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Characterization of permanent deformation performance of asphalt mixture by multi-sequenced repeated load test

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HIGHLIGHTS

- A MSRL test was developed and indicators including CASR and CCSM were proposed.
- Both MSRL and RL tests were performed at different loading conditions.
- The effects of loading order, loading cycle, stress level were investigated.
- Analysis of variance was carried out for indicators from both MSRL and RL tests.

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ABSTRACT

In an attempt to characterize the permanent deformation behavior of hot mix asphalt (HMA) under a more realistic loading condition, this study developed a multi-sequenced repeated load (MSRL) test. Comparing to conventional repeated load (RL) test, there are three characteristics for this new test. First, the loading scheme, containing a pre-loading sequence with stress level of 0.7 MPa and other 25 sequences involving stress levels from 0.6 MPa to 1.0 MPa, was self-defined by the test design function of UTM-25. Second, the number of repeated loading in each sequence was fixed, with 500 times in pre-loading and 50 times in every other sequence. Third, two new indicators, including compound average strain rate (CASR) and compound creep stiffness modulus (CCSM), were proposed to evaluate the rutting-resistant property of HMA. Both MSRL test at different loading orders and RL test under stress levels of 0.7 MPa and 1.0 MPa were conducted on three types of mixtures with two binders at temperature of 60 °C, respectively. The findings indicate that the effects of loading order are insignificant on the permanent deformation of HMA in secondary stage. Besides, average strain rate (ASR) has a nonlinear growth as stress level increases. Based on MSRL test results, coefficient of variance for new indicators is satisfactory. Through analysis of variance, it is also found that new indicators, with much reduced levels of confidence, have much better potentials to statistically differentiate mixtures with different SBS modified binders than conventional ones like flow number (FN), FN index and so on.

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1. Introduction

Permanent deformation, also termed rutting, is one of the major distresses occurring in hot mix asphalt (HMA) pavements. Rutting in HMA pavement can be generated in any structural layer, however, as for a large majority of highways established in China, which often have semi-rigid bases considered as elastic materials, it is believed that the unrecoverable deformations generated in base, subbase and subgrade are insignificant, and rutting is contributed majorly by unrecoverable deformation accumulated in HMA layers. Rutting growth is significant in summer, where the extreme high pavement temperature contributes to the instability of the HMA mixture, especially where softer asphalt binder has been used or under excessive traffic loading. Rutting is considered a structural failure that undesirably reduce ride quality and service life of pavement, and will lead to vehicle hydroplaning caused by water pooling after rains with a high potential for traffic accidents. Moreover, maintenance or rehabilitation activities for pavement rutting are financially costly [1]. Therefore, how to accurately characterize the permanent deformation behavior of the HMA and effectively distinguish the high temperature performance between different mixtures, based on appropriate evaluation test and indicator, is vital for HMA mixture's design and rutting prediction.

Various laboratory and field tests have been developed to evaluate the rutting-resistant property of the HMA mixture. These tests include dynamic modulus (DM) test, repeated load (RL) test, flow time (FT) test, flow number (FN) test [2–5], and accelerated loading

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tests (APTs), which includes various loaded wheel testers (LWTs), laboratory and field test tracks [6–9].Typical LWTs include the UK wheel tracking device [10], the Georgia LWT [11], the asphalt pavement analyser (APA) [12], the Hamburg wheel tracking test (HWTT) [13] and so on. In general, the APTs can be conducted on specimens or pavement sections, and is considered to be better correlated with field rutting performance than other laboratory tests. However, the full-scale test cannot offer mechanical parameters to predict rutting and guide the pavement design, as well as extremely money and time consuming [14].

Walubita et al. [1] comparatively evaluated the HWTT, DM and RL tests and concluded that the HWTT is the most practical test for routine HMA mixture design, and the RL and DM tests were found to be better suitable for structural design applications, such as obtaining input parameters for mechanistic-empirical models. However, dynamic modulus obtained from DM test can hardly reveal permanent deformation of HMA mixture, since the deformation measured in this test is mainly elastic and viscoelastic deformations that both are recoverable. Therefore, the RL test, which shows great potential for assessment of rutting-resistant performance of HMA mixtures, could be used as a supplement to the HWTT test.

The conventional indicators proposed based on RL test [15], including flow number (FN), strain rate and accumulated strain at FN, are widely used to evaluate the rutting-resistant potential of asphalt mixture. However, some researchers [16,17] concluded that due to the influences of mathematical model, data processing, variability between duplicates, and test error, the coefficient of variation of FN could be up to 81%. Thus, the big variability of FN often leads to inaccuracy for characterization of the HMA mixture. Walubita et al. [18] proposed a new indicator called FN index, which exhibited a better correlation with field performance data than FN, accumulated strain and strain rate. Thereafter, Yu et al. [14] used both FN index and accumulated strain to differentiate the impacts of several factors, and found FN index is better at depicting the high-temperature performances of the specimens. While Zhu et al. [19] found that strain slope of the secondary stage has a good correlation with rutting depth of the asphalt pavement. From the above, it can be seen that the validity and stability of existing indicators are uncertain and inconstant.

All the above-mentioned tests are conducted at single stress loading condition, however, the loading condition in realistic pavement is varying and complicated. In order to simulate the field loading condition as close as possible, Jiang et al. [20] developed an optional multiple repeated load (OMRL) test based on axle load spectrum of actual pavement. However, there are two drawbacks of this test. For one thing, the determination process of the number of loading cycles for each stress level is somewhat complex and requires the specific axle load spectrum of a certain pavement section, which is difficult to obtain for those without such resources. For another, although the two new indicators proposed based on the test, including least average strain rate (LASR) and multiple flow number (MFN), could distinguish different mixtures under a more realistic loading condition, they are unable to be used as mechanical parameters for rutting prediction model.

To sum up, the loading conditions for existing test methods still have room to improve, and new indicators, which can be helpful for rutting prediction, and have a reduced coefficient of variance, and offer a statistically significant differentiation of rutting-resistant performance for HMA mixtures, need to be proposed.

2. Study objective

This study explored a multi-sequenced repeated load (MSRL) test, which aims to simulate in situ loading condition by applying multiple loading sequences involving varying stress levels. The range of stress level was determined according to the actual axle load spectrum of Yanjiang highway in Jiangsu Province in China. The average strain rates (ASR) under various stress levels could be derived from the creep curve of MSRL test without testing too many specimens, so that the rutting-resistant performance between different mixtures can be compared at various stress levels, rather than at only one stress level as RL test. The SMA-13, AC-13 and AC-20 mixtures with two SBS modified asphalt binders were investigated in this study. The impacts of different loading orders and different stress levels on permanent deformation were analyzed. Moreover, analysis of variance for both newly proposed indicators from MSRL test and conventional indicators from RL test were carried out and compared.

3. Test design and materials

3.1. Mixture design

For highways constructed a decade ago in Jiangsu Province, SMA13, AC-13 and AC-20 mixtures with styrene-butadienestyrene (SBS) polymer modified asphalt binder of PG70-22 were frequently for top and middle asphalt layers. In order to further minimize pavement rutting, SBS modified asphalt of PG76-22, which is considered to have better rutting-resistant potential, has been more and more used instead of PG70-22 for construction and maintenance in recent years. Therefore, SMA13, AC-13 and AC-20 mixtures with these two binders were chosen for investigation.

The aggregate gradations for these mixtures were designed the same as those for asphalt layers of Yanjiang highway in Jiangsu Province, as exhibited in Fig. 1. The aggregates used for fabrication were basalt for SMA-13 and limestone for both AC-13 and AC-20. The crushed limestone powder, with size under 0.075 mm, was used as mineral filler. According to Superpave volumetric design for hot-mix asphalt, for both PG70 and PG76 binders, the optimal asphalt content was determined as 5.9% for SMA-13, 4.8% for AC-13 and 4.4% for AC-20. In addition, lignin fiber, accounting for 0.3% of the total weight of specimen, was added only for SMA-13 mixture during fabrication process in order to enhance stability.

The cylindrical specimens with 150 mm in diameter and 180 mm in height were firstly fabricated by the Superpave gyratory compactor (SGC). Then they were cored and cut to obtain smaller ones with 100 mm in diameter and 150 mm in height for tests in this study. The target air void content for all specimens tested was controlled within 4.0 ± 0.5%.

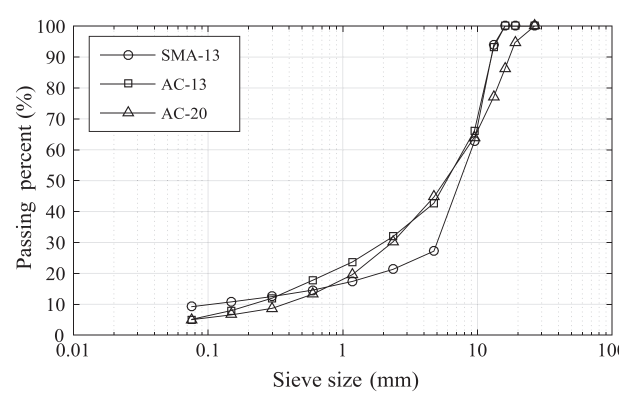

Fig. 1. Gradations for mixtures investigated in this study.

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