Construction and Building Materials 66 (2014) 259–267

Contents lists available at ScienceDirect

Construction and Building Materials

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

Application of bitumen rheological parameters to predict thermal cracking behavior of polymer modified asphalt mixture

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HIGHLIGHTS

- The mixture fracture temperature does not match the bitumen cracking temperature.
- It appears that the bitumen PG specification is conservative with respect to single-event thermal cracking.
- The broad range in mixture fracture temperatures indicates that not all of the PG xx-22 bitumens may perform the same.
- The modifying effect of EVA is related to not only the dosage but also the low test temperature.
- Ranking of mixtures based on fracture stress does not correlate well with the ranking based on fracture temperature.

ARTICLE INFO

Article history:
Received 23 November 2013
Received in revised form 17 May 2014
Accepted 19 May 2014

Keywords:
EVA
Low temperature cracking
BBR
Creep compliance
Performance grade
Burger model

ABSTRACT

Effects of bitumen rheology on low temperature properties of polymer modified asphalt mixtures were studied. The rheology of the bitumens were characterized using SHRP bending beam rheometer (BBR), and the low temperature properties of the mixtures were evaluated by indirect tensile strength test and creep compliance test at different polymer contents. The results indicate that, in most cases, polymer modification do not show significant low temperature performance grade improvements as compared to the corresponding base bitumen. The mixture fracture temperature does not match as well bitumen cracking temperature. Based on the results obtained, it was concluded that not all of the bitumens with same low temperature performance grade may perform the same. The results indicate that it would be very difficult to establish general relationships between properties of polymer modified bitumen and the performance of pavement at low temperatures leading to the conclusion that the most sensible would be to evaluate the performance on the polymer modified asphalt mixture.

1. Introduction

Low-temperature cracking, also referred to as thermal cracking, is one of the failure modes in flexible pavement [1]. Thermally induced cracking may be a problem in cold regions, as well as in areas which experience large variations in daily temperatures. There are two different types of thermally induced cracks [2]. One of them, referred to as thermal fatigue cracking, results from thermal cycling in areas with extremes in daily temperatures. The thermally induced stress during the day is usually below the strength of the material and consequently no cracking occurs. However, with time, the daily thermal stress contributions accumulate and, over a sufficiently long time, cracking may occur. The second type of thermal cracking, which is dealt with in this research study, is low-temperature cracking. This occurs when the thermal stress induced at low-temperature exceeds the tensile strength of the asphalt concrete.

Over the years, a great number of laboratory and field investigations on low-temperature cracking have been published and several test methods for characterization of low temperature behavior described [2]. Many different types of factors have been shown to influence the low-temperature performance of asphalt mixtures, such as material, environmental and pavement structure factors. Among the material factors, the properties of the bitumens are probably the most important [2]. This paper is aimed to predict low-temperature performance of polymer modified asphalt mixtures based on bitumens rheological parameters and mechanical testing of asphalt mixtures. Rheological characteristics of the bitumens were measured using SHRP dynamic shear rheometer

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http://dx.doi.org/10.1016/j.conbuildmat.2014.05.070
0950-0618/

and bending beam rheometer. Low temperature properties of asphalt mixtures were characterized by the fracture temperature and dissipated energy ratio calculated using creep compliance and strength tests. Relations between low temperature characteristics of bitumens and asphalt mixtures were also discussed.

2. Materials

The properties of aggregate and bitumen used in this research study were presented in Tables 1 and 2 respectively. The ethylene vinyl acetate (EVA) copolymer with Melt indices (MI) of 158, and its vinyl acetate (VA) was 18% by mass was chosen in this research study. Three levels of EVA content were used, namely 2%, 4% and 6% by weight of bitumen. The polymer modified bitumens were prepared using a low shear mixer at 180 °C and a speed of 125 rpm [3]. The mixing time was two hours [3]. The aggregate mixture gradation in this research study was shown in Fig. 1. Marshall method was used to determine the optimal bitumen content. The optimum bitumen content was 5.6% for Control mixture. An optimum bitumen content of 5.6% was chosen for all mixtures so that the amount of bitumen would not confound the analysis of the test data [4,5]. Table 3 shows various bitumens and mixtures used in this research study.

3. Methods

3.1. Superpave bitumen tests

The dynamic shear rheometer test at the frequency of 10 rad/s (1.6 Hz) was conducted at high temperatures (46–82 °C) and intermediate temperatures (13–31 °C) for control of permanent deformation at high temperatures and fatigue cracking at intermediate temperatures respectively. As a result of dynamic shear rheometer test, the G^* and δ parameters were obtained. For studying the characteristics of bitumen in low temperatures (<0 °C), which leads to low temperature cracking, the BBR test was conducted at −12 to −24 °C. Two parameters were obtained through this test; stiffness and the rate of change of stiffness with time (m-value) at 60 s loading. All rheological tests were performed on three replicates at each temperature and polymer content.

3.2. Indirect tensile strength test

The indirect tensile strength test is used to determine the tensile properties of the asphalt mixture which can be further related to the cracking properties of the pavement [6]. This test is summarized in applying compressive loads along a diametrical plane through two opposite loading strips. This type of loading produces a relatively uniform tensile stress which acts perpendicular to the applied load plane, and the specimen usually fails by splitting along the loaded plane. This test was performed at −10 °C and 0 °C on both control mixture and modified ones. Specimens were monotonically loaded to failure along the vertical diametric axis at the constant rate of 12.5 mm/min [1]. The test was performed on three replicates at each temperature and polymer content.

Table 1
Aggregate properties.

Properties	Test method	Result
Coarse aggregate		
Los Angeles abrasion (%)	AASHTO-T96	20
Angularity (%)	ASTM-D5821	100
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Elongation	BS-812	11
Flakiness	BS-812	22
Bulk specific gravity (gr/cm^3)	AASHTO-T85	2.654
Apparent specific gravity (gr/cm^3)	AASHTO-T85	2.709
Water absorption (%)	AASHTO-T85	0.8
Fine aggregate		
Plasticity index	AASHTO-T89,90	Non-plastic
Sand equivalent	AASHTO-T1769	38
Bulk specific gravity (gr/cm^3)	AASHTO-T84	2.617
Apparent specific gravity (gr/cm^3)	AASHTO-T84	2.719
Water absorption (%)	AASHTO-T84	1.4
Filler		
Sand equivalent	AASHTO-T1769	Non-plastic
Specific gravity (gr/cm^3)	AASHTO-T100	2.702

3.3. Creep compliance test

Currently the suggested test temperatures for the creep procedure are 0, −10, and −20 °C. Because of the variability in bitumen grades and the resulting low-temperature properties of asphalt concrete, some specimens are extremely stiff at −20 °C, while others may be too compliant at 0 °C. The test temperatures used in the creep procedure should, therefore, change according to the bitumen grade used [1]. The relationship between bitumen stiffness and mixture stiffness is not 1:1; a given change in bitumen stiffness will produce a somewhat lower change in mixture stiffness [1]. It was suggested by NCHRP that the current test temperatures of 0, −10, and −20 °C be maintained for mixtures made using PG XX-22 and PG XX-28 bitumens. For PG XX-16 and PG XX-10 bitumens or mixtures that have been severely age-hardened, the recommended test temperatures should be −10, 0, and +10 °C. For PG XX-34 bitumens (or softer), the recommended test temperatures should be −30, −20, and −10 °C [1]. Three replicates of each mixture were prepared and tested at each temperature.

4. Results

4.1. Analysis of variance (ANOVA)

A two-factor analysis of variance (ANOVA) was performed to check the significance of the individual factors on the design objectives. The parameters like S and m values of bitumens, tensile strength and creep stiffness of asphalt mixtures were considered as the dependent variables. The two fixed factors considered are polymer content and temperature. The hypothesis is that there is no significant effect of the two-factors on the measured engineering properties. The significance was tested considering 95% confidence interval. To reduce calculations, only the creep stiffness value at 60 s was used in the analysis. The results of ANOVA were presented in Table 4. The dependent variables were significantly influenced by the polymer content and temperature, and the interaction between the polymer content and temperature.

4.2. Evaluation of bitumen low temperature properties

4.2.1. BBR and DSR test results

The test results of DSR and BBR at different temperatures were presented in Tables 5–8. It can be concluded that, no matter what the value of EVA is and whether the bitumen is modified or not, with the drop in temperature the S-value increases while m-value decreases.

4.2.2. Cracking temperature of bitumens

According to ASTM D2872 recommendations for control of permanent deformation (rutting), the $G^*/\mathrm{Sin}\,\delta$ at high performance temperature (HT) for unaged bitumen and residue aged bitumen after rolling thin film oven (RTFO) test should be more than 1 kPa and 2.2 kPa respectively. According to ASTM D6648 recommendations to control the low temperature cracking at low performance temperature, which is 10 °C less than test temperature, stiffness of bitumen should be less than 300 MPa, and m-value should be greater than 0.3 at 60 s loading. Table 9 presents the minimum temperature at which the unaged and RTFO $G^*/\mathrm{Sin}\,\delta$