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Analysis of viscous flow properties of asphalt in aging process

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HIGHLIGHTS

- The visco-flow properties of asphalt in the aging process are analyzed.
- The visco-flow activation energy (E_η) is used to evaluate the visco-flow property of asphalt.
- E_η increases continuously with the deepening of aging.
- E_η shows a good negative correlation with the rate of creep stiffness (m).
- E_η shows a good linear correlation with colloidal instability index (I_c).

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ABSTRACT

The inevitable change in asphalt properties owing to aging exists in the cycle of pavement decay under the loading from both weather and traffic. To analyze the viscous flow properties of asphalt in the aging process, a series of aging simulation tests were conducted on five regular asphalt samples for different time by rolling thin film oven (RTFO) in the laboratory, and then Brookfield rotational viscosity (RV), dynamic shear rheological test (DSR), bending beam rheometer (BBR) and component analysis (CA) tests were carried out on these samples. The parameter visco-flow activation energy (E_η) was obtained by means of Arrhenius equation according to the viscosity values of asphalt at different temperatures. The changing regularity of E_η during the aging process was analyzed. On the base of DSR, BBR and CA test result analysis, the relationship of E_η with $G^*\sin\delta$, $\tan\delta$, m-value and Ic was discussed respectively. The results and analysis indicate there is significant effect of aging on viscous flow behavior of asphalt. With the deepening of aging, E_η increases continuously. The average growth rate of E_η for the same asphalt in several aging stages varies considerably due to the difference in anti-aging performance. There is no remarkable relationship between E_η and DSR rheological parameters, while E_η shows a good negative correlation with the rate of creep stiffness (m) and also a good linear correlation with colloidal instability index (I_c). Therefore, the viscous flow property of asphalt is closely related to the low temperature creep behavior and colloidal structure.

1. Introduction

The aging behavior of asphalt in service has been recognized as the major factor affecting the durability of asphalt pavement [1,2]. In the cycle of pavement decay, the inevitable change in asphalt properties occurs owing to the lack of durability, which is defined as the resistance to change in physical chemical properties of asphalt with time under the loading from both weather and traffic [3]. However, asphalt aging in the field is difficult to investigate because such studies are extremely time-consuming, costly and quite complicated due to many different variables such as temperature, sunlight (UV), precipitation, wind and so on [4]. The aging simulation in the laboratory is still one of the most effective methods to investigate the aging properties of asphalt binder and mixture.

Many researchers have paid much attention to the aging behavior and aging resistance of asphalt, and have proposed considerable evaluation test methods and parameters. And the changing rule of conventional performance indicators of asphalt in the aging process has been widely studied [5–10]. As a visco-elastic material, the performance of asphalt has close relationship with its rheological properties [11]. Shenoy [12] analyzed the high temperature

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Table 1
Properties of asphalt binders.

Test indicators	Asphalt sample					Test method
	A	B	C	D	E	
Softening point (R&B)/°C	46.2	46.3	50.6	47.3	47.4	ASTM D 36
Ductility (15 °C, 5 cm/min)/cm	86.6	>150	>150	>150	>150	ASTM D 113
Penetration (25 °C, 5 s, 100 g)/0.1 mm	91	96	69	81	118	ASTM D 5
Viscosity (@135 °C)/Pa·s	0.368	0.348	0.668	0.346	0.369	ASTM D 4402

rheological properties of aged asphalt. Wang et al. [13] discussed the effect of aging on rheological properties of crumb rubber and SBS modified asphalt. Huang et al. [14] analyzed the relationship between the rheological properties and microstructure of SBS modified asphalt. Li et al. [15] and Zhu et al. [16] discussed the effect of short and long term aging on the high temperature rheological properties of aged asphalt using Dynamic Shear Rheometer (DSR).

The study of aging behavior and mechanism of asphalt has practical significance in guiding the recycling of asphalt concrete mixture. In this study, the viscous flow properties of asphalt in aging process are investigated through laboratory tests. The Arrhenius equation was used to obtain the visco-flow activation energy (E_η) to analyze the effect of aging on the viscous flow properties of asphalt from the view of thermodynamics and rheology. The authors discussed the changing regularity of E_η and the relationship of E_η with rheological and structure parameters such as G*sin δ, tan δ, m and I_c during the aging process.

2. Materials

Five ordinary virgin asphalt samples were used for laboratorial aging tests. Their fundamental properties were tested and listed in Table 1.

3. Test methods

3.1. Aging simulation procedures

Oxidation reaction is the mechanism of asphalt thermo-oxidative aging. Though aging conditions such as temperature and oxygen concentration are different, their aging mechanisms are similar for different-temperature aging simulation [17]. As discussed by Petersen [18], the normal oven can be considered as an alternative to produce short-term and long-term Aging of binders in the absence of more accurate and sophisticated RTFO and PAV equipments. In this research, the rolling thin film oven test (RTFOT) aging simulation was adopted.

RTFOT is a wide-used approach to simulate the short-term aging of asphalt. It is believed that the scope of the RTFOT can be expanded to predict long-term age-hardening performance of asphaltic binders by extending the exposure duration of asphalt samples in the oven over a wide range of testing temperatures [19]. In this research, five asphalt binders were artificially aged according to the RTFOT procedure (AASHTO T240) with extended oven durations. All asphalt samples were aged for 85, 180 and 360 min at a constant temperature of 163 ± 1 °C.

3.2. Viscosity test

Brookfield viscometer (DV-II) was used to measure the viscosity of aged asphalt in different state as well as unaged asphalt in order to evaluate the high-temperature rheological properties of asphalt. The viscosity values of asphalt samples at different temperatures according to ASTM D4402 are listed in Table 2.

3.3. Dynamic shear rheological test

To analyze the relationship between the viscous flow properties and the rheological performance of asphalt samples in the aging process, the high-resolution Bohlin CVO 150 dynamic shear rheometer (DSR) equipment was adopted to measure the complex shear modulus property, denoted as G*, and the phase angle, denoted as δ of the samples according to the Superpave binder specification ASTM 7552. The parameter G* is described as the measure of the total resistance to deformation after the exposure to the repeated pulses of shear stress. The parameter δ quantifies the amount of recoverable and nonrecoverable deformation [20]. The DSR sweep test was run under the strain-controlled mode (γ = 12%) at the frequency of 10 rad/s (1.59 Hz) and the test temperature of 60 °C. All rheological tests were performed on three replicates under each test condition.

3.4. Beam bending rheological test

The thermal cracking performance of asphalt pavements is related to the low-temperature rheological properties of the asphalt binder contained in the mix. The Superpave™ Bending Beam Rheometer (BBR) was adopted to quantify the level of deflection or creep under a 980 ± 50 mN seating load automatically applied on the standard asphalt beam specimens lasting for a total of 240 s. The BBR test was conducted according to ASTM D6648 standard test specification. The performance parameters of interest are the creep stiffness $S(t)$ and m. The creep stiffness is the stiffness value at 60 s after the continuous application of the 980-mN constant load for 240 s while the parameter m is the slope of the log

Table 2
Asphalt viscosity at different aging states.

Asphalt	Aging time/min	Test temperature/°C				
		85	105	125	135	145
A	0	15.3	2.59	0.602	0.368	0.236
	85	24.4	4.08	0.897	0.523	0.319
	180	38.2	6.45	1.267	0.741	0.436
	360	98.0	12.14	2.285	1.188	0.671
B	0	12.2	2.14	0.560	0.348	0.214
	85	16.5	2.89	0.741	0.438	0.272
	180	23.1	3.7	0.968	0.556	0.339
	360	57.4	7.13	1.520	0.845	0.498
C	0	23.6	4.50	1.177	0.668	0.415
	85	36.8	7.18	1.770	1.050	0.651
	180	61.5	10.30	2.473	1.447	0.883
	360	147.0	23.10	4.552	2.367	1.337
D	0	14.6	2.49	0.567	0.346	0.222
	85	23.1	3.58	0.873	0.513	0.314
	180	36.4	5.39	1.254	0.733	0.425
	360	96.3	11.53	2.458	1.158	0.654
E	0	14.6	2.44	0.595	0.369	0.23
	85	20.8	3.40	0.864	0.508	0.315
	180	30.7	4.71	1.188	0.677	0.408
	360	73.8	9.41	2.089	1.111	0.612