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Laboratory investigation into mechanical properties of cement emulsified asphalt mortar

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HIGHLIGHTS

- Mechanical properties and dry shrinkage of CEAM were tested at three different A/C ratios.
- Cement hydration heat was measured and the microstructures were examined.
- A/C ratio significantly affected mechanical properties and cement hydration.
- CEAM could combine the advantages of both portland cement and asphalt.

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ABSTRACT

The present study investigated the mechanical properties of cement emulsified asphalt mortar (CEAM) as a damping material for ballastless high-speed rail track bed. CEAM has unique properties that differ from concrete and asphalt alone as this hybrid material combines the high strength of portland cement composites and the flexibility of asphalt materials. In this study, uniaxial compressive strength (UCS), indirect tensile (IDT) strength, tensile strength ratio (TSR), dynamic modulus and phase angle, and shrinkage were tested on CEAM samples at three different asphalt/cement (A/C) ratios. The cement hydration heat of the paste was measured and the microstructures of CEAM were examined to analyze the interaction between cement and asphalt and to explain its effect on the mechanical properties of CEAM. The results from this study show that CEAM exhibited loading rate- and temperature-dependent properties, indicative of a typical viscoelastic material. Cement could hydrate effectively and both cement and asphalt acted as a binder in the hybrid material as they were in cement or asphalt mix alone. The A/C ratio showed a significant effect on the mechanical properties and cement hydration heat of CEAM.

1. Introduction

High-speed railways have been getting worldwide attention in these days. One requirement to build high-speed rails is to move away from ballasted tracks and towards non-ballasted concrete slab tracks. Traditional ballasted track design consists of rail laid on timber or concrete ties and supported by an aggregate bed [1]. Although it is functional for low speed transportation, this design is not suited for high speed rail systems as the increased speed can cause issues with the track, such as lateral and horizontal movement in the track known as "floating" and churning of the stone ballast [1,2]. The non-ballasted concrete slab track is a widely used high speed railway track structure that addresses these issues and is currently being used in many countries such as Japan, China and Germany [2]. Typical concrete slab track designs consist of a concrete track slab placed on top of a concrete bed, with a cushion layer in between to help dampen the system (Fig. 1). The material commonly used as a cushion layer for this structure, cement emulsified asphalt mortar (CEAM), is a mix of cement, asphalt emulsion, fine aggregate, and several chemical admixtures [3]. CEAM is a key component of ballastless high-speed rail track system and its mechanical properties (such as strength, stiffness, and damping) play an important role for a smooth and safe ride [2–4]. CEAM has unique properties that differ from concrete and asphalt alone as this hybrid material combines strength of cement mortar and flexibility of asphalt binder.

Many studies have been conducted to investigate the behavior and performance of the CEAM mixtures. However, the earlier

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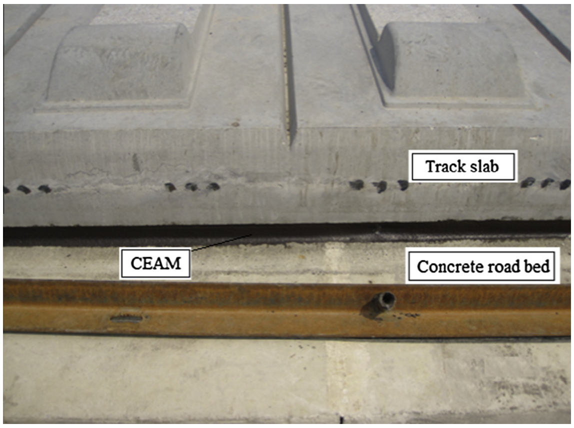

Fig. 1. Slab track of high-speed rail.

studies have been focused on the beneficial effects of portland cement as an additive to asphalt emulsion in cold mixes [5–7]. Until recently researchers have started to explore the possibility of using CEAM as a cushion material for high-speed rails. Since this material consists of two types of binder – portland cement and asphalt binder, both binders play important roles in the performance of CEAM. Oruc et al. [8] studied the influence of cement on the mortar at high cement contents. Their test results show that mechanical properties of CEAM were significantly improved by the addition of cement. Zhang et al. [9] investigated the rheological properties of fresh cement asphalt paste (CA paste), and examined the effects of asphalt emulsion, temperature, and time. Their study shows that the anionic asphalt emulsion is more effective than the cationic type in that the former exhibits favorable adsorption onto the surface of cement grains. They also found that the temperature sensitivity of the rheological properties of the CA paste depends on the type and content of asphalt emulsion. Pouliot et al. [10] explored the interaction between cement and asphalt emulsion particles, demonstrating that the hydration process of cement was affected by the presence of a small quantity of emulsion. Their study shows that the presence of asphalt droplets leads to a significant reduction in compressive strength and elastic modulus as well as a slight decrease in flexural strength of the CEAM. Wang et al. [11,12] found that binder contents could affect the mastic–aggregate interface adhesion, internal air voids and their distribution in the cement asphalt emulsion materials. Lu et al. [13] used F-type superplasticizer (FSP) as the isolation layer outside the micelles in cationic emulsified asphalt in CEAM. They found that asphalt emulsion and cement could mix effectively without the generation of any viscosity by demulsification. They also added sodium carboxymethylcellulose (CMC-Na) to improve and restrain settlement and stratification of fresh CEAM.

2. Objective and scope

The objective of this study was to investigate the mechanical properties of CEAM for use in the rail industry. The study was focused on the effects of asphalt to cement ratio (A/C) on the mechanical properties of CEAM. The properties evaluated include uniaxial compressive strength (UCS), indirect tensile strength (IDT), dynamic modulus (E^*) and phase angle as well as damping ratio, and shrinkage of the material at different asphalt to cement (A/C) ratios. In order to explain the effects of A/C ratio on the material, the heat of hydration was tested and the microstructures were also examined.

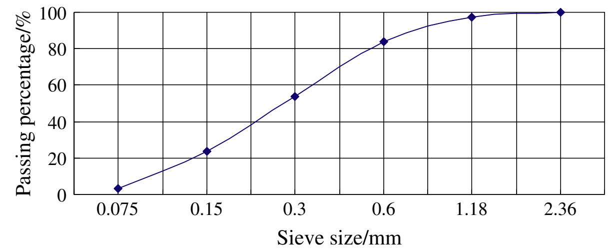

Fig. 2. Natural sand gradation for CEAM.

3. Materials

The mix design used in this study are presented in Table 1. All mixes were made using Type III portland cement. Based on the preliminary research by the authors [11,12], Type III portland cement was chosen for its high early strength to help counteract the slow setting time and retarding effect of the emulsion [3]. For design purposes anionic type SS-1H emulsified asphalt with 60% residue was used following the recommendation from the manufacturer based on its slow setting speed in order to prolong the time for sample preparation. High range water reducer (HRWR) and air entertainer (AE) admixtures were added to increase the workability and performance of CEAM. A sufficient number of small air bubbles produced by AE can help enhance the damping ability of CEAM [14]. Fly ash (FA) was incorporated to decrease viscosity of the mortar to make it easier to be mixed and constructed [15]. The mixes were divided into 3 groups based on their asphalt residue to cement ratio (A/C): Group A (A/C = 0.22), Group B (A/C = 0.43), and Group C (A/C = 0.65). The research efforts were made to balance the content of asphalt emulsion and cement in the CAEM so that the mortar is flexible and also strong enough to support high speed railway traffic loading. Fig. 2 shows the gradation of natural sand used in the mixes.

4. Sample preparation

A mechanical mixer was used to mix the CEAM to ensure consistency in the samples. The specimens to be used for compressive strength test were cast using 50 mm steel cube molds. After 48 h the samples were demolded and field cured in a temperature controlled room at 20 °C for 28 day in guidance of ASTM C31 [16]. For the IDT strength and dynamic modulus tests, samples were cast using 100 mm diameter and 200 mm high cylinder molds. The samples were then demolded and cured in a wet curing room until tested. For the IDT strength test, the samples were cut into 50 mm thick specimens before testing. The samples for dynamic modulus test were cut into 150 mm high specimens to fit the sample size requirement for this test.

For the shrinkage test, samples were cast using a double compartment steel mold in accordance with ASTM C490 [17]. The samples were demolded and field cured in a temperature controlled room for 28 days.

Table 1
Proportions of CEAM (kg/m^3).

Group	Cement	Emulsified asphalt	Water	Natural sand	FA	HRWR	AE
A	400	144	197	1006	40	11	2.2
B	400	288	140	919	40	11	2.2
C	400	432	82	833	40	11	2.2