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Evaluation of permanent deformation of multilayer porous asphalt courses using an advanced multiply-repeated load test

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HIGHLIGHTS

- An advanced multiply-repeated load test was developed to replicate the field conditions.
- Rutting resistance of multilayer porous asphalt courses was evaluated by the developed test.
- The applicability of different multilayer porous asphalt courses was discussed.

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ABSTRACT

Multilayer porous asphalt (PA) courses have the advantages of runoff mitigation, rainwater management and noise reduction. The objective of this paper was to develop an advanced multiply-repeated load test which can effectively simulate the field conditions, including confinement condition, actual temperature distribution, and axle load spectrum. And it was used to evaluate the rutting resistance of multilayer PA courses in this study. Rutting resistance of single, double, and triple-layer PA courses and traditional dense graded asphalt courses (control) were investigated under three axle load spectrums. Rutting resistance indicators, such as multiple flow number and loading sensitivity curve, were utilized to evaluate the rutting resistance. The result indicates that the percentage of heavy axle loads in the load spectrum plays a vital role in the rutting development of multilayer PA courses. The rutting resistance of four multilayer asphalt courses was compared and the control was the best, following by the single, double, and triple-layer PA courses. The addition of fiber in porous asphalt mixture can remarkably improve the rutting resistance of multilayer PA courses. Based on the results, it can be concluded that the single-layer PA courses can be used in heavy traffic roads and has been validated by field constructions. The double and triple-layer PA courses are only recommended in medium traffic roads, and the performance in the field need further investigated and validated.

1. Introduction

Porous asphalt (PA) mixture characterized with a high content of air voids about 20%, is typically used in multilayer porous asphalt pavement, to reduce runoff, improve road safety, and lower noise [1–3]. In China, most of asphalt courses consist of surface layer, middle layer, and bottom layer. Multilayer PA courses include single-layer PA courses (S), double-layer PA courses (D), and triple-layer PA courses (T), which uses the PA in the surface layer, surface and middle layer, as well as the full-depth layer, respectively [4–6]. Recently, China government proposed a new city construction concept, named as "spongy city", which is aimed to drain, store, retain, recycle and clean the rainwater. Therefore, multilayer PA pavements have the potential to be utilized in "spongy city" construction.

Single-layer PA pavement has been widely used in many countries. 67% of the existing road surface in Japan is used PA, and the single-layer PA pavement still in good state after fifteen years' service [7]. In the United States, permeable friction curse (PFC) and open-graded friction curse (OGFC) are used in the surface layer in many states [8]. The thickness of OGFC in the United States is commonly 20–25 mm, and OGFC was generally considered as non-structural layer [2,9,10]. So, limited studies evaluate the structural capacity of single-layer PA pavement, let alone the multilayer PA pavement. But some states, including South Carolina, and other countries consider OGFC layers as providing structural capacity to the pavement structure [11]. Noise reduction has widely motivated the use of PA in Europe as the surface course, and PA is typically constructed with a 40–50 mm layer thickness [5]. Compared with

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traditional dense graded asphalt mixture, PA also acts as a filter and removes the pollutants from runoff water [12]. The performance of drain-ability, noise reduction, and cleaning rainwater depends on the volumetric properties and the thickness of PA. The single-layer PA pavement has a limited improvement of these functions because of the thin layer. Currently, Japan and some European countries propose double-layer PA to provide greater capacity for clogging mitigation, drain-ability, water storage, and noise reduction [4,6]. Obviously, multilayer PA pavements with a larger thickness of PA can greatly improve the pavement functionality. Because PA has a high air void and difficulty to ensure proper stone on stone contact in the field, they are more susceptible to deformation than dense graded asphalt mixtures [11]. When considering single-layer PA courses, rutting is not a major concern because it is placed in relatively thin layers. However, multilayer PA courses may have greater potential for rutting when exposed to heavy traffic loads and serious overloading, especially during periods of high temperature. The structural capacity of multilayer PA courses is vital to the design of multilayer PA pavement. Little information is found regarding the rutting resistance of multilayer PA courses. Therefore, determination of the rutting resistance of multilayer PA courses is essential to the multilayer PA pavements design, and laboratory test should be close to the field condition as much as possible.

There have been a number of laboratory tests to evaluate the permanent deformation of asphalt mixtures. Laboratory tests mainly include Marshall Stability test, Hamburg Wheel Tracking Tester (HWTT), Asphalt Pavement Analyzer (APA), dynamic creep test, and etc. [13]. Compared with Marshall Stability test which is poorly correlated to field performance [14], and HWTT and APA test which could not obtain the mechanical properties of materials and parameters of pavement design [15], dynamic creep test was recommended as one of the best test for evaluating the permanent deformation of asphalt mixtures [14,16], which was developed by Monismith et al. in 1970s based on the concepts of axial compression test [17]. When considering PA, HWTT and APA test were used to evaluate the rutting resistance of PA [9,18]. Three important aspects of dynamic creep test are the confinement condition, temperature, and the loading pattern. In the laboratory tests, the fixed confinement stress, uniform temperature distribution, one stress level, and single-layer specimen are generally selected, which are greatly different from field conditions [19]. To eliminate these differences, Gu et al. proposed an advanced dynamic creep test which can simulate the confinement condition and temperature distribution in the field conditions [14]. The confinement condition was simulated by using a small diameter loading head which can create a lateral confinement in the specimen, and that is similar to actual pavement. A specimen temperature control system was utilized to achieve a temperature gradient along the depth which is similar to field pavement temperature distribution.

However, the advanced dynamic creep test was conducted at only one repeated stress level, which is greatly different from the loading conducted on the pavement under field conditions. Wheel loading applied to the actual pavement is various, and overloading phenomenon is serious in China. The loading on specimen should include multiple repeated loads to simulate actual traffic loading. Jiang et al. proposed an optional multiple repeated load (OMRL) test which can perform multiple stresses on the specimen to simulate the axial load spectrum in actual pavement [16]. Compared with the dynamic creep test, the OMRL test was simulated the actual traffic load distribution and the overloading was also taken into consideration. The results of OMRL test were more realistic than dynamic creep test because of using an actual axle load spectrum.

Due to the relatively lower rutting resistance of PA, a critical point in designing multilayer PA pavements is to determine its resistance to permanent deformation failure. In order to effectively evaluate the permanent deformation of multilayer PA courses through laboratory testing, it is expected to simulate the confinement condition, temperature distribution, and the wheel load under field conditions simultaneously. In addition, to investigate the applicability of using different multilayer PA courses for different traffic levels, the new test method should be able to quantify and differentiate proposed multilayer PA courses.

2. Objectives and methodology

The objective of this research was to develop an advanced multiply-repeated load (AMRL) test to evaluate the rutting resistance of multilayer PA courses under field conditions. In the AMRL test, the confinement condition of pavement was simulated by designing the diameter of loading head. The pavement temperature distribution was simulated by a temperature control system. The axle load spectrum of actual pavement was obtained from a pavement management system (PMS), and simulated by performing multiple stresses in several increments without rest between each increment. Varying multiplayer specimens, including: single-layer PA courses, double-layer PA courses, triple-layer PA courses, and traditional dense graded asphalt courses (control) were fabricated with the same thickness as the actual pavement structure. Based on the results, the influence of axle load spectrum, mixture types, and fiber on the rutting resistance of multilayer PA courses were analyzed. The rutting resistance of different multiple PA courses was compared, and the applicability of using multilayer PA courses for different traffic levels was discussed.

3. AMRL test method

To simulate the confinement condition, pavement temperature distribution, and loading pattern under the actual pavement conditions, the laboratory test should simultaneously satisfy the following requirements:

(1) Multilayer specimens with the same thickness as the actual asphalt courses, including surface, middle, and bottom layer.
(2) Lateral confinement stress was created by the specimen and closed to the actual pavement.
(3) The temperature of specimen was varied with the depth, creating a temperature gradient similar to the actual pavement.
(4) The loading conducted on specimen with multiple stress levels, based on axle load spectrum obtained from actual pavement.

Table 1
Multilayer specimen details.

Specimen number	Surface layer	Middle layer	Bottom layer
Control	4 cm AC-13 (PG 76-22)	6 cm Sup-20 (PG 76-22)	8 cm Sup-25 (PG 64-22)
S1	4 cm PA-13 (HVA)	6 cm Sup-20 (PG 76-22)	8 cm Sup-25 (PG 64-22)
S2	4 cm PA-13 (HVA) + polyester fiber (0.3%)	6 cm Sup-20 (PG 76-22)	8 cm Sup-25 (PG 64-22)
D	4 cm PA-13 (HVA)	6 cm PA-20 (PG 76-22)	8 cm Sup-25 (PG 64-22)
T	4 cm PA-13 (HVA)	6 cm PA-20 (PG 76-22)	8 cm PA-25 (PG 76-22)