Construction and Building Materials 111 (2016) 644–651

Contents lists available at ScienceDirect

Construction and Building Materials

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

Relating asphalt binder elastic recovery properties to HMA crack modeling and fatigue life prediction

Jun Zhang [a,*], Geoffrey S. Simate [b], Sang Ick Lee [c], Sheng Hu [c], Lubinda F. Walubita [c,d,e]

[a] Department of Civil Engineering, Texas A&M University, College Station, TX 77843, USA
[b] University of the Witwatersrand, Johannesburg, P/Bag 3, Wits 2050, South Africa
[c] Texas A&M Transportation Institute (TTI) – The Texas A&M University System, College Station, TX 77843, USA
[d] Iliso (Z) Consulting Engineers Ltd, Lusaka, Zambia
[e] Transportation Research Center, Wuhan Institute of Technology, Wuhan, China

HIGHLIGHTS

- Binder elastic recovery is hypothesized to play a significant role in the fatigue cracking resistance.
- Two standardized tests are used to characterize binder elastic recovery properties.
- Two laboratory tests are used to characterize HMA properties of stiffness and fracture.
- HMA with high binder elastic recovery properties (⩾59%) has a long M-E predicted fatigue life.
- No clear trend is observed in predicted fatigue life for HMA with low elastic recovery (<59%).

ARTICLE INFO

Article history:
Received 11 November 2015
Received in revised form 4 February 2016
Accepted 23 February 2016
Available online 21 March 2016

Keywords:
Asphalt binder
Elastic recovery
MSCR
HMA
Cracking
Fracture properties
Fatigue life
Mechanistic-empirical (M-E)
TxME

ABSTRACT

Fatigue cracking is one of the major distresses occurring in hot-mix asphalt (HMA) pavements, which is a consequence of accumulation of damage under repeated load applications and changes in the environmental conditions. HMA is predominantly composed of aggregates and asphalt binder, where the latter plays a significant role in the HMA fatigue performance. The elastic recovery of asphalt binders is one of the characteristic properties that are hypothesized to play a significant role in the fatigue cracking resistance of HMA pavements. In this study, the relationships between the asphalt binder elastic recovery properties and the HMA fatigue performance were comparatively investigated. Two asphalt binder tests, namely the elastic recovery (ER) and multiple stress creep recovery (MSCR) tests were conducted to comparatively characterize the asphalt binder elastic recovery properties in the laboratory, and their results were then correlated to the predicted HMA fatigue life based on the TxME modeling software, which was subsequently validated with other laboratory test results and field performance data. Eleven typical Texas HMA mixes collected from different construction sites were used for the study. Overall, the results indicated that HMA mixes with high asphalt binder elastic recovery properties (⩾59%) exhibited better cracking resistance potential with long predicted fatigue life (>150 months), which was also consistent with other studies and field performance observations. For mixes with low elastic recovery properties (<59%), there is no clear correlation with the predicted fatigue life.

1. Introduction

Fatigue cracking is one of the major distresses occurring in hot-mix asphalt (HMA) pavements, which is a consequence of accumulation of damage under repeated load applications [1]. HMA is predominantly composed of aggregates and asphalt binder, where the latter plays a significant role in the HMA fatigue performance.

Superpave Performance Grade (PG) specification addresses the asphalt binder property related to HMA fatigue performance by measuring a parameter $G^* \sin\delta$ at intermediate temperatures, where G^* and δ are the complex shear modulus and phase angle, respectively. However, this parameter was initially and primarily developed for non-modified asphalt binders [2]. With the current wide spread usage of modified asphalt binders, it is now becoming a challenge to effectively relate and quantify the expected HMA mix fatigue performance using the $G^* \sin\delta$ parameter. Thus, this study was undertaken to investigate alternative asphalt binder

* Corresponding author.
E-mail address: j-zhang@tamu.edu (J. Zhang).

http://dx.doi.org/10.1016/j.conbuildmat.2016.02.175
0950-0618/

properties relative to the HMA fatigue performance, namely the asphalt binder elastic recovery property.

Polymer modified asphalt binders are widely used in HMA pavements, and one of the major improvements in these modified asphalt binders is the elastic recovery property, which is the degree to which an asphalt binder recovers to its original shape after release of the loading application. It is hypothesized that greater propensity to elastic recovery is desirable in HMA pavement to increase the fatigue cracking resistance performance [2]. Few studies have been conducted to investigate the relationship between the asphalt binder elastic recovery property and HMA fatigue characteristics [2].

Based on the aforementioned discussions, this study was initiated to investigate the relationship between the asphalt binder elastic recovery properties and HMA fatigue performance. To achieve this objective, two asphalt binder tests, namely elastic recovery (ER) and multiple stress creep recovery (MSCR); and two HMA performance tests, namely the, Dynamic Modulus (DM) and OT fracture test, were conducted [3–6]. The corresponding laboratory test results were then used to predict HMA fatigue life based on mechanistic-empirical (M-E) modeling with the Texas Mechanistic-Empirical (TxME) Flexible Pavement System software, which was subsequently validated with field performance data. Overall, this study was initiated to address the following three questions:

(1) What is the relationship between ER and MSCR results for measured asphalt binder elastic recovery property?
(2) What is the relationship between asphalt binder elastic recovery property and asphalt mixture stiffness?
(3) What is the relationship between asphalt binder elastic recovery property and HMA fatigue performance?

2. Experimental plan

Fig. 1 presents a schematic of the laboratory tests and the experimental research plan that was employed in this study. Two standardized asphalt binder tests, namely the ER and MSCR tests and two HMA performance tests including the DM and OT fracture were conducted. As illustrated in Fig. 1, the DM and OT fracture tests also provided input data for the M-E modeling with the TxME software in addition to characterizing the fundamental HMA properties such as modulus and fracture properties.

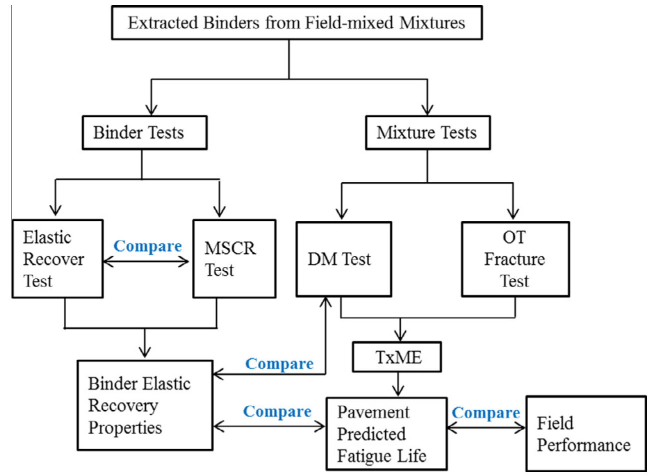

Fig. 1. Schematic illustration of the laboratory tests and experimental plan.

3. Laboratory test methods

This section presents details of the laboratory tests employed in this study and includes the ER, MSCR, DM and OT fracture tests.

3.1. The ER test

The elastic recovery test was performed in accordance with AASHTO T301 using a ductilometer and briquette specimens shown in Fig. 2 [3]. The specimens were conditioned in a water bath at 25 °C for one hour. The test was displacement-controlled and the asphalt binder specimens were pulled apart at a constant speed of 5 cm/min to an elongation of 20 cm, and held for 5 min. Then, a cut was made in the middle of the specimen and allowed them to remain in the ductilometer for recovery. After one hour, the percent elongation recovery was determined using the following equation:

$$\%\ \text{elongation} = \frac{20 - x}{20} \times 100 \tag{1}$$

where x = final reading in centimeters after bringing the two severed ends of the specimen back together [3].

3.2. The MSCR test

The MSCR test is creep and recovery test performed on an asphalt binder sample using the Dynamic Shear Rheometer (DSR) in accordance with AASHTO TP 70-10 [4]. The asphalt binder sample was 25 mm in diameter and 1 mm in thickness. The test was conducted at the high working temperature of the asphalt binder, which was controlled by the use of a water bath in the DSR machine setup. For each cycle, a Haversine shear load was applied to the sample for 1 s, followed by a 9-second rest period. Two stress levels of 0.1 kPa and 3.2 kPa were applied successively, and a total of 10 cycles were conducted for each stress level. A typical MSCR test results with two applied stress levels are shown in Fig. 3. As observed from the figure, the MSCR test characterizes the recovery properties of the asphalt binder under the shear creep load, which is the percent recovery.

3.3. The DM test

Unconfined DM testing is an AASHTO standardized test method used for characterizing the stiffness, measured in terms of the dynamic complex modulus ($|E^*|$), and visco-elastic properties of HMA mixes (AASHTO TP62-03) [6]. The DM is a stress-controlled test involving application of a repetitive sinusoidal dynamic compressive axial load (stress) to an unconfined HMA specimen over a range of different temperatures (i.e., −10, 4.4, 21.1, 37.8 and 54.4 °C) and loading frequencies (i.e., 0.1, 0.5, 1, 5, 10, 25 Hz) for each temperature. The typical parameter that results from the DM test is the $|E^*|$, which was computed as:

$$|E^*| = \frac{\sigma_0}{\varepsilon_0} \tag{2}$$

where σ_0 is the compressive axial stress and ε_0 is the corresponding compressive axial resilient strain. For graphical analysis and easy interpretation of the DM test data, $|E^*|$ master-curves were also generated as a function of the loading frequency using the Pellinen et al.'s [7] time-temperature superposition sigmoidal model shown in Eqs. (3) and (4):

$$\log|E^*| = \delta + \frac{\alpha}{1 + e^{\beta - \gamma \log(\xi)}} \tag{3}$$

$$\log(\xi) = \log(f) + \log(a_T) \tag{4}$$

where ξ is the reduced frequency (Hz), δ is the minimum $|E^*|$ value (MPa), α is the span of $|E^*|$ values, and β and γ are shape parameters. Parameters f and a_T are the loading frequency and temperature shift