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Investigation of sand mixture interlayer reducing the thermal constraint strain in asphalt concrete overlay

Zhiqi Sun [a,*], Yongli Xu [b], Yiqiu Tan [a,c,*], Lei Zhang [a], Huining Xu [a], Anxin Meng [a]

[a] School of Transportation Science and Engineering, Harbin Institute of Technology, Harbin 150090, China
[b] School of Civil Engineering, Northeast Forest University, Harbin 150090, China
[c] State Key Laboratory of Urban Water Resource and Environment (Harbin Institute of Technology), China

HIGHLIGHTS

- Reduce significantly the constraint-strain of the asphalt concrete overlay.
- Quantify the constraint-strain of composite structure with sand mixt interlayer.
- Calculate the restraint coefficient k only with strain response.
- Calculate the resistance coefficient C_x and thermal stress on the overlay with temperature.

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ABSTRACT

Semi-rigid base material is widely used because of its lower costs, yet the issue of the incompatibility of cement materials and asphalt materials in the semi-rigid-base asphalt pavement is particularly significant in cold regions. This study examined and quantified the benefits of adding sand mixture interlayer to the semi-rigid base of the asphalt pavement to reduce the thermal-constraint strain of the asphalt concrete overlay with thermal loading. For the two-layer system, the restraint coefficient of the layer structure and interlaminar shear coefficient were calculated on the principles of thermoelasticity theory. For the three-layer structure with sand-mixture interlayer, constraint strains in the interface were determined on pairwise comparison. Results indicate a significant reduction in the constraint-strain of the asphalt concrete overlay and base layer of the three-layer structure. And the constraint-strains of the asphalt concrete overlay of the three-layer structure are nearly identical to samples of the two-layer system with asphalt-treated base. The essential parameters obtained during the calculation are used as the verification calculation of pavement structure design in cold regions.

1. Introduction

More than 90% of highways in China contain semi-rigid-base asphalt pavement. This pavement structure can easily fail, due to the incompatibility of the different characteristics with regard to thermal expansion and drying shrinkage [1] of the cement materials and asphalt materials. In addition, due to the inherent propensity of thermal expansion and dry shrinkage of the cement-stabilized base, it is problematic for researchers to discover a means of preventing the base from cracking. When the cracks appear in the semi-rigid base, the crack tip easily transformed into stress concentration and this fact causes the rapid appearance of crack at the surface layer [2,3].

The European Long-Life Pavements Group of the Forum of European National Highway Research Laboratories has arguably conducted the most comprehensive study on long-life pavements in Europe to date, in which semi-rigid pavements are considered [4,5]. Low temperature cracking is one of the major failures in cold regions and in most countries with cold climates, huge amounts of money are spent annually on the repair of the overlays of roads and highways. Pavement distress leads to frequent rehabilitation that increases the global cost of pavement sections, so longer service life is of great interest when life-cycle cost is considered.

Studies on material resistance to thermal cracking have been focused on the low-temperature properties of bitumen binder and asphalt mixture [6–8]. Chen et al. modified the thermal properties of asphalt mixture to resist the effect of environmental

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* Corresponding authors at: School of Transportation Science and Engineering, Harbin Institute of Technology, Harbin 150090, China.

E-mail addresses: 14b932006@hit.edu.cn (Z. Sun), tanyiqiu@hit.edu.cn (Y. Tan).

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temperature [9]. Du et al. used a highly oriented heat-induced structure to reduce pavement temperature and alleviate rutting in summer [10]. Du and Chen concluded that this could prove resistant to temperature shock as well, but may fail if shrinkage characteristics are not modified in cold climate regions where the lowest temperature experienced is very low and the cold season is very long. The main reason for thermal cracking is the constraints caused by the lower layer. Therefore, the key method to resist thermal cracking is to reduce the constraint strain of the asphalt concrete overlay.

Current researchers are focusing on interlayer shear failure, and on reflective cracking of the semi-rigid base asphalt pavement. With regard to interlayer shear failure: To avoid interlaminar shear failure, many researchers are studying the shear stress of a composite pavement structure, and the different models that take the interlayer bonding condition as the variable [6,11–14]: Liu et al. found that irregular rough interfaces improve the shear performance on interlayers; Bocci and Canestrari [15,16] by using reinforced asphalt membrane and epoxy asphalt as interface materials between the steel deck and asphalt concrete layers, showed that the shear resistance of the interlayer system could be improved, and the epoxy asphalt effect was better. Although shear stress was the main reason for the debonding of layers, the main disease that caused the cracking of the pavement was the tensile stress caused by the lower layer restraint in cold regions [17]. As a stress-relief layer, the asphalt sand mixture could provide sufficient interface shear strength and fatigue resistance due to the high elastic asphalt content of 9% [13].

A review of current approaches in addressing the reflective cracking problem, reveals that many researchers seeking to extend the service life of asphalt pavement developed a number of different design strategies, including increased overlay thickness and modified overlay [18–20], joint sawing and sealing, composite geotextile interlayers [21,22], and stress relief layers [2,4,23–25]. But increased overlay thickness, modified overlay, and joint sawing and sealing, raised the cost of pavement construction. The use of geotextile interlayers had improved pavement performance with a reinforcement function, but it is worth nothing that it may cause delamination at the interface [25].

Based on the results of field and laboratory research programs, the anti-reflective composite interlayer system was discussed, and the results showed that the stress-relief layer (a sand mixture interlayer) not only can dissipate the stress concentration at the cracks tips but also can reduce vertical and horizontal cracking displacements at the bottom of the overlay [2]. Considering permanent deformation because of the low stiffness of stress relief layers, Olumide et al. indicated that introduction of a stress relief layer increases deflection, but it could delay reflective cracking [25]. These researchers demonstrated also the importance of using stress-relief layers with good fatigue resistance characteristics based on structural pavement performance. Additionally, they showed that the stress relief layer with dense characteristic prevents the water from eroding toward the lower layer of the pavement. Therefore, in this study, a sand mixture was selected as the material of stress-relief layer.

It can be concluded from the foregoing discussion that if interlaminar restraint stress and reflective cracking is finally resolved, the semi-rigid base asphalt pavement will have great potential as a durable pavement. But even so, low-temperature cracking is still an unsolved issue for the semi-rigid base asphalt pavement in cold regions. Our study applied thermal contraction tests to capture strain response under different temperatures, considering three structures. This paper aims to quantify, by contrasting a sand-mixture interlayer with the thermal-strain effect of the asphalt concrete overlay of the composite structure. The restraint coefficient of the layer structure, and interlaminar shear coefficient with temperature, were calculated respectively, based on thermoelasticity theory. This study provided the means of decreasing the thermal cracking of pavement structure, and also provided an essential parameter for the calculation of the thermal stress of asphalt pavement.

2. Experimental Methods

2.1. Materials and mixtures

The tests were carried out with three specimens obtained from the same structure. The nominal maximum size of aggregate for asphalt concrete is 16 mm, 4.75 mm for sand mixture, and 25 mm for the Asphalt-Treated Base (ATB) mixture as well as the Cement-Treated Base (CTB) layer. The asphalt concrete applied SBS-modified asphalt (SBS-AC), the sand mixture for the stress-relief layer applied high elastic bitumen binder (HE-AC), and the binder of ATB and CTB applied neat asphalt binder and Portland cement, respectively. Fig. 1 shows the gradations for SBS-AC, HE-AC and ATB. Table 1 provides the basic performance of materials applied in this study. The composition of the CTB in the mix design was shown in Table 2. SBS-AC, HE-AC and ATB were designed via the Marshall method, and their optimum asphalt contents were 4.6%, 9.0% and 3.4%, respectively.

2.2. Methodology

Considering the climate conditions in the cold regions of northeast China, the lowest temperature near −30 °C would generally last for a month. Thermal cracking occurs when a pavement's ability to dissipate stress buildup from thermal contraction was exceeded. But it capacity to dissipates more rapidly the thermal stress compared with thermal contraction above 20 °C. So the temperature ranged from 20 °C to −30 °C was determined. To obtain the interface strain response of composite beams under thermal loading, the temperature ranged from 20 °C to −30 °C at intervals of 10 °C, using an environmental chamber. To make the temperature distribution of the sample even, the samples were kept for 4 h at every temperature point. The SBS-AC and ATB specimens were prepared respectively by molding 300 × 300 × 50 mm^3 and 300 × 300 × 70 mm^3 slabs with asphalt concrete, following the Standard Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering (JTG E20-2011, T0719). The slabs were cut, yielding three beams specimens (300-mm-long × 100-mm-wide). The CTB specimens are prepared by pouring cement in molds measuring 300 × 100 × 100 mm^3, then left to cure for 28 days.

To avoid friction interference, five glass rods were placed under each specimen. The configuration of the strain gauges is shown in the Fig. 2. There were two types of strain gauges in this paper. The lengths of the strain gauge located in the middle layer were 100 mm (SU1, IDU1/IDL1, IIDU1/IIDL1 and TU1/TM1/TL1), and they were 20 mm in the interface of the composite structure (IDU2-IDU4/IDL2-IDL4, IIDU2-IIDU4/IIDL2-IIDL4 and TU2-TU4/TMU2-TMU4/TML2-TML4/TL2-TL4). There were three types of composite structure, as shown in Fig. 2(b), (c) and (d). The tack-coat material applied was modified emulsified asphalt with a spray volume of 0.2–0.3 dm^3/m^2.

2.3. The Young's modulus of SBS-AC

Young's modulus of asphalt mixture was captured by the static tensile test in an environmental chamber with a beam 30 mm × 35 mm × 250 mm. The samples were kept for four hours at 10 °C, 0 °C, −10 °C, −20 °C and −30 °C. The loading rate was 0.007 mm/s. To ensure that the specimens were undamaged, the tensile strain was kept in the 100 $\mu\varepsilon$ range. So Young's modulus of the asphalt