Construction and Building Materials 188 (2018) 88–100

Contents lists available at ScienceDirect

Construction and Building Materials

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

Viscoelastic characterization of aged asphalt mastics using typical performance grading tests and rheological-micromechanical models

A. Tanakizadeh, Gh. Shafabakhsh [*]

Faculty of Civil Engineering, Semnan University, Semnan, Iran

HIGHLIGHTS

- The asphalt mastics VE properties were estimated using micromechanical models.
- The DSR and BBR results of mastics show a good consistency based on Wicket plots.
- The 4-phase model shows the most accurate predictions of VE properties of mastics.
- The proposed rheological-micromechanical method presented rational predictions.
- The proposed method shows the rational results when compared with 2S2P1D model.

ARTICLE INFO

Article history:
Received 24 May 2018
Received in revised form 16 July 2018
Accepted 9 August 2018

Keywords:
Viscoelastic characteristics
Micromechanical models
Aging
Asphalt mastic
Recycled asphalt
Performance grading
Master curve

ABSTRACT

The performance grading (PG) tests use aged asphalt specimens to simulate the in situ performance of asphalt binder. The main purpose of this study is to examine the existing micromechanical models, such as the inverse rule of mixtures, Hashin-Shtrikman, generalized self-consistent scheme (GSCS), and 4-phase, to determine the dynamic shear modulus of aged asphalt mastics. The Wicket and the vGP (van Gurp-Palmen) plots were advisable tools for checking the PG test results consistency and Time-Temperature superposition principle validation on three different asphalt mastics. The generalized logistic sigmoidal model (GLSM) yielded well-fitted master curves of modulus and phase angle based on the models' predictions for full linear viscoelastic (LVE) characterization. The 4-phase model had the best modulus predictability even better than the well-known 2S2P1D (2 Spring-2 Parabolic element-1 Dashpot) model that followed by the inverse rule of mixtures, Hashin-Shtrikman, and GSCS models. All of the models had an excellent phase angle predictability that was comparable with 2S2P1D model predictions. It is recommended to combine the typical PG tests of asphalts, a well-defined micromechanical model like 4-phase, and a well-known rheological master curve model such as GLSM for estimating the LVE properties of asphalt mastics promisingly.

1. Introduction

Asphalt concrete as a three-phase system consists of coarse aggregates, mastic, and air voids. The mastic is a blend of asphalt and mineral filler (smaller than 75 μm) that binds larger aggregates in the composite. The mastic properties affect the stress development and performance of the asphalt concrete at high, intermediate, and low temperatures as well as workability of it [1].

The asphalt binder and its mastic have a linear viscoelastic (LVE) nature in a range of temperatures that they experience in the field, from subzero temperatures in which thermal cracking is a predominant distress to high temperatures where rutting is a prevalent issue, and under small-strain loading conditions [2–4]. The performance grading (PG) system uses LVE properties such as dynamic modulus and phase angle to determine asphalt binder behavior under different environmental conditions. The materials are conditioned using rolling thin film oven (RTFO) (AASHTO T240) and pressure aging vessel (PAV) (AASHTO R28) to simulate how they will perform early in life during production and compaction and after 5–7 years, respectively. Besides, many models for prediction of the asphalt mastic properties have developed based on unconditioned materials. Among them, the micromechanical models have attracted the researchers for determining LVE parameters due to their mechanistic context and relating bulk behavior of material to properties of its constituents. Since the PG tests evaluates the RTFO-aged and PAV-aged asphalt, we can use

---

[*] Corresponding author at: Faculty of Civil Engineering, Semnan University, Semnan 35131-19111, Iran.

E-mail address: ghshafabakhsh@semnan.ac.ir (Gh. Shafabakhsh).

https://doi.org/10.1016/j.conbuildmat.2018.08.043

the results of routine PG tests (DSR and BBR tests) in a range of frequencies (e.g. 0.1–10 Hz) to model the behavior of asphalt mastic in close to the field conditions either after laying down or in service stage after 5 or more years. The main purpose of this study is exploring some micromechanics-based models to characterize LVE properties of asphalt mastics in close to the field conditions. To reach the main goal, the following objectives must be fulfilled:

1. Determining LVE properties of the aged asphalt binders and mastics using the PG test procedures at some loading frequencies
2. Examining the test results consistency and Time-Temperature superposition principle application
3. Exploring the micromechanical models for prediction of the aged mastics modulus
4. Constructing the master curves of asphalt mastics modulus by fitting a well-known rheological model and reaching rational phase angle values
5. Evaluating the models predictability through statistical analysis and cross-plots.

The verified models can be applied for characterizing asphalt mastics using only typical PG tests of asphalt binders at selected loading frequencies. Except verification of some micromechanical models using the aged asphalt binders and mastics that expands application of these models, this study combines a well-known logistic sigmoidal model with different micromechanical models to overcome the deficiencies of the micromechanical models in predicting phase angle values. Moreover, the models are verified using only typical PG tests results in a limited range of frequencies. Therefore, the procedure can be accomplished easily in every asphalt laboratory equipped with DSR and BBR. It is only necessary that the PG tests be carried out at some loading frequencies other than typical 10 rad/s (1.59 Hz).

The following section presents a literature review about asphalt mastics characterization and the micromechanical models used for predicting asphalt composites LVE properties. It followed by materials and methods used in this study and discussion of the results.

2. Background

2.1. Asphalt mastic characterization

The asphalt mastic behavior affects the asphalt mixture performance from mix design and compaction stage until many years after laying down and service in different field conditions. The LVE properties of asphalt mastic like dynamic shear modulus and phase angle influence the performance of asphalt concrete under various encountered conditions [5]. Many studies explored characterization of the mastics and evaluated the effects of mastic on asphalt concrete [2–4,6–12]. They consist of mechanical [6,8], linear and non-linear rheological [3,4,11,12], and multiscale characterization [9] of asphalt mastics. In addition, researchers have investigated the low temperature [13,14], fatigue [15,16], and rutting [17,18] performance of asphalt mastics as well as damage and fracture properties [19,20] of them.

Asphalt mastic is a blend of asphalt binder and filler (aggregates pass #200 sieve). The filler particles are dispersed in an asphalt binder matrix, and the overall behavior of the mastic is changed respect to asphalt binder. This change can be seen on LVE properties and performance related parameters of mastics such as accumulated permanent deformation and fatigue life. Therefore, a group of studies has focused on the effects of filler properties on asphalt mastic LVE characteristics and performance. The volume concentration, particle size distribution, air voids content, and chemical composition are some of the filler properties influenced asphalt mastic behavior [1,21–26].

A bit of work has been done to examine the effect of aging on the properties of the mastic. In a laboratory study with mastics, Moraes and Bahia [27] investigated effects of the mineral fillers on stiffness and glass transition temperature of PAV-aged asphalt binder. The results showed that a selected filler concentration and mineralogy type might reduce the oxidative aging of asphalt binder. Liu et al. have studied the effects of aging on rheological properties of asphalt mastic and asphalt-filler interaction ability. The aging improved the cohesion properties of asphalt mastics and the rutting resistance of them. The low-temperature properties of asphalt mastic were decayed with an increase in aging degree [28]. Mazzoni et al. have investigated the fatigue and self-healing properties of asphalt mastics containing aged polymer modified binders. Regardless of the filler concentration in the mastic, the aged polymer modified asphalt added to the mastics increased the fatigue endurance limit of asphalt mastics [29].

The researchers have proposed different modeling procedures to analyze the LVE properties and performance of asphalt mastics under various conditions and without conducting expensive and time-consuming laboratory tests on them. The numerical implementation of LVE model of asphalt mastics using finite element model (FEM) [30,31] and discrete element model (DEM) [32,33] methods and evaluation of damage in mastics through continuum mechanics and micromechanics [34,35] are some of the studies in this field.

Some of studies [36,37] employed the rheology-based models such as Nielsen and Nielsen-modified Kerner's equations for investigating the stiffening effects of mineral fillers in asphalt mastics. The models predicted the modulus of asphalt mastics as a function of filler volume fraction. The generalized Einstein coefficient (K_E) was an indicator of physiochemical effects between asphalt binder and filler particles that was contributed to stiffening mechanism. Since a single volume fraction of filler is used in the present work, this type of models cannot be employed to reach the intended purpose of this study in spite of rational results have been shown in the literature. In addition, the rheology-based models do not consider the effects of constituents' properties well, while the micromechanical models take into account the filler and binder properties. Based on the scope of the present study, we describe some of the micromechanical models in next section.

2.2. Micromechanical models

The researchers have studied the mechanical performance of asphalt mixtures and mastics based on micromechanical modeling. Their studies cover a range of models from simple relationships derived from the rule of mixtures to complex ones implemented using numerical methods.

Buttlar et al. applied a plain form of generalized self-consistent scheme model to predict the reinforcement mechanisms of fillers in the mastics. The mastics were prepared with a viscosity graded AC-20 asphalt binder and four types of filler with volume fractions of 0.05, 0.15, 0.25, and 0.40. The GSCS model showed reasonable results in predicting the reinforcement levels of the asphalt mastics [5]. Shashidhar and Shenoy used a simplified form of Christensen and Lo model to describe the dynamic mechanical behavior of asphalt mastics. One asphalt binder type and four types of filler were mixed with filler volume contents of 6% to 31% of the mastic. The test results obtained from Dynamic Shear Rheometer (DSR) measurements were at a single temperature and loading frequency. The simplified model predicted the stiffening ratios independent of the asphalt binder stiffness [38]. Kim and Little characterized LVE properties of asphalt mastics using DSR test results, Hashin model, and Christensen & Lo micromechanical