Elucidating Deterioration due to Wheel-Rail Rolling Contact

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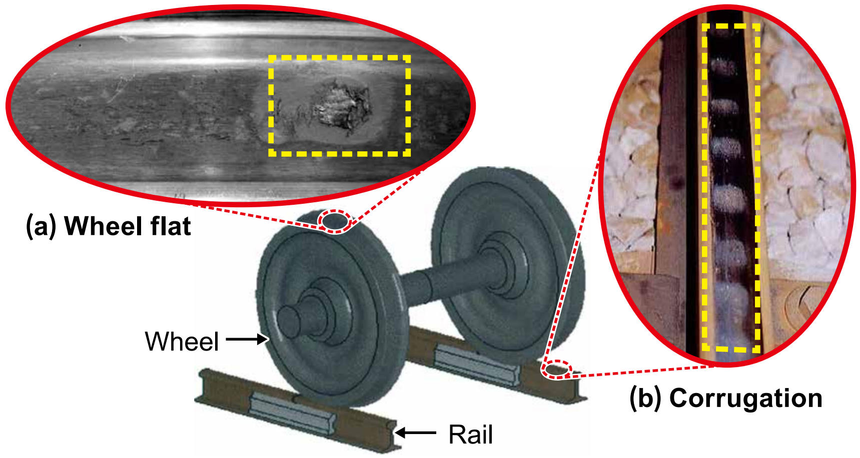


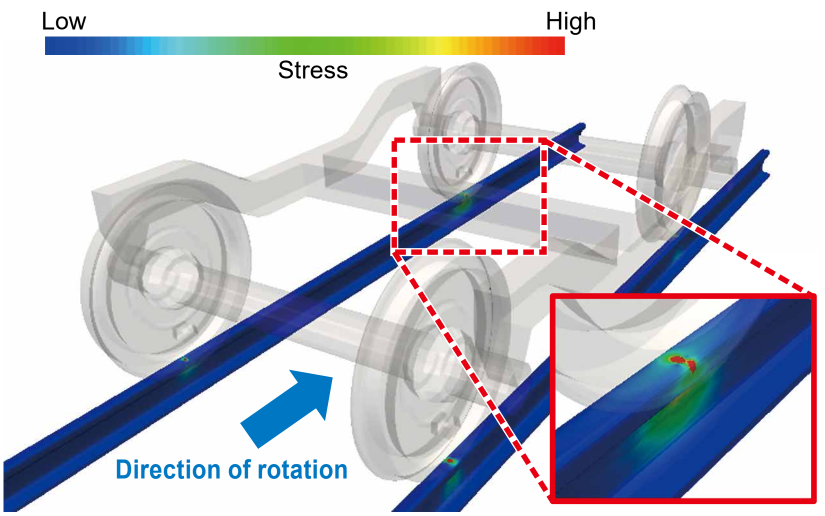
Examples of damage to wheels and rails

As vehicle wheels repeatedly roll on rails, the wheels and rails gradually deteriorate (Examples of damage to wheels and rails). There are various deterioration phenomena that are related to many causes such as the hardness and temperature of the material, in addition to the magnitude and direction of the acting force. Thus, to elucidate the mechanism of deterioration phenomena and propose countermeasures against the deterioration, RTRI is developing the Wheel-Rail Rolling Contact Simulator, which provides a method of simulating rolling contact between wheels and rails (Example of calculation using the Simulator (result of visualization of railway bogie stress distribution during curve running)). This paper shows the results of performing a numerical simulation targeting hollow wear of wheels, one of the deterioration phenomena, after making improvements for handling thermal effects and wear.

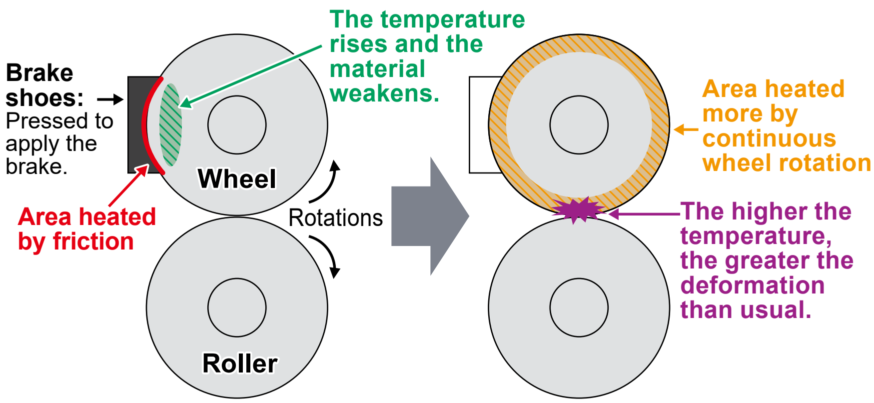
Reproducing wheel-rail contact phenomena using numerical simulation is an effective means for elucidating deterioration phenomena and estimating deterioration causes. Thus, we are working on the development of the Wheel-Rail Rolling Contact Simulator (hereinafter merely “Simulator”), which provides a simulation method that can continuously reproduce the contact state while solving the force balance between the wheel and rail).

One of the wheel deterioration phenomena is hollow wear, which refers to the tread of the wheel being permanently deformed into a hollow shape (Hollow wear conceptual diagram). Previous tests conducted by RTRI have demonstrated that the higher the wheel temperature, the greater the amount of permanent deformation. From this fact, it is considered that hollow wear is a phenomenon in which wheels with temperature rises due to the brakes and reduced strength come into contact with the rails, causing the wheels to undergo greater plastic deformation than usual (Mechanism of formation of hollow wear shape, estimated from test results). However, in tests, only the final wheel shape can be known, making it impossible to identify which of the above causes is the primary cause of permanent deformation.

Thus, to the Simulator, we added a function that can consider thermal effects, permanent deformation, and wear, and reproduced the experimental wheel deformation state by using a numerical simulation.



Example of calculation using the Simulator
(result of visualization of railway bogie stress distribution during curve running)

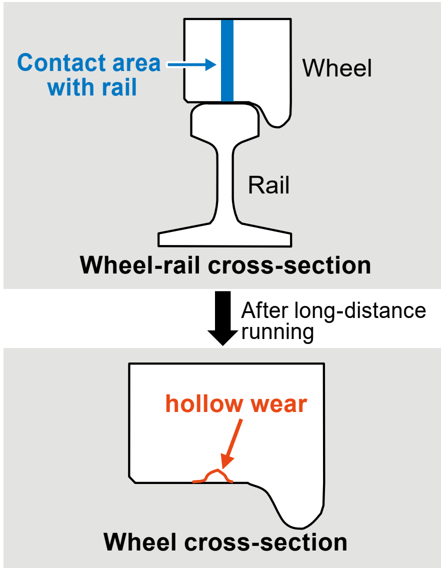


Mechanism of formation of hollow wear shape, estimated from test results

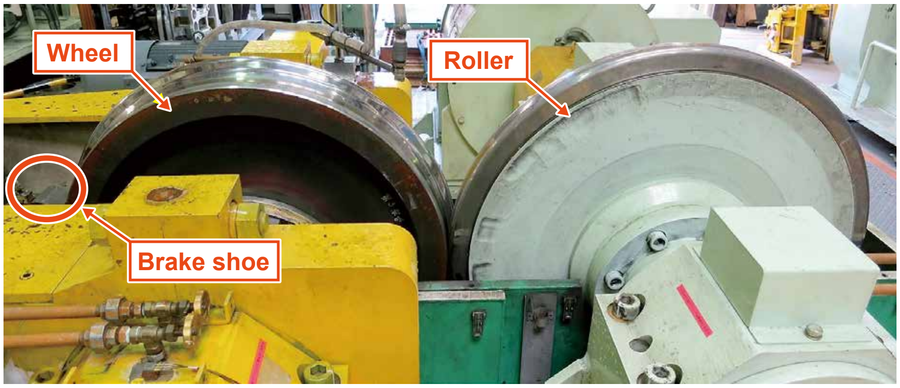
Heat Computation

There are three methods of heat transfer: heat conduction (heat transfer in an object), heat transfer (heat transfer between contacted objects), and radiation (heat transfer by electromagnetic waves), which can all be handled by the simulation method we are currently developing. In addition, the method can also take into account the heat generated by the friction between objects (i.e. frictional heat).

Thus, in this development, we assumed a



Hollow wear conceptual diagram



Brake test equipment

brake shoe contact area on the wheel side instead of actually pressing it against the wheel. We have developed a mechanism (heat input boundary) that automatically applies the amount equivalent to frictional heat according to the wheel rotation speed, to the wheel surface (i.e. the area that generates heat due to friction in Mechanism of formation of hollow wear shape, estimated from test results) in the contact area. This reproduces the wheel temperature rise while reducing the computation load.

The Simulator enables conducting numerical simulations that take into account the relationship between material deformation and heat.

Calculation Example Considering the Effects of Heat

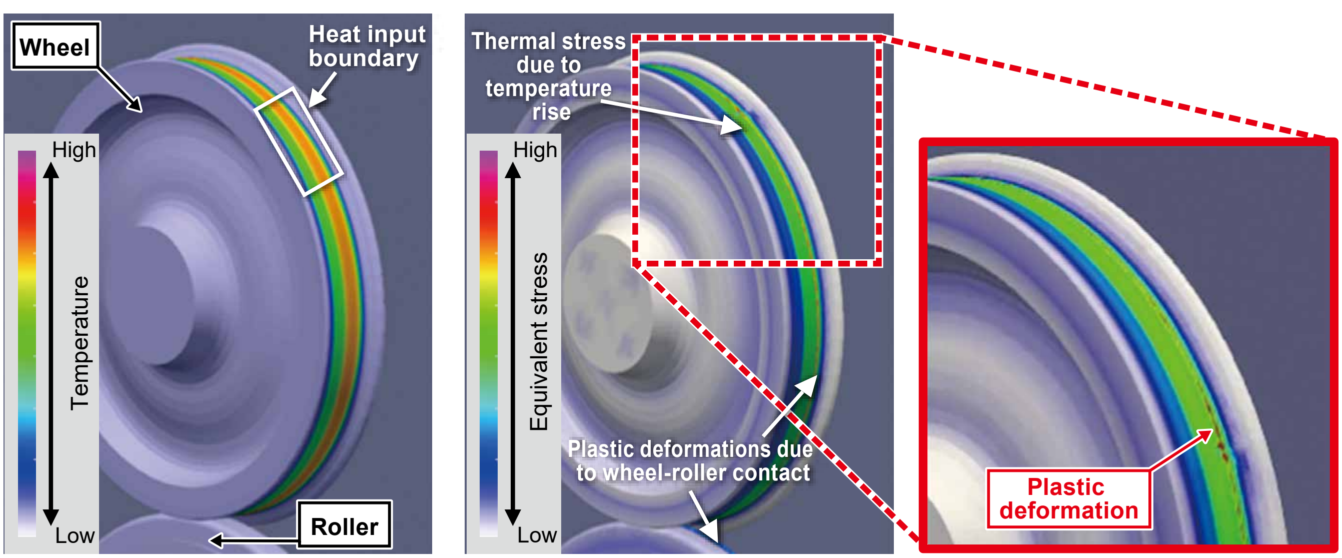
Brake test equipment shows RTRI's test equipment that uses disc-shaped wheels (rollers) that imitate wheels and rails. This simulates the braking of an actual railway vehicle by accelerating the wheel to the predetermined rotation speed and then pressing the brake shoe against the wheel tread.

The test decelerated the wheel from 130 km/h by pressing the brake shoe and measured the temperature by the sensor embedded inside the wheel. We have verified that the numerical simulation method we have developed reproduces the deceleration of the wheels and the rise of the temperature with an error of approximately 10%.

In addition, the numerical simulation can calculate and visualize attributes that are difficult to measure (e.g. equivalent stress acting on a wheel or roller; state of plastic deformation) and can be useful for elucidating the mechanism of damage phenomena (Results of wheel deceleration simulation that considers thermal effects (wheel temperature distribution and equivalent stress distribution)).

Wear Computation

There are multiple types of wear, and we adopted the Archard's law from several

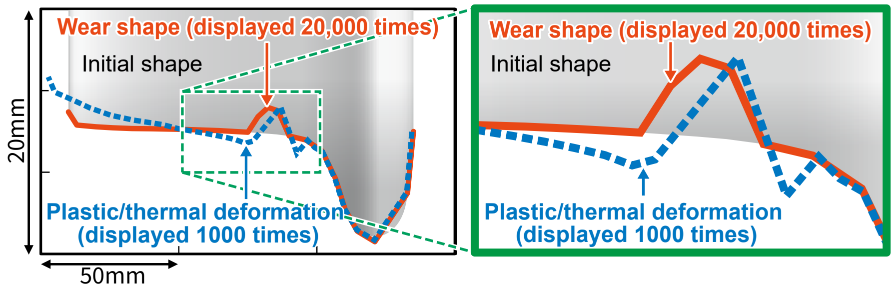


Results of wheel deceleration simulation that considers thermal effects (wheel temperature distribution and equivalent stress distribution)

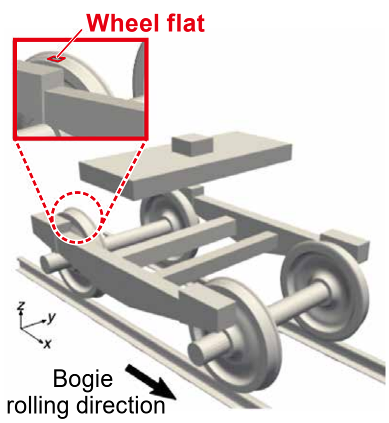
equations that have been proposed to model wear. We have proposed and introduced the new concept of a wear assignment ratio, where the respective wear amounts are assigned according to the ratio between the wheel and rail hardness. The use of this method results in the following: if the hardness's of the wheel and rail are significantly different, the wear amount that completely matches the case of using Archard's law can be obtained; if the hardness of both is close, the wear amount is evaluated to be less than before. We have verified that the simulation results of wear by the developed method generally match the amount generated in tests conducted within RTRI.

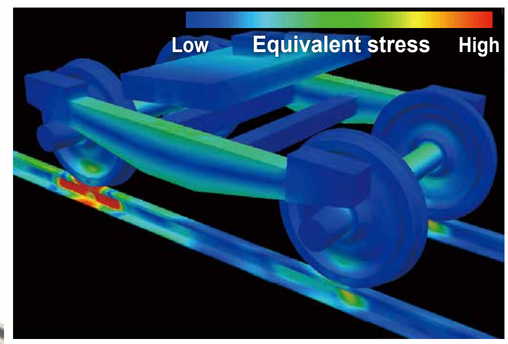
Example of Hollow Wear Computation

Using the Simulator, we performed a numerical simulation that simultaneously considered thermal effects, plastic deformation, and wear. Hollow wear simulation results (initial shape of wheel cross-section, plastic/thermal deformation, and wear shape) contains deformation diagrams of the wheel cross-section that was used for calculating the amounts of plastic and thermal deformation and wear resulting from wheel rotation, by using a model with the same shape as the analysis model used in Results of wheel deceleration simulation that considers thermal effects (wheel temperature distribution and equivalent stress distribution). The amount of thermal deformation due to temperature rise and the amount of plastic deformation due to wheel-rail contact are displayed at 1,000 times the initial shape, and the deformation amount due to wear is displayed at 20,000 times. From Hollow wear simulation results (initial shape of wheel cross-section, plastic/thermal deformation, and wear shape), we verified that plastic or thermal deformation is approx. 20 times larger than the shape change due to wear, suggesting that it is highly possible that hollow wear is a deterioration phenomenon caused by plastic or thermal deformation rather than wear.



Hollow wear simulation results
(initial shape of wheel cross-section, plastic/thermal deformation, and wear shape)





Simulation example of a bogie using a wheel with tread flat damage
(analysis model, and equivalent stress distribution during impact between the flat section and rail)

Conclusion

The Simulator can contribute to elucidating the mechanism of deterioration phenomena by focusing on processes such as the occurrence and growth of deterioration phenomena, such as the case of hollow wear simulation. We aim to study the following: (i) the distribution of the force generated between the wheel and rail and the range of effects of the propagated force can be studied by performing simulations using an analysis model, as in Simulation example of a bogie using a wheel with tread flat damage (analysis model, and equivalent stress distribution during impact between the flat section and rail), in which the wheel and rail are damaged in advance, and (ii) by investigating the state near the force generating portion in detail, the effects of deterioration of the wheel or rail on other members can be studied and the mechanism and for proposing countermeasures based on them can be elucidated.

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