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# Experimental investigation on the effect of tangential force on wear and rolling contact fatigue behaviors of wheel material

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ABSTRACT

The study aims to explore the effect of tangential force on wear and rolling contact fatigue (RCF) behaviors of wheel material using a JD-1 wheel/rail simulation facility. The normal, tangential and lateral forces between the wheel/rail rollers are controlled, and the magnetic power brake was used to generate the tangential forces (16–330 N). The results indicate that the surface hardness and wear loss of wheel rollers increase with the tangential force increasing. The surface cracks mouths are perpendicular to the resultant directions of the frictional forces. There are visible secondary cracks and multilayer cracks and the interlayer material of multilayer cracks are easy to break. The compositions of wear debris consist of $Fe_2O_3$, $Fe_3O_4$ and iron.



## 1. Introduction

Wheel/rail interface plays a fundamental role in determining the reliability of heavy-haul and high-speed railway transportation [1]. The operating pressure of transportation is greatly increased and higher requirements are needed for the wheel/rail system. During braking and traction processes, poor adhesion can make the wheel to slip on the rail surface, which results in serious wear and damage of wheel/rail interface [2]. As a consequence, a new impulse in the study of the damage and failure mechanisms and in the development of new materials has been done in the last years [3–5]. The problem is very important and actual, as demonstrated by several accidents happened in recent years, just related to damage and failure of wheel/rail in the contact zone [6]. Some surface oblique cracks can be observed on the railway wheel treads in China, as shown in Fig. 1a. These oblique cracks are consistent with the RCF cracks in zones 1 and 2 shown in Fig. 1b [7,8]. Furthermore the surface oblique cracks can be observed on the rail treads in Ref. [9]. During subsequent operations, these cracks propagate and the damaged zones expand. In order to clarify the causes of RCF, it is helpful to note that the crack mouth is ideally orientated perpendicular to the resultant direction of the frictional force [10]. Thus, it can be deduced that the damage in Fig. 1 is caused by a combination of lateral forces on the wheel tread when passing through the lower rail of curves dominating in zone 1 and tangential force dominating in zone 2 [8].

Previous work focused on the study of the cracks initiation of wheel/rail RCF failure using various experimental and numerical approaches [11–14], as well as the tribological behaviors of different wheel/rail materials under various rolling–sliding conditions [15]. Cracks initiate at the surface and subsurface. Subsurface cracks initiation requires a stress concentration caused by a large material defect, such as a void or inclusion [16]. Evidence is provided to show that in the case of wheel/rail contact, rolling contact fatigue cracks initiated on the surface typically develop as a consequence of frictional rolling–sliding contact which causes plastic flow of the surface material.

As the plastic deformation exceeds the fracture strain of the material, the surface crack is formed. However, the cracks propagate not only due to the rolling contact loading, but also due to the effect of low viscosity fluid [17]. Increasing the slippage improves the tractive effort which leads to a shorter fatigue life. However, if the slippage is further increasing, the wear aggravates, which may wear away cracks. This will correspond to an apparent increase in fatigue life [18]. The balance between crack formation and wear being is referred to as the “magic wear rate” [8]. Serious wear and damage of wheel/rail interface accelerate the failure of wheel/rail materials and pose a threat to the running security of railway system [19–21].

Reviewing the previous work about wheel and rail damages, tangential force, an important factor which influences wheel/rail performances, has not been studied sufficiently. In this study, a JD-1 wheel/rail simulation facility was used to investigate the effects of tangential force on wear and rolling contact fatigue behaviors of wheel

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material. In particular, the development of cracks on wheel roller with different tangential forces, the lamellar structure cracks and secondary cracks were explored using various microscopic examinations.

## 2. Experimental details

### 2.1. JD-1 wheel/rail simulation facility

The experiments were carried out under dry condition using a JD-1 wheel/rail simulation facility, as shown in Fig. 2. The tester is composed of a small roller with a diameter of 68 mm served as wheel roller (5) and a larger roller with a diameter of 1050 mm served as rail roller (7). The rail roller is powered and controlled by a DC motor (B). The tangential force between the simulating rollers is obtained by the magnetic powder brake (11) installed to small wheel roller shaft (6) during continuous rolling testing operation. The power of magnetic powder brake can be controlled and changed to simulate different tangential forces. The forces on the wheel/rail interface (normal, tangential and lateral forces) are measured and recorded by means of three force sensors. The angle between the outer front wheel of the train and the outer rail of the curve is called the attack angle. Moving the turning plate (9) of wheel/rail simulation facility can form the requisite attack angle between the rail roller (7) and wheel roller (5), shown in Fig. 2.

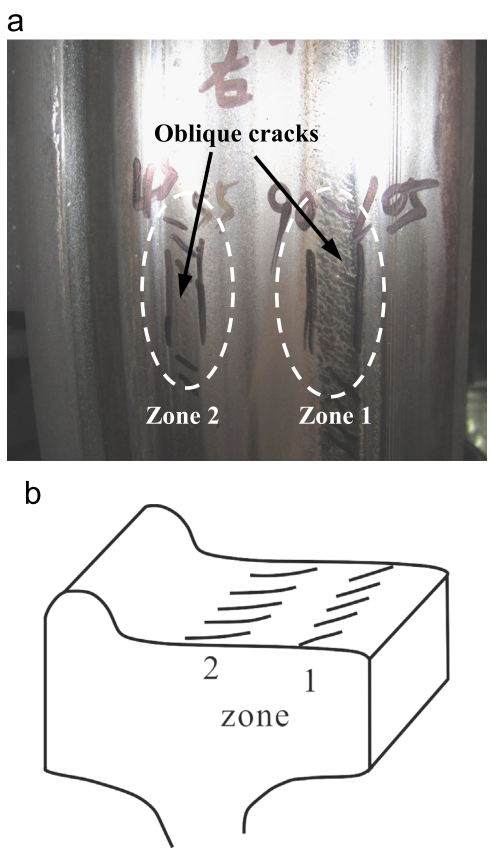


**Fig. 1.** Surface cracks of wheel tread, (a) surface oblique cracks; (b) definition of zones of cracks on the wheel treads.

During the testing process, the average contact stress between wheel and rail, and the ratio of long axle to short axle of the ellipse at contact patch in laboratory were set to be identical with those on site. The geometric sizes of simulating wheel and rail are determined by means of the Hertz simulation rule [22], shown in Eqs. (1) and (2).

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

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

| Roller | C | Si | Mn | P | S |
|---|---|---|---|---|---|
| Wheel | 0.56–0.60 | $\leq$ 0.40 | $\leq$ 0.80 | $\leq$ 0.020 | $\leq$ 0.015 |
| Rail | 0.65–0.75 | 0.10–0.50 | 0.80–1.30 | $\leq$ 0.025 | 0.008–0.025 |

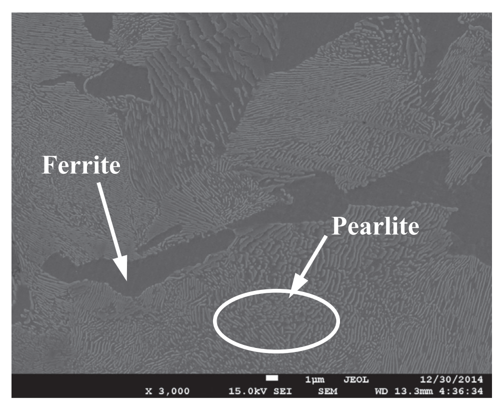


**Fig. 3.** Microstructure of wheel material.

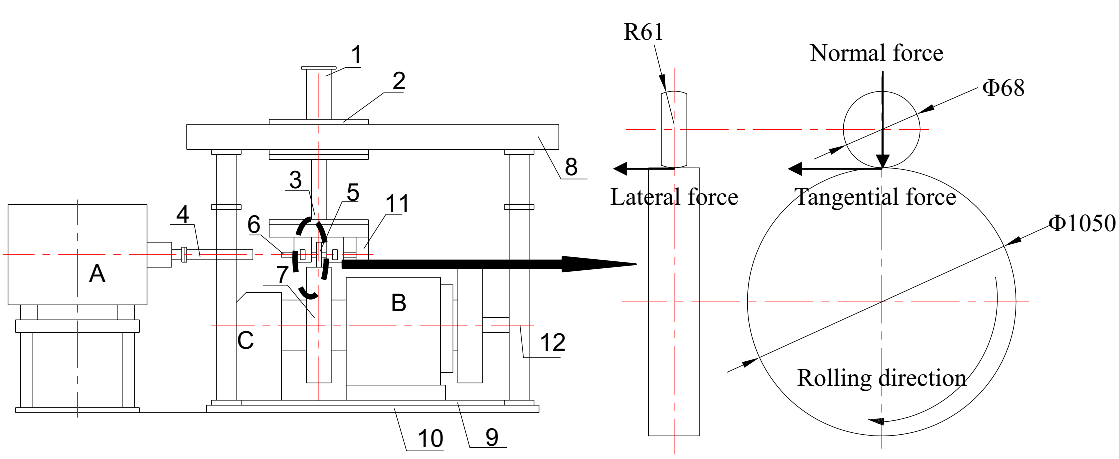


**Fig. 2.** JD-1 wheel/rail simulation facility and scheme size of simulating wheel and rail rollers. 1. Normal loading cylinder; 2. Loading carriage; 3. Spindle and yoke; 4. Universal shaft; 5. Wheel roller; 6. Wheel shaft; 7. Rail roller; 8. Lateral loading cylinder; 9. Turning plate; 10. Base plate; 11. Magnetic powder brake; 12. Speed measuring motor; A, B. ZQDR-204 DC motor; C. Gear box.