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Performance evaluation and preventive measures for aging of different bitumens

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HIGHLIGHTS

- The bitumen with inferior aging properties was selected.
- The Irganox1010 shows the best ability to resist aging of the selected bitumen.
- The proper Irganox1010 content for preparation of the aging resistant bitumen is 0.4–0.6%.

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ABSTRACT

The aging performance of bitumen and its preventive measures have attracted more and more attentions all over the world. In this paper, three different bitumens (denoted as A, B and C) were exposed to thermal and ultraviolet (UV) aging at different UV intensities. The physical parameters of bitumens were compared for the selection of bitumen with inferior aging properties. To improve the aging resistance of the selected bitumen, various anti-aging additives were used to modify the bitumen via melt blending. The modified bitumen with excellent aging resistance was obtained through physical properties evaluation and Fourier transform infrared analysis. Results indicate that bitumen A exhibits the best thermal and UV aging resistance, then the bitumen B, and the bitumen C shows the worst thermal and UV aging resistance. Among the anti-aging additives used, antioxidant Irganox1010 shows the best ability to resist both the thermal and UV aging of the selected bitumen C. The selected bitumen C with excellent aging resistance can be prepared with the addition of the Irganox1010 at a proper content of 0.4–0.6%.

1. Introduction

Bitumen aging has attracted many researchers' attention since the aging of bitumen is considered to be one of the main factors deteriorating pavement performance [1–3]. It is well known that the bitumen aging consists of two aspects: thermal-oxidative aging that is caused by heat and oxygen [1,3,4], and photo-oxidative aging that is caused by the ultraviolet (UV) irradiation and oxygen [2,5,6]. Although both the heat and UV light can degrade bitumen properties, their effects on bitumen aging are not the same [7,8]. The aging behavior of bitumen would be much more complicated if the heat and UV irradiation are combined together [9].

With respect to the prevention of bitumen aging, some methods concerning the thermal- or photo-oxidative aging have been investigated [10–17]. Various modifiers such as antioxidants [10–12], UV absorbers [12,13], organic montmorillonite [14], carbon black [15,16] and other phosphorus compounds [17], can exhibit an improved resistance of bitumen to the thermal- or photo-oxidative aging. Nevertheless, the measure that is capable of inhibiting bitumen from both thermal- and photo-oxidative aging is less put forward in the present study.

The bitumens from different origins vary remarkably in properties and chemistry. Therefore, the aging properties depend largely on types and origins of bitumen [18–20]. For bitumen that is susceptible to the thermal and UV aging, a modification may be useful for the prevention of bitumen aging and extension of pavement life. However, the works dealing with the selection of inferior

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binders as well as measures to prevent bitumen from both thermal and UV aging have not been done sufficiently until now.

In view of this, three different bitumens were exposed to the thermal and UV aging at different UV intensities. The bitumen with inferior aging properties was selected by comparing physical parameters of the three binders. To improve the thermal and UV aging resistance of the selected bitumen, various anti-aging additives were used to modify the bitumen via melt blending. Finally, the modified bitumen with excellent aging resistance was obtained through physical properties evaluation and Fourier transform infrared (FTIR) analysis.

2. Materials and methods

2.1. Materials

Three 80/100 penetration grade bitumens of different origins (denoted as A, B and C) were used. The bitumen A was obtained from SK Corp., Korea. The bitumen B was provided by Panjin Northern Asphalt Co., Ltd., China. The bitumen C was supported by Petrochina Karamay Petrochemical Company, China. Physical properties of the bitumens are shown in Table 1.

The anti-aging additives used were as follows: light stabilizers (Octabenzone, Bumetrizole, Tinuvin770), antioxidants (Irganox1010, Irgafos168). All of the anti-aging additives were supplied by Nanjing Milan Chemical Co., Ltd., China. The physical properties of these anti-aging additives are shown in Table 2.

2.2. Preparation of anti-aging additive modified bitumens

The anti-aging additive modified bitumens were prepared via melt blending using a high speed shearing machine. To begin with, the bitumen was heated until it was absolutely flowing. Then the preweighted bitumen and various additives were blended in an iron container at a fixed mixing speed of 2000 rpm. The modified bitumens were finally obtained after the mixtures were blended at 150 °C for 30 min. The virgin bitumen was also processed by the same methods to be the control sample.

2.3. Aging procedures

Both the thermal and UV aging were performed using an intelligent numerical control photo-thermal aging oven (Model LHX-205, China). The binders were poured into an iron plate (140 mm in diameter) to form a thin film of about 3 mm. Then the samples were placed into the oven to undergo the thermal and UV aging. The light came from a UV high pressure mercury lamp. The lamp was 500 W with main wavelength of 365 nm. In order to simulate the thermal and UV aging, the UV intensity was adjusted at 0 (i.e. thermal aging), 950 and 1200 $\mu W/cm^2$. The temperature was set at 60 °C. All samples were taken out and tested after aged for 168 h.

2.4. Physical properties test

The penetration, ductility, softening point and viscosity of the binders before and after aging were measured according to the standards ASTM D5-06e1, ASTM D113-07, ASTM D36/D36M-09 and ASTM D4402-06, respectively.

2.5. Ultraviolet–visible spectroscopy test

The absorbance and reflectance of the anti-aging additives were measured using an ultraviolet–visible (UV–Vis) spectrophotometer (UV2550, Shimadzu, Japan). The $BaSO_4$ was used as a standard in the UV–Vis experiment. The wavelength range was selected within the UV region of 220–400 nm.

Table 1
Physical properties of the bitumens.

Bitumens	Penetration, 25 °C, 0.1 mm	Ductility, 10 °C, cm	Softening point, °C	Viscosity, 60 °C, Pa s
A	88	115.7	44.5	144
B	89	132.2	46.9	163
C	87	102.0	46.7	163

Table 2
Physical properties of the anti-aging additives.

	Appearance	Melting point, °C	Light transmittance, %	
			450 nm	500 nm
Octabenzone	Light yellow needle-like powder	48	82	91
Bumetrizole	Light yellow crystalline powder	140	85	92
Tinuvin770	White powder	83	92	95
Irganox1010	White crystalline powder	120	96	98
Irgafos168	White powder	180	98	98

2.6. Fourier transform infrared spectroscopy test

The Fourier transform infrared (FTIR) spectroscopy is able to offer quickly reliable data regarding aliphaticity, aromaticity and oxygenation rate of bitumen, which is very helpful to evaluate the aging effect of bitumen. The FTIR spectrometer (Nexus, Thermo Nicolet Corp., America) was used to record the spectra of bitumens before and after aging. Sample solutions (5% by weight) were prepared in carbon disulfide. The solution was dropped onto a blankly scanned KBr cell and dried for a moment to form a thin film. All spectra were recorded in wavenumber ranging from 4000 to 400 cm^{-1}. The number of scans was 64 times and the spectral resolution was 4 cm^{-1}.

3. Results and discussion

3.1. The aging properties of different bitumens

The aging properties of the bitumens are evaluated by softening point increment (SPI) and viscosity increment (VI), which can be calculated by Eqs. (1) and (2), respectively.

$$SPI = SP_{Aged} - SP_{Unaged} \tag{1}$$

$$VI = V_{Aged} - V_{Unaged} \tag{2}$$

where SP_{Unaged} is the softening point before aging, SP_{Aged} is the softening point after aging, °C; V_{Unaged} is the viscosity before aging, V_{Aged} is the viscosity after aging, Pa s.

The effect of thermal and UV aging on SPI and VI of different bitumens is shown in Figs. 1 and 2, respectively. Compared with the thermal aging (0 $\mu W/cm^2$), the SPI and VI values of the binders are much bigger after the UV aging (950 $\mu W/cm^2$). The SPI and VI values increase further for all bitumens when the UV intensity rises to 1200 $\mu W/cm^2$. The results indicate that the combination of thermal and UV irradiation results in a much greater aging degree than

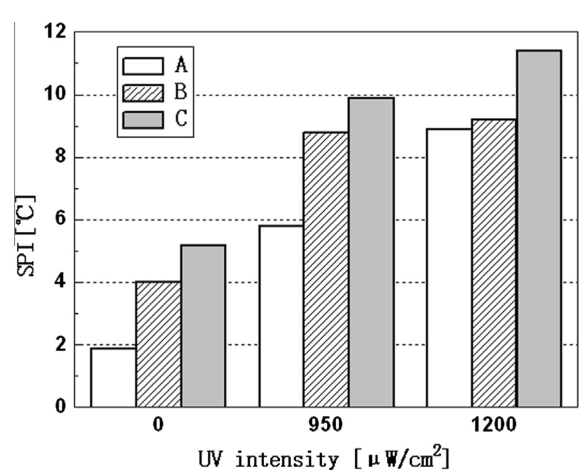

Fig. 1. Effect of thermal and UV aging on SPI of different bitumens.