Construction and Building Materials 144 (2017) 442–450

Contents lists available at ScienceDirect

Construction and Building Materials

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

Rheological characteristics of alternative modified binders

Lingqing Liu [a], Feipeng Xiao [b,*], Henglong Zhang [c], Serji Amirkhanian [d]

[a] School of Highway, Chang'an University, Xi'an, China
[b] Key Laboratory of Road and Traffic Engineering of Ministry of Education, Tongji University, China
[c] School of Civil Engineering, Hunan University, Changsha, China
[d] Department of Civil, Construction, and Environmental Engineering, University of Alabama, Tuscaloosa, USA

HIGHLIGHTS

- Two base binders and fourteen modified binders produced with seven alternative additives were studied.
- Rheological characteristics of binders at high and low temperature at three aging states were discussed.
- Both binder source and additive type have influence on the rheological properties.
- Recovery percentage has a good correlation with the phase angle of the alternative binders at RTFO state.

ARTICLE INFO

Article history:
Received 30 December 2016
Received in revised form 17 March 2017
Accepted 26 March 2017

Keywords:
Polymer
Alternative
Rheology
MSCR
Aging state

ABSTRACT

The rheological characteristics of two base binders and fourteen modified binders produced with seven additives at three aging states were studied. The test results included viscosity, failure temperature, rutting resistance factor, phase angle, complex modulus, percentage recovery value, fatigue factor, stiffness and m-value. It can be concluded that a proper concentration of alternative additive could be used to effectively achieve PG 76-22 binders. In addition, the binders modified with two of three new polymers showed weak resistances to low temperatures. Furthermore, the recovery percentages of alternative binders were relatively correlated to their phase angles at the short aging states. Meanwhile, this study also indicated that both binder source and alternative type determined the rheological characteristics of their modified binders.

1. Introduction

It is well known that polymerized asphalt binders have higher viscosity, softening point, and failure temperature as well as greater elastic recovery, bonding strength and ductility [1–4]. These polymers generally include traditional styrene–butadiene–styrene (SBS), styrene–butadiene-rubber (SBR), and crumb rubber, as well as Elvaloy®, ethylene vinyl acetate (EVA), polyethylene, and others [2,5–7].

It is generally considered that a blended polymer and virgin asphalt result in the absorption of the light molecular weight oil fraction and the swelling of the polymer [4,6,8,9]. These swollen strands of the polymer connect together in the asphalt and form a three-dimensional network, which effectively improves the performance characteristics of the modified asphalt binders [8]. However, these polymers generally have various molecular structures and the formed three-dimensional network varies from one polymer to another. Therefore, the internal cohesive and adhesive behaviors of these polymerized asphalt binders are dependent on the base binder source and polymer type [5,9].

SBS behaves like an elastic rubber at ambient temperatures and like a plastic when heated. However, crumb rubber from scrap tire is generally difficult to process due to cross-linked properties. The asphalt binders modified with elastomeric modifiers such as crumb rubber, SBS, and SBS-rubber yielded higher recoveries than those made with plastomeric modifiers, such as Elvaloy and EVA [10].

Some research articles indicated that approximately 75% of all polymer modified asphalts utilized elastomeric modifiers as the additives to improve the performance properties, while only 15% of them used plastomeric. The remaining 10% of modified asphalts used other materials, such as sulphur and acid [11–14]. In general, plastomers exhibit high early strength but are less flexible and more prone to fracture under high strains than elastomers [15].

* Corresponding author.
E-mail address: fpxiao@tongji.edu.cn (F. Xiao).

http://dx.doi.org/10.1016/j.conbuildmat.2017.03.193

Kodrat et al. [16] reported that the effect of polyphosphoric acid (PPA) on the Superpave grading properties was significant, and the increased high-temperature grade was dependent various concentrations and the binder source [16]. In addition, the low-temperature grade was not affected for most binders [16].

In addition, some specific alternative materials were used to blend with asphalt binder to produce the modified binders and had great performance at high and/or low temperatures. The use of SBS grafted with polar monomer can be considered a suitable alternative for modification of binder in pavement [17]. Wu et al. (18) reported that polyester fiber and floc xylogen fiber were used to prepare fiber-asphalt binders [18]. It was found that waste high density polyethylene (HDPE) modified bituminous binders provide better resistance against permanent deformations [19]. Rizvi et al. [20] indicated that the bone glue modification not only reduced the initial cost, but also improved the long-term performance characteristics of pavement [20].

The objective of this study is to explore the rheological characteristics, compare the differences of these properties, and investigate the potential application of two base binders and their modified binders from SBS and other six alternative additives at three aging states, including two elastomeric modifiers, three plastomeric modifiers, and one acid.

2. Experimental design and test methodologies

2.1. Materials

In this study, two neat binders PG 64-22 (referred to A and B) were used to produce the modified asphalt binders PG 76-22. The main rheological properties of these two base binders are shown in Table 1. The test results included viscosity, failure temperature at virgin state, $G^*/\sin\delta$ at virgin and rolling thin film oven (RTFO) states, as well as $G^*\sin\delta$, stiffness and m-value at pressure aged vessel (PAV) state.

In addition, the basic physical and chemical properties of SBS and six alternative additives are shown in Table 2. The SBS, oxidized polyethylene, Propylene-maleic, 10% -40 mesh ambient rubberized asphalt, Polyphosphoric acid (PPA) with 2% SBS, reactive elastomeric terpolymer and terminally blended rubberized asphalt were named 1–6 and TB in this study. Amongst these seven additives, oxidized polyethylene, Propylene-maleic and reactive elastomeric terpolymer were three new polymers. Meanwhile, two base binders without any additives were denoted A0 and B0. Obviously, SBS and crumb rubber are typically used in asphalt industry to produce modified PG 76-22 binder. Other polymers from various chemical companies were also being applied to improve the performance of asphalt binder and its modification techniques to achieve the cost-effective and environmentally friendly purposes.

2.2. Sample preparations

In this research, the modified asphalt binders were prepared in the lab or directly shipped from asphalt supplies. For example, two base binders, two SBS modified binders, and the terminally blended rubberized asphalt were provided by the manufactures. Other modified asphalts were produced in the lab according to the recommendations from material suppliers. Polymers 2 and 3 (3% by weight of base binder) were blended with asphalt binders by a high shear speed of 1000 rpm at 165 °C for 30 min before further tests. 10% -40 mesh crumb rubber was mixed with the base binders at 177 °C for 30 min and a same speed with polymers 2 and 3. Similar mixing process was applied to PPA (0.5%) combined with SBS (2%) modified binders. Different from other production process, polymer 6 (3%) was mixed with asphalt binder first and then the modified binders were stored in an oven of 165 °C for 24 h in accordance with the recommendations of the supplier.

2.3. Test methodologies

The prepared modified asphalt binders were tested to explore the rheological properties according with the recommendations from Superpave binder specifications. The samples were applied to the tests as shown in Table 3. Three aging states of various binders were evaluated in this study. The RTFO and PAV aging procedures followed the AASHTO T 240 and AASHTO R28, respectively. BBR test was performed according to AASHTO T313.

Additionally, Fourier Transform Infrared Spectroscopy (FTIR) test was used to evaluate the molecular components of two base binders in terms of levels of soot, sulfates, oxidation, nitro-oxidation, glycol, fuel, and water contaminants. The chemical bonds in a molecule could be obtained when the infrared absorption spectrum was determined according to the unique FTIR spectra of pure compounds and a molecular "fingerprint" [21].

3. Test results and discussion

3.1. Base binder

It is well known that the base binder plays an essential role in impacting the rheological properties of asphalt binder as well as the performance behaviors of asphalt mixtures. Thus, in this study, as shown in Table 1, two binders from different sources show noticeable difference in viscosity, failure temperature, $G^*/\sin\delta$, $G^*\sin\delta$, stiffness and m-value. These differences were mainly derived from the basic components of the binders, including the percentages of saturate, aromatics, resin, and asphaltene, which were broadly used to define the chemical combination of an asphalt binder.

As shown in Fig. 1, the absorbance values of C—C strength, C—H bending, and C—H bend at wavenumber of 1598, 1454, 1375, and 719 are remarkably different. This FTIR test results address that two binders have significant differences in molecular components. Therefore, these two binders selected to produce the modified binders in terms of the seven additives were able to help the researcher effectively understand the rheological property variations of these modified binders.

Table 1
Rheological properties of base binders.

Binder type	Source	Aging states						
		Unaged			RTFO	PAV		
		Viscosity (135 °C) (cp)	Fail temp. (°C)	$G^*/\sin\delta$ (64 °C)	$G^*/\sin\delta$ (64 °C) (kpa)	$G^*\sin\delta$ (25 °C) (kpa)	Stiffness (−12 °C) (Mpa)	m-value (−12 °C)
PG 64-22	A	645	2.03		4.94	1429	103	0.376
PG 64-22	B	465	1.28		2.87	3229	257	0.312