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Developing an optional multiple repeated load test to evaluate permanent deformation of asphalt mixtures based on axle load spectrum

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HIGHLIGHTS

- Based on the analysis of axle load spectrum, an OMRL test procedure and analysis method was developed.
- Four loading sequences were selected for the OMRL test.
- The rutting properties of virgin mix and 50% RAP mix were compared according to both OMRL test and dynamic creep test.

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ABSTRACT

An optional multiple repeated load (OMRL) test, capable of simulating the axial load spectrum in real pavement, was developed to evaluate the rutting susceptibility of asphalt mixture. This new test was conducted at the temperature of 60 °C under multiple stresses determined by a simplified axle load spectrum considering the pavement management system (PMS). A pre-stage dynamic creep test was employed to determine the loading cycles of the first increment. Two kinds of asphalt mixtures were compared in the OMRL test with varying orders of multiple stresses and they were also tested in dynamic creep test under five different loading levels. As the test results show, loading sequences have a significant impact on the high-temperature performance of asphalt mixtures. The curve of permanent strain rate versus stress level could fit well with a power-law model in the dynamic creep test, and a similar result can be obtained by the OMRL test. However, the OMRL test shows higher efficiency than the traditional dynamic creep test. Besides, the secondary stage of the OMRL test fits a broken-line model since various stress levels are conducted on the specimen. The newly proposed lowest average strain rate (LASR) and multiple flow number (MFN) could evaluate the rutting resistance of asphalt mixtures under a more realistic loading condition. Overall, this OMRL test provides a better understanding of the rutting behavior of asphalt mixtures to improve the mix design and field performance.

1. Introduction

It is a main concern that rutting or permanent deformation of hot mix asphalt (HMA) mixture caused by combined affecting factors is one typical distress occurred in the surface layer of pavement. During the last decades, with the rapid development of highway construction, the traffic volume has increased significantly in China and the overloading phenomenon is extremely serious, which are the main reasons why some newly-built pavements have suffered severe distress of rutting after few years of service [1]. The damage of rutting shortens the service life of the surface layer of pavement, and it is detrimental for the road safety by causing dangerous driving behaviors like vehicles hydroplaning or uncontrollable sliding in rainy days [2]. Therefore, it is essential to evaluate the rutting resistance of different asphalt mixtures under varying conditions accurately and reliably, which is in great assistance for appropriate design of pavement material. Many researches [3,4] have been devoted to develop various laboratory tests to characterize the rutting resistance of asphalt mixtures. The Marshall Stability test provides the flow and stability as the assessment criteria for the high-temperature stability performance of asphalt mixtures, which is based on empirical laws and blamed for poor correlation to field performance [5]. Other kinds of empirical tests are the Accelerated loading tests (APTs) consisting of various loaded wheel tests (LWTs) and laboratory or field test tracks [6]. The APTs are widely adopted around this world, such as Asphalt Pavement Analyzer (APA) [7] and Hamburg Wheel Tracking Tester (HWTT) [8], which can simulate the dynamic response of asphalt mixture specimen or pavement structures to

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the repeated vehicle load applications in small or full scales. Unlike the Marshall Stability test, the APTs could correlate well with the field rutting performance, but the mechanical parameters of the road materials could not be obtained from the test results [9]. In order to derive the fundamental property of asphalt mixtures to guide the pavement structure design and predict the development of rutting distress, various uniaxial and tri-axial loaded tests were developed, such as static creep test, dynamic creep test and dynamic modulus test [10,11]. However, previous studies conclude that the static creep test poorly evaluates the rutting potential of asphalt mixtures compared with the dynamic creep test since the static loading condition makes a big error. In addition, the $|E^{*}|$ from dynamic modulus test can hardly indicate the high-temperature performance of asphalt mixtures either for the strain of dynamic modulus test is too small to reveal any characteristics of permanent deformation. Therefore, the dynamic creep test was considered to be one of the best methods to assess the rutting resistance of asphalt mixtures, which was developed by Monismith et al. in 1970s based on the concepts of axial compression test [12]. An indicator called flow number (FN, defined as the number of load cycle corresponding to the minimum change rate of permanent axial strain) was derived from the dynamic creep test, which had good correlation with the field rut depth and the potential to predict rutting resistance of asphalt layers.

Many factors of the permanent deformation tests influence the experimental results, such as temperature, loading levels, loading frequency, boundary condition and so on [13–15]. Considering that the overloading phenomenon is severe in China but the dynamic creep test is performed at one stress level and temperature, to better simulate the field condition, which is under various ranges of temperatures and stress levels, an optional multiple repeated load (OMRL) test was proposed. This OMRL test was conducted under multiple stress levels in several increments with no rest between each increment, and the axle load spectrum obtained from a pavement management system (PMS) was analyzed firstly to determine the significant stress levels with high proportions in the axle load spectrum. As a result, the stress levels for the OMRL test is optional according to the distribution of traffic loading. In this study, a new test procedure and analysis method is proposed to fulfill this OMRL test. There are some advantages for this new test: 1) the loading condition of OMRL test is related to the axle load spectrum of one road prepared for design or maintenance, so it could rank the asphalt mixtures targeted for one road more precisely. 2) Since the OMRL test is conducted under several stress levels, it offers more meaningful information regarding to the rutting resistance of different materials. 3) OMRL test is more efficient than dynamic creep test.

2. Objective

The main objective of this study is to develop an OMRL test procedure and analysis method, based on the analysis of axle load spectrum, to better characterize the high temperature performance of asphalt mixtures under various stress levels. This new test should be easy to perform and allow the operator to better control the input parameters as well as the test results without any harm to the accuracy. Two common used asphalt mixtures in Yanjing highway in Jiangsu Province China were selected to be tested according to the OMRL test with varying orders of stress levels. The axle load spectrum of Yanjing highway was handled before to obtain the represent stress levels. To illustrate the comparison between the OMRL test and the conventional dynamic creep test, these two selected asphalt mixtures were also tested by the dynamic creep test at varying stress levels. Newly proposed indicators derived from the OMRL test were utilized to estimate the rutting potential of asphalt mixture. The connection and difference between the OMRL test and the dynamic creep test were evaluated to better uncover the rutting property of asphalt mixture.

3. Material and mix design

In order to verify the applicability of this innovative permanent deformation test based on repeated axle load spectrum, two common asphalt mixtures were selected for this study. The first mixture contained 50% RAP (designated as 50% RAP mix), and the second one had no RAP (designated as virgin mix). The nominal maximum aggregate size (NMAS) of both mixtures was 13 mm. Representative samples of RAP were obtained from the top layer of Yanjing highway in Jiangsu Province China. The aggregate gradations of both mixtures were designed as shown in Table 1. A styrene–butadiene–styrene (SBS) modified asphalt binder of PG76-22 was used for the virgin mix as the virgin binder and a SBS modified asphalt binder of PG70-22 was used for the hot recycling mix as the virgin binder. Optimal asphalt content was determined to be 5.1% by the weight of mix for both mixtures.

All specimen tested in this experimental work were fabricated by a superpave gyratory compactor (SGC). For the new permanent deformation test, the SGC samples with 180 mm in height and 150 mm in diameter were produced first. Then the samples were cored and cut to obtain the target size of 150 mm in height and 100 mm in diameter. An air void level of 4% (±0.5%) was targeted for the final specimens.

4. Procedures of the OMRL test

4.1. Simplifying the axle load spectrum

The average axle load spectrum of Yanjing highway in recent five years was obtained from the pavement management system (PMS) in Jiangsu Province, China. Four common axle–wheel groups, like single-axle single-wheel, single-axle double-wheel, double-axle double-wheel, and three-axle double-wheel groups, could all be converted into the single-axle double-wheel groups [16]. Fig. 1 demonstrated the average axial load distribution of converted single-axle double-wheel groups. Even through the repeated times of axial load between 20 KN and 60 KN is high, it was not considered in this test since the load is too light to cause any significant destructive effects on the road. Considering that the repeated times of axial load between 60 KN and 160 KN are more than 99% of the total repeated times of axial load bigger than 60 KN, it is reasonable to determine the main range of axial load as 60 KN–160 KN, and the range was divided into four intervals: 60–80 KN, 80–100 KN, 100–120 KN, 120–160 KN. The mid-value of four intervals (70 KN, 90 KN, 110 KN, 140 KN) were set as the representative axial loads, which could be converted into four stress levels according to Eq. (1). Since the contact area increases with the increase of tire pressure, the relationship between tire pressure and axial load is not linear [17]. The percentages of the repeated times for four stress levels were calculated out and the results are listed in Table 2.

Table 1
Aggregate gradations and mix design results.

Sieve size (mm)	Passing percent (%)	
	Virgin mix	50% RAP Mix
16.0	100.0	100.0
13.2	94.1	94.5
9.5	75.5	75.5
4.75	52.9	52.8
2.36	38.1	37.2
1.18	26.1	26.6
0.60	18.0	19.2
0.30	12.5	13.1
0.15	9.2	9.6
0.075	6.2	6.7
Optimal binder content (%)	5.1	5.1
Target air void (%)	4.0	4.0