Study on China Railway Heavy Freight Car Wheels

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Summary: In this paper, the using condition of wheels in heavy freight car was introduced, and the problem of which in Da-Qin railway line was indicated. Then, typical wheel failure cases were investigated, and the amelioration of heavy freight car wheels was put forward. On this condition, new material heavy freight car wheels were assessed on actual cars. The assessing results demonstrated that the integrated use of new material wheels behaves more excellent on various performances than that of general wheels.

Index Terms: heavy transport, freight car, wheel, failure, wear

1 INTRODUCTION

In China, railway freight transport is the most important transportation of freight, especially for bulk cargo. With the Qinghai-Tibet railway and some landmark railways putting into use, railway becomes the symbol of modernization. Running the heavy freight car and developing the heavy transportation are the significant way to increase Chinese railway transport capacity. From the beginning of the "eighth five years plan", China has included the heavy transport as the important content of railway development in the plan.

The heavy transport technology is the direction of railway freight transport by international reorganization. The benefits of heavy transport are confirmed by the actual business achievement of different countries. Increasing axle load is a major method by all countries for heavy transport. By the long-term application assessment, the method is proved to increase the income and reduce the repair costs. Moreover, the R&D of new technologies and equipments is improved to promote heavy transport for more progress.

In recent years, Chinese railway freight transport develops rapidly. Generally speaking, however, its railway freight transport apparently falls behind the developed countries. With the national economy rapidly developing, the shortage of freight cars is more and more prominent. By the international heavy freight transport railway practice, the axle load of freight cars is increased to realize the heavy transport and appropriately increase the operation speed of freight car to improve the railway transport capacity, finally as an effective way to solve the shortage of transport capacity.

In October, 2006, the 40t load axle ore cars of Qiqihar Railway Rolling Stock Co. LTD and Zhuzhou Railway Rolling Stock Co. LTD were qualified by Australia BHP railway. In 2007 from the two factories the BHP ordered 1000 cars to test. That is the symbol of 40t load axle officially entering the market.

At present, because of the requirement of heavy transport economic benefits and development of new material technology, the researches of heavy freight car wheels are still kept in forefront. With reference to wheels research, consistently in the research development of 10 years before, from the directions the researches include materials, wheel types; from the content the researches include failure mechanism, relation of wheels and rails and brake shoes, steel acts, statistic analysis, properties, fabrication technology and the ultimate operation performance, new wheels, detection technology etc. These research results have been published on near previous international wheel and axle conference. Some results have been converted to specific items of standards.

2 THE OPERATION CONDITIONS OF CHINESE HEAVY FREIGHT CAR WHEELS

Wheel is the major part of traction for railway transport.
In Chinese railway freight transport development history, the major size and steel of freight car wheel do not obviously change. In the shape, the original tilted plate was changed into S plate. In addition, the axle hole size adapted to the different axle load is the chief method. From the early 60s, the beginning of the first wheel manufactured by China to present, the properties of CL60 steel do not change in nature whatever two ministries agreement and the current Chinese railway standard. There is apparently behind the foreign abundant steel programs. Since the near twenty years, the technology progress of freight car wheels mainly concentrates on the fabrication technology, configuration research and actual application including upgrading the fabrication technology of rolled steel wheel and the imported production process of new cast steel wheel. The main work focuses on improving the metallurgy quality with considerable investment and technology works. Comparing with traditional technologies of using 30 years, new technologies thoroughly advance the innate quality of China wheel, and essentially the China wheels attain to international leading level. With respect to wheel configuration design, the S type plate is successfully developed by adopting finite element method instead of tilted plate. Besides, the various types of worn profile treads replace the tapered tread and the results of the brand new design of deep basin-type convergent plate for cast steel wheel and thin rim weight loss wheel etc. not only enrich the wheel family but make the China wheel design level reach the international development.

However, enhancing the service performance of wheel steel obviously falls behind the railway development. For a long time, the CL60 (cast steel ZL-B) is adopted to produce the wheels both passenger and freight cars. With the development of heavy transport railway, the CL60 (cast steel ZL-B) is difficult to adapt the characteristic of heavy transport. For accommodating the development of heavy transport, the research of heavy transport wheel must be carried out to solve this problem.

The operation conditions inevitably change with the different transport load. Furthermore, the influence of wheel must be focused. At present, the technologies of the China heavy transport wheel distinctly fall behind the development of heavy transport. In recent years, the operation conditions of wheel using on heavy transport prove the fact. Therefore, the research of heavy transport wheel must be developed rapidly to solve the bottleneck problem.

The wheel need bear thermal load. And it has two sources; first is braking on tread and second is wheel-rail adhesion reducing or more braking load to cause wheels sliding, and then producing wheel-rail sliding frictional heat. With regard to freight cars, in the braking on tread way the braking force inevitably increases with more axle load and faster speed.

The wheels endure great thermal load when braking. Meanwhile, for more braking load and more sliding distance the probability of thermal damage defects, even heat crack accident, increases with intensifying the trend of sliding friction between wheel and rail.

Furthermore, the force between wheel and rail inevitably increases with increasing axle load to result in exacerbating wheel-rail wear. Finally the probability of contact damage increases. It is demonstrated that on the simulation of wheel-rail test bench the rail wear rate of 25t axle load bigger 40% than that of 21t. The wear of wheel increases relatively. It should be noted that for the contact force between wheel and rail increasing the rates of break off of wheel and rim accident increase.

It is perceived that the rate of happening contact damage, abnormal wear and thermal damage defect of heavy axle load wheel is lead to increasing by the operation conditions changing. The above view is verified by the operation experience of heavy transport wheels at home and abroad.

According to the investigation of Da-Qin line, the operation conditions of C64 type freight cars of 23t axle load are obviously better than that of C76 and C80 type freight cars of heavy E-type wheel. Presently the wheels (HESA, HEZB) materials of all types freight cars are adopted to the CL60 steel of Chinese railway standard TB/T2817-1997 and TB/T 1013-1999. The main problems are serious wear of tread and flange, break off of flange (as Figure 1) about the unsatisfactory operation effects regardless of rolled and cast wheels. Even if it does not occur serious rolling wide of rim, the wear thickness of wheels is beyond 3mm which is much larger than that of CL60 steel of D-type wheel equipped on the C64 and so on below 23t axle load.

![Figure 1 Wear of 25t axle load HESA wheel](image)

By the systematic investigation and analysis for domestic and foreign heavy wheels, the different operation conditions determine the basic R&D direction of Chinese heavy
wheel. That is the wheel with high resistance to contact damage, resistance to wear and resistance to thermal damage.

According to the failure analysis of wheels, it is demonstrated that the failure type of heavy transport wheels is different from one of normal condition wheels. Whether the performance of E-type wheels currently using on the heavy freight cars accommodates the requirement of operation conditions in Da-Qin line (like heavy transport, rail and line) or not need to be investigated, researched and proofed. Meanwhile, the match of wheel and rail of heavy transport need to be researched.

The American heavy transport is always in a leading position in the world. The wheels using on the above 25t freight cars are made of AAR C-level steel. Through the actual operation conditions for many years, AAR C-level steel wheels have an excellent state. This is a successful experiences.

3 TYPICAL FAILURE ANALYSIS CASES OF CHINESE HEAVY FREIGHT CAR WHEELS

Over the past decades, the domestic relevant research institutions and factories analyzed and researched on many different types wheels. Furthermore, they accumulated considerable datum and experiences. Following is the typical failure analysis for the wheels damage of freight cars in Da-Qin line.

3.1 Analysis of Rim Sample

The rim crack of HESA type wheel on C76 freight cars, the macro appearance as Figure 2, the 130mm long block has broken off of rim. According to the results of the detection the total length of rim crack is 270mm (including the location of breaking off). By measured, the thickness of rim is about 48mm.

By the results of ultrasonic detection, the edge of crack is confirmed. And by saw cutting to open the crack, it is two couple parts as Figure 3. The observation of appearance is obvious fatigue crack curve and crack source (as arrows). The crack source is flat because of rolling friction. By measured, the rim crack is 15mm below tread and 67mm away from the wheel rim outer side.

The metallographic examination of sample of crack source, by repeatedly grinding and observing the residual inclusions were not found. The metallurgical structure on crack source is seen as Figure 4.

There is a thick white layer which thickness is 130μm on the crack source. The Figure 5 is the micro Vickers-hardness of white layer and matrix structure below it.

From the measurement of micro Vickers-hardness, the white layer hardness is much higher than that of matrix. It is demonstrated that the white layer forms at very high repeatedly stress.
The surface of crack source forms white layer and deformation layer. It is declared that after crack initiation a great load affect the surface of crack source.

By observing macro appearance morphology, there are two typical inner fatigue cracks on rims of wheels. Because this defect is a common phenomenon in wheel history, it is generally accepted that the defect is a metallurgy manufacture problem. The main feature is that the fatigue crack source is a certain depth range of the tread of wheel and rail contact and there are fatigue curves at the fatigue crack growth area. When the fatigue crack propagates a larger size reaching a rapid growth stage, the crack reaches the outer side of rim, inner side or tread. If this situation can not be found, it will break off of rim. The fatigue crack initiation of rim has properties of low stress high cycle fatigue. That is a fatigue fracture of which the operation stress is below the material yield strength. The main reason of failure and damage is that at a certain depth range of the contact surface of wheel and rail (generally the depth is 15 – 20mm below the contact surface of wheel and rail), there are line inclusions (Al2O3) with a certain size.

But in this analysis, the line inclusions and residual traces can not be found at the crack source of two cracks on rim. There are two reasons for this situation. First are smaller inclusions because they might be ground for processing metallographic samples; second the crack source is strongly deformed by high extrusion and load friction in the process of crack propagation. Therefore the line inclusions and residual traces which caused crack initiation can not be found.

The required attention is that the level of metallurgy significantly improved is the common situation. Once cracks on rims of several wheels are abnormal. It is demonstrated that there must be other induced factors except that the main reason of causing the cracks on rims is steel smelting. From operation conditions, these wheels of 23t big axle load, so the load on wheel is also big. According to relative fatigue theories, critical defect dimension of crack initiation reduced when the stress increased. It is meant that at the high load the inclusions of wheel steel within the safe size range might be the source of crack initiation.

3.2 The Analysis of Sample of Abnormal Wear Wheel

For the abnormal wear of freight car wheels in Da-Qinn line, the rims which are from two wheels of one axle and different degrees of wear are analyzed respectively. There are 4.0mm vertical wear of tread and 34.2 thickness of rim for the relative normal wheel; and for the serious one, the depth of vertical wear is 11.9mm and thickness of rim is 28.2mm. For convenient, the numbers of two wheel is No.1 and No.2. The No.1 is without rolling high of flange and No.2 is with a serious phenomenon of rolling high of flange.

Compared with other wheels models, the entire tread of No. 1 wheel is relative uniform and the most serious wear is from middle to gauge of No. 2 tread. The two results are as Figure 6 and Figure 7 respectively.
hardness of No. 2 with serious wear is slightly lower than that of No. 1.

In addition, the surfaces microstructures of flanges and treads of two wheels are observed, respectively as Figure 8 ~ Figure 12.

From the surfaces structures of flanges and treads of two wheels, the surface of flange of No. 1 which is normal wear is not observed the plastic deformation layer and additionally the plastic deformation layer of its tread is thin without crack. On the other hand, there are obvious plastic deformation layers of both No. 2 flange and No. 2 tread with serious wear. Furthermore, the initiation cracks of its surface are seen in the deformation layers, and especially the crack propagation of its tread is deep. The directions of cracks and plastic deformation are consistent and the shelling formed by further propagation.

According to inspection and analysis of all physical and chemical properties of two wheels, there is no difference between No. 2 with serious wear and No. 1. It is demonstrated that the reason of No. 2 serious wear is not owing to the factor of its materials.

There are serious metal plastic deformation and initiation crack on the surface of No. 2 tread. It is illustrated that the direct reason of serious wear is a relatively big load on the No. 2.

According to research results, the ZL-B and CL60 steel on the basis of 60 steel, the 840mm wheel outside diameter is not enough to correspond with heavy transport of 25t axle load. By the analysis of the hardness match of wheel and rail, the hardness and resistance to wear of heavy wheels are needed to improve. Through the analysis of the domestic and foreign heavy freight car wheels, the changes of operation conditions determine the basic direction of Chinese big axle load freight cars. It is meant
that there are resistance to contact damage, resistance to wear, resistance to thermal damage and higher hardness of wheels.

Figure 12  Plastic deformation layer of surface of No.2 flange 100 ×

4  The R&D FOR THE NEW MATERIAL HEAVY FREIGHT CAR WHEELS

According to operation investigation and failure analysis for heavy freight car wheels using on Chinese railway, the wheel researchers and factories directionally research the new material heavy freight car wheels in China taking into consideration resistance to thermal damage, resistance to contact fatigue and resistance to wear and determine a project for the new heavy freight car wheel steel which were implemented industrialized trial manufacture scheme, and reasonably regulated rolling and casting, heat treatment etc. Furthermore, the new material wheels were manufactured for trial.

4. 1 Wheels Manufactured for Trial

The carbon content of wheel steel is the main factor to determine materials wear. By the carbon content increasing, the resistance to wear is enhanced. According to the current operation experience, when the carbon content increase, the trace element alloying is adopted to improve the steel toughness and reduce the sensitivity of crack, sliding and shelling of wheels for enhancing the resistance to shelling.

For the alloy design of raising transformation point, by the method of theoretical calculation, the influence of alloy elements Si, Cr, Mn on the transformation point of the existing system of the wheels of steel components is calculated by thermodynamic software Thermo-Calc. From the point of improving the performance of resistance to shelling of wheel steel, the relatively realistic and effective principles of alloying is Si content increasing. When the carbon content is 0.58% - 0.75% and the Si content is 0.17% - 1.20%, the components of wheel steel are designed and the influence of C, Si content on the wheel operation performance which are resistance to wear and resistance to damage.

The new material wheels were concentrated on the researches of normal performance, wear performance respectively. The results of examination demonstrate that they have an excellent operation performance. Their resistance to wear is obviously improved to compare with normal CL60 wheel and ZL-B wheel. Moreover, the resistance to damage satisfies the operation requirement of current 120km/h freight cars, especially the resistance to wear improved.

4. 2 Wheels Loaded for Assessment

At present, a small amount of the new heavy freight car wheels are already loaded to qualify for test. The results of examination demonstrate that they have an excellent operation performance. Their resistance to wear is obviously improved to compare with normal CL60 wheel and ZL-B wheel. Additionally, the phenomena of abnormal wear like the wear of flange and rolling wide of rim are not observed. Furthermore, the wheels treads situations are not distinctly observed about braking spalling and contact fatigue etc.

The measurements of vertical wear of treads are as Table 1.

<table>
<thead>
<tr>
<th>Wheel type</th>
<th>Car type</th>
<th>C80</th>
<th>C80B</th>
<th>C80H</th>
<th>C80BH</th>
<th>Average wear</th>
<th>Wear reduction of trial wheels to normal ones</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rolled wheel for trial</td>
<td>0.41</td>
<td>0.40</td>
<td>0.43</td>
<td>0.48</td>
<td>0.43</td>
<td>30%</td>
<td></td>
</tr>
<tr>
<td>CL60 wheel</td>
<td>0.55</td>
<td>0.55</td>
<td>0.61</td>
<td>0.71</td>
<td>0.61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cast wheel for trial</td>
<td>0.50</td>
<td>0.61</td>
<td>0.46</td>
<td>0.63</td>
<td>0.55</td>
<td>13%</td>
<td></td>
</tr>
<tr>
<td>ZL-B wheel</td>
<td>0.56</td>
<td>0.66</td>
<td>0.59</td>
<td>0.67</td>
<td>0.62</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 2 Measurements of wear areas of cross-sectional treads (mm²)

<table>
<thead>
<tr>
<th>Wheel type</th>
<th>C80</th>
<th>C80B</th>
<th>C80H</th>
<th>C80BH</th>
<th>Average wear</th>
<th>Wear reduction of trial wheels to normal ones</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rolled wheel for trial</td>
<td>29.3</td>
<td>29.8</td>
<td>31.5</td>
<td>33.1</td>
<td>30.9</td>
<td>32%</td>
</tr>
<tr>
<td>CL60 wheel</td>
<td>37.7</td>
<td>39.9</td>
<td>49.4</td>
<td>54.1</td>
<td>45.3</td>
<td>---</td>
</tr>
<tr>
<td>Cast wheel for trial</td>
<td>40.3</td>
<td>40.2</td>
<td>59.6</td>
<td>63.4</td>
<td>50.8</td>
<td>14%</td>
</tr>
<tr>
<td>ZL-B wheel</td>
<td>47.0</td>
<td>49.3</td>
<td>66.2</td>
<td>73.9</td>
<td>59.1</td>
<td>---</td>
</tr>
</tbody>
</table>

From the measurements of vertical wear, the wear of two trial wheels is both obviously lower than those of normal wheels.

The measurements of wear areas of cross-sectional treads are as Table 2.

From the measurements of wear areas of cross-sectional treads, the wear areas of trial wheels are lower than those of normal wheels. It is consistent with the measurements of vertical wear of treads.

Presently, when the operation conditions of new material heavy freight car wheels are kept to be observed, the amounts of trial wheels will increase in order to be assessed as an entire column freight car. Furthermore, the assessments of new material heavy freight car wheels will establish the superiority of operation performance and lay a foundation for future promotion of heavy freight car wheels.

5 CONCLUSION

Presently, the abnormal wears of flange and tread are the main problem for the heavy freight car wheels using on Chinese railway. Meanwhile, because of increasing the freight loads, the defect critical dimension of crack initiation of wheel materials may be reduced. Before it is meant that the inclusions of wheel steels in the range of safe dimension are possibly the origin of crack initiation under the high loads. These several parts changing need a higher require for manufacturing the heavy freight car wheels.

For the actual requirement of operation conditions of heavy transport freight cars, from the point of improving materials and manufacture techniques, the new material heavy freight car wheels are researched and produced. Furthermore, they are test on actual freight cars. So far, the new material heavy freight car wheels have an excellent test performance.

REFERENCES

[7] Zhang Bin, Lu Guan-Jian, Fu Qiu-Qin etc, Failure analysis and metallography of damage in railway wheels and tyres [M], Beijing; China railway publishing company, (2002), No. 29.
[8] Zhang Bin, Fu Qiu-Qin, Zhang Hong etc, A primary report for survey on import passenger vehicle wheel of Wuhan rail bureau [Z], Beijing; China academy of railway science Metals & chemistry research institute; Qingdao; Sifang rolling stock research institute, (2005).
[9] A survey on heavy railway E type freight car wheel in Da-Qinn line [Z], Datong; Taiyuan rail bureau Hu dong car depot.
[10] Zhang Feng, Cheng Gang, Research on relation of wheel fracture toughness property and microstructure with performances [J], Physical testing and
chemical analysis (Part A: Physical testing), vol. 40, (2004), No. 4, 172-175.

