Construction and Building Materials 162 (2018) 229–238

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Evaluation of epoxy asphalt-based concrete substructure for high-speed railway ballastless track

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HIGHLIGHTS

- Three epoxy asphalt-based concretes (EACs) were designed and evaluated.
- Epoxy asphalt-based concrete substructure (EAC-S) was proposed for the high-speed railway ballastless track and evaluated.
- The EACs could improve the cracking resistance and deformability of substructure.
- The EAC-S has better capacity in vibration attenuation than the conventional substructure.

ARTICLE INFO

Article history:
Received 26 April 2017
Received in revised form 4 November 2017
Accepted 5 December 2017

Keywords:
High-speed railway ballastless track
Asphalt concrete railway substructure
Epoxy asphalt-based concrete
Material performance
Structural performance

ABSTRACT

In order to improve the serviceability and service life of high-speed railway ballastless track, the epoxy asphalt-based concrete railway substructure (EAC-S) is proposed. Three epoxy asphalt-based concretes (EACs), containing the conventional epoxy asphalt concrete (CEAC), the rubber powder modified epoxy asphalt concrete (REAC), and the thermoplastic matrix asphalt modified epoxy asphalt concrete (MEAC), were designed at first. Afterwards, the material performance of the EACs was evaluated by a series of laboratory experiments. Finally, a finite element model was developed to investigate the structural performance of EAC-S. Results show that all the three EACs are suitable for the high-speed railway substructure, and the EACs could improve the cracking resistance and deformability of substructure. The designed EAC-S has better capacity in vibration attenuation than the conventional substructure, and could improve the stress and deformation behavior of the subgrade bed.

1. Introduction

Railway is one of the most important transportation methods for passengers and freight in China. With the development of both high-speed and heavy-load trains, the security, stability and durability of railway substructure have necessitated the higher requirements. Due to the high strength, the Portland cement concrete (PCC) has been widely used for railway substructure over the decades. However, investigations have shown that the rigid PCC substructure (PCC-S) exhibits inferior resistance to deformation, and is liable to crack but difficult to maintain [1–3]. Therefore, there is a trend for the high-speed and heavy-load trains requiring the smoother and tougher substructure.

Asphalt concrete (AC) is a construction material traditionally used for the highway pavement, and the viscoelastic strength and modulus make it better suited for railway substructure [3]. Early in 1894, the AC slab with the thickness of about 15 cm was used in an electric railway infrastructure in California, USA [4]. Afterwards, some attempts of AC railway substructure (ACRS) were made in other countries. The Japan National Railway proposed a reinforced roadbed, composed of the AC layer and the crushed concrete layer, to reinforce the subgrade surface of ballasted railway, and the reinforced roadbed could eliminate the moisture fluctuations in the subgrade and reduce the subgrade deformation [5]. GETRAC® is a ballastless railway structure used in German high-speed rail, and the AC layer in the GETRAC® is constructed between the concrete track slab and the subgrade bed with the thickness of about 35 cm [6]. The asphalt trackbed had been applied to China railway during 1960s–1990s, and it mainly used various asphalt materials, especially the emulsified asphalt, to make the granulated ballast trackbed form an integral substructure [7]. However, because of lacking a systematic research of the structure and mate-

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https://doi.org/10.1016/j.conbuildmat.2017.12.028
0950-0618/

rial of the asphalt trackbed, there were some problems in the application of asphalt trackbed, and this structure was replaced by the PCC slab ballastless track since 1990s. After that, the AC layers are only served as function layers in the slab ballastless track. In the China Railway Track System I (CRTS-I) track structure (Fig. 1), which is one of the most widely used slab ballastless track in China, the cement asphalt mortar (CA mortar) is casted between the track slab and the PCC base, playing the roles of leveling, supporting and vibration isolation [8], and the Surface Asphalt Mixture Impermeable (SAMI) is paved on the subgrade surface layer, playing the role of waterproof treatment [9]. In recent years, to meet the fast development of high-way railways in China, some researches on the ACRS have been performed. Fang et al. [10,11] and Yang et al. [12] proposed using the dense-graded AC layer to replace part of the upper subgrade layer, and the simulation results show that the AC layer could lower the ground vibration level, and the ACRS has better loading performance, temperature sensitivity, and less deformation than the traditional slab track. But in general, the systematic research on ACRS in China has not been well established. Therefore, the ACRS has not yet been applied to the practical project in China so far.

As the railway substructure undergoes the load repetitions of trains and various environmental conditions, it makes greater requirements on the strength and durability of ACRS. The early application lessons of asphalt trackbed in China illustrates the important of proper material selection for ACRS. Many researchers evaluated various asphalt mixtures for ACRS. Rose and Hensley [13,14] studied the railroad trackbeds that incorporate a hot-mix asphalt (HMA) layer as the underlayment or overlayment, and found that the HMA layer could improve the load-carrying capability of the trackbed and eliminate the moisture fluctuations in the subgrade, and also no damage or crack was detected in the asphalt trackbed after many years of service [15]. In the past decades, the development of modified asphalt technology has improved the strength and performance of AC significantly, and many researchers have studied the feasibility of various modified asphalt concretes for the railway substructure. Zhong et al. [16] investigated the potential application of rubber-modified asphalt concrete in railroad trackbeds, and the laboratory test results show that adding crumb rubber could increase the damping ratio of asphalt mixtures and increase the stiffness that is adequate for the railway substructure. Lee et al. [3,17] evaluated the performances of asphalt mixtures with styrene-butadiene-styrene (SBS), crumb rubber modified (CRM) and PG64-22 asphalt binders for the asphalt concrete directly fastened track system, and found that SBS and CRM asphalt mixtures could perform well for the application of railway substructures, but all these asphalt mixtures performed weak moisture susceptibility. To improve the durability of railway track in seasonal frozen areas, Li et al. [1] evaluated the performances of slag-based asphalt concrete with the Basic Oxygen Furnace (BOF), and the results showed that with the increase of the BOF replacement rate, the vibration attenuation, bearing capability, antifreeze capability, and insulation effect of BOF-asphalt concrete railway substructure were improved. In terms of above studies, the asphalt concrete for the railway substructure should have adequate stiffness to meet the requirement of railway substructure, and on this basis the ACRS is expected to lower the vibration, improve the load capability and moisture susceptibility.

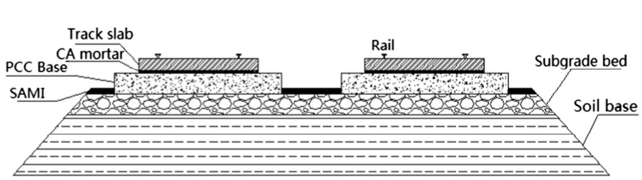

Fig. 1. The CRTS-I type railway slab ballastless track.

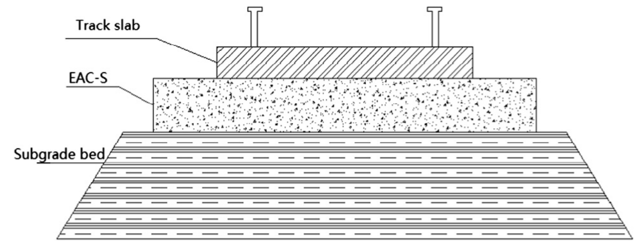

Fig. 2. EAC-S.

Epoxy asphalt is a two-phase chemical system in which a thermosetting acid epoxy (continuous phase) is blended with conventional asphalt (disperse phase). Compared to conventional and polymer modified binders, the thermosetting epoxy asphalt possesses unique properties in the sense that it is not only tough but also elastic at typical temperatures, has superior anti-fatigue, does not soften much at high temperatures, and has strong resistance to aging and chemical attack [18]. Therefore, epoxy asphalt concrete shows excellent performance, such as the high stiffness, superior load capability and durability, strong resistance to deformation and moisture damage. In addition, the damping ratio of epoxy asphalt concrete is much greater than that of PCC [19], indicating that epoxy asphalt concrete could be an attractive material for vibration attenuation of railway substructure. All of these property researches of epoxy asphalt concrete show that it is a potential material for railway substructures.

In recent years, efforts have been spent to take advantage of the unique properties of epoxy asphalt and develop several epoxy asphalt-based concrete (EAC), such as the lightweight epoxy asphalt concrete [20], the rubber powder modified epoxy asphalt concrete [21], and the thermoplastic matrix asphalt modified epoxy asphalt concrete [22]. However, these EACs are mainly designed as a pavement material for the highway bridges, and some attempts of applying them to the protective course has also been made in several railway steel bridges in China [23], while few researches on the application of EAC to the railway substructures were found. Therefore, the performances of the new epoxy asphalt-based concrete railway substructure (EAC-S) should be analyzed to ensure its applicability to the high-speed railway.

The main objective of this paper is to evaluate the performance of EACs used for the railway substructure. Three EACs were investigated, containing the conventional epoxy asphalt concrete (CEAC), the rubber powder modified epoxy asphalt concrete (REAC), and the thermoplastic matrix asphalt modified epoxy asphalt concrete (MEAC). The material performances of these EACs were assessed through laboratory experiments; the EAC-S was designed based on the CRTS-I type track structure through replacing the rigid PCC-S with the EAC layer, as shown in Fig. 2, and a numerical analysis was conducted to study the structural performances of EAC-S.

2. Experimental research

2.1. Materials and specimen preparation

2.1.1. Raw materials

In this research, five concrete materials were utilized: C40 concrete which is used as the conventional PCC-S materials; three EACs to be used as the EAC-S material; and AH70 grade asphalt concrete, which was proposed as the ACRS material in the literature [10–12], to be used as a reference.

The C40 concrete was made with Swan/P.O 42.5 Portland cement (Chinese Standard of Common Portland cement), limestone gravel (coarse aggregate), silica sand (fine aggregate), and water. The cement used in this research is produced by Tianhua Concrete Co. Ltd, in Dalian, China, and the content of clinker plus gypsum in the