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Experimental study on aging properties and modification mechanism of Trinidad lake asphalt modified bitumen

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HIGHLIGHTS

- TLA can effectively ameliorate aging resistance of thermal-oxidative and UV-aging.
- TLA modification on asphalt was mainly physical modification.
- TLA can improve the intersection effect between asphaltene and other components in bitumen.
- Asphalt with TLA was a more stable system than without modifier.

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ABSTRACT

Trinidad lake asphalt (TLA) modified bitumen was prepared to study effect on aging properties and study modification mechanism. The aged blend was prepared by thin film oven test (TFOT), pressure aging vessel (PAV) and ultraviolet (UV) radiation, respectively. Morphology characteristics of modified bitumen were investigated by infrared spectra (IR) and atomic force microscope (AFM). The retained penetration (RP) can be increased while viscosity aged index (VAI) and softening point increment (ΔS) get decreased after aging simulation. It indicated the addition of TLA can effectively ameliorate aging resistance of thermal-oxidative and UV-aging. The susceptible degree of softening point ratio was higher than ΔS but lower than RP. From IR spectra, there are no new absorption peaks added for TLA addition and the modification was mainly physical. Investigation of AFM showed that addition of TLA change the intersection effect between asphaltene and other bitumen components to form the more stable system. Besides, the association effect of the dispersed phase improved system rigidity, softening point and viscosity.

1. Introduction

Bitumen have been the preferential materials of pavement construction due to the excellent viscoelastic properties [1]. However, bitumen is prone to be aged especially for exposing to air, heat and UV light during storage, transportation, construction and service stages [2]. In recent years, proper modified asphalt materials have been widely searched and applied to enhance pavement performance on anti-aging properties [3]. Trinidad lake asphalt whose main components are naturally weathered bitumen and filler is gradually utilized as modifier to obtain the increase of pavement strength [4]. Besides, Marshall stability, elastic modulus and tensile stress were also found to be elevated in laboratory test [5]. Nevertheless, TLA modified asphalt are generally applied as functional waterproofing materials in bridge deck or overlap due to the lack of thorough research on TLA modification process and mechanism [6,7]. Besides, empirical recipe and index test are still used for TLA mixing with conventional asphalt because related fundamental properties are not well explored [8]. There have been no detailed reports about effect of TLA-modified asphalt on aging properties.

It is significant to characterize aging performance and provide an explanation of modification mechanism to enlarge application scope. In this study, the aging properties of TLA-modified asphalt were investigated by PAV, TFOT and UV aging experiments. In addition, aging mechanism was analyzed by researching chemical structure and aggregation structure through FT-IR and AFM tests.

2. Experimental

2.1. Materials

The 70/90 penetration grade bitumen were selected as virgin asphalt and TLA was used as modifiers. Physical properties and chemical component were listed in the following tables (see Tables 1 and 2).

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Table 1
Physical properties and chemical component of virgin asphalt.

Physical properties & chemical component	SK-70	SK-90
Penetration (25 °C, 0.1 mm)	67	83
Softening point (°C)	48.4	46.2
Ductility (15 °C, cm)	119	150
Viscosity (135 °C, Pa s)	0.61	0.48
Viscosity (60 °C, Pa s)	314	157
Saturates (%)	16.57	16.65
Aromatics (%)	41.67	49.29
Resin (%)	30.92	24.49
Asphaltene (%)	10.84	9.57

Table 2
Physical properties of Trinidad lake asphalt.

Physical properties	TLA
Penetration (25 °C, 0.1 mm)	1.1
Softening point (°C)	165.1
Ash (%)	30.0
Density(25 °C, g cm^{-3})	1.327

2.2. Preparation of modified bitumen

Virgin asphalt was proceed by melting and blending around 180 °C in the high shear mulser. The modifier, a certain amount (5 wt%, 10 wt%, 20 wt% and 30 wt%) of TLA, was added into the virgin asphalt with the external addition method and stirred for 60 min. Besides, another virgin asphalt was conducted the same process to obtain the blank specimen.

2.3. Aging procedures

Thin film oven test (TFOT) was conducted on the blend according to ASTM D 1754 with the asphalt thin file oven for duration of 5 h at the temperature of 163 °C. Related physical property tests were addressed on the TFOT aged specimen. Pressure aging vessel (PAV) was subsequently conducted on the TFOT-aged specimen in accordance with ASTM D 6521 by using asphalt pressure aging machine [9,10]. The PAV conditions were controlled as 100 °C, 2.1 MPa of air and 20 h. Physical properties of the PAV-aged specimen were evaluated by related tests.

Photo-oxidation aging was conducted as the type of ultraviolet radiation (UV). The 30 ± 0.5 g weight asphalt through TFOT aging were placed on a flat round pan and subjected to ultraviolet radiation in the homemade asphalt UV aging oven. Thickness of asphalt thin film was about 2 mm and distance between the specimen and ultraviolet lump was set as 450 mm. The light source was tubular high voltage mercury ultraviolet lamp of 500 W and the intensity of ultraviolet was about 800 μw/cm^2 and working temperature was set as 80 °C. The UV-aged specimen was also evaluated to determine physical properties.

Changes of asphalt physical properties includes retained penetration (RP), softening point increment (ΔS) and viscosity aging index (VAI) around aging process were adopted as the indices to study the effect of TFOT, PAV and UV aging on TLA modified asphalt [11–13]. The indices are computed as formulas (1).

$$C = \lg\lg(\eta_2 \times 10^3) - \lg\lg(\eta_1 \times 10^3) \quad (1)$$

where C, the index of asphalt viscosity, can be evaluated for asphalt aging and η_1, η_2 stand for viscosity before and after aging process.

$$\Delta S = \text{Aged softening point increment} - \text{Unaged softening point value} \quad (2)$$

$$\text{RP} = \frac{\text{Aged penetration value}}{\text{Unaged penetration value}} \times 100 \quad (3)$$

2.4. Physical properties test

Physical properties includes penetration (25 °C), softening point and viscosity were tested according to Chinese specifications GB/T 4509-1998, GB/T 4507-1999 and SH/T 0739-2003, respectively [14–16].

2.5. Preparation of the specimen for IR spectra test

TLA powder was tested as KBr pellet and the asphalt specimen were dissolved in CS_2 solution to prepare 5 wt% solutions. The solution was dropped on the KBr pellet with groove and the solvent was removed by FT-IR spectrometer.

2.6. Preparation of the specimen of AFM test

The specimen was prepared by casting the hot asphalt on the glass flake and the diameter of film should be controlled as 10 mm. Working temperatures was set as 5 °C. The sample was analyzed in an atomic force microscope. The scanning mode was tapping mode and the probe was Si_3N_4 cantilever probe.

3. Result and discussion

3.1. Retained penetration

Fig. 1(a) shows the RP of TFOT-aged asphalt with different TLA addition dosage. For SK-70, RP value increased from 66 to 90 as leveling up the TLA addition dosage, which means the addition of TLA can largely improve asphalt performance of short-term thermal-oxidation. Comparing with SK-70, the RP value of SK-90 was larger which indicated the better improvement effect of SK-90 from TLA addition. Fig. 1(b) shows the RP of PAV-aged asphalt with different dosages of TLA addition. For SK-70, RP value increased from 43 to 62 as the dosage of TLA addition boomed to 20%. Similar with the result of TFOT, SK-90 asphalt presented the better performance of long-term thermal-oxidation than SK-70 asphalt under improving effect of the same dosage from TLA addition.

3.2. Softening point increment

Fig. 2(a) shows the ΔS of TFOT-aged asphalt with different TLA addition dosages. It can be found that ΔS of modified SK-70 asphalt

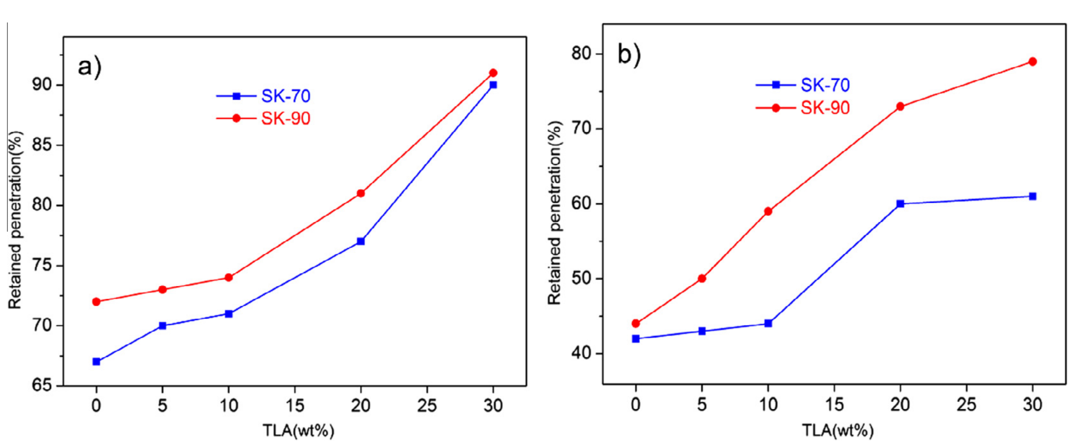

Fig. 1. The RP of (a) TFOT-aged and (b) PAV-aged asphalt with TLA addition dosage.