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Sub-scale simulation and measurement of railroad wheel/rail adhesion under dry and wet conditions

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ABSTRACT

The adhesion characteristics of railroad wheels against rails were simulated using a sub-scale wheel/rail configuration. The apparatus consists of a small roller to simulate the locomotive or rolling stock wheel and a large roller to simulate the rail. The scale of the wheel/rail profiles, relative to full size, is 1:4. Results indicated that this laboratory test can be used to adequately simulate and evaluate the adhesion behavior of the wheel/rail interface under various conditions. Under dry conditions, the adhesion coefficient of wheel/rail has a sharp initial increase of between 0% and 1.5% as creep ratio increases, and then a slight reduction of up to 5%. The presence of water or oil markedly decreases the adhesion coefficient of wheel/rail. With an increase of speed and due to the water volume in the wheel/rail surface, the adhesion coefficient drops. With an increase of lateral force, the adhesion coefficient of wheel/rail increases. Axle load has no obvious effect on the adhesion coefficient in the presence of water. Tree leaves have an important effect on the adhesion coefficient and should be cleared away from the contact surface of wheel/rail if water is present. Further work on improving adhesion and damage of wheels on rails should be studied and explored under a range of low adhesion conditions.

1. Introduction

The adhesion of the wheel/rail interface is a crucial factor in railway transportation, as it determines the acceleration and braking capabilities of train [1–3]. Therefore, the loss of adhesion coefficient of wheel/rail has a vital influence on both traction and braking. Low adhesion of the wheel/rail interface leads to wheel sliding on the rail surface during the traction process and accelerates the surface damage of wheel/rail materials, such as skidding marks of rail surface and scratch damage of wheel tread, as shown in Fig. 1. On the other hand, poor adhesion may lead to extended and unpredictable stopping distance [4,5]. Therefore, maintaining correct levels of the adhesion coefficient in railway transportation is essential [6].

It is well known that fundamental mechanisms of the wheel/rail adhesion have not yet been established completely up to now. It is affected by many factors, such as water, leaves, lubrication oil, wear debris, axle load, surface roughness, and so on [7–10]. In order to understand the mechanism of the adhesion under various conditions, some experiments and numerical calculation have been carried out [11–13]. Sanding as a friction modifier can increase the adhesion coefficient of wheel/rail under wet and oil conditions [14,15]. Andrews [16] proposed an empirical relationship that the adhesion increased proportionally with the product of particle hardness and size of the mineral powders. In addition, the friction behavior and control under the thin film and lubrication conditions have been explored at the wheel/rail interface [17].

At present, a number of methods have been used to assess the adhesion characteristics of wheel/rail. Laboratory bench techniques have been used including pin-on-disc, disc-on-flat and twin disc testing [6]. Field measurement of adhesion behavior has been taken using track-mounted tribometers. As we all know, the simple twin disc testing is difficult to reproduce the real wheel/rail contact behavior. Furthermore, a new experimental device has been produced in order to investigate creep force characteristics between wheel and rail [18]. An important point to be kept in mind regarding simulation is that a good facility for simulating mutual adhesion characteristics of the wheel/rail interface, need not only offer researchers much more controls over experimental variables but also to be convenient and time-saving as more as possible.

In this paper, a sub-scale wheel/rail configuration was designed and used to simulate and evaluate the adhesion characteristics of the wheel/rail interface using JD-1 wheel/rail simulation facility. In particular, the adhesion coefficient of wheel/rail under dry and wet conditions was explored in detail.

2. Experimental details

2.1. JD-1 wheel/rail simulation facility

All experiments were carried out using JD-1 wheel/rail simulation facility [19], as shown in Fig. 2. The tester consists of a

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Nomenclature

λ	creep ratio
ω_w	rotating speeds of wheel roller
ω_r	rotating speeds of rail roller
i	ratio of rotating speed
$(q_0)_{\text{lab}}$	maximum contact stresses in the laboratory
$(q_0)_{\text{field}}$	maximum contact stresses in the field
a	length of semi-major axis of the contact ellipse
b	length of semi-minor axis of the contact ellipse
$(a/b)_{\text{lab}}$	ratio of semi-major axis to semi-minor axis of the contact ellipses between the wheel and rail in the laboratory
$(a/b)_{\text{field}}$	ratio of semi-major axis to semi-minor axis of the contact ellipses between the wheel and rail in the field
p	normal force

small roller to simulate the locomotive or rolling stock wheel (called as "wheel roller") and a large roller to simulate the rail (called as "rail roller"). A sub-scale wheel and rail configurations are designed on the basis of LM wheel tread and 60 kg/m rail profiles used in China railway. The scale of the wheel/rail profiles, relative to full size, is 1:4. The diameters of wheel roller and rail roller are 240 mm and 1030 mm, respectively. The schema of geometric size of the wheel/rail rollers is shown in Fig. 3.

The creep ratio of this apparatus is defined by the following formula:

$$\lambda = \frac{\omega_W R_W - \omega_r R_r}{\omega_W R_W} = 1 - \frac{\omega_r R_r}{\omega_W R_W} = 1 - 4.292\, i \tag{1}$$

where λ is creep ratio between the wheel and rail rollers; ω_w and ω_r are the rotating speeds of the wheel and rail rollers, respectively; R_w

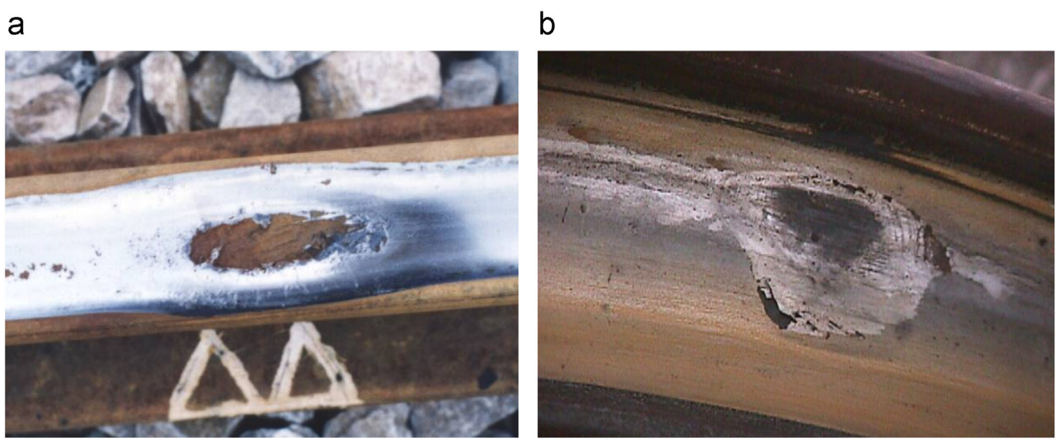

Fig. 1. Typical damages of wheel/rail under low adhesion condition. (a) Skidding marks on the rail surface and (b) wheel scratch on the tread.

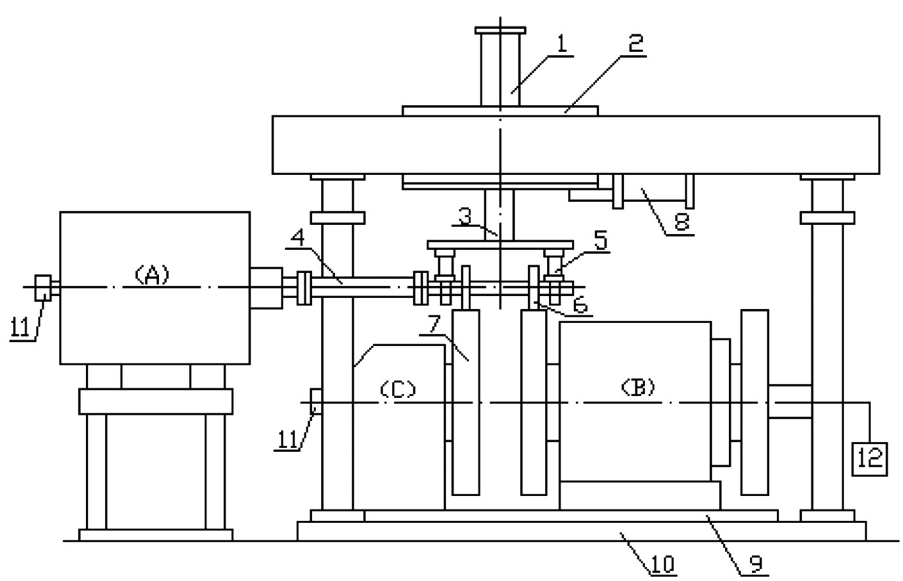

Fig. 2. JD-1 wheel/rail simulation facility. 1-Vertical loading cylinder; 2-Loading carriage; 3-Spindle and yoke; 4-Universal shaft; 5-3D load sensor; 6-Simulation wheel; 7-Simulation rail; 8-Lateral loading cylinder; 9-Turning plate; 10-Base plate; 11-Optical shaft encoder; and 12-Speed measuring motor; A and B-ZQDR-204 DC motor; C-Gear box.