat treatment. Although the damage on welded joint decreases greatly, other types of damage remained.

4 CONCLUSIONS

Based on our investigation and analysis, we conclude the following:

(1) Lateral wear can be greatly reduced by:
   a. Using U77MnCr and PG4 rail with hardness of 370HB at the running surface.
   b. Reduce the super elevation on curved track by 10% - 15%
   c. Solid lubricate the rail one time every day
(2) The initiation and propagation of spalling can be controlled by minimizing rail inclusions and by timely grinding, especially of the rail gauge corner.
(3) The fatigue rate can be minimized by improving the purity and toughness of rail, using thermoplastic pad-
ding, improving the maintenance of rail, improving elasticity of track and limiting the dynamic stress of track.

(4) The defects on rail welded joints can be greatly decreased by optimizing the welding technique and heat treatment after finish welding, improving the toughness and elasticity and the hardness of welded joints.

We believe that the gross passing tons on heavy axle load rail can be improved by O. 9 - 1. 2 billion ton to 1. 5 billion ton based on the above countermeasures.

REFERENCES


