Technical solutions to extend the service life of solid roll wheels of passenger carries

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Abstract. Rail transport plays an important role in the economy. This especially applies to passenger transportation, in particular in the Republic of Uzbekistan, where the problem of passenger rail transport is very acute. The fact is that passenger cars in Uzbekistan are mainly purchased from other countries. The volumes of our own production are very limited and most often consist of major repairs of cars produced in the 40-60s of the last century. This paper presents the results of studies that ensure the safety of passenger transportation by extending the service life of the wheel pairs of the corresponding cars.

1 Introduction

Railway transport is developing rapidly in the world; accordingly, the problems of the industry, especially its scientific and technical issues, are being quickly resolved [1-5]. The creative team of the Scientific Research Center for Railway Transport (SRCRT) also makes its own contribution to solving various scientific and technical problems of railway rolling stock in Uzbekistan [6-10]. This also applies to the solutions proposed by NICZhT to replace traditional steels and cast irons, widely used in car construction, with lighter materials and their processing technologies [11-15]. However, there are still many unsolved scientific problems in the country's transport industry [16-20].

When wheels interact with rails, an irreversible wear process occurs on the surfaces of both wheels and rails. The condition of these surfaces greatly influences the safety of rolling stock and the operational efficiency of cars in general. Wheel defects such as spalling of the outer edge of the wheel rim refer to local sectoral destruction in the form of surface spalling of metal at the outer edge in the area of the chamfer of the wheel rim, which is characterized by a significant depth and length along the tread surface, sometimes reaching a length of up to 200 mm (Fig. 1), and more. In particular, spallation of the wheel rim occurs as a result of fatigue processes: from the action of normal and tangential forces through the development of cracks that form at a depth of 8-10 mm in the presence of a local stress concentrator in the form of a shell, non-metallic inclusion and other defects shown in Figure 2. C Using calipers and a meter, you can measure the width of the wheel rim and the width of the remaining part of the wheel rim at the breakaway point. The width of the rim from the flange to the wheel flange must be at least 120 mm and no more than 135 mm.

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Spalling on the surface of the wheel rim is characterized by two types of destruction: ductile and brittle. These types of metal destruction have unique consequences associated with a combination of various surface and internal defects that transform into fatigue cracks under the influence of high alternating stresses. Internal defects in the metal of a wheel rim are associated with the heterogeneity of the constituent chemical elements, and the manufacturing technology of wheel rims in production also significantly influences it. A number of experiments were carried out and various design solutions were developed related to improving the dynamic characteristics of rolling stock, namely the mitigation of vertical and lateral loads acting from wheel pairs to the rails and back, reducing noise and vibration, thereby extending the service life of wheel pairs of cars [1,3,7]. However, the problem of increasing the resource and extending the service life of railway wheels during the interaction of rolling stock with rails for the railways of the Republic of Uzbekistan is an urgent task.

The purpose of this work is to search for technical solutions that provide increased service life of solid-rolled wheels of passenger transport. To achieve the goal in this work, the following tasks have been solved, such as the development and improvement of existing integrated methods, technologies and technological equipment used to increase the service life of wheel pairs of rolling stock, aimed at increasing the operating efficiency of railway transport. This is a solution to a strategically important scientific and technical problem of the existing railway industry of Uzbekistan.

2 Research methodology

The development of new technical solutions related to extending the service life of used wagon wheels with various defects is due to the lack of primary production of ferrous metal and the production of wheel rims and axles in the country, which leads to an increase in the purchase of wagon wheel sets year after year. To ensure uninterrupted operation of passenger
cars, the railway company “Uzbekistan Temir Yollari” JSC currently purchases wheel sets from neighboring countries, for example, from Russia for foreign currency, and the price for one wheel pair is estimated by us at an average of 300 thousand rubles, which is approximately 3 thousand dollars, thereby the rise in prices continues. In this regard, it was decided to develop and propose a constructive solution that responds to all-weather conditions and provides high comfort when moving passenger cars and thereby extends the service life of existing wheel rims that have defects in the form of chips on the wheel rim, due to the possibility of installing a polyurethane rings on the tread surface of the wheel after turning to the required size. This method can be justified due to its low cost, as well as the availability of material in the form of liquid polyurethane.

3 Results and discussion

The essence of the developed technique is presented in Figure 3, which shows diagrams of turning a landing recess on the rim of a solid-rolled wheel (Figure 3a) to the required dimensions and forming a ring of high-strength polyurethane (hereinafter referred to as PU) in it.

![Diagram of turning a recess on the wheel rim and forming a PU ring in it: a – turning the landing recess on the rolling surface of the wheel to the required dimensions; b – formation of a polyurethane PU layer in the landing recess; 1 – rim of a solid-rolled wheel; 2 – polyurethane matrix; 3 – reinforcing high-strength fibers.](image)

Fig. 3. Scheme of turning a recess on the wheel rim and forming a PU ring in it: a – turning the landing recess on the rolling surface of the wheel to the required dimensions; b – formation of a polyurethane PU layer in the landing recess; 1 – rim of a solid-rolled wheel; 2 – polyurethane matrix; 3 – reinforcing high-strength fibers

It is important to note that the required parameter is that for turning the recess on the running surface of the impeller (Fig. 3c), the thickness of the rim should not be less than 30 mm.

The recess of the wheel rim is turned to a depth of 8-10 mm, and then the rolling surface of the wheel is degreased and the process of pouring liquid two-component high-strength polyurethane begins (Fig. 3b) as follows: Wheel 1 is installed on the lower part of the plaster mold 2 (Fig. 4), and High-strength fibers (Fig. 3c) with a diameter of no more than 2.5 mm are wound on the recess for PU reinforcement. Then, the rubber seal 3 is installed, and the top cover of the mold 4 is closed. The top cover of the mold 4 has two necks 5 for pouring liquid polyurethane 6.

After complete hardening of the polyurethane, we obtain a solid-rolled railway wheel with a high-strength polyurethane ring (Fig. 3d), where the polyurethane rings act as a...
The sacrificial element of the wheel that absorbs all static and dynamic loads during the operation of the car.

The use of a high-strength polyurethane ring as a sacrificial element of a wheel is determined by a wide range of physical and mechanical properties (Table 1-4) of polyurethane (PU) products, which, with certain uneven wear, can be turned using a wheel lathe with a similar technology to a steel wheel during repairs.

The creation of modern composite materials for structural purposes, as well as their use in the design of cars, became possible thanks to the development and use of high-strength and high-modulus glass, carbon, boron and organic fibers, whiskers and fibers of metal oxides, carbides, borides and nitrides, as well as reinforcing materials based on metals, steels and alloys with high strength (2500-5000 MPa) and high modulus of elasticity. The use of high-strength fibers to reinforce a polyurethane ring is associated with a reduction in internal stresses from vertical and lateral loads at high speeds, increasing the service life of polyurethane rings used on the rolling surface of solid-rolled wheels.

According to the presented diagram of the two-point contact of the rail and the wheel with the polyurethane ring (Fig. 5), it shows that the main transmitted vertical loads 1 from the car are directly absorbed by the polyurethane ring, which considers itself a sacrificial element of the car wheel pairs. Lateral loads 2 are absorbed by the wheel flange, and also, due to its configuration, the wheel flange holds and guides the car when moving along the rails, even during severe centrifugal pumping, which strongly depends on the high strength of the flange material, which makes it indispensable.

The method of covering the rolling surface with a high-strength polyurethane ring makes it possible not only to extend the service life of solid-rolled wheels, but also reduces vibration and shock, while increasing the comfortable ride of passenger cars.

**Table 1.** Physical and mechanical properties of well-known brands of antifriction composites materials

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Adiprene SKU -100/167/300</th>
<th>SKU-PFL 74 SKU-PFL -100M</th>
<th>SIC PU -5</th>
<th>TT 129/194</th>
<th>SUREL -20F</th>
<th>OXAFEN OPM -94</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density, kg/m³</td>
<td>800-1300</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1300-1400</td>
</tr>
<tr>
<td>Shore hardness, (A)</td>
<td>up 70 to 100</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>150 HB</td>
</tr>
<tr>
<td>Tensile strength, MPa</td>
<td>30-50</td>
<td>45-65</td>
<td>32-45</td>
<td>35-58</td>
<td>37-60</td>
<td>80</td>
</tr>
<tr>
<td>Compressive Strength, MPa</td>
<td>in the range 70-110</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>180</td>
</tr>
<tr>
<td>Working temperature, ºC</td>
<td>-</td>
<td></td>
<td>40 … + 250</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Fig. 4.** Scheme of pouring liquid polyurethane onto the wheel tread: 1 – solid-rolled wheel; 2 – lower part of the form; 3 – rubber seal; 4 – upper part of the form; 5 – necks for filling PU; 6 – liquid polyurethane
Dry friction coefficient | 0.20 – 0.40 | 0.10 – 0.23

**Table 2.** Physic-mechanical properties of various high-strength reinforcing fibers

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>SATURN (UV)</th>
<th>HITEX 46-N (UV)</th>
<th>KEVIAR 49 (AB)</th>
<th>AVICO (BV)</th>
<th>NICALON-200 (KB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density, g/sm³</td>
<td>1.70-1.83</td>
<td>1.70-1.83</td>
<td>1.40-1.60</td>
<td>2.2-2.6</td>
<td>2.4-2.6</td>
</tr>
<tr>
<td>Tensile strength, MPa</td>
<td>4650-4960</td>
<td>4500-5500</td>
<td>2550-3000</td>
<td>2545-3200</td>
<td>2500-3000</td>
</tr>
<tr>
<td>Elongation at break, %</td>
<td>1.5-2.0</td>
<td>1.5-2.0</td>
<td>2.5-3.0</td>
<td>0.8-1.2</td>
<td>1.0-1.8</td>
</tr>
</tbody>
</table>

The loading diagram of a rail and a solid-rolled wheel with a polyurethane ring is shown in Figure 5.

![Diagram](image)

**Fig. 5.** Diagram of two-point contact between a rail and a wheel with a polyurethane ring: 1 – vertical contact point “wheel-rail”; 2 – horizontal contact point “wheel-rail”

**Table 3.** Analytical data when a passenger car moves at various speeds

| Wheel diameter in the range of 880-867 mm, with a rim thickness of at least 30 mm |
|-------------------------------|----------------|----------------|----------------|----------------|----------------|
| Wheel diameter in mm | 3868 | 881 | 1302 | 1322 | 1776 | 1762 | 2170 | 2203 | 2604 | 2643 | 2686 | 3084 | 3080 | 3472 | 3525 | 3907 | 3965 |
| Speed, km/h | 40 | 60 | 80 | 100 | 120 | 140 | 160 | 180 | 200 | 220 | 240 | 260 | 280 | 300 | 320 | 340 | 360 | 380 |
| kev/min | 864 | 608 | 1302 | 1322 | 1776 | 1762 | 2170 | 2203 | 2604 | 2643 | 2686 | 3084 | 3080 | 3472 | 3525 | 3907 | 3965 |

However, just as every scientific development and technique has its own disadvantages, this method of extending the service life of solid-rolled wheels also has two disadvantages. One of them is the inability to use this method on freight rolling stock, due to the heavy weight of the cargo, and the second disadvantage is that the use of this method is possible only when using a disc or shoe (electromagnetic) braking system for passenger cars or trams. This dependence on brake systems is due to the fact that when using a shoe braking system on the wheel tread, the surface of the wheel and the brake shoe are very hot to a temperature of 450-500 ºC, which can lead to loss of functionality of the polyurethane ring.

**Table 4.** Relative wear of the polyurethane ring depending on the speed of a passenger car with a gross weight of 60 tons
A polyurethane ring installed on the tread surface of a solid-rolled wheel experiences various colossal loads when the train moves. Due to their low elasticity, polyurethane rings dampen and absorb all vertical loads. Figure 6 shows loading patterns for the tread surface of a wheel with a polyurethane ring. When the train moves, polyurethane rings, in addition to vertical and horizontal loads, also experience centrifugal forces of the wheel at high speeds of more than 160-180 km/h.

<table>
<thead>
<tr>
<th>Speed km/h</th>
<th>20</th>
<th>40</th>
<th>60</th>
<th>80</th>
<th>100</th>
<th>120</th>
<th>140</th>
<th>160</th>
<th>180</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative wear mm/h</td>
<td>0.25</td>
<td>0.4-0.45</td>
<td>0.6-0.70</td>
<td>0.75-0.85</td>
<td>0.9-1.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The initial thickness of the PU ring is 14-15 mm

**Fig. 6.** Schemes for loading the tread surface of a wheel with a PU ring: a – loaded state of the wheel, interaction with the rail; b – finite element model of a loaded wheel with an axle

Strength calculations of the polyurethane ring were carried out in accordance with the technical and regulatory documents GOST 33211 - 2014, GOST 33788-2016, etc., in the engineering program SolidWorks 2016.

Based on the review and analysis of the shortage of wheel pairs, as well as studies of various wheel designs with improved damping characteristics, it is possible to develop a design and method for extending the service life of solid-rolled wheels using polyurethane rings on the tread surface of solid-rolled wheels. The results of strength calculations confirm the high reliability and endurance of polyurethane rings to loads of 80 kN (Table 3, Figure 7), with a safety margin exceeding the permissible by 0.7%.
Fig. 7. Results of strength testing of a polyurethane ring: a – maximum equivalent voltage of the PU ring according to Misis; b – safety margin of the PU ring at maximum load; c – service life of the PU ring

Thus, the authors carried out calculations and final strength tests of polyurethane rings. Based on the calculations and experimental studies, the actual and permissible values of the strength properties of products were obtained, which are given in Table 5.

The data in Table 5 shows that the results of the studies indicate the possibility of their use in the process of both repairing old (out-of-service) and production of new cars at specialized industrial enterprises of Uzbekistan.

<table>
<thead>
<tr>
<th>Test parameters</th>
<th>Actual</th>
<th>Acceptable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applied load on the PU ring, kN</td>
<td>80.0</td>
<td>74-76</td>
</tr>
<tr>
<td>Maximum equivalent stress according to Misis, MPa</td>
<td>16.8</td>
<td>32-45</td>
</tr>
<tr>
<td>Minimum safety factor</td>
<td>2.9</td>
<td>2-2.2</td>
</tr>
<tr>
<td>Minimum service life, number of cycles, thousand</td>
<td>650</td>
<td>1^a</td>
</tr>
<tr>
<td>Mesh size of the finite element model of the PU ring, mm</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

4 Conclusion

The developed and proposed method makes it possible to partially extend the service life of solid-rolled wheels, thereby saving the cost of purchasing new expensive wheelsets, and at the same time increasing the comfort of passenger transportation by rail, which is a priority for the rapidly developing economy of the Republic of Uzbekistan.

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