Construction and Building Materials 133 (2017) 39–50

Contents lists available at ScienceDirect

Construction and Building Materials

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

Mechanistic performance evaluation of pavement sections containing RAP and WMA additives in Manitoba

Dahae Kim [a,*], Amirhossein Norouzi [b], Said Kass [c], Tara Liske [c], Y. Richard Kim [a]

[a] Dept. of Civil, Construction, & Environmental Engineering, North Carolina State University, Campus Box 7908, Raleigh, NC 27695-7908, United States
[b] Pavement Services Inc., 6026 NE 112th Avenue, Portland, OR 97220, United States
[c] Materials Engineering Branch, Manitoba Infrastructure & Transportation, Canada

HIGHLIGHTS

- Evaluation of WMA and RAP mixtures in MIT pavement sections.
- The fatigue and rutting characterization of asphalt mixtures with dynamic modulus, S-VECD, and TSS tests.
- Performance prediction of MIT pavement sections using LVECD structural analysis program.
- Comparisons of the field performance and the predicted performance from LVECD analysis.

ARTICLE INFO

Article history:
Received 14 October 2015
Received in revised form 22 November 2016
Accepted 10 December 2016

Keywords:
Asphalt pavement
RAP
WMA
Fatigue cracking
Rutting
TSS test
S-VECD test
LVECD program

ABSTRACT

Over recent decades, the utilization of reclaimed asphalt pavement (RAP) and warm mix asphalt (WMA) in mixtures has increased dramatically due to the environmental and economic advantages of these materials. This paper presents the fatigue and rutting characterization of mixtures that contain RAP and/or WMA obtained from Manitoba in Canada. In addition to mechanical testing, numerical simulations of the fatigue cracking and rutting performance of the pavement sections were performed, and the results were compared to field observations. The results obtained from the Layered Viscoelastic pavement analysis for Critical Distresses (LVECD) program and from the field measurements show good agreement, thereby indicating that the LVECD program is able to predict reasonable pavement performance for the RAP and WMA mixtures. The field performance and the predicted performance were used to evaluate the effects of RAP and/or WMA additives on the fatigue cracking and rutting performance of the mixtures.

1. Introduction

RAP is considered a viable alternative to virgin materials because it reduces the need for both virgin aggregate and the amount of new asphalt binder, which is the most expensive component in asphalt concrete [1–4]. RAP has become an increasingly attractive material to state highway agencies because asphalt binder costs have increased over the last few years. It has been shown that the performance of pavements that contain up to 20% RAP is similar to that of pavements composed of virgin materials with no RAP [5–7]. However, state transportation departments have expressed concern over the lack of available information regarding the use of high percentages (i.e., higher than 20%) of RAP in mixtures and the subsequent pavement performance [8,9]. This concern originates from the fact that the addition of RAP to a virgin mixture increases the stiffness of the mix because the aged binder that is used in RAP mixtures makes the mixtures stiffer and more brittle than non-RAP mixtures. In short, RAP has both advantages and disadvantages that must be considered for its appropriate usage as a paving material.

WMA represents an emerging group of technologies for the asphalt industry. Several WMA technologies are being used at present, including foaming, organic, and chemical additives. WMA allows the producers of asphalt pavement material to lower the temperature at which the asphalt mixtures are produced and placed on the road [10,11], which serves to conserve energy and thus reduce production costs. However, because the production

* Corresponding author.
E-mail addresses: dkim15@ncsu.edu (D. Kim), amir@psipdx.com (A. Norouzi), said.kass@gov.mb.ca (S. Kass), tara.liske@gov.mb.ca (T. Liske), kim@ncsu.edu (Y.R. Kim).

http://dx.doi.org/10.1016/j.conbuildmat.2016.12.035
0950-0618/

temperature of WMA is lower than that used for traditional asphalt, the degree of binder oxidation is less than for hot mix asphalt (HMA), which can result in less resistance to permanent deformation. In fact, numerous laboratory studies indicate that most WMA technologies decrease rutting resistance [12,13]. Thus, despite their environmental and economic benefits, both RAP and WMA have elicited some concerns and require further study.

Therefore, based on the aforementioned concerns and information, the purpose of this paper is to evaluate the fatigue and rutting performance of RAP and WMA mixtures via laboratory characterization tests, predict the amount of pavement distresses using the Layered Viscoelastic pavement analysis for Critical Distresses (LVECD) program, and compare the predictions with the field observations. The mixtures and field performance data used in this study were collected from Manitoba Infrastructure and Transportation (MIT) sections. These MIT sections contain mixtures that are composed of RAP, WMA technologies, and a combination of RAP and WMA.

2. Models and test methods

In this study, the fatigue cracking and rutting performance of asphalt mixtures was modeled using the simplified viscoelastic continuum damage (S-VECD) model and the shift model, respectively. These material models were implemented into the LVECD program for the pavement performance simulations.

Three main tests were performed in this study using an Asphalt Mixture Performance Tester and Material Testing System to characterize the material models: (1) the dynamic modulus test to determine the linear viscoelastic characteristics following AASHTO T342 [14], (2) the cyclic direct tension test for the S-VECD model following AASHTO TP107 [15], and (3) the TSS test to characterize the shift model [16]. The material and pavement models and the test methods for the characterization of the material models are described in the following subsections.

2.1. Dynamic modulus testing for linear viscoelastic characterization

HMA is well known as a linear viscoelastic material at small strains, which means that this viscoelastic material has both viscous and elastic properties. The dynamic modulus ($|E^*|$) can be defined by measuring a specimen's stress-strain relationship under continuous sinusoidal loading at different frequencies and different temperatures. In this study, dynamic modulus tests were performed in load-controlled mode in axial compression in accordance with AASHTO T342 [14]. Tests were completed for all the MIT study mixtures at 4 °C, 20 °C, 40 °C, and 54 °C and at frequencies of 25, 10, 5, 1, 0.5, and 0.1 Hz. The load levels were specified by trial and error so that the strain amplitudes were between 50 and 75 microstrains to prevent damage to the specimens [17]. The testing was conducted from low to high temperatures and from high to low frequencies in order to minimize damage to the specimens.

2.2. S-VECD model and cyclic direct tension test

The viscoelastic continuum damage (VECD) model is a well-known continuum damage mechanics-based model that has been applied effectively to predict the performance of asphalt concrete mixtures under different modes of loading. The primary material property determined in the VECD model is the so-called damage characteristic curve (DCC). Underwood et al. [18] developed a simplified version of the VECD model, i.e., the S-VECD model, in which the DCC is characterized from cyclic direct tension tests in an efficient manner. Later, Sabouri and Kim [19] developed an energy-based criterion that allows the prediction of the fatigue failure of a mixture from the results obtained from the S-VECD cyclic direct tension tests. According to this failure criterion, as damage grows, the material loses its maximum stored pseudo strain energy, which reflects the material's ability to store energy at that particular time. The difference between the current stored maximum pseudo strain energy and the corresponding undamaged state is referred to as the *total released pseudo strain energy*. The rate of change of the averaged released pseudo strain energy values throughout the history of the fatigue test is denoted as G^R. It has been shown that the G^R and fatigue life (N_f) are highly correlated, because the faster the damage accumulates, i.e., releasing higher amounts of energy during fewer numbers of cycles, the more quickly the material should fail. Details regarding the S-VECD model tests and the G^R failure criterion can be found elsewhere [19–21].

In summary, the works of Underwood et al. [18] and Sabouri and Kim [19] have resulted in the S-VECD model that is composed of the DCC and the G^R-based failure criterion. The DCC defines how damage evolves as the material is loaded, and the G^R-based failure criterion defines when the failure occurs.

The S-VECD model has several advantages over existing fatigue cracking models, and it is worth mentioning a couple of these strengths in this paper. First, both the DCC and the energy-based failure criterion are independent of temperature, stress/strain amplitude, loading frequency, and mode of loading. This independency feature of the S-VECD model allows the determination of the mixture's fatigue cracking performance at different temperatures, different stress/strain amplitudes, different loading frequencies, and different modes of loading from only a few cyclic tests using three to four strain amplitudes at a single temperature, thus reducing the testing time dramatically. Second, the S-VECD model is based on the material's constitutive relationship; therefore, it allows seamless integration into a mechanistic pavement model for pavement performance predictions.

S-VECD cyclic direct tension tests were performed at 10 Hz under three different strain amplitudes (high, medium, and low) in such a way to create a spread of number of cycles to failure (N_f) within ranges of less than 5000, between 5000 and 25,000, and more than 25,000 cycles, according to AASHTO TP107 [15]. In order to minimize the effects of viscoplasticity, AASHTO TP 107 suggests using the PG designation of the base binder to determine the proper test temperature, as shown in Eq. (1).

$$T\ (^\circ\mathrm{C}) \leqslant \frac{\textit{High temperature binder PG grade} + \textit{Low temperature binder PG grade}}{2} - 3 \leqslant 19\,^\circ\mathrm{C} \quad (1)$$

Also, fingerprint dynamic modulus tests were conducted to check for sample-to-sample variability before running the cyclic direct tension tests. The dynamic modulus value measured from this test is specified as $|E^*|_{fingerprint}$ and was used to calculate the dynamic modulus ratio (DMR) via Eq. (2). $|E^*|_{LVE}$ is the linear viscoelastic dynamic modulus value of the material at the particular temperature and frequency of the test. A DMR value in the range of 0.9–1.1 guarantees that the linear viscoelastic properties obtained from the dynamic modulus tests can be used effectively in S-VECD analysis.

$$DMR = \frac{|E^*|_{fingerprint}}{|E^*|_{LVE}} \quad (2)$$