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The influence of rolling direction reversal on wear and RCF cracks on the wheel tread

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Abstract

Trains often operate as a shuttle service. When a train arrives at the terminal station, its direction of travel is reversed, and therefore so is the rolling direction of the wheels. It is therefore important to investigate how the crack propagation, and wear on the wheel tread are changed by reversing the rolling direction. In this study, twin disc wear-fatigue tests were carried out under various conditions to study the effect on the behavior of rolling contact fatigue (RCF) cracks and wear. Also, finite element analyses (FEA) were performed in order to clarify the results of these tests. In the lubricated condition, the cumulative wear tended to increase when the rolling direction of the wheel specimen was reversed if the slip ratio was 1%. On the other hand, in the dry condition, there was almost no change in the wear before and after reversing. FEA suggested that, when the wheel specimen was reversed, lubricant was trapped in the RCF crack and the friction coefficient between the crack faces was reduced, leading to shear mode crack growth and increased fatigue wear.

Keywords: wheel, rolling direction reversal, wear, rolling contact fatigue, finite element analyses.

1 Introduction

Railway wheels suffer various damages in operation. Among them, wear and rolling contact fatigue (RCF) are extremely important problems that can shorten the life of the wheel.

Among the factors affecting the wear and RCF, the influence of rolling direction reversal of wheels has not been well studied. Generally, trains operate as a shuttle service. When a train arrives at the terminal station, its direction of travel is reversed, and so is the rolling direction of the wheels. It is important to consider this influence in railway lines with few curved sections, such as Shinkansen lines, because almost the same portion of the tread contacts the rail.

Tyfour and Beynon [1] performed the unlubricated twin-disc tests using the wheel and rail steel and indicated that direction reversals can decrease the wear rate. The largest decrease in rail wear rate occurred with frequent reversals. They [2] also investigated the influences of reversing direction on RCF initiation and propagation of rail discs with water lubrication. They noted that reversing the direction of rolling increased RCF life. Zeng et al. [3] investigated the wear behavior of railway wheel steel under the combined condition of bi-directional operation and variable amplitude loading. They showed that, under dry conditions, the wear rate significantly dropped at the moment of the bi-directional operation, and then it rose with the increase in reversed rolling cycles until a steady wear state was reached.

At present, the existing models for the wear of wheel make the assumption that the loading on a wheel is unidirectional. This is because it is yet to be clarified how the wear behaves under the rolling direction reversal of the wheel.

In this study, we conducted a series of wear and fatigue tests using a twin-disc machine and finite element (FE) simulation of the tests to elucidate how reversing the rolling direction of the wheel affects the wear and RCF cracks on the wheel tread.

2 Methods

The rolling direction was reversed by inverting the wheel disc after a certain number of rolling cycles. Wheel discs were machined from the cross-section of a standard wheel rim and run against rail discs from the railhead. Both discs are 12 mm thick and 30 mm in diameter. The test conditions are given in Table 1. In the wet conditions, the contact area was lubricated with water containing 5% oil using a gravity-drip system that supplied about one drip per second. After each predetermined number of cycles, the discs were removed and weighed. At the end of each test, some discs after the test were sectioned and photographed to observe the crack morphologies and microstructural changes by optical metallography.

In addition, the elastoplastic analysis was performed using the commercial FE code MARC to simulate the tests. Since the stress and strain generated by non-conforming contact are limited to the contact area, the circumferential direction of both specimens was made only for 30°. A Coulomb-type friction law was presumed, and the friction coefficients between the discs were set to 0.1 and 0.4 for wet and dry conditions, respectively. On the surface of the wheel disc, there is a crack of 0.2 mm in length. The FE mesh is indicated in Fig.1.

The Archard wear model was used for modeling wear due to rolling and sliding contact.

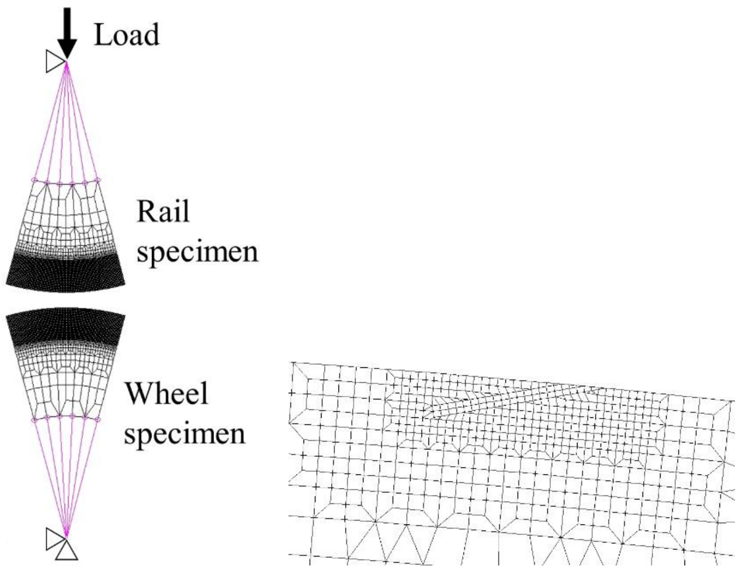
$$\dot{w} = K \frac{\sigma V_{\mathrm{rel}}}{H} \tag{1}$$

where $\dot{w}$ is the wear rate, K is the wear coefficient, σ is the normal stress, V_{rel} is the relative sliding velocity and H is the hardness. In the simulation, K was set to 1×10^{-7} and 1×10^{-4} for wet and dry conditions, respectively.

In addition, the crack tip sliding displacements (CTSDs) were obtained by FE analyses. CTSD changes during the disc rolling, and its range is important in determining crack growth behavior. In this study, CTSD was considered to explain the increase in wear rate after reversal under wet conditions.

Test number		101	102	103	201	202	301	302	303	304	305	306
Disk material		Rail : Normal rail steel Wheel : STY80										
Initial surface roughness(μm)	Rail	0.4										
	Wheel											
Maximam contact pressure(MPa)		1100										
Percentage creepage(%)		1	1	1	3	3	3	1	1	1	1	1
Test speed: (rail-wheel)(RPM)		990-1000	990-1000	990-1000	970-1000	970-1000	970-1000	990-1000	990-1000	990-1000	990-1000	990-1000
Total number of cycles		1000000	2500000	1500000	1200000	1500000	10000	40000	30000	20000	25000	40000
Number of cycles/reversal		800000	2000000	1200000	Non reversal	1200000	Non reversal	Non reversal	20000	Non reversal	20000	20000
Test enviroment		Wet					Dry					

Table 1 Test conditions.

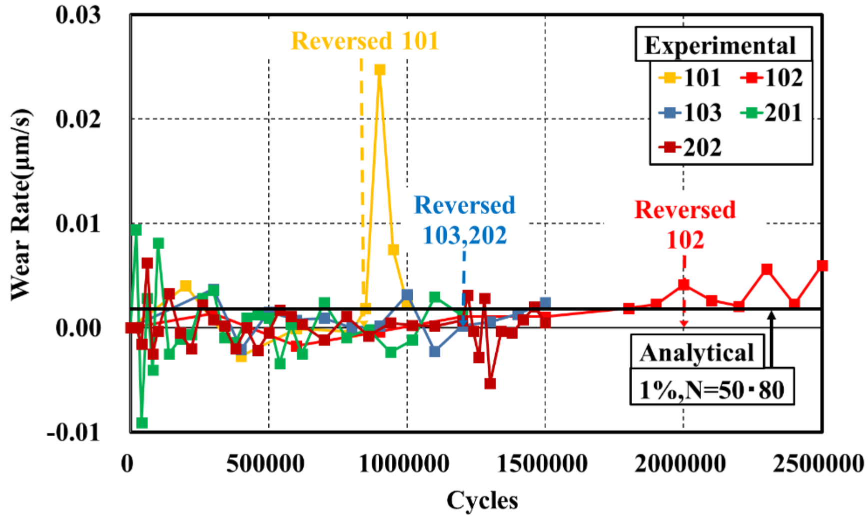


(a) Entire mesh. (b) Near the crack area.

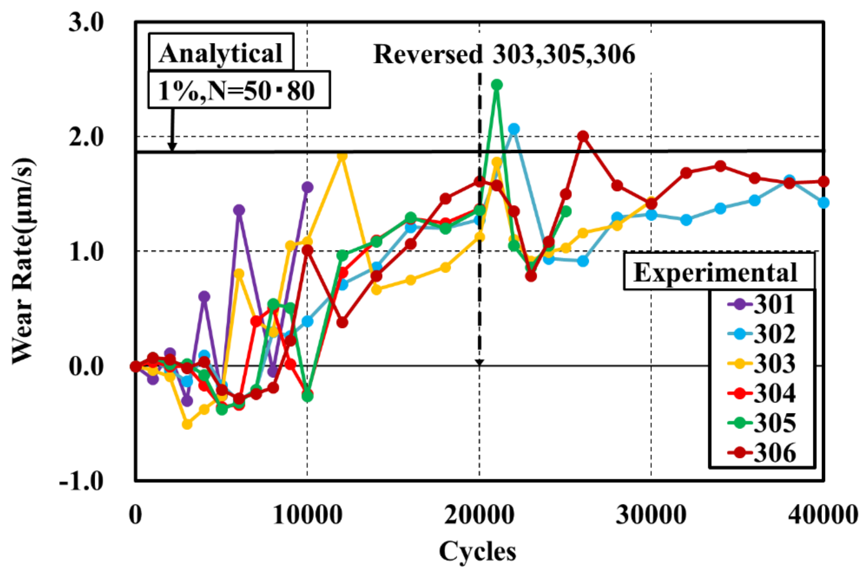
Figure 1: FEM mesh.

3 Results

Typical results obtained by the twin-disc tests and FE analyses using the Archard model are indicated. Figure 2 shows the changes in wear rates of wheel discs. It can be clearly seen that reversing the rolling direction increased the wheel wear in wet conditions. However, it cannot be explained by the Archard model. This is because the model does not take into account the delamination wear induced by the fluid.



(a) Wet condition.



(b) Dry condition.

Figure 2: Wear rates of wheel specimen under various conditions.

Figure 3 (a) and (b) are the cracks in the wheel disc before and after the reversal in test 202, respectively. The cracks clearly tended to propagate parallel to the surface when the disc was reversed, and the resulting long and thin wear sheets delaminated.

In case of (a), the crack tip entered the contact zone between the two discs before the mouth. Therefore, no fluid is expected to be trapped because the crack is closed starting from the tip, while the mouth remains open. Because the presence of fluid in the crack is known to be essential for RCF, it is difficult for the crack to continue to propagate. By contrast, in case of (b), the crack is filled with fluid just before its mouth reaches the contact area, whereupon the mouth is sealed. Therefore, the fluid is trapped in the crack and acts as a lubricant to reduce the friction coefficient, and cracks tend to propagate easily and large delamination sheets are apt to form.

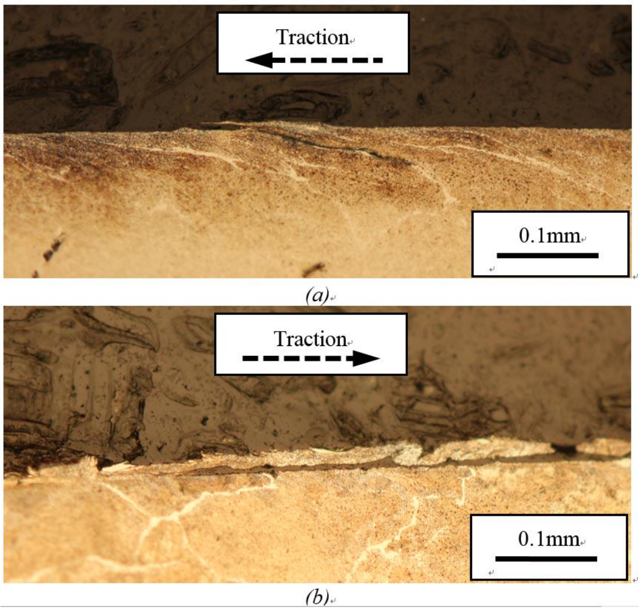


Figure 3: Circumferential section through detected crack zone of wheel disc in test 202. (a) After 1.2×10^6 cycles run unidirectionally. (b) After 3.0×10^5 cycles reversed after 1.2×10^6 cycles [4].

Figure 4 compares CTSD of the wheel disc before and after the reversal under wet and dry conditions. The *b* and *e* in the abscissa are the contact half-width and the distance between the center of the contact area and the crack mouth, respectively. CTSD was measured at 0.01 mm from the crack tip. In the wet conditions, the range of CTSD (ΔCTSD) before the reversal was about 0.2 μm, while after the reversal, it was about 0.4 μm. This means that the amount of crack propagation after the reversal is higher than that before the reversal. In contrast, in the dry conditions, ΔCTSD is almost the same before and after the reversal. Therefore, the amount of crack propagation before and after the reversal is considered to be almost the same in the dry condition.

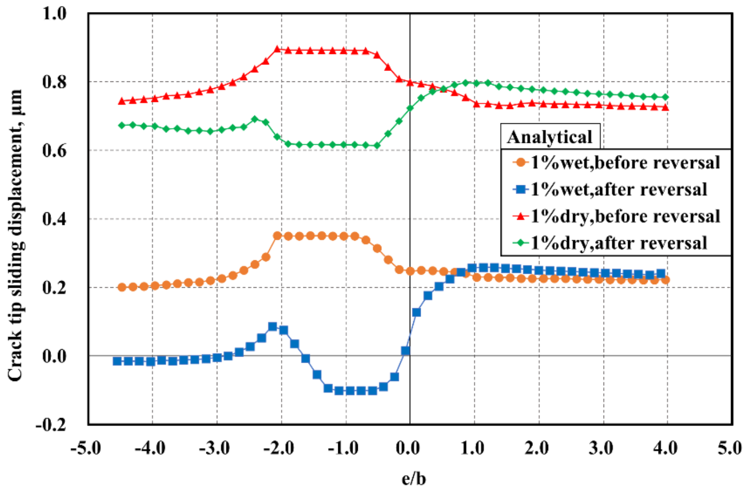


Figure 4: Variations of CTSD of the crack in wheel disc under various conditions.

4 Conclusions and Contributions

In this study, we conducted a series of twin-disc wear and fatigue tests and FE simulations of the tests. The results are as follows.

In the wet conditions, the wear rate increased when the rolling direction of the wheel disc was reversed. In contrast, in the dry conditions, the wear rate was much higher than in the wet conditions, however, it changed little before and after the reversal. The Archard model could not explain the increase in wear rate after the reversal in wet conditions, because the model does not take into account the delamination wear induced by the fluid.

Some discs after the test were sectioned and photographed to observe the crack morphologies and microstructural changes by optical metallography. In wet conditions, when the wheel disc was reversed, the cracks clearly tended to propagate parallel to the surface, and the resulting long and thin wear sheets delaminated. In this case, the crack is filled with fluid just before its mouth reaches the contact area between the wheel and rail discs, whereupon the mouth is sealed. Therefore, the fluid is trapped in the crack and acts as a lubricant to reduce the friction coefficient, and cracks tend to propagate easily and large delamination sheets are apt to form.

In order to explain the increase in wear rate after the reversal under wet conditions, CTSDs were obtained by FE analyses. In the wet conditions, the ΔCTSD after the reversal was almost twice as large as that before the reversal. This means that the amount of crack propagation after the reversal is higher than that before the reversal. In contrast in the dry conditions, the ΔCTSD is almost the same before and after the reversal. Therefore, the amount of crack propagation before and after the reversal is considered to be almost the same.

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