Construction and Building Materials 26 (2012) 552–557

Contents lists available at ScienceDirect

Construction and Building Materials

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

The properties of asphalt binder blended with variable quantities of recycled asphalt using short term and long term aging simulations

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ARTICLE INFO

Article history:
Received 1 August 2010
Received in revised form 18 May 2011
Accepted 18 June 2011
Available online 16 July 2011

Keywords:
Recycled asphalt pavement
High percentage recycled asphalt
Aging
DSR
Dynamic shear moduli
Viscosity

ABSTRACT

The objective of this paper is to characterize the rheological properties of asphalt binders blended with various amounts of asphalt extracted from a recycled asphalt pavement (RAP) mixture. Three asphalt binder aging states were simulated and evaluated: unaged, rolling thin film oven (RTFO) aged, and pressure aging vessel (PAV) aged. A Superpave PG 58-28 binder was applied as control binder and another four RAP binder percentages were studied in this research, 30%, 50%, 70% and 100%. Rotational viscosity testing was conducted with a Brookfield viscometer. Temperature and frequency sweep tests were conducted using a dynamic shear rheometer. Master curves were constructed based on the dynamic shear moduli (G^*). The results showed that there are significant differences in dynamic shear moduli (G^*) master curve performance for high percentage RAP binder blends versus virgin binders at the three aging states. Increasing RAP concentration and further aging conditions contribute to the increased stiffness and viscosity of RAP binder blends.

1. Introduction

A potential solution for the transportation industry to build economical and sustainable roadways is increasing the use of recycled asphalt pavements (RAP). National publications reporting the attempts to incorporate the Superpave™ mixture design with RAP binder blending include: NCHRP Report 452 [1], which was designed to be used as a reference to incorporate RAP materials within the Superpave™ mixture design. NCHRP Report 452 summarized current regulations and identified procedures used to determine RAP binder properties. The most significant recommendation from NCHRP Report 452 was to divide RAP binders into three tiers. These tiers are based on AASHTO standards for sufficient and adequate RAP and virgin binder blending. McDaniel and Shah in 2003 expanded the scope of NCHRP 9-12 in order to investigate RAP materials and aggregates. Their study focused on Midwest pavement materials and the effects which increased RAP materials have on asphalt mixture performance [2,3]. It was concluded that RAP blending charts were appropriate for determining RAP binder performance. McDaniel and Shah's research results were also consistent with NCHRP 9-12 results. This implicates that the stated national recommendations could apply to the Midwest RAP materials also [3]. Currently, NCHRP Project 9-46 is in the process of developing a mixture design procedure which is applicable for high RAP mixtures (>25% RAP). An outcome of the NCHRP Project 9-46 is to recommend changes in the current specifications for high RAP mixtures in order to improve high RAP mixture longevity.

To characterize recycled asphalt binders, common AASHTO standards are followed. These specifications include: no modification for RAP mixes up to 15%, one temperature grade modification for HMA mixtures containing 15–25% RAP, and for mixtures containing more than 25% RAP, a RAP blending chart for HMA mixture design would be required. National procedures for asphalt extraction and recovery for asphalt binders include: AASHTO T164 quantitative extraction of asphalt binder from hot mix asphalt (HMA), ASTM D2172 Standard Test Methods for Quantative Extraction of Bitumen From Bituminous Paving Mixtures, AASHTO T170 Recovery of Asphalt from Solution by Abson Method, ASTM D1856 Standard Test Method for Recovery of Asphalt from Solution by Abson Method and ASTM D 4887 Test Method for Preparation of Viscosity Blends for Hot Recycled Bituminous Materials. ASTM specification D4887 can be used to determine the appropriate blending proportion between virgin and RAP binders.

Al-Qadi et al. [2] conducted research characterizing mixing efficiency from RAP binders. This research quantified asphalt binder blending from various RAP binder blend percentages. The results from this investigation would be used to improve future RAP binder blending procedures. It was concluded that (1) a high mixing efficiency exists between high percentage RAP and virgin binders, (2) complete blending between RAP and virgin binders is a reasonable assumption, and (3) currently, there is not consensus standard correlating the percentage of actual blending occurring between RAP and virgin binders [2]. RAP binder mixing efficiency using chemical tracers were determined by Lee et al. [4]. Chemical dye

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doi:10.1016/j.conbuildmat.2011.06.057

Table 1
Asphalt Binder Specimen Composition (% by weight).

Asphalt binder blend	Virgin binder %	RAP binder %
Control binder	100	0
30% RAP binder	70	30
50% RAP binder	50	50
70% RAP binder	30	70
100% RAP binder	0	100

was used as a tracer in this study to measure blending dispersion efficiency for binders containing rejuvenation agents [4]. In Japan, a RAP research project observed the performance of RAP mixtures using two processing methods, (1) blending old RAP materials with HMA, and (2) heating HMA and RAP together at a plant to create the pavement mixture [5]. Yamada's made three conclusions from his study: (1) RAP binders are more viscous than conventional mixes; (2) there was incomplete restoration of the RAP binder properties using binder restoring catalysts; (3) RAP mixtures resisted fatigue and moisture better than the control mixtures [5]. Chen et al. [6] determined the performance of aged RAP binders using a normalized viscosity ratio. This investigation showed that the normalized viscosity ratio could accurately predict asphalt binder performance and the degree of RAP binder blending interaction. Chen et al. [7] also proposed to improve the binder revitalization process by using a normalized viscosity ratio versus using blending charts for RAP binders. The investigation concluded that the degree of blending between the RAP and virgin asphalt binders was greater than previously assumed [7].

Finally, Daniel and Lachance [8] showed that the mixture gradation affected the void properties of asphalt mixtures containing RAP. Asphalt mixture strength is dependent upon how well the original asphalt interacts with the RAP binder, especially for laboratory created samples containing RAP binders [8]. This paper aims to quantify RAP binder performance relative to the amount of RAP binder present within asphalt specimens. This goal will be accomplished using Superpave™ binder characterization testing. Hot mix asphalt binder specimens will be considered using RAP material characteristics under high RAP binder percentages by weight as shown in Table 1.

2. Objectives and scope

The objective of this paper is characterizing rheological properties of asphalt binders blended with various amounts of asphalt extracted from a recycled asphalt pavement (RAP) mixture. This objective was accomplished by completing the following tasks: (1) analyze the performance of RAP binders for short and long term aging simulations using RTFO and PAV ovens, and (2) determine asphalt binder performance for high percentage RAP binders using the asphalt binder proportions.

This paper is focused on the rheological performance of RAP binders. This paper intends to analyze the short and long term aging effects of RAP binder blends, asphalt binder viscosity, and asphalt binder stiffness under variable frequency conditions.

3. Materials and experimental procedures

The virgin binder used for this project was a PG temperature 58-28. The source of RAP obtained for this project was from Hancock, Michigan. This source of RAP contained milled pavement base and surface material. The RAP stockpile material contained base and surface materials without further differentiation between the materials. Therefore the recovered asphalt binder is assumed to take on the averaged bulk material properties from the RAP stockpile. Typically, the surface layers of asphalt pavement will have more exposure to oxygen and ultraviolet light. This will lead to further asphalt binder aging and stiffening versus the rate of asphalt binder aging within the base layers of asphalt pavement. The RAP material used within this project contained an asphalt content of 4.8% and a Superpave binder high temperature grade of 88 °C. The mixture design for the RAP asphalt mixture and control mixture followed Michigan Department of Transportation (MDOT) specifications for an E3 mixture [9]. The E3 mixture is designed for a low to intermediate traffic level (1 million < equivalent single axle loads or ESALs < 3 million). This gradation was designed under Superpave™ specifications from MDOT. The author's investigation into the rheological binder properties of high RAP binders was one component of a larger comprehensive study to determine the properties of high RAP mixtures.

3.1. Asphalt binder extraction and recovery procedure

Laboratory extraction and recovery of RAP binders were conducted using the following AASHTO and ASTM standards: asphalt extraction for the RAP binder specimens followed ASTM D2172-05 test A: standard test methods for quantitative extraction of bitumen from bituminous paving mixtures [10]. Asphalt recovery for the Hancock RAP binders followed ASTM D 1856 standard test method for recovery of asphalt from solution by Abson method [11]. With the asphalt binder extraction and recovery methods the solution used was trichloroethylene.

3.2. Asphalt binder aging procedures

After the extraction and recovery phase of this investigation, the asphalt specimens were subjected to artificial aging from ASTM D 1856 standard test method for recovery of asphalt from solution by Abson method during the process of extraction. The high temperature grade from the recovered asphalt was 88 °C. The rolling thin film oven (RTFO) and pressure aging vessel (PAV) ASTM D6521 were implemented [13]. In order to simulate short term asphalt production aging, the RTFO was used in accordance with AASHTO T240 [12]. The asphalt specimens were aged at 163 °C for 85 min. Using the RTFO asphalt residue, the virgin binder and asphalt-recycled asphalt blends were then placed in the PAV oven at 100 °C for 20 h. The PAV oven simulated the long term aging of the asphalt binder specimens. In order to simulate the aging of RAP blended asphalt binder, the asphalt binders were subjected to Superpave™ binder performance testing under pre-construction conditions (virgin binder), and then the asphalt binder was short term aged with the RTFO to simulate HMA plant aging. After the asphalt binder and RAP blended binders were subjected to further DSR testing before being placed within the PAV for 20 h. Finally the PAV aged binders were tested with the DSR.

3.3. Asphalt binder performance testing

The rheological testing procedure for testing the asphalt binders consisted of two Superpave™ tests. Asphalt binder rotational viscosity and the dynamic shear rheometer were used to test specimens under various simulated aging conditions using the RTFO and PAV ovens. Three asphalt binder testing replicates were completed for these procedures.

The Brookfield viscometer was implemented by the authors to determine viscosity at 135 °C. This procedure was used to determine viscosity of the binders for pumping and mixing [14]. The method for measuring rotational viscosity for this investigation was taken from ASTM D4402: standard test method for viscosity determination of asphalt at elevated temperatures using a rotational viscometer or AASHTO T316 viscosity determination of asphalt binder using rotational viscometer [15,16]. The #27 spindle was used to determine asphalt binder viscosities for this project using 10.5 g of binder for the unaged binder state.

Using a dynamic shear rheometer (DSR), multiple tests were conducted to determine complex shear modulus (G^*) for to producing a complex modulus master curve with a reference temperature of 13 °C. The three test specimens investigated consisted of the following: control samples containing PG temperature 58-28 virgin binder, recovered RAP binder samples, and blended binder samples containing virgin binder blended with recovered RAP binder. The tested blended binder samples consisted of high RAP binder samples of 50% and 70% RAP binder by weight of specimen. DSR testing was used to characterize the viscoelastic behavior of the asphalt binder and consisted of testing for rutting and fatigue cracking susceptibility using an 8 mm DSR plate. Low temperature frequency sweep testing with the DSR was used to indicate binder fatigue cracking potential. DSR testing for the low temperature consisted of using an 8 mm plate. The DSR binder testing considered six frequencies: 0.01, 0.1, 1, 5, 10, and 25 Hz at a reference temperature of 13 °C. Other DSR testing temperatures used in this investigation to develop master curves included 13, 28, 40, 58, and 70 °C. These temperatures were selected to develop the DSR master curve and served as low to intermediate temperatures to determine asphalt performance for the asphalt binders.

The DSR measures complex modulus (G^*) and phase angle (δ) giving a complete analysis of the asphalt binder behavior at pavement service temperatures. The test procedure for the DSR is given in AASHTO 315: determining the rheological properties of asphalt binder using a dynamic shear rheometer (DSR), where the asphalt sample is positioned between a fixed plate and an oscillating plate [14]. Three test replicates were conducted for this procedure. Physical property measurements using the DSR for asphalt binder are made using unaged, oven aged (RTFO binder), and PAV aged binders. Due to the stiffness of RAP blended binders the use of an 8 mm DSR plate was used for all testing in this investigation.