Construction and Building Materials 188 (2018) 68–87

Contents lists available at ScienceDirect

Construction and Building Materials

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

Development of a national database of asphalt material performance properties in support of perpetual pavement design implementation in Australia

Saeed Yousefdoost [a,*], Erik Denneman [b], Andrew Beecroft [a], Binh Vuong [c]

[a] Australian Road Research Board (ARRB), Australia
[b] Australian Asphalt Pavement Association (AAPA), Australia
[c] Swinburne University of Technology, Australia

HIGHLIGHTS

- Mechanical properties for 28 dense-graded Australian asphalt mixes are characterised.
- Rheological properties of the asphalt mixes' binder constituents are characterised.
- This database facilitates the introduction of the FEL concept in Australia.
- It will also result in a pavement-specific estimate of damage accumulation over time.

ARTICLE INFO

Article history:
Received 17 March 2018
Received in revised form 13 August 2018
Accepted 14 August 2018

Keywords:
Asphalt mix mechanical properties
Dynamic modulus
Binder rheological properties
Complex shear modulus
Phase angle

ABSTRACT

There were concerns in the Australian industry that the current pavement design procedure was producing excessively conservative asphalt thicknesses. One of the barriers to producing a new design method is that there is limited data on the material characteristics of asphalt mixes. The Australian Asphalt Pavement Association (AAPA) initiated the Asphalt Pavement Solution for Life (APS-fL) project in 2010 to address this gap. This paper presents the outcomes of the first phase of the project in which a database of mechanical properties for 28 typical dense-graded Australian asphalt mixes was established, along with rheological properties of their binder constituents. Dynamic modulus tests were carried out on the asphalt mixes at various temperatures, loading frequencies, and confinement pressures. Virgin, Rolling Thin Film Oven aged (RTFO-aged), mastic and recovered binders were also tested for their rheological properties in the Dynamic Shear Rheometer. In this paper, the mechanical behaviour database on asphalt mixes has been presented in the form of sets of master curves and shift factors' fitting parameters at all levels of confinement pressure. The binder rheological properties are expressed in terms of viscosity A-VTS charts as well as complex shear modulus and phase angle master curves and fitting parameters. The established database can be used in mix-specific pavement design approaches. It also facilitates implementation of the perpetual pavement design concept in Australia.

1. Introduction

In 2011, the Australian Asphalt Pavement Association (AAPA) initiated the Asphalt Pavement Solution for Life national project (APS-fL) to address the industry concerns that current pavement design procedures were producing overly conservative asphalt thickness requirements. It was believed that part of the problem was the use of unrealistic material properties due to limited data on the material characterisation of Australian asphalt mixes [1,2].

In the existing Australian pavement design approach, asphalt moduli are considered to be lower at elevated temperatures, which in turn will result in greater strain levels even in thick asphalt pavements. This will result in greater thickness requirements for asphalt layers in hot climates. Several studies have highlighted the consequences of this approach including [3,4]. This theory is also backed by little to no evidence of fatigue damage on thick asphalt pavements across regions with hot climate in Australia [4,5].

* Corresponding author at: Future Transport Infrastructure, Australian Road Research Board (ARRB), 21 McLachlan St, Fortitude Valley, QLD 4006, Australia.
E-mail address: saeed.yousefdoost@arrb.com.au (S. Yousefdoost).

https://doi.org/10.1016/j.conbuildmat.2018.08.078
0950-0618/

The other shortcoming of the current pavement design model is that the asphalt modulus is calculated at a single design temperature (Weighted Mean Annual Pavement Temperature) [6]. There is also no link between the traffic speed and the pavement response. A valid reason for the approach is the lack of reliable and long-term monitoring of pavement performance.

The characterisation of asphalt material properties across the full range of temperatures and loading speeds experienced by a pavement is expected to improve the accuracy of predicting the response of a pavement to loading and subsequent performance. Furthermore, by linking this database to the Fatigue Endurance Limit (FEL) of the pavement, the perpetual pavement concept can be introduced to Australia. The result of this would be that the maximum thickness of asphalt could be determined beyond which any increase in design thickness will result in little to no increase in structural capacity of the pavement [7]. It is anticipated that many pavements around Australia will subsequently be constructed at reduced thickness and with less conservatism.

In recent years, the potential to make improvements to the existing asphalt pavement design procedure has been highlighted [4]. One of the nominated areas for improvement includes producing pavement specific estimate of damage accumulation over time. This is achieved by combining realistic material characteristics as functions of traffic distributions and climatic inputs such as the pavement temperature. In the United States in particular, similar approaches have been more widely implemented as part of a more sophisticated pavement design methodology as outlined in the Mechanistic-Empirical Pavement Design Guide [8]. The first phase of the APS-fL project was to establish a national database of mechanical properties of typical Australian asphalt materials most commonly used in major projects. This aspect was accomplished with the intent of developing a framework for initiating and introducing the concept of perpetual pavement design into the Austroads Mechanistic-Empirical Design procedures. To establish this database, dynamic modulus testing was chosen to best characterise the mechanical behaviour and performance properties of the asphalt mixes, as it has gained recent worldwide acceptance for characterising asphalt mixes across the full temperature and frequency range. In addition, dynamic modulus testing will enable the development of master curves which will enable linking of the Australian mix characterisation with international research.

Dynamic modulus ($|E^*|$) is a fundamental property of asphalt mixes, which is required as a material input in most mechanistic-empirical pavement design systems. As a result of the National Cooperative Highway Research Program (NCHRP) project 9–19 [9–11] and project 9–29 [12–15], the Asphalt Materials Performance Tester (AMPT), formerly known as the Simple Performance Tester (SPT), was developed to measure dynamic modulus and evaluate the performance of Superpave HMA mixes in the US [9].

To characterise the rheology of the binder constituent of the asphalt mixes, binders were tested for their complex shear modulus, phase angle and complex viscosity in the Dynamic Shear Rheometer (DSR). The DSR is capable of quantifying linear viscoelastic properties of the binder which makes it well suited for characterising binders across the in-service pavement temperature range [16].

A number of asphalt material performance property databases are already available in the literature, but nearly all of them have been developed for the US asphalt mixes, thus, there is concern about whether the US developed asphalt material databases are applicable to the Australian asphalt design framework. Some of these databases include Witczak, Federal Highway Administration (FHWA), North Carolina Department of Transportation (NCDOT), Western Research Institute (WRI), Citgo, North Carolina State University (NCSU), and the Long-Term Pavement Performance (LTPP) project. Details on the material properties and specification of these databases can be found elsewhere [17–24].

This paper presents a mechanical property database established for 28 typical Australian asphalt mixes in order to support the implementation of the perpetual pavement concept in Australia. It also intends to provide researchers, for the first time, a comprehensive database of performance properties of typical Australian asphalt mixes and their binder constituents. An extensive suite of laboratory testing was carried out to establish this database which is the largest of its kind in Australia to date. The scope of the experimental work and laboratory characterisation tests included dynamic modulus and volumetric tests on asphalt mixes, and DSR tests on the constituent binders for 28 individual asphalt mixes.

2. Materials and methods

2.1. Experimental plan

This study focused on establishing a database of mechanical properties for 28 standard dense graded asphalt materials produced by Australia's leading asphalt producers. The asphalt samples consisted of 15 mixes with Nominal Maximum Aggregate Size (NMAS) of 14 mm and 13 mixes with NMAS of 20 mm. The asphalt samples were carefully selected and nominated to make sure that the samples covered the spectrum of Australia's most commonly used asphalt materials in major projects (including aggregates and binders). Details of the aggregate type and gradation, binder type and content, mix design method, compaction efforts, RAP content, filler type and content and volumetric properties of 14 and 20 mm mixes are presented in Tables 1 and 2 respectively.

In AAPA's proposed perpetual pavement design procedure, dynamic modulus of the asphalt is taken into account as an input into the design process, therefore the main focus of this study was measuring and establishing master curve parameters for dynamic modulus values of the mixes. The asphalt phase angles were only recorded as supplementary data for future investigations.

The research methodology and experimental plan adopted in this study is outlined in Fig. 1. Asphalt suppliers in this study were asked to provide their asphalt product, binder, and filler constituent of their mixes separately. Asphalt mixes were then tested in the Asphalt Mixture Performance Tester (AMPT) for dynamic modulus (E^*) and phase angle (δ). Binders and fillers were tested in the Dynamic Shear Rheometer (DSR) for their complex shear modulus (G^*), phase angle (δ) and complex viscosity (η^*) in virgin, post-RTFO (in accordance with AS/NZS 2341.10:2015 standard), recovered and mastic (blend of the virgin binders and the filler component of the mixes, blended in proportions according to the job mix formula) conditions.

2.2. Sample preparation

Given the objective to model actual field performance of the nominated asphalt samples; the experiment was designed using plant-produced asphalt mixes. It was believed that these materials more closely matched the reality of asphalt produced and placed in the field. Asphalt samples were taken in loose form from plant production and were then cooled and delivered to the laboratory. Samples were coded to avoid disclosure of the mix design details of the mixes, for commercial purposes.

The mix design of the studied asphalt samples was based on two common methods currently being used in Australia: (a) Marshall mix design method (Marshall compaction) and (b) the Aus-