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Effect of spherical dents on microstructure evolution and rolling contact fatigue of wheel/rail materials

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ABSTRACT

Surface dents may occur on both rail head and wheel tread and have a deep influence on their microstructures. This investigation aims at exploring the microstructure evolution and RCF of wheel/rail materials with spherical dents. The experimental results, obtained through a suitable instrumented roller-rig, highlight the different microstructure evolutions not only between rail and wheel, but also between front and rear areas of dent. Electron backscattered diffraction data shows that the grains around dent on wheel have higher strain, misorientation and quantity of large angle grain boundaries than those on rail roller, leading to a weaker RCF resistance in wheel rollers. Meanwhile, cracks tend to propagate in front area of dent on rail and rear area of dent on wheel.

1. Introduction

The rolling contact fatigue caused by cyclic rolling contact between the wheel tread and rail head, has significant effects on service life of wheel/rail materials. Initial researches demonstrated how factors such as rolling direction [1], contact pressure distribution [2], and fluid entrapment [3] affects the RCF of wheel/rail materials. Furthermore, to meet the increasing demand for speed and load capacity coming from modern railway transportation, the high-speed and heavy-haul railway systems have rapidly developed, leading to new damage types potentially connected to RCF. Nowadays, there is a number of different failures that appear on wheel/rail surface such as corrugation [4], squats [5], head checks [6] and wheel flat [7].

With the progress of sensors on test machines and of computer hardware, many studies have been carried out to explore the wear behaviors and wheel/rail RCF life by means of various experimental and numerical methods. Zhu et al. [8] pointed out that, either increasing surface roughness or having thick oxides increases wear, while, thin oxides help to protect contacting surfaces, producing negligible wear and a smooth surface. Compared with the experimental result, Daves et al. [9] set a multi-scale model and predicted the crack growth direction considering stick-slip behavior of wheel/rail contact. By changing the attack angles on wheel rail surface, Huang et al. [10] found that RCF cracks tend to grow in depth on the rail rollers while they are easy to become parallel to the surface on the wheel rollers. Ekberg et al. [11] showed how stress gradient (especially in highly stressed regions) should be dealt with in fatigue design analyses. Ignesti et al. [12] and Innocenti et al. [13] established a development model for wheel and rail profile to predict their service lives. Nejad et al. [14] pointed out that the fatigue life decreases with an increase of the stress field in wheel-rail contact zone. By means of numerical method, Taraf et al. [15] found that defects or small friction coefficient are a plausible explanation to the initiation of deep subsurface fatigue cracks.

The surface damage could be another inducement for RCF cracks initiation. The surface damage can be caused by the hard body coming from the external environment. The hard body may stem from the drop of freight train goods (such as the minerals), or the ballast stones rolled up by the passage of the trains. Once the hard body entered the wheel/rail interface and crashed, the damage occurs both on the rail and wheel surfaces. Subsequently, in the service phase, this surface damage will change the contact condition and affect the service life. Therefore, a large number of researches have been carried out to study the effect of surface damage on wheel/rail materials in recent years. Using full scale experimental method, Stefano et al. [16] detected the vertical RCF cracks around the dents on the wheel tread. Based on evolution process of different dent shapes on rail surface, Gao et al. [17,18] found that conical and pyramidal dents had an obvious influence on fatigue life while neither transverse nor longitudinal scratches had any influence on disc life. Seo et al. [19] pointed out that the RCF cracks would initiate and propagate when the diameter of dents reaches a certain size.

In this study, the role played by surface spherical dents in the microstructure evolution and wheel/rail RCF is carefully investigated. The

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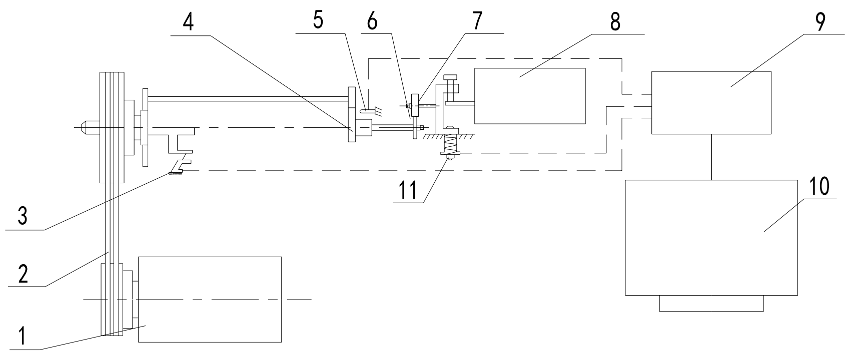

Fig. 1. Schematic diagram of the machine.
1. DC motor; 2. Drive belt; 3. Torque sensor; 4. Drive shaft gears; 5. Photosensor; 6. Lower roller; 7. Upper roller; 8. Driven shaft gears; 9. Controller; 10. Computer; 11. Load sensor.

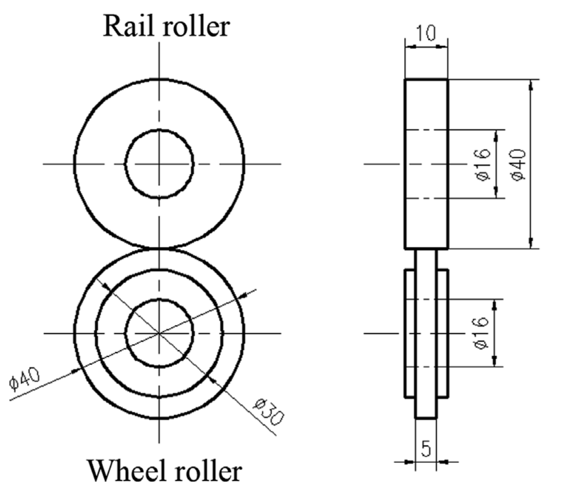

Fig. 2. Scheme size of the wheel and rail rollers.

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

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

Table 2
Experimental details.

Test roller	Size of dents	Rolling direction	Matched roller
RS	Rail roller with small dents	Unchanged	WN
RM	Rail roller with middle dents	Unchanged	WN
RL	Rail roller with large dents	Unchanged	WN
RN	Rail roller without dent	Unchanged	WN
WS	Wheel roller with small dents	Changed per 12000 cycles	RN
WM	Wheel roller with middle dents	Changed per 12000 cycles	RN
WL	Wheel roller with large dents	Changed per 12000 cycles	RN
WN	Wheel roller without dent	Changed per 12000 cycles	RN

experiments for investigating the effects of spherical dents on RCF of wheel/rail materials were performed by using a rolling-sliding wear testing machine. In particular, the microstructure evolution of wheel/rail materials around the dents was also exhibited through Electron Backscattered Diffraction (EBSD) measures. The relationship between microstructure of wheel/rail material and RCF cracks around the dents were discussed. The experimental results highlight the different microstructure evolutions not only between rail and wheel materials, but also between front and rear areas of the dent. More particularly, EBSD

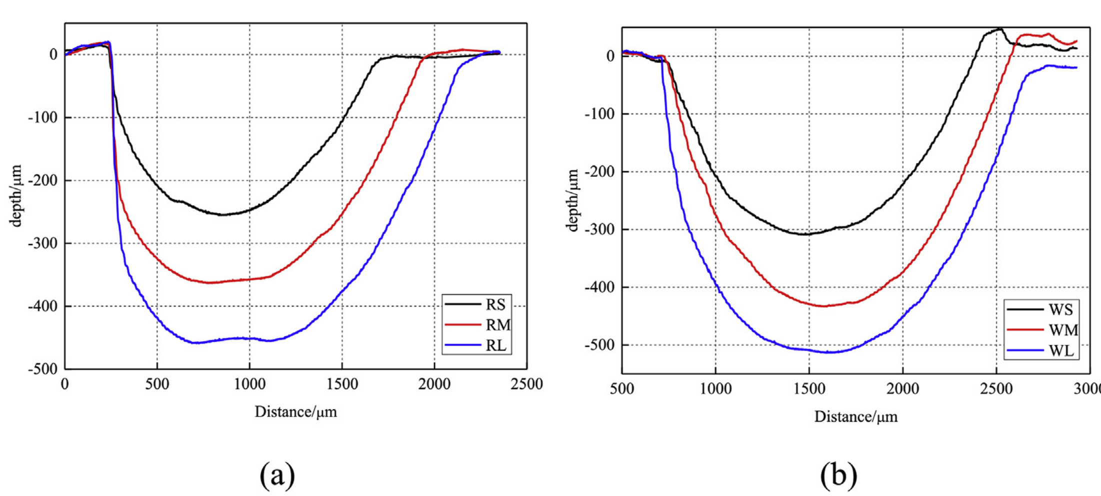

Fig. 3. Scheme of dents on wheel/rail simple before testing, (a) rail; (b) wheel.