Factors that Influence the Adhesion Coefficient between Wheel and Rail

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In rain or snow, the adhesion (friction) force between the wheel and rail often decreases due to the lubricating action of the water film existing between the two surfaces. Wheels slip when the adhesion force is smaller than the driving force during acceleration and wheels slide when the adhesion force is smaller than the braking force during braking. These phenomena create operating concerns through poor braking or acceleration performance and cause slipping or sliding flaws on the wheel/rail contact surface, which can increase noise and vibration when trains run. To remove these surface flaws, wheel treads are often turned and rails are usually ground. When wheel tread and rail surfaces are seriously damaged, wheels and rails are replaced. Thus, this surface damage inevitably contributes significantly to the maintenance costs of railways. To ensure the safety and stability of transport and save the maintenance costs, we undertook a program to quantify the factors that affect the adhesion force under wetting conditions and find measures to suppress the decreases thereof.

In this study, we accounted for the factors that seemingly influence the adhesion force under wetting conditions, such as train running speed, wheel loads, surface roughness of wheel/rail and water temperature. We studied the degree of influence of each factor through a numerical analysis applying the mixed lubrication theory and through laboratory tests using a two-disc rolling contact machine. As a result, we were able to clarify that running speed, water temperature and surface roughness have comparatively large effects on the adhesion coefficient.

See Fig. 1 for a numerical analysis model for the case where a water film exists between wheel and rail. Figure 1 assumes a state of mixed lubrication where some metallic solids are in direct contact with each other and coexist with those in contact with a water film sandwiched in between the solids. In Fig. 1, Wc denotes the load supported through roughness protrusions in contact and Wh the load supported by the water film. The adhesion coefficient μ is given by the following equation.

$$\mu = \frac{\mu_c W_c + \mu_h W_h}{W}$$

Where:

μ_c : Boundary friction coefficient at the contact surface between metallic solids

μ_h : Shear coefficient of the water film

W : Wheel load

We applied the elastohydrodynamic lubrication theory and used a Greenwood - Williamson rough surface contact model (with the heights of roughness protrusions assumed to follow a Gaussian distribution) to obtain the solutions of numerical analysis through the Newton - Raphson iterative procedure. Figures 2 and 3 show the results of the numerical analysis induding the relations between water temperature, surface roughness and adhesion coefficient. These Figures indicate a trend that higher values of water temperature and surface roughness result in increased values of adhesion coefficient.

Figure 4 shows the contact between wheel and rail specimens of a two-disc rolling contact machine together with a water injection system used in this study. Although it would have been desirable to set the same speed as that used in the numerical analysis for high-speed trains, we set the maximum speed at 100 km/h as this was the limit of the testing machine. Figures 5 and 6 show the test results including the relations between water temperature, surface roughness and the maximum traction coefficient (equivalent to the adhesion coefficient). We were able to confirm that as water temperature or surface roughness increases, the adhesion coefficient follows suit. This is the same as the result obtained through the numerical analysis.

Based on the above results obtained through a theoretical analysis and laboratory tests, we can conclude that, if practically possible, it is effective to increase the temperature of the water film existing between wheel and rail or the wheel/rail surface roughness as methods to suppress decreases in the adhesion coefficient between wheel and rail under wetting conditions.

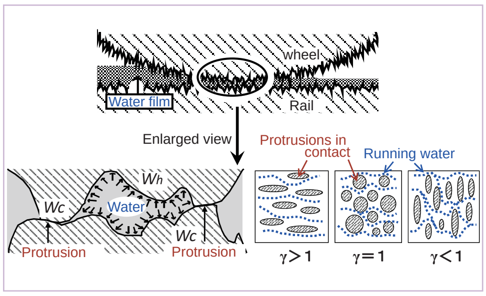

Fig. 1 Numerical analysis model of wheel/rail

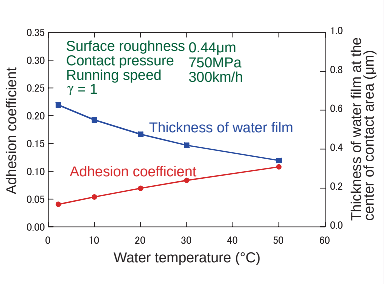

Fig. 2 Relation of water temperature versus adhesion coefficient

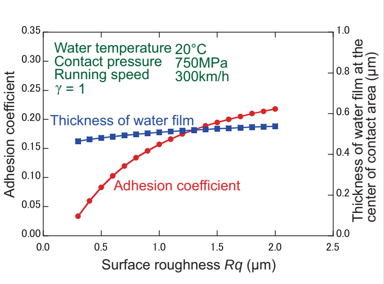

Fig. 3 Relation of surface roughness versus adhesion coefficient

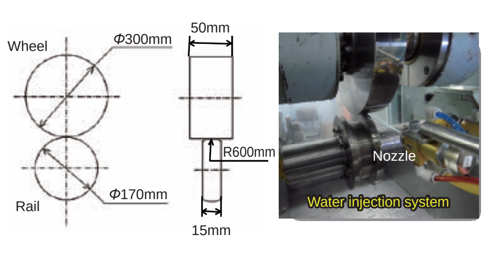

Fig. 4 Test specimens of the two-disc rolling contact machine installed with water injection system

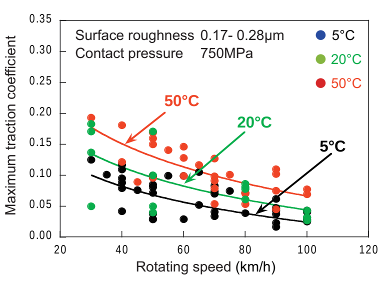

Fig. 5 Relation between water temperature versus the maximum traction coefficient

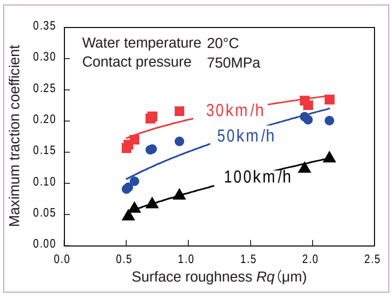

Fig. 6 Relation between surface roughness versus the maximum traction coefficient