Construction and Building Materials 174 (2018) 293–301

Contents lists available at ScienceDirect

Construction and Building Materials

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

Rutting resistance of porous asphalt mixture under coupled conditions of high temperature and rainfall

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HIGHLIGHTS

- A multi-physics repeated loading permanent deformation test was developed.
- Coupled conditions were designed and investigated based on the rainfall process.
- Rutting resistance of PA mixture was evaluated under real coupled conditions.

ARTICLE INFO

Article history:
Received 24 November 2017
Received in revised form 10 April 2018
Accepted 12 April 2018

Keywords:
Porous asphalt mixture
Rutting resistance
Multi-physics repeated loading permanent deformation test
Coupled condition
Moisture damage

ABSTRACT

Porous asphalt (PA) mixtures work real coupled conditions of high temperature and rainfall in rainy summer weather. The objective of this study is to develop a multi-physics repeated loading permanent deformation (MRLPD) test that can evaluate the rutting resistance of the PA mixture under such real coupled conditions. A multi-physics chamber was designed for the MRLPD test to achieve real coupled conditions of dry, rainfall onset, ongoing rainfall, and rainfall end, which are consistent with the rainfall process. Under the rainfall onset and ongoing rainfall conditions, the rutting resistance of the PA mixture is lower than that under the dry condition. PA mixture shows the poorest rutting resistance under the ongoing rainfall condition. The presence of water in the pores creates pore pressure, which facilitates moisture damage and consequently decreases the rutting resistance. The more time the PA mixture stays in a saturated state, the lower the rutting resistance is. PA mixture exhibits the best rutting resistance under the rainfall end condition because the pore pressure absorbs part of the loads and the decreased temperature of the specimen. The rutting resistance of the PA mixture is more sensitive to temperature and overloading than to moisture damage. Under the coupled conditions, high temperature accelerates the evolution of moisture damage, which leads to the acceleration of rutting failure.

1. Introduction

Porous asphalt (PA) mixtures are described by a high air void (AV) content (i.e., usually between 18% and 22%) and a gapped aggregate gradation compared with traditional dense graded asphalt mixtures [1,2]. The high AV content contributes to the advantages of runoff mitigation, wet safety improvement, and spray reduction by allowing the rainwater to drain through its porous structure away from the road [3,4]. Unlike with dense graded asphalt mixtures, the pore network of PA mixture is saturated with rainwater under rainy weather and retains rainwater after rainfall [5]. Therefore, on a summer rainy day, PA mixture works under a coupled condition of wheel loads, high temperature, and rainwater. It has been reported that the rutting resistance of PA mixtures is lower than traditional dense graded asphalt mixtures [6], and rutting is the dominating distress in the summer. Rutting not only reduces the permeability and service life of the PA mixture but also creates a road safety concern [7,8]. In addition, water has detrimental effects on the performance of dense graded asphalt mixtures (i.e., moisture damage), and moisture damage is a prelude to and accelerates other types of damage, such as rutting and cracking [9–11]. Most provinces in southern China are pluvial, high-temperature regions in the summer. Therefore, it is essential to evaluate the rutting resistance of PA mixtures under summer coupled conditions of high-temperature and rainfall.

Rainwater in asphalt mixtures causes premature and severe pavement distresses [10]. In previous literature, moisture damage was generally manifested as adhesion failure between asphalt and the aggregate or a cohesion failure of the asphalt mastic [12–14].

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https://doi.org/10.1016/j.conbuildmat.2018.04.104
0950-0618/

Moisture diffusion, asphalt binder erosion, and cyclic pore pressure are the three main physico-mechanical processes of moisture damage [15]. The static immersion test (ASTM D1664) and the immersion compression test (ASTM D1075) are representative tests to evaluate the moisture sensitivity for loose coated aggregate and compacted mixtures, respectively [13]. Usually, conventional tests consist of a conditioning and evaluation phase, which are two separate steps during testing [14]. However, the function of wheel loads and environmental conditions cannot separate according to the field conditions [16]. Therefore, these tests fail to achieve a real coupled condition of wheel loads, temperature, and water.

As mentioned above, moisture damage is independent damage as well as a serious contributor to various types of distresses such as cracking and rutting [9–11]. In the summer, permanent deformation accumulates under the effects of wheel loads, high temperature, and moisture damage. Many laboratory permanent deformation tests have been developed to evaluate the permanent deformation of asphalt mixtures. Hamburg Wheel Tracking Tester (HWTT) and Asphalt Pavement Analyzer (APA) are typically used to evaluate the rutting resistance of PA mixtures [6,17]. HWTT and APA can obtain a direct indicator of rutting resistance. However, the mechanical properties of materials and parameters of pavement design could not be obtained from them [18]. As a result, dynamic creep test was developed to derive the fundamental properties of asphalt mixtures and is highly recommended to evaluate the rutting resistance of asphalt mixtures [19,20]. However, in the dynamic creep test, the lateral confinement of a specimen is fixed, which is inconsistent with the changing confinement in the actual pavement [8,21,22]. Gu et al. and Li et al. proposed an advanced repeated loading permanent deformation (ARLPD) test by using a smaller diameter loading head, which can simulate the changing confinement stress in the field and better evaluate the rutting resistance of asphalt mixtures [8,21,22]. Moisture damage and permanent deformation interact with each other under the coupled conditions. Mehrara and Khodaii made an effort to evaluate the moisture sensitivity of dense graded mixtures using dynamic creep test under saturated and dry conditions [23]. The results indicated that moisture causes permanent deformation early in their service life, and a lower rutting resistance was found in the saturated sample than the dry sample [23]. Dehnad et al. also utilized the dynamic creep test to evaluate the effects of load frequency and temperature on the moisture damage of dense graded mixtures [9]. Moisture damage increased with the increment in load frequency and temperature. Dehnad et al. also believed that the dynamic creep test could be used to evaluate the moisture damage of dense graded mixtures [9].

However, the PA mixture is quite different from dense graded mixtures in the AV content, AV distribution, and AV interconnectivity. The PA mixture was filled with rainwater, and the degree of saturation depended on the rainfall process under rainy weather. Moisture damage has a more pronounced influence on the performance of the PA mixture than on dense graded mixtures [10]. The rutting resistance of the PA mixture under the coupled conditions of high temperature and rainfall has not been evaluated. Moreover, the development of a new test to evaluate the rutting resistance of the PA mixture under real coupled conditions is required.

2. Objectives and methodology

The objective of this research was to evaluate the rutting resistance of a PA mixture under the coupled conditions of high temperature and rainfall. A multi-physics repeated loading permanent deformation (MRLPD) test was developed to simulate the changing confinement and achieve the real coupled conditions. Coupled conditions including dry, rainfall onset, ongoing rainfall, and rainfall end, corresponding to the rainfall process, were achieved using a newly designed multi-physics chamber. An ARLPD test was performed under the dry condition as the control. Dense graded asphalt concrete (AC) as a comparative analysis was also evaluated by the MRLPD test. The influences of the mixture type, different coupled conditions, temperature, and overloading were assessed and discussed.

3. Materials and mixture design

The PA mixture and AC with a nominal maximum aggregate size (NMAS) of 13.2 mm (PA-13 and AC-13) were designed in this study. PA-13 is the most common mixture used in the surface of permeable asphalt pavement. AC-13 is the most used concrete in dense graded asphalt pavement surfaces. High-viscosity asphalt (HVA) was used for PA-13, which is typically used in China to improve the raveling resistance and strength of PA mixtures. HVA is characterized by an extremely high kinetic viscosity (60 °C) of 143202 Pa·S and an extremely high softening point of 91 °C. Styrene-butadiene-styrene (SBS) modified asphalt (PG 76–22) was used for AC. The average AV of PA-13 and AC-13 are 18.5% and 4.2%, respectively. Fig. 1 shows the details of the two aggregates gradations.

Specimens used in the MRLPD test and ARLPD test were fabricated by a Superpave gyratory compactor (SGC) with a diameter of 150 mm and height of 170 mm. Three replicates were prepared for each test.

4. ARLPD test and MRLPD test

4.1. Test setup

The ARLPD test and the MRLPD test were performed on UTM-25. A loading cycle of 1 s duration (0.1 s haversine load period and 0.9 s rest period) with a preload 20 kPa was applied to the loading head. The peak of the haversine load was 700 kPa corresponding to the tire pressure of a standard wheel load of 100 kN. During the test, the vertical deformation was measured by linear variable differential transducers (LVDTs) and recorded by the UTM-25.

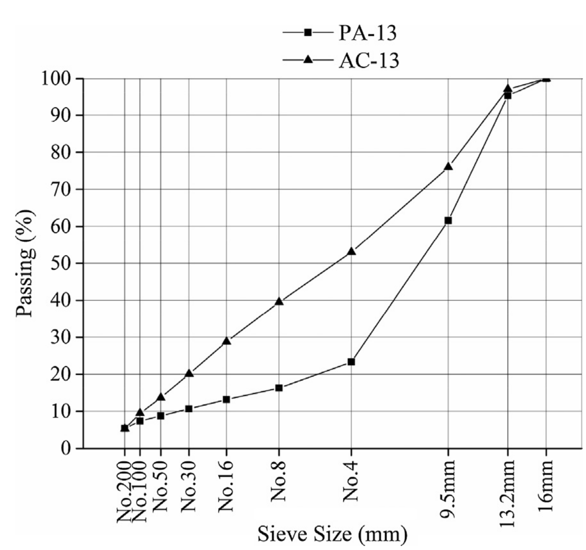

Fig. 1. Investigated gradation of PA-13 and AC-13.