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Interlaminar shear fatigue and damage characteristics of asphalt layer for asphalt overlay on rigid pavement

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HIGHLIGHTS

- We developed a test apparatus and method to evaluate interlaminar shear fatigue.
- We developed an interlaminar shear fatigue equation by analyzing interlaminar shear fatigue tests.
- The asphalt overlay located at the transverse joints is prone to fatigue cracking.
- Thermal fatigue damage occurs mainly on the surface of asphalt overlay.

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ABSTRACT

According to the failure characteristics of asphalt overlay on rigid pavement, a special-purpose test apparatus and method were developed for interlaminar shear fatigue tests to evaluate interlaminar shear fatigue of asphalt overlay on rigid pavement, and an interlaminar shear fatigue equation was determined by analyzing the correlation between fatigue life and shear stress obtained from interlaminar shear fatigue tests. The damage mechanics theory, heat transfer theory and the Finite Element Method (FEM) were adopted to analyze fatigue damage characteristics and cracking mechanism of asphalt layer. The result showed that under repeated traffic loading, the asphalt layer located at the existing transverse joints of the rigid base on the side of traffic loading, is prone to fatigue cracking, and the crack extends upward along the tip due to the tensile stress; thermal fatigue damage occurs mainly on the surface of asphalt overlay, the horizontal tensile stress on the surface of asphalt overlay decreases linearly with the increase of temperature variation times, and the fatigue life of asphalt overlay decreases with the increase of the amplitude of temperature variation; and it is recommended to choose asphalt mixtures with features such as relatively low thermo-contraction character, low modulus and high tensile strength to guarantee the expected cracking resistance and durability of asphalt overlay on rigid pavement.

1. Introduction

In recent years, asphalt pavements with different bases, such as PCC (plain cement concrete), RCC (roller compacted concrete), LCC (lean cement concrete), JPC (jointed plain concrete) or CRC (continuously reinforced concrete) have been rapidly developed in China. Numerous early-built cement concrete pavements are repaved with asphalt overlay for concrete pavements rehabilitation. Asphalt overlay has been widely used in concrete pavements rehabilitation due to its low cost [1,2]. Rigid base can greatly improve the bearing capacity of pavement structure. Asphalt overlay can reduce the thermal warping stress and load stress for rigid base and effectively enhance the driving comfort [3,4]. However, there exists a great difference between the resilient modulus of rigid base and that of asphalt overlay, and they have poor deformation compatibility in volume expansion and shrinkage. Generally, asphalt overlay is thin, sometimes only a few centimeters thick, and with the decrease of asphalt stiffness modulus, cohesive force and shear strength, it is likely to induce distresses like slip, crack, deformation, etc. under long term action of high-temperature and traffic loading [5]. Asphalt overlay is prone to reflective cracking at the existing transverse joints [2,6,7].

It has shown that traffic loading and temperature variation are considered as two main causes for reflective cracking in asphalt overlay after a period of service [8]. A simple direct shear apparatus has been developed to evaluate shear fatigue property of asphalt overlay on rigid pavement, and a rigid pavement overlay

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design procedure has been developed for Texas SDHPT [9]. A simplified procedure has been developed for fatigue cracking in asphalt overlay on rigid pavement [10].

The interlaminar shear strength is determined mainly by the direct shear method at home and abroad. However, the direct shear method only considers the horizontal stress without the vertical compressive stress. Therefore, the direct shear apparatus cannot simulate the actual shear state of pavement structure accurately, and it cannot exactly evaluate the interlaminar shear strength or shear fatigue performance of pavement structure. However, there is no special test apparatus or method to evaluate interlaminar shear fatigue of asphalt overlay on rigid pavement, and there are few studies on fatigue damage characteristics or cracking mechanism of asphalt overlay on rigid pavement. It is important to carry out a related research on interlaminar shear fatigue of asphalt overlay on rigid pavement, which can provide a scientific and theoretical support for effective design, construction and daily maintenance of asphalt overlay on rigid pavement. In this study, a special-purpose test apparatus and method were developed for interlaminar shear fatigue tests to evaluate interlaminar shear fatigue of asphalt overlay on rigid pavement, and an interlaminar shear fatigue equation was determined through interlaminar shear fatigue tests.

2. Interlaminar shear fatigue test

A special-purpose test apparatus and method have been developed. Both horizontal stress and vertical compressive stress are considered through this apparatus. It can simulate the actual shear state of pavement structure better. The newly-developed test apparatus has been used in interlaminar shear fatigue tests to evaluate interlaminar shear fatigue of asphalt overlay on rigid pavement.

2.1. Test apparatus

Tests have been conducted by using the newly-developed test apparatus (a test apparatus and method for interlaminar shear fatigue test of composite asphalt pavement, Patent No. CN102519808 B, shown in Fig. 1).

The test apparatus consists of loading system (Material Testing System-810, USA), briquetting, supporting block and supporting platform. The lower end of loading rod is connected with briquetting, and supporting block is set up on supporting platform. Steel balls fixed by stent are set up between supporting block and supporting platform. The notch shape of briquetting is the same as that of supporting block. The briquetting and supporting block are inclined towards the same direction by 26°34′ to simulate the actual shear state of pavement structure under the extreme condition of vehicle emergency brake. The existing studies show that horizontal stress is half of vertical compressive stress in pavement structure under vehicle emergency brake, so the inclination angle is $\alpha = \arctan 0.5 = 26°34'$ [4].

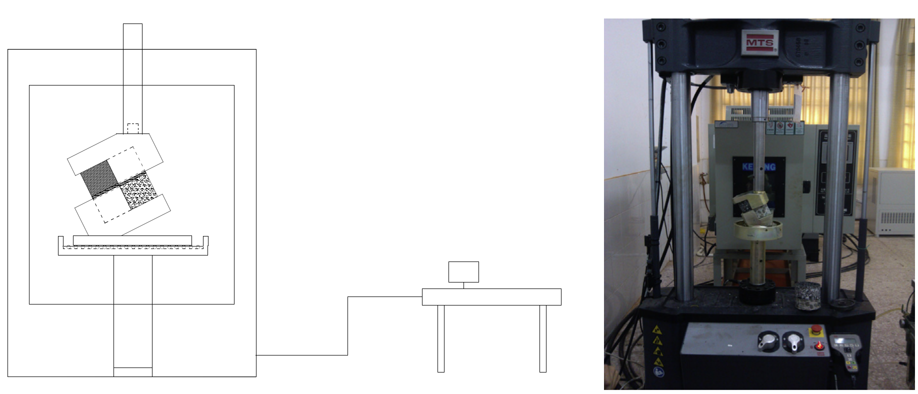
2.2. Material

The cement concrete mixtures were made by HuaXin cement P.O.42.5 (Portland cement). The strength of the cement concrete is C35. The cement concrete mixtures proportions have been made to meet design strength, as shown in Table 1. The adhesive material were made by SBS asphalt (YH-791). The molecular structure of SBS is linear. The dosage of SBS was 4%. The property of SBS asphalt are shown in Table 2. The synthetic gradation of asphalt mixtures (AC-13) is shown in Table 3. The asphalt-aggregate ratio of AC-13 was OAC = 4.7%.

2.3. Core specimen preparation

Cement concrete base (5 cm thick) of specimens were manufactured in the special double-deck rutting testing mould (300 × 300 × 100 mm). When pouring it in mould, the cement concrete should be vibrated and compacted enough. The surface of cement concrete was treated by baring treatment to remove laitance. The cement concrete specimens were put in the standard curing room until the designed strength reached, and the curing time of the specimens lasted for 28 days. Then, the cement concrete specimens were cleaned and placed in an oven (170 °C) for 30 min. The SBS modified asphalt was placed in an oven (175 °C) to heat uniformly. The cement concrete specimens sprinkled with adequately-heated SBS modified asphalt evenly (the spraying quantity is 1.4 kg m^{-2} [5]). Crushed stones (a single-particle size of 13.2 mm to 16 mm) uniformly spread over the SBS modified asphalt surface (the spraying quantity is 50% of asphalt's spraying area) and were compacted immediately and tightly to make them wrapped with asphalt as much as possible.

After the SBS adhesive layer was cooled to room temperature, the well mixed asphalt mixtures were poured over the adhesive layer in mould and were modeled by the wheel rolling forming machine. They were demould after cooling to room temperature. Then, core samples were extracted from the composite specimens by core-drilling machine, then polished by polishing machine. The core samples had a diameter of 5 cm and a height of 10 cm. Several groups of specimens were prepared for further testing. Each group consisted of at least four effective specimens. When specimens



(a) (b)

Fig. 1. Schematic diagram (a) and photo (b) of the special-purpose test apparatus.