WHEEL TREAD PROFILE EVOLUTION FOR COMBINED BLOCK BRAKING AND WHEEL-RAIL CONTACT – RESULTS FROM DYNAMOMETER EXPERIMENTS

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ABSTRACT
Wheel treads are subject to different types of damage such as wear, rolling contact fatigue (RCF), thermal cracks, plastic deformation and also flats caused by wheel sliding. Some of these phenomena is followed by a change in tread profile which results in frequent wheel reprofiling to keep rich comfort of the vehicle.

In this study, a series of full-scale tread braking experiments, including wheel-rail rolling contact, were conducted in order to clarify the influencing factors of evolution of wheel tread profile. The experiments focused on plastic deformation and wear caused by rolling contact and tread braking.

The presented results show that the maximum tread depression is 0.20 mm at the rolling contact center after 40 times stop braking actions. This is considered to be caused by plastic deformation of the wheel tread induced by high contact pressure and material softening due to high temperatures from tread braking. This result is supported by the observed protrusion of the tread near the rolling contact area and also by a difference of hardness between the rolling contact area and other tread area.

1. BACKGROUND
Wheel treads are subject to different types of damage such as wear, rolling contact fatigue (RCF), thermal cracks, plastic deformation and also flats caused by wheel sliding. These phenomena are followed by a change in tread profile which induce wheel-rail contact forces, both vertically by wheel out-of-roundness and laterally by impaired vehicle dynamics. This will accelerate deterioration of track and vehicle components and cause vibration and discomfort for passengers[2]. For reducing cost of wheel repair and maintenance, an understanding of the mechanisms of tread damage is essential. However, several factors affect wheel tread damage such as speed, axle load, wheel-rail adhesion, wheel material, braking conditions, etc[3]-[7].

In the present study, the focus is on the evolution of the tread profiles of wheels subject to block braking and wheel-rail contact. Conditions of conventional block braked trains are investigated. In order to reproduce wheel tread wear, full-scale dynamometer experiments [1] are carried out with tread braking using sintered brake blocks and the wheel-rail contact accomplished by a rail-wheel. Repeated stop braking is performed. The profile and hardness of the tread are measured and evaluated. Also temperatures and crack development are observed.

In the parallel paper [8] thermally induced cracking of the wheel treads at the brake test stand tests is studied experimentally and numerically.

2. EXPERIMENTAL CONDITIONS
The full-scale brake dynamometer employed in this study is shown in Figure 1. In the experiments, the block braked wheel is in rolling contact with a rail-
Fig. 1. Experimental setup in dynamometer

Table 1 Testing conditions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheel material</td>
<td>ER79</td>
</tr>
<tr>
<td>Diameter of wheel</td>
<td>855 mm</td>
</tr>
<tr>
<td>Brake block</td>
<td>Sintered block</td>
</tr>
<tr>
<td>Wheel load</td>
<td>10 tons = 98 kN</td>
</tr>
<tr>
<td>Moment of inertia</td>
<td>2550 kgm² (corresponds to 20 tons axle load)</td>
</tr>
<tr>
<td>Wheel-rail contact position</td>
<td>Stable</td>
</tr>
<tr>
<td>Initial wheel temperature</td>
<td>60 °C</td>
</tr>
<tr>
<td>Initial speed of braking</td>
<td>160 km/h, 130 km/h</td>
</tr>
<tr>
<td>Wheel speed in cooling operation</td>
<td>50 km/h</td>
</tr>
<tr>
<td>Brake block pressing force</td>
<td>30 kN</td>
</tr>
<tr>
<td>Number of tread braking cycles</td>
<td>2x40 times</td>
</tr>
</tbody>
</table>

Table 2 Testing results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>130km/h</th>
<th>160km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Braking speed</td>
<td>260 kW</td>
<td>330 kW</td>
</tr>
<tr>
<td>Maximum power</td>
<td>6.5 MJ</td>
<td>10 MJ</td>
</tr>
<tr>
<td>Braking energy</td>
<td>50 sec.</td>
<td>60 sec.</td>
</tr>
</tbody>
</table>
at the brake block contact area, and Position D, which is at the outside of the contact area, depression of the tread is extremely small.

The observed deviation from the initial tread profile is a result of a combination of wear (i.e., removal of material) and of plastic deformation which moves material laterally on the wheel tread. The wear can be caused both by the block and the rail-wheel contacts while the plastic deformation is caused by the contact with the rail-wheel at elevated temperature in the wheel. The tendency for the experiment at 130 km/h initial braking speed is same as at 160 km/h although the depression / protrusion is larger at the higher speed.

Figure 5 shows the evolution of the wheel tread profile around the contact area between the braked wheel and the rail-wheel. At Position A, which is at the center of rolling contact area, depression of the tread is observed. On the other hand, at Position B, which is just outside the rolling contact area, the tread is found to protrude. At Position C, which is...
Fig. 6. Depression relative to initial tread profile as function of axial position on tread and of accumulated braking energy for braking speed 130 km/h.

Fig. 7. Depression relative to initial tread profile as function of axial position on tread and of accumulated braking energy for braking speed 160 km/h.

Fig. 8. Hardness results.
A more detailed analysis of the observed evolution of the tread profile is presented in Figures 6 and 7 where the depression of the initial tread profile as function of axial position on the tread and of accumulated braking energy are shown for the four positions on the wheel tread indicated in Figure 5. The ratio depression to braking energy was found to be about 500x10^{-6} mm / MJ in position A (center of rolling contact area) and almost zero in position C which is for contact with the block only.

The hardness of the rolling contact area (Position A) is higher than the area which is only in contact with brake block (Position C), see Figure 8. The hardness at the flange means the original hardness of wheel. The value is intermediate between the values at Position A and Position C.

4. DISCUSSION

It is found that the wheel tread profile evolution at severe stop braking is affected mainly by plastic deformation of wheel material caused by rolling contact at elevated temperature. The wheel temperature increases due to tread braking which softens the wheel material, resulting in increased deformation by the rolling contact.

At these conditions a characteristic evolution of microstructure of the steel material takes place, which indicates occurrence of high-strain rate deformation at intermediate temperatures[11]. This will also cause evolution of mechanical properties of the wheel material along with the evolution of microstructure[12].

However, also some wear (removal of material) occurs in this area. Outside the rolling contact area, the plastic flow of wheel material from rolling contact will cause a protrusion of the tread, a protrusion that can be modified by wear caused by the brake block. In fact, wear on the tread can only be detected after the 160km/h braking cycles, where the protrusion near the contact is smaller than what can be presumed from a consideration of volume constancy. It should be noted that the pressure from the brake block (≈ 1 MPa) is much lower than the rolling contact pressure (≈ 1 GPa) and can be disregarded with respect to plastic deformation. Moreover, the results indicate that frictional wear of the wheel tread by contact with the brake block is small at severe stop braking, as compared to plastic phenomena.

The hardness distribution shows a clear difference between the rolling contact area and the tread area which is only in contact with the brake block. Both areas are heated by the block and are thus subject to annealing and softening of the material. However, the rolling contact area is subject to plastic deformation and work hardening which increases its hardness. Similar results are found from a study of wheels from revenue traffic[12]. The detailed mechanism of the strength evolution will be understood through the investigation of microstructure characteristics[13].

Another aspect is the evolution of the contact patch between the wheel and the rail-wheel. Information on this was obtained by use of pressure-sensitive paper. The shape is found to change from an ellipse having dimensions about 14 mm × 12 mm into a 25 mm × 11 mm ellipse after 40 stop braking actions from speed 160 km/h. Thus, it is found that wheel tread deformation increase the area of the contact patch which, in turn will lower the contact pressure which will hence reduce further plastic deformation. It should also be mentioned that in the present experiments the contact patch does not move laterally on the wheel, which is a deviation from the operation conditions.

5. CONCLUSION

In the present study, a series of full-scale tread braking experiments, including wheel-rail rolling contact, were conducted in order to clarify the influencing factors of evolution of wheel tread profile. The experiments focused on plastic deformation and wear caused by rolling contact and tread braking. It is found that the wheel tread evolution at severe stop braking is affected mainly by plastic deformation.

The presented results show that the maximum tread depression is 0.20 mm at the rolling contact center after 40 times stop braking actions. This is caused by plastic deformation of the wheel tread induced by high contact pressure and material softening due to high temperatures from tread braking. This result is supported by protrusion of the tread near the rolling contact area and also by the observed difference of hardness between the rolling contact area and other tread area.

Future investigations could include different wheel materials, brake block materials, speeds, braking loads, contact loads, etc. Further insight should be gained by numerical modeling and simulation.
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6. REFERENCES