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# An investigation into the effect of train curving on wear and contact stresses of wheel and rail

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ABSTRACT

Some important papers concerning the studies on rail wear and wheel/rail contact stresses are briefly reviewed. The present paper utilizes a numerical method to analyze the effect of railway vehicle curving on the wear and contact stresses of wheel/rail. The numerical method considers a combination of Kalker's non-Hertzian rolling contact theory, a material wear model and a vertical and lateral coupling dynamics model of the vehicle/track. In the analysis, the important factors influencing on the wear and the contact stresses are, respectively, the curving speed, the curved track super-elevation and the rail cant. Compared to the present model, some concerned models and results in the published papers are in detail discussed. Through the detailed numerical analysis, it is found that the difference between the normal loads of the left and right of the wheelset increases linearly with increasing the vehicle curving speed. The material wear volume per length along the rail running surface has a tendency to grow. However, the variation of the maximum normal contact stress has a large fluctuation as the curving speed increases. The increase of the maximum contact stress depends greatly on not only the normal load but also the profiles of the wheel/rail. Increasing the track super elevation efficiently lowers the normal load difference of the left and right of the front wheelset, and the contact stresses and the wear. The rail cant has a great influence on the low rail wear of the curve track. An increase in rail cant results in a great increase in the low rail wear of the curved track, and a decrease in the outside rail wear. These conclusions are very useful in the maintenance of the track.

## 1. Introduction

The wear and rolling contact fatigue of wheels and rails cost China railways about 1.2 billions US dollars per year. The wear and fatigue occur predominantly on sharp curved tracks, joint rails and turnouts [1,2]. When a wheel rolls over a rail with a large slide, a large amount of material on the wheel or rail running surface is removed due to larger contact stresses and high temperature [3]. Fig. 1a and b illustrates, respectively, severe side wear and severe corrugation occurred on high curved rails. Such wear causes the great change of rail profile and, therefore, strongly affects the running behavior of railway vehicles, such as motion stability, riding comfort and derailment safety. The wear amount and the present shape of the rail in service are the key criteria for rail replacement at railway sites. However, the wear is often utilized to extend the use life of the rails which have small cracks on their running surfaces at railway sites. As well known, the rail has two types of damage: cracks and wear. Proper wear rate occurring on the rail running surface is able to eliminate small existing cracks or suppress the growth of existing cracks efficiently [4]. According to the mechanism many railway companies on the world developed the optimum techniques of rail grinding [5–7]. For instance, MRS in Brazil applied the advanced technique of rail grinding to the maintenance of the heavy haul track, and the use life of rails used in the heavy haul increased doubly [8]. Therefore, railway companies are much concerned with the studies and treatment of rail wear. Rail wear studies are very complicated, and involve many subjects, such as structural coupling dynamics of railway vehicle and track, rolling contact mechanics, tribology, metallurgy, and numerical method.

In the past, many papers on wheel/rail wear were published. In 1976, using Amsler testing machine of two rollers, Bergley made an investigation into the wear of wheel flanges against the sides of the rails, caused by rolling/sliding contacts sustaining high cyclic stresses at low slide/roll ratios [9]. He concluded that the severe wear of contacts at low slide/roll ratios is caused by high resolved cyclic stresses that result in continual plastic deformation of the surface layers. Using the same testing facility, three wear regimes of wheel/rail steels in rolling/sliding contact were identified by Bolton et al. [10,11]. The characteristic of wear modes within these

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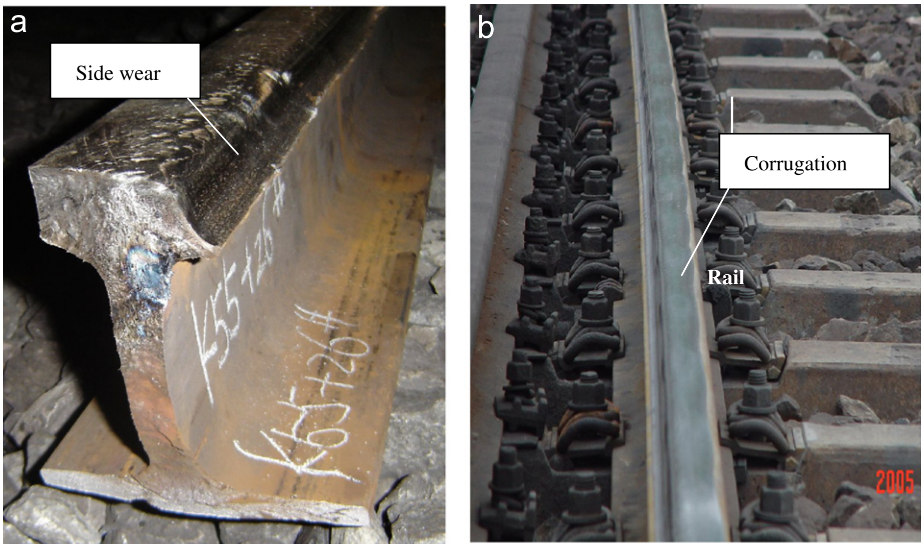

**Fig. 1.** (a) Curved rail side wear and (b) curved rail corrugation.

regimes, referred to as types I, II and III, was determined through metallurgical examination. Relations between the wear rates and test contact parameters, for wear types I and II, can be presented by mathematical expression. It was found that the wear modes occurred in side-worn rail on curved track correlated with laboratory wear types II and III to the extent that the laboratory test offers a prediction of the wear status of rail in service [12]. Tyfour et al. [13] made an investigation into the steady-state wear behavior of pearlitic rail steel after a certain number of rolling–sliding cycles through test in detail. Also the effect of strain hardening and unidirectional plastic strain accumulation on the wear behavior was studied. The test result shows that the start of the steady-state wear rate coincides with the cessation of plastic strain accumulation and additional strain hardening, namely, the steady-state wear rate is established when the material with the same history of strain hardening and accumulated unidirectional plastic strain reaches the surface and the unidirectional plastic strain limit to failure is reached. In their results it was found that the rates of strain accumulation and strain hardening present maxima at the beginning of the rolling/sliding process, and decrease in non-linear fashion to stop after a certain number of cycles. Muster et al. [14] observed and analyzed the effect of different grades of rail steel in service on the resistance to wear and fatigue damage. Tournay and Mulder [15] analyzed the transition from the wear to stress regime of the rails in service. They found that tighter gauge tolerances led to rail crown grinding producing tighter contact bands, and improved vehicle tracking properties. The concentrated contact formed on the wheel tread enhancing hollow wear band. Since the lateral excursions of the wheelsets often occur outside, the deep hollow wear band, small contact areas, high contact stresses and large longitudinal creepages as a result of the large instant radius difference generated on the wheelsets, often form. This can cause high longitudinal material flow, shelling and checking in the rails. Ueda et al. [16] clarified the effects of carbon content on the rolling contact wear in pearlitic steels through a detailed two-cylinder rolling contact wear test, using pearlitic steels with a carbon content ranged from 0.8 to 1.0 mass%. They obtained conclusions as follows: (1) the wear resistance of pearlitic rail steels improves as carbon content and rolling contact surface hardness increase, and the rolling contact surface hardness is a main factor affecting the wear; (2) the rolling contact surface hardness increases due to raising the working-hardening rate of the rolling contact surface as carbon content increases. That is because an increase in the cementite density increases the amount of dislocation in the matrix ferrite and promotes the grain refinement of the matrix ferrite. Therefore, the matrix ferrite is strengthened. Through experimental examinations of the tractive rolling contact between rail and wheel using two-roller test machine, Deters and Proksch [17] found that the wear volume rise turned out to be proportional to the increase of the acting pressure and the creepage between the two rollers. An increase in the circumferential speed of the test rollers caused a reduction in the wear volume. A significant wear decrease at the driven roller modeling rail could be achieved by periodically reversing the direction of the acting traction force.

Actually, the wear and rolling contact fatigue of wheel/rail depend greatly on their profiles and contact surface status, the geometry sizes of track and dynamical behavior of railway vehicle coupled with the track. Their numerical analysis needs the power and efficient numerical method considering the factors mentioned above. Such a numerical method can help identify the risk of severe or catastrophic wear resulting from increased train speeds and axle loads, and determine more efficient maintenance schedules for track and rolling stock [18]. Shen et al. [19] numerically analyzed the influence of rail lubrication on freight car wheel/rail wear rates. Their numerical model considered a $C_{60}$ freight car of China with two sets of standard 3-piece trucks, called “TRUCK 8” under the condition of steady-state curving through a rigid curved track. The steady-state curving indicates that the accelerations of the system in the calculation were neglected. Only the equations for a single-track/half-car body were solved in order to reduce the numerical computation. Rail lubrication was simulated through changing the friction coefficient between the wheels/rails. The non-linear creep forces in the Hertzian elliptical contact areas of the wheels/rails were calculated with the model put forward by Shen et al. [20]. The numerical results indicated that for the curved tracks with radii less than 400 m, the wheel/rail wear rate, under lubrication, may be reduced to 40% of that without lubrication. Jendel [21] developed a wheel profile wear prediction tool based on a load collective concept, where time-domain dynamics simulation of the vehicle coupled with track was carried out based on actual