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Mechanical property and damage evolution of concrete interface of ballastless track in high-speed railway: Experiment and simulation

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HIGHLIGHTS

- Full-field evolution of strain distribution of test specimen is obtained using the DIC technique.
- Cohesive zone model for describing the interface stress-displacement relationship is proposed.
- Interface fatigue S-N curve of a ballastless track in high-speed railways is acquired.
- Interface damage evolution of ballastless track under cyclic temperature loads are investigated.

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ABSTRACT

The interface damage of ballastless tracks in high-speed railway is considered as one of the most critical damage problems, however, the mechanical property and damage evolution of the concrete interface of ballastless tracks are rarely ascertained, and maintenance of the interface damage has been a heavy burden on the modern railway networks. This work aims to reveal the damage constitutive relationship and fatigue performance of the concrete interface of double-clock ballastless track based on experimental tests and simulation analysis. Firstly, by making the composite specimen composed of half track-slab concrete and half supporting-layer concrete and by designing experiment programs for the interface cracking test, the full-field evolution of strain distribution of the specimen under monotonic splitting loading is obtained based on the digital image correlation (DIC) technique, and the key parameters of a cohesive zone model for describing the interface stress-displacement relationship is determined. Subsequently, the interface damage evolution is investigated by applying cyclic splitting loads, and the interface fatigue *S-N* curve is acquired and validated by comparing with relevant references. It is found that the fatigue life of the concrete interface can be easily predicted with only knowing its secondary growth rate of the opening displacement amplitude. Furthermore, to elucidate the practical application of the experiment data and proposed models, the interface damage evolution of the double-block ballastless track under monotonic and cyclic temperature gradient loads are investigated, respectively. Simulation results show that much attentions should be paid to the negative temperature gradient load (below −60 °C/m) that could cause initiation of interface cracks. The proposed fatigue *S-N* curve enable a convenient and effective prediction for the interface fatigue damage of ballastless track with different service state under random loading cycles.

1. Introduction

Ballastless track system has been the prior solution for the rapid development of high-speed railways worldwide, with wide application in China, Japan, Germany, Korea, etc. [1,2]. Generally, high-speed ballastless track is composed of track-slab, mortar layer, concrete base or supporting-layer, which is a layered structure with decreasing elastic modulus from the top to bottom layer. For some ballastless tracks, such as China Railway Track System (CRTS) II slab track and CRTS double-block slab track, different layers are connected by interface adhesion in order to endure cyclic train dynamic loads and environmental loads. Therefore, the interface strength, such as the interface between the track-slab and the supporting-layer (or mortar layer), is relatively small compared with component strength. In this regard, the concrete interface is

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considered as one of the weakest part for ballastless track to sustain a safety operation performance. The operation condition of ballastless tracks in high-speed railways is quite complicated. The interface damage or crack could be induced first by cyclic temperature loads, and then accelerated by repeated train dynamic loads. Furthermore, rainwater will be inevitably permeated into the interface crack and trapped at the interface to produce dynamic water pressure under train dynamic load, leading to the propagation of the interface crack, as shown in Fig. 1. The interface damage could not only significantly reduce the stiffness, strength and stability of the entire track system, but also cause local buckling or longitudinal instability of the track system under complex longitudinal loads. Field investigation also shows that the interface damage of ballastless track is one of the most typical diseases in its long-term service, which will cause the failure of ballastless track and result in serious safety problems [3].

There are two kinds of interface damage mechanisms for ballastless tracks, one kind is the quasi-static damage or dynamic damage which occurs in a short operation time, mainly due to remarkable and sudden temperature change or severe train dynamic loads. It should be note that interface damage due to quasi-static loadings is independent to a time factor unlike the interface damage due to dynamic loadings. The other kind is the fatigue damage that caused by cyclic loads while the induced interface stress is far less than the interface strength. In most cases except for extremely cold areas and poor geological condition areas, the fatigue damage is more common and widely occurs for ballastless tracks, also for other components of railway systems [4,5]. This damage problem is yet an essential challenging task for the rapid development and large-scale operation of high-speed ballastless tracks.

To understand the damage mechanisms of ballastless track under quasi-static or dynamic load, a number of researchers investigated the damage behavior at the interface adjacent to the cement asphalt (CA) mortar layer of slab tracks. The CA mortar is composed of the cement, asphalt emulsion, sand and a variety of admixture composition, which is placed between the slab and the concrete base to ensure desirable elevation and high smoothness of the slab tracks. Dai and Su [6] investigated the interfacial bond–slip behavior of the continuous slab track structure by conducting full-scale field ballastless track structure tests under longitudinal and transverse shear load. Chen et al. [7] studied the effect of acid rain environment on the degradation of cement asphalt (CA) mortar in practical engineering, finding that one of the main reasons for the material degradation is the loss of asphalt and asphaltenes under the coupled effects of loads and rain. Fu et al. [8] proposed a statistical continuous damage constitutive model for CA mortar considering the strain rate based on impact loading test using a Split Hopkinson Pressure Bar (SHPB). Cao et al. [9] analyzed the interface damage mechanism of slab track under the coupling effect of train load and water, and the effects of load characters, water viscosity, and crack shape were studied under the coupled hydro-mechanical effect. Liu et al. [10] investigated the interface bonding mechanism of CA mortar to two type repair

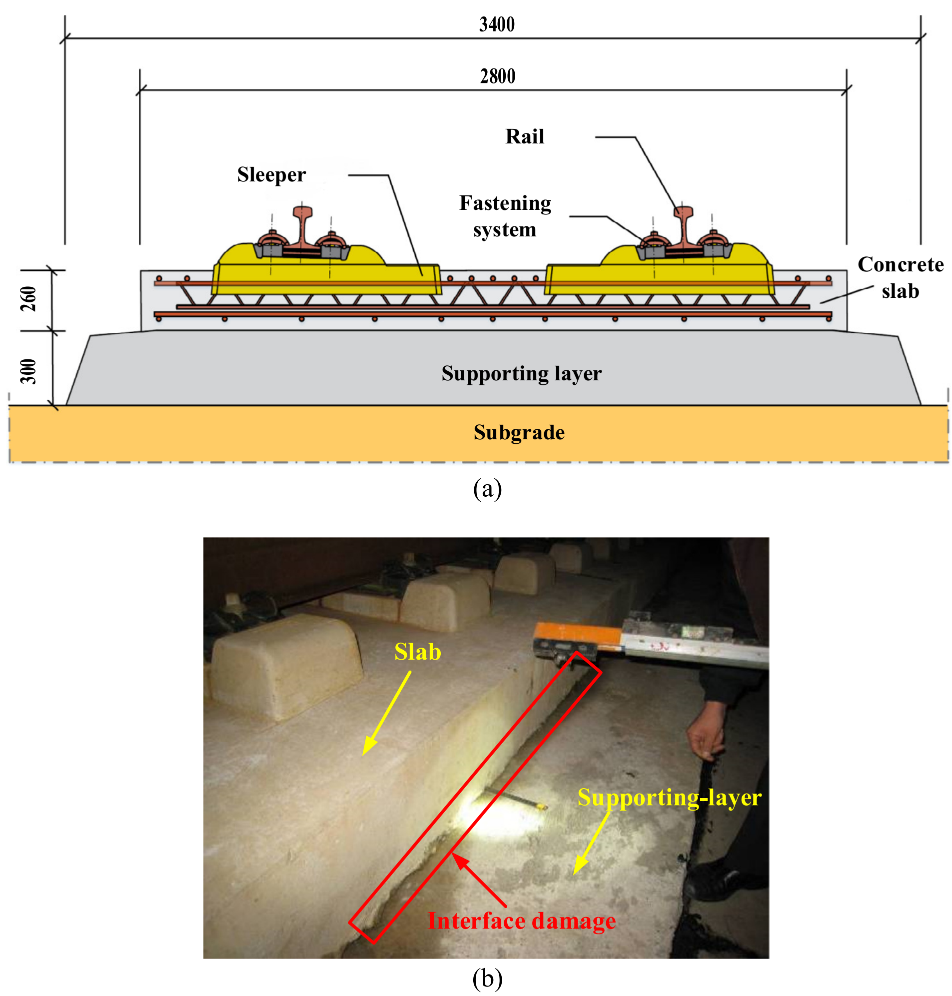

Fig. 1. Double-block slab track in Chinese high-speed railways: (a) schematic of CRTS double-block slab track; (b) interface damage of double-block slab track.