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Evaluation of permanent deformation of asphalt mixtures using different laboratory performance tests

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HIGHLIGHTS

- A new test was developed to evaluate the permanent deformation of asphalt mixtures.
- The fiber-reinforced mechanism for asphalt mixture was studied from microscopic view.
- We used a varying pressure in PTT to simulate the actual confinements in pavement.
- A correlation was analyzed between the test results from PTT and wheel tracking test.

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ABSTRACT

The laboratory tests were conducted to evaluate the effects of polyester fiber on permanent deformation of asphalt mixtures. The results indicate the fibers improve the deformation resistance of mixtures. The confinements in the partial triaxial test (PTT) have significant effects on the permanent strain of mixtures. The varying confinement in the PTT better simulates the actual confinements in pavements. A stronger correlation of test results from the PTT and the wheel tracking test was found. It is concluded that the addition of polyester fibers improves the mechanical performance of mixtures, and the PTT method is a reliable new test method.

1. Introduction

Asphalt has been primarily used as a binder to construct asphalt pavements on highway. Asphalt, as a kind of polymeric material, has obvious viscoelastic characteristics [1]. The asphalt pavement is prone to rutting when heavy loads are applied at high ambient temperatures. The accumulation of irrecoverable strain in asphalt pavement layers is one of major causes to cause rutting [2]. Rutting has been one of the common distresses in pavements that affects riding comfort for road users and causes high maintenance costs for road agencies [3].

Modified-asphalt with additives is usually used to change the phase composition and improve the engineering properties of asphalt mixtures. Among various additives, polymer fibers are mainly used to enhance the rutting resistance of asphalt pavements [4]. Previous researchers have reported that polymer fibers not only increased the Marshall stability and reduced the voids in mineral aggregates to improve the cohesion between aggregates [5,6], but also increased the viscosity and stiffness of asphalt mastics and improved asphalt mixture's moisture susceptibility, rutting resistance, fatigue life, and durability [7,8].

In developing an experimental testing method for evaluating the rutting resistance of asphalt mixtures, most researchers have used wheel tracking test, the uniaxial compressive creep test, the triaxial repeated load test (TRT), the indirect tension test, and the bending creep test [9]. The wheel tracking test simulates traffic loading on pavements by applying a wheel load on a slab specimen. The testing conditions are similar to pavements in service and the rut depth is measured after a specific number of loading cycles [3]. The wheel tracking test has been proven to be an effective method to evaluate the rutting potential in asphalt pavements [2].

Another commonly used test to measure the permanent deformation of asphalt mixtures is the TRT, which is conducted by applying repeated vertical loading in a triaxial setup [10].

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Results obtained from the TRT are typically presented in terms of the cumulative permanent strain versus the number of loading cycles [11]. Goh and You [12] developed a new simple stepwise method to determine the flow number in TRT. Taherkhani [13] investigated the uniaxial and triaxial steady-state deformation behavior of realistic asphaltic mixtures using uniaxial and triaxial creep tests.

Although the TRT has been used as an alternative to the wheel-tracking test, there are concerns on the ability of this test as an effective method to distinguish the permanent deformation behavior of different types of asphalt mixtures [2]. Additionally, the constant confining pressure in the TRT was not realistic compared to the field condition because the confinement in the pavement structure changes with temperatures, traffic loads, and the surrounding material. Therefore, the TRT cannot simulate the stress conditions encountered in the real pavements. Moreover, the application of triaxial test, such as the TRT, is limited due to the relatively complicate testing procedure and expensive equipment.

2. Objective

In this study, a new creep test was developed, named the partial triaxial test (PTT), to evaluate the permanent deformation behavior of asphalt mixtures. One significant advantage of the new test is that the confinement pressure in the PTT were generated from the surrounding asphalt material and thus changed with temperature, loading, and the mechanical properties of the surrounding material. Thus, the new testing method could better simulate the confinement conditions of asphalt mixtures in the filed condition than the traditional traiaxial repeated load test (TRT).

The focus of this study is to investigate the effects of polyester fiber on permanent deformation of asphalt mixtures at the high temperature using the TRT and the PTT. Different loading levels were applied on the specimens to evaluate the development of permanent strain and strain rate under repeated loading cycles. For comparison, the laboratory wheel tracking tests were utilized to directly measure the rutting depth and dynamic stability of the asphalt mixture. In addition, the correlation between the total accumulative rut depth and the strain slope value at the secondary stage in the TRT and the PTT was discussed.

3. Materials and testing method

3.1. Raw materials

Polymer (styrene–butadiene–styrene (SBS)) modified asphalt binder with a performance grade of PG76-22 was obtained from Zhenjiang Meilun Bitumen Co. Ltd, China. The basic properties of asphalt binder were given in Table 1. The crushed amphibolites aggregate (Pengcheng Aggregate Co., Ltd., China.) was used for preparing asphalt mixtures. The properties of the aggregate are summarized in Table 2. Additionally, the properties of crushed limestone powder and polyester fiber provided by manufacturers were shown in Table 3.

Table 1
Properties of the SBS modified asphalt binder.

Properties	Standard	Testing results
Penetration	ASTM D5-61	5.8 mm
Ductility at 5 °C	ASTM D113-86	48.7 cm
Softening point	ASTM D36-26	80.2 °C
Viscosity at 135 °C	ASTM D4402	2.3 Pa s
Flash point	ASTM D92	336 °C

Table 2
Properties of the used aggregate.

Properties	Standard	Testing results
Coarse aggregate angularity (%)	ASTM D5821	100
Fine aggregate angularity (%)	AASHTO T304	46.8
Flat/elongated particles (%)	ASTM D4791	2.6
Clay content (%)	AASHTO T 112	0.4
Coarse aggregate specific gravity (g/cm^3)	ASTM C-127	2.843
Coarse aggregate absorption (%)	ASTM C-127	0.46
Fine aggregate specific gravity (g/cm^3)	ASTM C-128	2.839
Fine aggregate absorption (%)	ASTM C-128	0.63
Sand equivalent (%)	AASHTO T 176	78
Abrasion loss (Los Angeles) (%)	ASTM DC-131	16.7
Frost action (with Na_2SO_4) (%)	ASTM C-88	1.3
Polishing value	BS-813	0.96

Table 3
Properties of the crushed limestone powder and polyester fiber.

Material type	Properties	Testing results
Crushed limestone powder	Particle size	0–0.3 mm
	Specific gravity	2.773 g/cm^3
	CaO content	48.2%
	SiO_2 content	1.46%
	Passing percent in 0.3 mm	99.1%
	Passing percent in 0.15 mm	93.5%
	Passing percent in 0.075 mm	79.5%
Polyester fiber	Diameter	(0.016 ± 0.0025) mm
	Length	6 mm
	Relative density	1.32–1.40
	Melting point	248 °C
	Fire point	536 °C
	Tensile strength	517 ± 34.5 MPa
	Maximum tension strain	33 ± 9%

3.2. Asphalt mixtures

Sup19 and AC20 are often used as the middle layer of a typical 3-layer pavement structure in China. The middle layer is usually subjected to rutting at the high temperature, thus was chosen in this study.

3.2.1. Sup19 mixture

The preparation of Sup19 asphalt specimens was as follows. Based on the specific gravity of selected aggregates, asphalt binder content was calculated to be 4.1% by the mass of total mixture. The Superpave gyratory compactor (EP-31111model, US) was used to prepare asphalt mixture specimens. The number of gyrations for initial compaction ($N_{initial}$), design compaction (N_{design}), and maximum compaction (N_{max}) was 8, 100 and 160 gyrations, respectively. The diameter of the specimen cylinder was 150 mm. The applied axial pressure was 0.6 MPa, and angle of gyration was 1.25°, and the revolution of gyratory load was 30 r/min. The loose asphalt mixtures were aged in oven at the compaction temperature for 2 h prior to the compaction. This simulated the aging and absorption of asphalt binder during the construction of hot-mix asphalt pavements [14].

The final combined aggregate gradation for Sup19 was presented in Fig. 1. The limit values follow the Technical Specification for Construction of Highway Asphalt Pavement (JTG F40–2004) in China. The optimum asphalt content was found at 4.1 percent.

3.2.2. AC20 mixture

The Marshall method (ASTM D1559) was used to design the AC20 asphalt mixture. The identical cylindrical specimens with the Sup19 mixture (101.6 mm in diameter and 63.5 ± 1.3 mm in height) were produced with 75-blow compaction per side by Marshall Compactor. The final combined aggregate gradation for AC20 was given in Fig. 1. The optimum asphalt content was found at 4.4 percent.

The content of polyester fiber was selected 0.3 percent by the total mass of AC20 mixture to evaluate the effect of polyester fibers on dynamic creep properties of asphalt mixtures. The optimum asphalt content of the polyester fiber-reinforced asphalt mixture was found at 4.5 percent that is greater than the control AC20