Study on the Strength of 35t Coiled Steel Pallet for 100t Gondola Car

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Abstract. The Coiled Steel safety transportation has become an important part of railway freight transportation. Due to the special shape and heavy-weight of coiled steel, loading and reinforcing is very complexity, Displacement or rolling is much more likely to happen in transit. It will lead to eccentric loading, unbalanced loading, freight vehicle damaging, or serious accident due to coiled steel falls down from freight vehicle. At present, the coiled steel produced are larger in weight, larger in diameter and wider in plate width, with a maximum weight of 35t. The 100t gondola car is generally C_{100} and C_{100 A}. It has the advantages of longer length, larger load and larger capacity in the middle. It is the best choice for loading larger weight coiled steel. This paper used SolidWorks to build the model according to the design structure of the special coiled steel pallet for loading 35t coiled steel on 100t gondola car. Then the stress distribution of the pallet is obtained through the strength simulation experiment. The results show that the maximum stress of the pallet occurs at the ribs in the middle of the clamp on the side of the pallet, which exceeds the allowable stress of the material. Finally, the pallet is optimized to meet the actual transport requirements.

Introduction

The Iron and steel industry belongs to raw material industry and is the foundation of national economy. For China's iron and steel enterprises, railway is the preferred transportation mode for coiled steel. In China's railway freight transportation, the coil produced in rolls are usually called coiled steel, including hot-rolled coiled steel and cold-rolled coiled steel. The weight of coiled steel is determined by the marked load of railway vehicles in China railway transportation. With the increase of marked load of railway vehicles, the maximum single-piece weight of coiled steel can be transported has also increased from 30t of 60t and 61t general gondola cars to 35t of 70t general gondola cars. Because of the high density and the special shape of coiled steel, it is easy to displace and roll during transportation. In order to ensure the safety of coiled steel transportation, it is necessary to keep strict control on the quality of loading reinforcement materials while continuously optimizing loading reinforcement schemes. Therefore, in order to meet the need of transporting larger weight coiled steel, it is necessary to select the appropriate type of gondola car and design or improve the new coiled steel pallet.

Literature Review

Because the development of Railways in different countries is quite different, and the degree of tension in transportation tasks and capacity is also different, so the research on coiled steel transportation in different countries is also different.

In 1992, Inland Steel Flat Products, Conrail and Thrall Vehicle Manufacturing Company jointly developed a special truck named Colishield for American Steel Company, which only protects coils and simplifies loading and unloading operations. The car can be used to carry coiled steel with a width of not less than 1800 mm and a diameter of not exceeding 1830 mm. In 2004, North American Johnstown Company developed a coiled steel transporter vehicle, which can effectively transport coiled steel with diameter of 762 to 2032 mm.

In 2007, Zhuzhou Vehicle Factory of China South Locomotive and Rolling Stock Corporation Limited put forward a special pallet for C100 (C100A) gondola car to transport coiled steel. The whole device has a "V" shaped structure, which can effectively prevent rolling or displacement of coiled steel.
Heng Zhiguo (2004) used Finite Element Method to analyze the deflections of the truss and stress distribution of the components. Based on the margin of load-capacity of the component, some modification measures are presented. The trial-produce of the truss is done and the destructive tests on rail are completed. The results from the tests show that the truss can satisfy technical requirements.

Li Yichuan (2012) proposed the transportation method of loading coiled steels with container holders aiming at the hidden dangers for transporting coiled steels. Through the calculations for loading and securing as well as the comparative studies of stability, it is determined that it is safe reliable and feasible to transport coiled steels whose coil diameter is not more than 2 050 mm with container holders.

Li Jinsong (2012) figures that transporting coiled steel by steel seat could satisfy the basic requirement of safety, economization and convenience according to related technical and economic requirement. Then puts forward the suggestions on fully promoting the use of coiled steel transportation by steel seat.

Gao Junping (2012) creates the solid models and makes the simulation analysis about the strength of the steel pallet on different conditions, contrasts the dates of the test and the result of FEA. Finally, gives advices for the optimization for steel pallets to ensure the safety.

Chen Ketian (2013) built a math model based on the development processes and problems of goods loading according to the restricted conditions of gondola car. Then the problem is solved by combination of simulated annealing algorithm and genetic algorithm, and the algorithm is made out by programming. Then it is applied in the case of actual transportation to verify the feasibility, which is able to achieve the efficiency and transportation security.

Liu Xiaohua (2015) discusses the modeling and simulation of the RUL-C1 coiled steel pallet under shunting impact condition by Solidework, Hypermesh and Ansys, and then gains the actual work stress data by shunting impact test. Both of the results show that the coiled steel pallet is unqualified. Then the weak parts was improved, and the new test result shows that the improved coiled steel pallet is qualified to railway safety transportation.

The above research provides a reference for the research. This paper focuses on the strength of 35t coiled steel loaded on the pallet of 100t gondola car. Based on the existing pallet, the optimization design and modification are carried out. Solidworks is used for three-dimensional modeling and simulation. Then the strength test of the pallet is carried out to improve the pallet to meet the requirements of safe transportation.

### Modeling of Coiled Steel Pallet Based on SolidWorks

SolidWorks is a tool based on feature, parameterization and solid modeling. It builds three-dimensional models of each part of coiled steel pallet, and then assembles each part with assembly module to obtain the overall model of coiled steel pallet. The main parameters of C_{100} (C_{100A}) gondola car are shown in Table 1. The main structure includes car body, underframe, side wall, end wall, air brake device, hand brake device, bogie, inclined wedge load device, coupler buffer device and saddle assembly.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum load (t)</td>
<td>100</td>
<td>Inside length of vehicle (mm)</td>
<td>13710</td>
</tr>
<tr>
<td>The weight of the vehicle (t)</td>
<td>≤26</td>
<td>Inside width of vehicle (mm)</td>
<td>2892</td>
</tr>
<tr>
<td>Running speed (km/h)</td>
<td>120</td>
<td>Inside height of vehicle (mm)</td>
<td>1540</td>
</tr>
<tr>
<td>Minimum radius of passing through curve (m)</td>
<td>145</td>
<td>The height of floor to rail surface (mm)</td>
<td>1085</td>
</tr>
<tr>
<td>Length of vehicle (mm)</td>
<td>15800</td>
<td>Maximum height of vehicle (mm)</td>
<td>2543</td>
</tr>
<tr>
<td>Distance between bogie pivots (mm)</td>
<td>9200</td>
<td>Maximum width of vehicle (mm)</td>
<td>3180</td>
</tr>
<tr>
<td>Gauge</td>
<td>Complying with GB 146.1-1983 &quot;Rolling stock gauge for standard gauge railway&quot;</td>
<td></td>
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</table>
Using 100t gondola car, two 35t coils can be loaded simultaneously, and then a small tonnage of coils can be installed. This can make full use of the capacity of gondola car and avoid the waste of railway capacity.

In order to facilitate the overall modeling, this paper firstly carries out the model of the various components of the pallet, mainly composed of load-bearing baffle, back plate, cover plate, longitudinal beam, baffle arm and rubber cushion plate. Then SolidWorks is used to assemble the solid models according to the design structure of the coiled steel pallet. Finally, interference inspection is performed to check whether the assembly is reasonable. The entity model after assembly is shown in Figure 1.

![Coiled steel pallet assembly](image)

**Figure 1. Coiled steel pallet assembly.**

**Force of Pallet Loaded with 35t Coiled Steel**

**Force in Static State**

When the vehicle is in a stationary and uniform linear motion state, the force exerted by the coiled steel on the pallet comes from the gravity of itself. Along the two directions perpendicular to the contact surface, the component $F_1$ and $F_2$ act on the seats on both sides of the pallet. $F_1$ and $F_2$ depend on the weight of coiled steel, and the coil diameter determines the position of the seat plate of $F_1$ and $F_2$. The weight of coiled steel is about 35t. The weight, diameter and width of hot rolled coil satisfy the following relationships.

$$3.14 \times \left( \frac{R^2 - r^2}{1000000} \right) \times \rho \times \frac{d}{1000} = m$$

Where,
- $R$- Outer diameter of coiled steel, mm;
- $r$- Inner diameter of coiled steel, the value of this paper is 762 mm;
- $\rho$- Density of coiled steel, the value of this paper is 7.8t/m³;
- $d$- Width of coiled steel, mm;
- $m$- Weight of coiled steel, the value of this paper is 35t.

During loading, the lowest point of coiled steel is not accessible to the horizontal cover of the pallet. Ideally, according to the geometric relationship, the minimum outer diameter of coiled steel is 1637 mm. Considering that the coil will be deformed due to its own gravity, which will lead to the contact between the lowest point and the cover plate, the minimum outer diameter of the hot rolled coil is 1700 mm, and the corresponding width is 2475 mm in this paper.

When the tangent point tangential to the wedge bearing surface is at the top of the bearing surface when the coil is loaded, the outer diameter of the coil is specified to be the maximum at this time. In this paper, the maximum outer diameter of coiled steel is 1984 mm, and the corresponding width is 1703 mm.

Due to the width limitation of 100t general gondola car, the maximum plate width is 2295 mm, and the corresponding external diameter is 1753 mm.

Therefore, the outer diameter of hot rolled coiled steel ranges from 1753 mm to 1984 mm, and the width of plate ranges from 1703 mm to 2295 mm. The specification of hot rolled coil used in this paper has weight of 34.44 t, coil diameter of 1925 mm, plate width of 1800 mm. The total weight of
coil and pallet is 35t. The calculation of force $F_1$ and $F_2$ of coiled steel acting on coiled steel pallet under static loading:

$$F_1 = F_2 = 34.44 \times \cos 51.6^\circ \times 9.8 = 209.645 \text{ (kN)}$$  \hspace{1cm} (2)

**Force in Motion State**

When the vehicle is in motion, the longitudinal inertia force, the lateral inertia force, the vertical inertia force, the longitudinal and the lateral friction force should be calculated.

**The Longitudinal Inertia Force.**

$$T = t_0 Q(kN)$$  \hspace{1cm} (3)

Where, $Q$ - Weight of goods, $t$ ;

$t_0$ - Longitudinal inertia force per ton of cargo, $kN/t$.

The reinforcement between the pallet and the coil is rigidly reinforced, and the longitudinal inertial force per unit mass of coiled steel:

$$t_0 = 26.69 - 0.13Q_{\text{gross}} = 10.310(kN/t)$$  \hspace{1cm} (4)

Where, $Q_{\text{gross}}$ - Gross weight of goods, 126t ;

The longitudinal inertial force acting on the coiled steel is:

$$T_1 = 10.31 \times 34.44 = 355.076 \text{ (kN)}$$

The longitudinal inertial force acting on the coiled steel and pallet is:

$$T_2 = 10.31 \times 35 = 360.850 \text{ (kN)}$$

**The Lateral Inertia Force.**

$$N = n_0 Q(kN)$$  \hspace{1cm} (5)

Where, $n_0$ - Lateral inertia force per ton of cargo, $kN/t$.

$$n_0 = 2.82 + 2.2 \frac{a}{l} (kN/t)$$  \hspace{1cm} (6)

Where, $a$ - The distance of the cargo center from the transverse centerline of the vehicle, mm;

$l$ - Bogie pivot pitch, mm.

The distance between the center of gravity of the 35t coil and the transverse centerline of the vehicle is 4605mm.

The distance of the cargo center from the transverse centerline of the vehicle is 4605mm, and the bogie pivot pitch is 9210mm.

$$n_0 = 2.82 + 2.2 \times \frac{4605}{9210} = 3.92(kN/t)$$

The lateral inertial force acting on the coiled steel is:

$$N = 3.92 \times 34.44 = 135.005(kN)$$

**The Vertical Inertia Force.**

$$Q_{\text{vertical}} = q_0 Q(kN)$$  \hspace{1cm} (7)

Where, $q_0$ - Vertical inertia force per ton of cargo, $kN/t$.

$$q_0 = 3.54 + 3.78 \frac{a}{l} (kN/t)$$  \hspace{1cm} (8)
\[ q_0 = 3.54 + 3.78 \frac{4605}{9210} = 5.43 (kN/t) \]

The vertical inertial force acting on the coiled steel is:

\[ Q_{vertical} = 5.43 \times 34.44 = 187.001 (kN) \]

**The Longitudinal and the Lateral Friction Force.**

\[ F_{longitudinal} = 9.8\mu Q \ (kN) \quad (9) \]

\[ F_{lateral} = \mu (9.8Q - Q_{vertical}) (kN) \quad (10) \]

Where, \( \mu \) - The friction coefficient is 0.3 between steel and steel.

Longitudinal friction on the underside of the pallet:

\[ F_{longitudinal} = 9.8 \times 0.3 \times 35 = 102.9 (kN) \]

\[ F_{lateral} = 0.3 \times (9.8 \times 35 - 187.001) = 46.8 (kN) \]

**Simulation Analysis**

SolidWorks Simulation is used to simulate the strength of the pallet model, and the stress analysis results are obtained, so as to verify whether the strength of the design scheme can meet the actual transportation requirements.

In the strength analysis, it should be tested whether the strength of the pallet can meet the transportation requirements under the most unfavorable stress conditions.

Firstly, a static load example is created by using SolidWorks. The material of the designated pallet is Q235. Constraints are added to the model and loads are applied to the pallet.

The longitudinal inertial force acting on the coiled steel is 355.076 kN. Longitudinal friction on the underside of the pallet is 102.9 (kN).

Secondly, the pallet is meshed. The unit size is 101.17 mm, the tolerance is 5.05848 mm, the number of nodes in the whole model is 25084, and the number of units is 12753.

Mesh generation of coiled steel pallet is shown in Figure 2. Joint Stress in Different Parts of Coiled Steel Pallet is shown in Figure 3.

![Figure 2. Mesh generation of coiled steel pallet.](image)
Figure 3. Joint Stress in Different Parts of Coiled Steel Pallet.

The maximum stress of the pallet is 197MPa, which appears at the ribs in the middle of the clamp on the side of the pallet, exceeding the allowable stress of Q235, 156.7 MPa. The other parts did not exceed the allowable stress of Q235. It is necessary to optimize the pallet.

Optimization of Coiled Steel Pallet

The following mainly considers the improvement of the material of each component and the improvement of the structure of the coiled steel pallet.

Using Q450 with 300 MPa allowable stress can greatly improve the strength of the parts. Firstly, it can ensure the safety during transportation. Secondly, it can be used directly when the weight of the coil is larger in the future. However, such methods also have some shortcomings, such as the welding seam strength between different materials is insufficient, the material is expensive, resulting in unnecessary waste, and so on. Therefore, it is not the best method to replace the material of the larger force parts.

Adjustment the structure of the wedge bearing surface and the clamping block. The wedge-shaped bearing surface cover is optimized, and a transverse reinforcing steel is added to the corresponding position inside the cover plate, thereby reducing the stress on the bearing surface itself. The two square tubes of the clamping block are improved to be "eight" shaped structure, which changes from line contact to surface contact. It is able to offset the stress of some ribs. Expanding the contact range can also increase the friction force, thereby increasing the longitudinal stability of the pallet.

In addition, a rubber plate is arranged in the contact part between the square pipe and the reinforcing seat, and the rigid contact becomes a flexible contact, which can improve the stress condition of the pallet.

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References


