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Influence of friction modifiers on improving adhesion and surface damage of wheel/rail under low adhesion conditions

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ABSTRACT

The objective of this study is to investigate the influence of friction modifiers on improving adhesion and surface damage of wheel/rail under low adhesion conditions. The results indicate that water, oil and leaves are very easy to bring low adhesion phenomena. Sand, alumina particle and abrasive block can improve adhesion coefficient under various low adhesion conditions. Sanding significantly aggravates wear and surface damage of wheel/rail materials. It is proposed that alumina particles are more suitable for improving adhesion of wheel/rail interface based on a comprehensive analysis of experimental results.

1. Introduction

Inadequate friction of wheel/rail interface causes poor adhesion of trains during braking, which can lead to some safety issues due to extended-stopping distances [1–2]. Poor adhesion can make the wheel to slip on the rail surface during braking or traction process, which results in serious wear and damage of wheel/rail interface [3], as shown in Fig. 1. Furthermore, a white etching layer is the metallurgical feature associated with surface damage caused by severe wheel slip on the rail surface [4]. Therefore, the adhesion of wheel/rail interface is the most important parameter in braking and traction operation of train.

Previous work focused on the study of various third bodies between the wheel and the rail to explain the adhesion behavior using various experimental facilities and theoretical methods [5–10]. The adhesion coefficient is strongly dependent on the composition and rheological properties of the interfacial layer of wheel/rail [2]. When water, oil or leaves are added to the contact surface, there is an obvious fall of adhesion force of wheel/rail and it is easy to form low adhesion phenomena [3]. Furthermore, oil is found to have a dominant effect on adhesion coefficient in the presence of water [3,6]. On the other hand, the presence of an oxide layer under wet conditions further reduces adhesion coefficient [11].

Sanding is usually used in train operation to improve adhesion force at the wheel/rail interface during both braking and traction process [12–14]. However, in both static and dynamic tests, sanding aggravates severe surface damage and plastic flow, which can result in a high material removal rate and surface corrugation. A waterborne product can be brushed or sprayed on the top of the rail head to form a thin film [15]. This thin film enables the wheel/rail interfacial friction to be controlled in a range of 0.30–0.35, which will not impact on adhesion or braking requirements. The influence of thin film friction modifier technology on the development of rolling contact fatigue and wear has been evaluated on a full scale wheel–rail rig [16]. With the increase of traffic and axle loads in recent years, the adhesion plays a significant role in the wheel/rail interaction. Therefore, how to improve the adhesion level and avoid severe wear of wheel/rail interface is becoming a key problem.

In this paper, experiments for improving adhesion of wheel/rail under low adhesion conditions were performed using a rolling-sliding wear facility. In particular, the influence of friction modifiers on adhesion coefficient and surface damage under various conditions were explored in detail.

2. Experimental details

The experiments of the adhesion and damage of wheel/rail rollers were carried out using a rolling-sliding wear facility. The tester is composed of two rollers served as rail roller and wheel roller. The rollers are powered and controlled by a DC motor.

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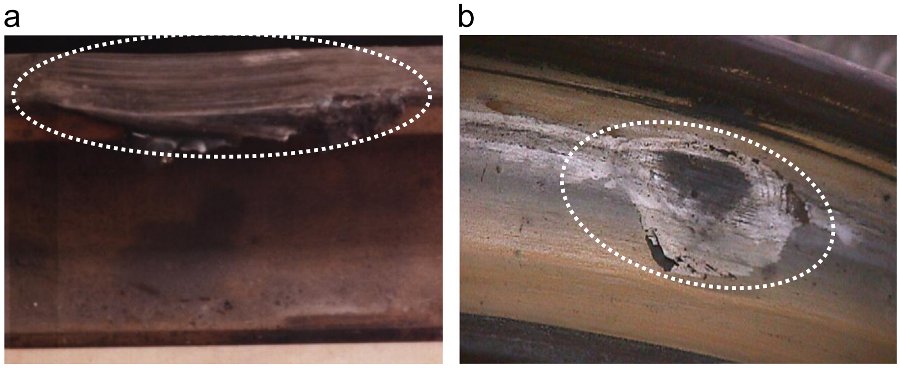

Fig. 1. Typical damages of wheel/rail under low adhesion: (a) skidding marks on the rail surface; (b) wheel flats on the tread.

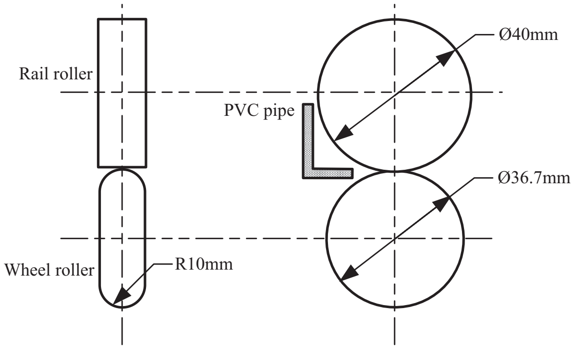

Fig. 2. Scheme of the wheel and rail rollers.

The geometric sizes of rollers are determined by means of Hertzian rule [17] shown below:

$$(q_0)_{lab} = (q_0)_{field} \tag{1}$$

where, $(q_0)_{lab}$ and $(q_0)_{field}$ are the maximum contact stresses in the laboratory and in the field, respectively. The scheme of geometric size calculated by the above equation is shown in Fig. 2.

The normal force of wheel/rail rollers is determined according to the above equation. The normal force of 135 N in the laboratory simulates axle load of 21 t in the field. The maximum contact pressure of wheel/rail rollers is about 1 230 MPa. The rolling velocities of upper roller (rail specimen) and lower roller (wheel specimen) are 0.754 m/s and 0.769 m/s. The slippage ratio of wheel/rail rollers is about 1.95%. The duration of each test is 60 min. The wheel and rail rollers are made of the wheel and rail steels applied in the field (Wheel: CL60, Rail: U71Mn). Their chemical compositions in weight percentage are presented in Table 1.

Table 1
Chemical compositions of wheel and rail rollers (wt%).

Roller	C	Mn	Si	S	P
Wheel	0.55–0.65	0.58–0.80	0.17–0.37	≤ 0.045	≤ 0.04
Rail	0.62–0.77	1.35–1.65	0.15–0.37	≤ 0.050	≤ 0.04

The adhesion experiments are performed under water, oil and leaves conditions. Water is continuously added to the contact surfaces of wheel/rail using a canal at a flow rate of about 1 ml/min. Oil is regularly brushed on the wheel/rail interface. The oil is L-HM46 lubrication oil (Manufactured by China Petroleum & Chemical Corporation). The mixture of oil and water is composed of 50% oil and 50% water. Fresh deciduous leaves obtained in October (Poplar tree leaves) are manually added to the wheel/rail interface and formed leaves contamination on the wheel/rail contact surface.

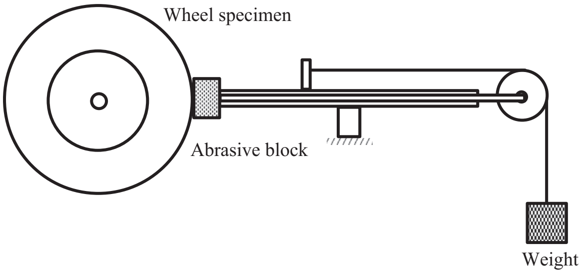

Fig. 3. Scheme of the application of abrasive block.

Three kinds of friction modifiers used in this study are sand, alumina particle and abrasive block. The average diameter of fine and coarse sands is about 500 μm and 1300 μm. Main composition of the sands is quartz and its hardness is about 7 Mohs. The diameter of the alumina particles is about 100 μm and the hardness is about 9 Mohs. The abrasive block is taken from the tread cleaning material used in CRH2 high-speed train-set in China. The abrasive block is synthetic resin material and main composition elements are Fe, Cu, Zn, Al, Ca, Si, O, and C. The sands and alumina particles are continuously added to the wheel/rail interface at about 10 g/min using a PVC pipe. The abrasive block is fixed on the wheel roller using a dead weight of 150 N (Fig. 3). The contact pressure between the abrasive block and the wheel roller of about 0.5 MPa is used to simulate to the full scale contact condition in the field.

The adhesion coefficient of wheel/rail interface is defined as the ratio of the tangential friction force between wheel and rail rollers (F_t) and normal force (F_n), shown in Eq. (2). The friction force and normal force of the interface of wheel/rail rollers are measured and recorded automatically on the computer using torque sensor and load sensor (Measurement error: ±5%). The rollers were ultrasonically cleaned in acetone and weighed using an electronic balance (TG328A, Measurement accuracy: 0.001 g) before and after testing. The wear of wheel/rail rollers is determined by mass loss. The wear and surface damage behaviors of wheel/rail rollers were analyzed by examining the mass loss, surface roughness and wear scar using roughness profilometer (JB-6C, China), optical microscopy (OLYMPUS BX60M, Japan) and scanning electronic microscopy (SEM) (QUANTA200, FEI, England).

$$\mu = \frac{F_t}{F_n} \tag{2}$$

3. Results

3.1. Low adhesion of wheel/rail

Fig. 4 shows the curves of adhesion coefficient under various conditions. It is clear from Fig. 4a that the adhesion coefficient of