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Study on wear and rolling contact fatigue behaviors of wheel/rail materials under different slip ratio conditions

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ABSTRACT

The objective of this study is to evaluate the effect of slip ratio on the wear and rolling contact fatigue (RCF) of wheel/rail materials using a rolling–sliding wear testing apparatus. The results indicate that two wear types are presented in terms of wear rate: type I (mild wear) and type II (severe wear). In type I wear, cracks propagate parallel to the surface. While in type II, the peeling is aggravated and spalling can be observed. With the slip ratio increasing, the wear mechanism of rollers transforms from slight oxidation wear and peeling to severe fatigue wear and spalling. Due to the mild wear and light plastic deformation in type I, the angle and depth of cracks show no obvious differences between the wheel and rail rollers. The crack depth and angle increase in type II wear owing to severe plastic deformation, while the depth is smaller on the wheel rollers. The size of flake wear debris presents an increasing trend and the main composition is Fe_2O_3 and metallic iron, and the content of iron diminishes with increasing oxidation.

1. Introduction

The adhesion and creep characteristics of wheel/rail affect the traction and braking performances of railway vehicles. In the wheel–rail contact, rolling and sliding appear simultaneously in the contact zone. In curves, the wheel flange may be in contact with the gauge corner of the rail, resulting in a large sliding motion. The contact zone can be divided into two regions: stick region (no relative sliding) and slip region [1]. With the tangential force increasing, the slip region increases and the stick region decreases. When the tangential force reaches a saturation value, the stick region disappears and entire contact area is in a sliding state. Various means of restoring the friction potential have been tried out in an effort to alleviate poor friction problems. Evidence suggests that controlled wheel slipping is effective under poor friction level condition [2].

The development of wear mechanisms and RCF property of the wheel and rail contact had been studied by various experimental and numerical methods [3–6]. The laboratory testing results showed a clear classification of three wear regions: type I (mild wear), type II (severe wear) and type III (catastrophic wear) [7]. Bolton and Clayton [8] determined the wear characteristics within three regions in the view of a metallurgical examination. Lewis and Olofsson [7] drew a large amount of experimental data relating to rail wear and plotted wear rate against $T\gamma/A$ (T: tractive force, γ: slip in the contact, A: area of contact zone) to clarify the wear region and transitions. Moreover, the effect of slip ratio on fatigue characteristics had been discussed using the traction coefficient and shakedown map [9–11]. It was found that the traction coefficient increased with an increase in the slip ratio and that fatigue strength decreased simultaneously. Taizo et al. [12] evaluated fatigue limits by the criterion of Hirakawa's RCF map under water lubricated conditions and found that the effect of slip ratio on RCF behavior was dominated by the stress intensity factors (SIF) and crack propagation towards the surface after branching.

In this study, the effect of slip ratio on wear and RCF behaviors of wheel and rail materials were investigated using a rolling–sliding wear machine. In particular, the wear transitions and the formation and development of cracks on the wheel and rail materials were explored by means of various micro-examinations.

2. Experimental details

A rolling–sliding wear testing apparatus was used to evaluate the effect of slip ratio on the wear and RCF of wheel/rail materials under the dry condition. The tester is composed of two rollers serving as a wheel roller (upper specimen) and a rail roller (lower specimen) [6]. The rollers are driven by a DC motor. Slip ratios of

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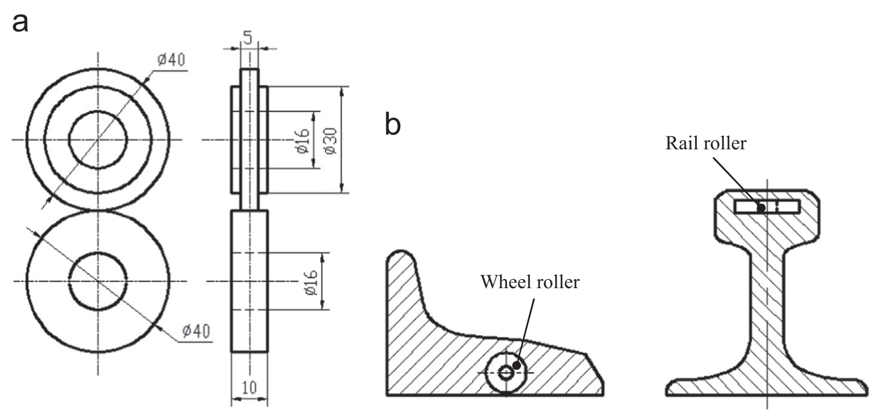

Fig. 1. Details of wheel and rail rollers, (a) size and (b) sampling position.

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

Roller	C	Si	Mn	P	S
Wheel (ER9)	0.56–0.60	≤ 0.40	≤ 0.80	≤ 0.020	≤ 0.015
Rail (U71Mn)	0.65–0.75	0.10–0.50	0.80–1.30	≤ 0.025	0.008–0.025

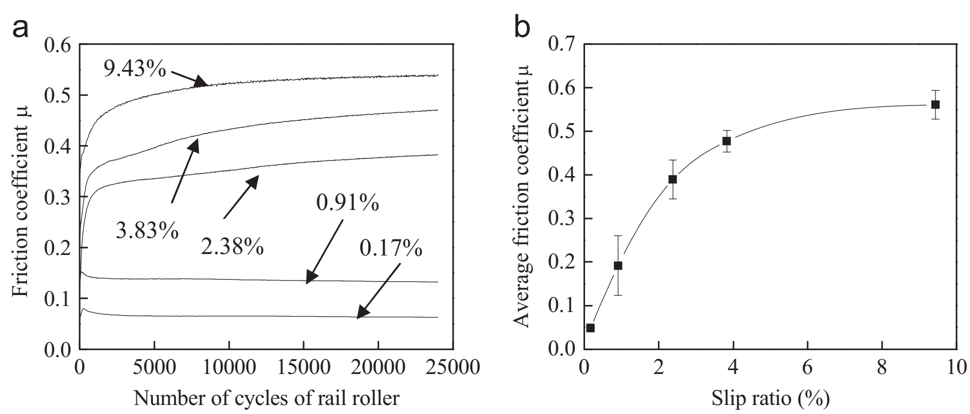

Fig. 2. Friction coefficient of wheel/rail rollers, (a) friction coefficient changing with the number of cycles of rail roller and (b) average of friction coefficient with SD bars.

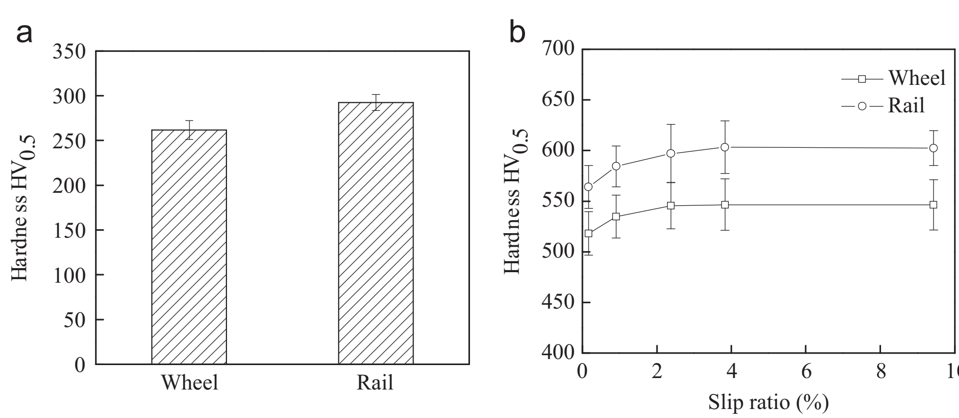

Fig. 3. Surface hardness of wheel/rail rollers, (a) before testing and (b) after testing.

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