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High temperature properties of high viscosity asphalt based on rheological methods

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HIGHLIGHTS

- Improvements in SHVA's high temperature property are obvious from 40 to 80 °C and 0.1 to 100 rad/s.
- The lowest γ_{acc} and the change of G_v illustrate that SHVA has better high temperature performance.
- The creep compliance can distinguish the property difference of high viscosity asphalts.
- SHVA has the best deformation recovery ability.

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ABSTRACT

This research aims to comparatively evaluate the high temperature properties of modified high viscosity asphalt (SHVA) by temperature and frequency sweep testing as well as repeated creep and recovery testing. Wheel-tracking testing was also introduced to verify anti-rutting properties of asphalt mixtures. The results indicated that the phase angles (δ) of high viscosity asphalts decreased with increased temperature. The lowest decrease rate of the complex modulus (G^*) reflected that SHAV had the lowest temperature susceptibility. The δ of neat asphalts were nearly unchanged with increased frequency, while the δ of modified asphalts clearly increased. Both temperature and frequency sweep tests indicated that improvements in anti-rutting performance (i.e., smaller δ and bigger G^*) of high viscosity asphalt were noticeable. Burgers model and a piecewise linear regression method showed high accuracy in simulating asphalt's creep process. Changes in binder creep stiffness and accumulated strain (i.e. 2.8, 2.6, and 2.4% for SBS, TPS and SHAV, compared to 96.4 and 102.9% for two neat asphalts) demonstrated that the polymer used in these modified asphalts significantly enhanced their stiffness and elastic properties. From the analysis of creep compliance, SHVA had the maximum elastic and minimum viscous proportions in comparison with the other four asphalts. Test results of the mixtures showed that the asphalt mixture with SHVA possessed the best high-temperature stability (9265 cycles/mm). Good agreement was found between the high temperature properties of the asphalts and mixtures.

1. Introduction

High viscosity modified asphalt is commonly used in ultra-thin asphalt pavement and open-graded friction courses (OGFC) and is characterized by extremely high viscosity and excellent cementitiousness. In our previous study, for the purpose of improving overall properties of asphalt mixtures, modified high viscosity asphalt (SHVA) was manufactured using SK70 neat binder, polymer, compatibilizer, and stabilizer, with the modification technology of SHVA also determined [1,2]. Although the asphalt mixtures with SHVA had better road performances than with TPS-modified asphalt (TPS is one of the best high viscosity asphalt modifiers). The differences between the technical indices of TPS and SHVA were not obvious. In particular, at 60 °C, capillary viscosities of the two asphalts were extremely high, such that is was difficult to distinguish between the high temperature performance of the high viscosity modified asphalt just by measuring its viscosity. Li [3] and Li [4] have indicated that most polymer-modified asphalts are non-Newtonian fluids at 60 °C, such that capillary viscosity in existing specifications does not really reflect high temperature

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performance. Many studies have attempted to find new indices, such as a rutting factor ($G^*/\sin\delta$) adopted in the Superpave binder specification, $G^*/(1 - 1/\tan\delta \sin\delta)$, that has been suggested by Shenoy to evaluate the high temperature performance of polymer modified asphalt [5]. However, these indices might not fully capture the rheological behavior of modified asphalts [6]. Nevertheless, the parameters obtained from rheological testing, including G^* and δ, in the oscillatory mode have been of great value for explaining asphalt's rheological behavior whether it was modified or not. Rowe, Anderson, Geng et al. [7–9] have recommended zero shear viscosity (ZSV) as an indicator of the rutting potential of modified asphalts. However, the value of ZSV can be influenced by many factors, such as the test method, experimental conditions, and the fitting model [10,11]. In addition, a highly-modified binder, which behaves as a viscoelastic solid, does not reach steady state flow status in the ZSV concept [12,13]. Bahia has researched the anti-rutting performance of asphalt pavement by calculating the viscous component of binder creep stiffness (G_v) through repeat creep recovery tests (RCRT) at high temperature [14]. The results showed that G_v well reflect the anti-rutting performance of the polymer-modified asphalts because the repeated creep loading in RCRT represented the actual loading in pavement. In this study, two neat binders, AS70 and SK70, and two modified asphalts, SBS-modified asphalt and TPS-modified asphalt (SBS and TPS for short, respectively), were chosen as controls, temperature sweep and frequency sweep testing were used to investigate the influence of temperature and frequency on SHVA anti-rutting performance. Through RCRT, the accumulated stain (γ_{acc}), viscous component of G_v, and creep compliance of five asphalts were analyzed to distinguish differences in their high temperature performance by a rheological method. Finally, mixture tests were performed to verify these differences.

2. Experimental

2.1. Materials

In preliminary study, SK70 (SK Holdings, South Korea), proper types and additions of modifiers, and optimal modification process were determined to obtain high viscosity asphalt (SHAV) [1,2]; all modifiers were commercial products.

TPS (Taiyu Co., Ltd., Japan, 12% addition by mass of neat asphalt) and AS70 neat binder (ExxonMobil Corp., USA) were used to prepare TPS-modified asphalt.

SBS-modified asphalt (SBS) was a commercially available product (Hubei Guochuang Hi-tech Material Co., Ltd., China). Note that this SBS-modified asphalt did not meet the requirements of high viscosity asphalt according to specifications (JTG F40-2004) because its capillary viscosity at 60 °C did not exceed 20,000 Pa·s.

Specifically, the technical indices of the five asphalts are listed in Table 1.

2.2. Test methods

2.2.1. Rheological properties

A Bohlin Gemin II type Dynamic Shear Rheometer (DSR; Malvern Instruments Ltd., UK) was used to investigate the rheological properties of the asphalts. A 25-mm diameter plate-plate geometry with a 1-mm gap was selected. In temperature sweep tests, the strain control mode was adopted, frequency fixed at 10 rad/s, and temperature incrementally increased (by 10 °C steps) from 40 to 80 °C. Frequency sweep tests were performed at 60 °C, with the frequency logarithmically increased from 0.1 to 100 rad/s (0.0159–15.9 Hz). Repeated creep and recovery tests (RCRT) contained 100 cycles, with each cycle consisting of a 1 s creep process and 9 s recovery process, with the frequency, stress level, and temperature set to 1.59 Hz, 300 Pa, and 60 °C, respectively.

2.2.2. Asphalt mixture property

The Marshall method (ASTM D-1559) was used to design the asphalt mixtures. OGFC-13 was selected in this study, with an objective aggregate gradation determined (Table 2). Through the Cantabro Test (ASTM D7064-04) and Draindown Test (AASHTO T 305), the optimal asphalt aggregate ratios of mixtures with SBS, TPS, and SHVA were determined as 4.2, 4.5, and 4.2%, respectively. The voluminal and mechanical indices of the Marshall samples are shown in Table 3. Wheel-tracking testing of all mixtures was performed at 60 °C according to T0719 (JTG E20-2011).

3. Result and discussion

3.1. Temperature sweep test

The δ and G^* are two parameters that reflect rheological properties. The former indicates the ratio between the elastic and viscous responses and is a measure of the total resistance to deformation. G^* indicates the material's stiffness. The δ of SK70 and AS70 were seen to increase gradually with temperature, which indicated that the elastic proportion of the two neat asphalts decreased with increased temperature (Fig. 1). Compared with the two neat asphalts, the δ of three modified asphalts were much smaller, which showed that polymers transferred elasticity to the asphalt, causing resistance to high temperature deformation. When the temperature rose from 40 to 50 °C, the δ of TPS and SHVA experienced a small increase, but when the temperature exceeded

Table 1
Technical indices of asphalts.

Test item	SK70	AS70	SBS	TPS	SHVA
25 °C Penetration/0.1 mm	70.2	63.9	54.1	43.4	52.3
(25 °C or 5 °C*) Ductility/cm	>100	>100	32.5	44.9	35.9
Softening point/°C	47.3	50.9	90.2	88.7	92.6
60 °C Capillary viscosity/(Pa·s)	442	456	8432	62,351	83,462
Toughness and tenacity/(N·m)	–	–	15.0	28.6	26.5
Toughness/(N·m)	–	–	6.3	16.2	18.3
Residue after RTFOT(163 °C, 75 min)					
Mass loss%	−0.02	−0.16	0.21	0.13	0.24
Penetration ratio/%	60.3	55.6	48.5	41.3	45.4
5 °C Ductility/cm	–	–	22.8	32.7	33.1
60 °C Dynamic viscosity/(Pa·s)	523	549	5369	21,358	47,609
Toughness and tenacity/(N·m)	–	–	18.3	28.6	30.3
Toughness/(N·m)	–	–	7.2	16.5	18.9

*Note: The ductilities of neat binders and modified binders were tested at 25 °C and 5 °C, respectively.

Table 2
Objective aggregate gradation.

Sieve size/mm	16	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
Total cumulative passing/%	100	96.5	67.6	20.7	14.1	9.8	8.6	7.4	6.3	4.7