Influence of Leaves on the Adhesion between Wheel and Rail

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Idling and sliding of wheels caused by fallen leaves in autumn often occurs on sloping sections of railway lines located in mountainous areas, which disrupts train operations. Countermeasures such as spraying sand and ceramic particles onto the wheel/rail contact zone are not sufficient. In order to find more effective solutions, it is necessary to clarify the mechanisms whereby fallen leaves cause loss of wheel/rail adhesion. The authors conducted running tests on a test track and investigated the influence of leaves on wheel/rail adhesion to gain insight into this problem and formulate practical countermeasures. This paper introduces the characteristics of adhesion in powering and braking and insight into why fallen leaves decrease adhesion.

Keywords: wheel/rail, adhesion, slipping, sliding, leaves, wet condition

1. Introduction

Trains accelerate and decelerate thanks to a tangential force known as “adhesion” which is exerted on the wheel/rail contact surface in the longitudinal direction (running direction of the train). If driving or braking force exceeds the adhesion force during acceleration or deceleration, wheels may slip when powering or slide while braking. This phenomenon increases accelerating or decelerating distances, which in turn affects punctuality of train service diagram. Significant slipping or sliding can even cause wheel burn on the rails and wheel flats, respectively.

Railway sections in mountainous areas are prone to leaves falling on the track from late autumn to early winter. Leaves on tracks are crushed by train wheels and pressed onto the rail surface. The accretion of leaves on the rail surface and the continuous passing of trains over time turn these leaves into a black film [1]. Past studies have shown that wheel slipping occurs frequently with the first train of the day passing through an affected section, furthermore in some cases not only were trains delayed but they were unable to move forward. Wheel slipping on early morning trains such as the first train of the day is thought to be due to wet rail surfaces [1-3]. It is thought that rail surfaces become wet due to early morning condensation forming on the rail surface as a result of significant fluctuations in temperature in cold seasons. Although some studies have analyzed the conditions where leaves cause wheel slipping or sliding [1-3] which in turn have led to countermeasures to control or prevent slipping and sliding, very few have investigated in detail the relationship between adhesion force and leaves, which is a significant factor in slipping and sliding [4-8].

In this study, trials were conducted to reproduce rail surface conditions in mountainous areas during the cold season in Japan from late autumn to early winter. Powering and braking tests were then carried out on the RTRI test track using a test vehicle to verify wheel slipping/sliding conditions and evaluate rail surface adhesion coefficients coinciding with frequent wheel slipping/sliding. The traction coefficient (the maximum traction coefficient is considered to be the adhesion coefficient) was then measured using test rings that imitate wheel/rail contact, whilst transitioning between wet and dry conditions and adding leaves to the contact surface. Observations were made of the influence of leaves in the various running conditions. The detail of this study and its results are presented below.

2. Vehicle running test

2.1 Overview of the test

As shown in Fig. 1, a test segment of approximately 20 m was configured along a straight section of the RTRI test track. An R291 series electric rail car train was selected for the test (2-car train set with 0.5M and 1.5T) which has an anti-skid valve installed on each axle of the M-car bogie. Only the electric brake on the M-car bogie was used for the tests, and not the air brake in the T-car bogie. A camera was installed on the bogie frame to observe the contact conditions of the left and right wheels on the rail while the train was running and to detect wheel slipping and sliding.

The powering tests were conducted by running the train from B to A, while the braking tests were conducted when the train ran from A to B; i.e. the two tests were conducted alternately while operating the train between A and B (see Fig. 1(a)). Table 1 lists the test conditions.

Before conducting the running tests, a mixture of leaves was spread on the rail surface of the variety usually found in mountainous areas and the train was run repeatedly while reproducing the relevant environmental conditions (see Fig. 1(b)). The rail surface was sprayed with a mist of water using a high-pressure sprinkler to reproduce
condensation on the rail surface. A running test was also carried out under the rain because it rained for a day during the test period.

The axle speed of the driving bogie and the running speed of the train were measured in both powering and braking runs. In addition, the value corresponding to the traction coefficient for the driving bogie (the 3rd axle) was determined on the basis of the total weight of the vehicle, the command values for the excitation current in the driving motor and the torque current.

2.2 Test conditions

Fig. 2 shows the two types of rail surface condition reproduced for the tests: a rail surface covered with pressed leaves (Fig. 2(a)) and one with a black film of crushed leaves (Fig. 2(c)). Wet conditions (Fig. 2(b) and (d), respectively) were also reproduced for these rail surface states. The conditions in Fig. 2(a) were obtained by spreading leaves on the rail surface and running the train over them to make them adhere to the surface. The conditions in Fig. 2(c) were created by spreading leaves on the rail surface and then running the train and spraying (atomized) water on the rail at intervals to generate the black film of crushed leaves on the rail surface.

Because the speed limit of the test track was 35 km/h, the speed of the train entering the test section (the initial speed for powering and braking) was set to 30 km/h.

Fig. 1 Overview of the test

Table 1 Test control conditions

| Power running test | Braking test |
|--------------------|-------------|
| Notch              | 3 - 4       |
| Deceleration (km/h/s) | 1.1 - 1.3  |
| Brake control      | Electric control |
| Slip detection     | Enabled     |
| Slide detection    | Enabled     |
| Re-adhesion control| Enabled     |

(a) Leaves (dry)   (b) Leaves (wet)   (c) Black accretion (dry) (d) Black accretion (wet)
2.3 Test results

The example results from the running tests in Fig.3 show the measurements obtained when powering with wet leaves on the rail surface. The results show the driving axle wheels slipping in the test section (pink and blue lines). The traction coefficient also fluctuates because re-adhesion control was applied following wheel slipping (emerald green line).

Figure 4 shows the relation between the rail surface condition and wheel slipping and sliding determined from results of the powering and braking tests. The results indicate that although significant wheel slipping and sliding did not occur in dry conditions even if there were leaves or the black film on the rail surface, significant wheel slipping and sliding occurred in wet conditions. In addition, wheel slipping and sliding not only occurred frequently inside the test section (20 m) in the presence of the wet black film on the rail surface, but also on the track before and after the test section. This can be explained as follows: When a train passes through the test section for the first time in wet conditions, the black film (in a paste form) is transferred from the rail surface to the wheel tread. This paste is then transferred to the rail surface outside the test section due to the rolling motion of the wheel. It is considered that wheel slipping outside the test section occurred due to a decrease in adhesion force on the wheels of following trains passing that point.

Figure 5 shows the conditions leading to a transfer of the black film from passing trains. An area covered with the black accretion was ground with abrasive paper to expose the base metal. The test train was run over this area and it was found that the black film formed from accretion of crushed leaves (black film) had been transferred onto the ground rail surface. Observations of the rail surface along the whole section where the test train had run revealed that the black film had been transferred along a fairly long distance outside the test section. It can be concluded from these results therefore, that slipping and sliding can occur both in and beyond mountainous areas where leaves fall on the rail surface.

3. Evaluation of adhesion coefficient

3.1 Overview of the test

Having established that the black film on the rail surface is a significant factor causing wheel slipping and sliding as shown in Fig. 4, the focus of the study was centered on the black film generated on the rail surface and evaluation tests were performed to determine its influence on the wheel/rail adhesion coefficient in wet and dry conditions.

Tests were conducted using the same method as powering and braking tests described in Subsection 2.1. The value corresponding to the maximum traction coefficient just before wheel slipping occurred was taken to be the adhesion coefficient.
3.2 Test conditions

To compare adhesion in wet and dry conditions, the thickness of the black film on the rail surfaces had to be spread as uniformly as possible. Given the difficulty in preparing a film with a uniform thickness using the method indicated in Fig. 2(c), crushed leaves were made into a paste and 10 ml of this paste was spread uniformly per meter of rail surface along the test section (20 m). Water was then sprayed onto the rail surface and the train was run to and fro to spread the black film as shown in Fig. 6. A running test was conducted in the rain in addition to the tests in wet and dry conditions because it rained for one day during the test period.

The speed of the train entering the test section (the initial speed for the powering and braking operations) was set to 30 km/h, however, the actual speed of the train entering the test section was slower than 30 km/h in some cases taking into consideration slipping and expected stopping distances for braking.

3.3 Test results

Figure 7 shows the average adhesion coefficient in dry, wet, and rainy conditions obtained during the powering and braking tests. These averages indicate a slight difference in the adhesion coefficient between powering and braking, but there was almost no change in the adhesion coefficient in dry conditions regardless of the presence or absence of the black deposit. The average adhesion coefficient in wet and rainy conditions however decreased significantly.

4. Laboratory tests

4.1 Overview of the test

To understand the adhesion behavior before a black film is generated on the rail surface, i.e. when the wheel presses fallen leaves on the rail surface in normal wet or dry conditions, a "rolling - sliding friction test rig" shown in Fig. 8 was used to simulate the contact between the
wheel and rail. The rig was used to measure the traction coefficient (the maximum traction coefficient is considered to be the adhesion coefficient) in different conditions: dry, wet, and with accumulated leaves.

The rig consisted of test rings with a diameter of 30 mm reproduce the wheel (wheel ring) and rail (rail ring) respectively. To reproduce the contact pressure between an actual wheel and rail, the tread surface of the wheel ring was flat while tread of the rail ring was arched with a curvature radius of 600 mm. Both rings were made of the same material as the part they imitated, i.e. they were cut from actual wheels and rails.

Regarding operating conditions, the rig was set with a load of 245 N (contact pressure was approximately 800 MPa), the rotational speed of the wheel ring was 800 rpm (circumferential velocity was approximately 4.5 km/h), with a slip ratio of 5% (slipping speed was approximately 0.2 km/h).

4.2 Test conditions and method

The laboratory test was conducted by inserting leaves between the wheel and the rail rings while alternating the state of the test rings from dry to wet continuously. The test condition was changed as described in items a) to e) below while the rings were being rotated, rather than maintaining it in a constant state. The condition indicated in item b) simulates green leaves blown onto the rail by a typhoon to compare this case with withered leaves falling on the rail. Wet conditions were obtained by spraying water between the wheel and the rail rings with a garden spray.

a) Transition from dry to wet conditions (simulating the start of rain)
b) With green leaves (simulating fresh leaves blown onto the rail by a typhoon)
c) With withered leaves (simulating leaves falling in autumn and winter)
d) Transition from dry to wet conditions, and then adding leaves (simulating condensation appearing on the rail surface, withered leaves falling on the rail, followed by a passing train)
e) Transition from dry conditions to presence of leaves, and then to wet conditions (simulating withered leaves falling on the rail, condensation occurring on the rail surface, followed by a passing train)

4.3 Test results

Figure 9 shows the fluctuation in traction coefficient when the wheel surface transitions from dry to wet. The traction coefficient was 0.6 - 0.7 and 0.2 - 0.3 under dry and wet conditions, respectively. In wet conditions, the traction coefficient decreased to approximately one third of that in dry conditions.

Figures 10 and 11 show the traction coefficient when fresh and withered leaves appear between the wheel and the rail rings respectively. Results show that the traction coefficient was 0.2 - 0.3 in the case of fresh leaves on the contact surface (Fig. 10), while it decreased significantly to less than 0.1 when the leaves were crushed and the pith squeezed out. This is even lower than the coefficient found when the contact surface is covered in a common type of oil. In the presence of withered leaves the traction coefficient was 0.2 - 0.3 (Fig. 11). However, when withered leaves where inserted between the wheel and the rail rings they were discharged from the contact zone without being crushed as the test rings rotated. The traction coefficients obtained therefore is considered to be the values corresponding to when the old leaves are actually sandwiched between the wheel and the rail rings.

Figure 12 shows the traction coefficient on the contact surface of the test rings as it transitioned continuously from dry to wet, and then with withered leaves. The test simulated conditions where a rail surface in a mountainous area first becomes wet and then has leaves crushed on it under the wheel, forming a layer on the rail surface. As in Fig. 9, the traction coefficient in wet conditions was half of that found in dry conditions. When withered leaves were added the traction coefficient decreased further to approximately one tenth and one fourth of the value obtained in
dry and wet conditions respectively.

Figure 13 shows the traction coefficient when the contact surface of the test rings transitioned continuously from dry to the addition of withered leaves, and then to wet conditions. The test simulated the falling of leaves on a rail surface in a mountainous area which are crushed by the wheels, and then moistened. As in Fig. 12, the traction coefficient decreased by two thirds when withered leaves were added, compared to dry conditions. When water was applied, the traction coefficient recovered slightly and increased. The reason is thought the crushed leaves slightly flown down by spraying water.

Laboratory test results indicated that the behavior of the traction coefficient when leaves were present on the rail surface varied between dry and wet conditions. It is posited that the adhesion coefficient decreases, creating conditions where wheels can slip easily, when leaves fall on an already wet rail surface and are then pressed by a wheel.

Figure 14 shows that the black film adhered to the test rings tread surfaces after the test using fresh leaves (the condition b)). In addition, Fig. 15(b) shows that the black film was also found on the surface of the test rings after tests under condition d). This black film was similar to the one generated on the rail surface in mountainous areas.

5. Discussion

The results from the powering and braking tests conducted on the RTRI test track show that the adhesion coefficient decreased significantly and that wheels tended to slip or slid when the black film on the rail surface became wet in mountainous areas. The reasons for this are considered to be as follows: in mountainous areas in autumn, leaves are crushed by the wheel of passing trains and the leaves adhere to the top surface of the rail. The rail surface becomes moist from condensation forming at night and/or early morning due to changes in temperature. Repetition of this process over several days creates a black film on the rail surface which gets thicker over time. This black film then forms a paste with the addition of rain and/or early morning condensation leading to wheel slipping or sliding as trains pass over it.

Nevertheless, results from tests to measure the traction coefficient when the contact surface between the test rings was covered with withered leaves and when transitioning continuously from dry to wet conditions demonstrated that the adhesion coefficient would decrease with wet leaves on the rail surface in mountainous areas. Furthermore, the adhesion coefficient was lower when leaves fell on an already wet rail surface and were then crushed by a passing wheel than when leaves first fell on a dry rail that only became wet afterwards and were then crushed by the passing wheel. These results therefore lead to the conclusion that wheel slipping and sliding tend to occur more
easily in mountainous areas where trains pass over leaves fallen on an already wet rail surface due to morning dew and/or frost.

6. Conclusion

Powering and braking tests were conducted on the RTRI test track under conditions simulating a rail surface a mountainous area, and the occurrences of wheel slipping and sliding were investigated. Furthermore, traction coefficient was measured on a rolling - sliding friction test rig in laboratory conditions simulating the time of year when leaves begin to fall in autumn. The results of the study produced the following conclusions:

1. The adhesion coefficient decreases significantly and wheels tend to slip or slide when a black film made from crushed leaves adheres to the rail surface and gets wet.
2. A black film is created from the repeated crushing of leaves by the train wheels on the rail surface and the rail surface repeatedly changing from dry (day-time) to wet (condensation forming at night and/or early morning due to changes in temperature) conditions.
3. The black film generated on rails in sections surrounded by many trees is transferred by the train wheels to other section along the line.
4. When leaves are pressed by the wheel on an already wet rail surface the adhesion coefficient decreases significantly causing frequent wheel slipping and/or sliding.

References

[1] Mamoru Sugahara: “Study on Slipping and Skidding in Track Section in Mountainous Area,” Proceedings of 67th Annual Conference of the Japan Society of Civil Engineers, VI-495, pp.989-990, 2012.
[2] Yi ZHU, Ulf Olofsson and Rickard Nilsson: “A field test study of leaf contamination on railhead surfaces,” Proc. IMechE Part F, Vol. 228(1), pp. 71-84, 2014.
[3] Kazumi Sakamoto, Masaomi Kosaka: “Countermeasure against Fallen Leaves in Geibi Line,” New Roadway, No. 12, pp. 14-15, 1989.
[4] Masanori Tanaka and other 4 authors: “Operation Method for Controlling DC Slipping in Track Section in which Leaves Spread on Rail,” 17th Railway Technology Union Symposium, S8-1-5, pp. 617-620, 2010.
[5] Atsushi Onodera: “Countermeasure for Preventing Slipping due to Fallen Leaves in Steep Gradient Section in Senzan Line,” Journal of Japan Train Operation Association, Vol.63, No. 5, pp. 248-251, 1988.
[6] O Arias-Cuevas and Z Li: “Field investigations into the adhesion recovery in leaf-contaminated wheel-rail contacts with locomotive sanders,” Proc. IMechE Part F, Vol.225, pp. 443-456, 2010.
[7] O Arias-Cuevas and Z Li: “Field investigations into the performance of magnetic track brakes of an electrical multiple unit against slippery tracks. Part 1: Adhesion improvement,” Proc. IMechE Part F, Vol.225, pp. 613-616, 2011.
[8] O Arias-Cuevas and Z Li: “Field investigations into the performance of magnetic track brakes of an electrical multiple unit against slippery tracks. Part 2: Braking force and side effects,” Proc. IMechE Part F, Vol.226, pp. 72-94, 2011.

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