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Effect of ultraviolet radiation in different wavebands on bitumen

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HIGHLIGHTS

- UV radiation in different wavebands give rise to different ageing effects.
- Effect of UV radiation on bitumen is closely related to sample thickness.
- UV radiation has a severer effect on low temperature rheological properties.
- Sulfoxide groups reach a plateau before carbonyl groups during UV ageing.

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ABSTRACT

Most researchers ignored the differences of spectrum of ultraviolet (UV) lamp when ageing bitumen. The effects of different wavebands of UV radiation on bitumen are studied in this paper. DSR results indicated that rheological properties of bitumen are not closely related to the ageing time when sample thickness is 1.13 mm. FTIR results illustrated that reactive sulfur atoms are completely oxidized before carbon atoms. Furthermore, the ageing effect on bitumen is highest with UV radiation ranging from 300 to 350 nm, medium with UV radiation ranging from 260 to 300 nm and lowest with UV radiation ranging from 350 to 400 nm. Consequently, different types of UV lamp give rise to different ageing effects on bitumen.

1. Introduction

Asphalt pavement has been applied in road construction for many years because of many advantages such as comfortableness and smoothness compared with cement concrete pavement [1–3]. However, asphalt pavement does not always perform as well as expected due to external environmental effects and internal material degradation [4,5]. The usability of asphalt pavement is easily declined due to bitumen ageing [6,7]. Bitumen ageing results in a harder and more brittle bitumen [8,9], which gives rise to the degradation of the physical and mechanical properties of the pavement [10]. Then the life span of the asphalt pavement will be shortened by different failures such as low temperature cracking and fatigue cracking [11–13].

Bitumen ageing includes short-term thermal oxidation ageing, long-term thermal oxidation ageing and UV ageing [14,15]. UV ageing and thermal oxidation ageing are two quite different types of ageing process [16]. UV radiation with wavelength of 10–400 nm corresponds to the region between visible light and X-rays in the domain of the electromagnetic radiation [17]. Based on biological effects on organisms, UV radiation can be divided into three wavelength classes: UVC (10–280 nm), UVB (280–320 nm), and UVA (320–400 nm). UVA accounts for about 8% and UVB accounts for less than 1% in the sun's UVR spectrum. Additionally, Most UVC are filtered by the ozone layer (O3) and cannot penetrate to the earth's surface [18]. UVR with longer wavelength indicates less energy and potentially less damage to all organisms [19].

The effect of UV ageing on bitumen has been drawn more attention from researchers in recent years [20,21]. The bitumen ageing process is complicated and the complexity increases when UV ageing is involved [22]. Unlike thermal oxidation ageing, there is still no unified UV ageing method [23,24]. The UV ageing method should strictly control the UV radiation from UV lamp compared to thermal ageing process. The waveband of UV radiation emitted from UV lamp in the lab usually include not only UVA and UVB but

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also partial UVC [25], which differs from the situation in reality. And different UV lamps have different spectral distributions, which means that spectral power at specific wavelength is different. As different wavelength UV radiations have different spectral powers, different spectral distributions of the radiation give rise to the disagreement with results of the experiment [26].

Zhengang Feng et al. [27] used an UV lamp with main wavelength of 365 nm to simulate the UV ageing process. The UV ageing time was 6 d and the thickness of bitumen film was about 2 mm. Song Xu et al. [28] used an UV accelerating oven to simulate the photo-oxidative ageing of bitumen. Samples were UV aged for 9 d under an UV lamp whose main wavelength is 365 nm. The thickness of samples was about 3.2 mm. Peiliang Cong et al. [29] conducted UV ageing in an UV weathering oven and the main wavelength of UV lamp is 340 nm. Asphalt binders with 3 mm thickness were UV aged for 7 d. Virginie Mouillet et al. [30] placed 10 μm thick samples in an ageing chamber and subjected it to UV radiation. Fluorescent lamps were applied and the ageing time is 60 h. V.F.C. Lins et al. [31] placed hot-mix asphalt in a Xenon Weather meter with a xenon arc light source to simulate the photo-oxidative process. Samples were UV aged for following cycles: UV ageing for 64 min and water spray for 16 min. Some references including different UV ageing conditions were shown in Table 1, where the researchers didn't consider the UV radiation and sample thickness during UV ageing process.

In this paper, two types of bitumen samples with different thickness were UV aged for different ageing time to study the effect of sample thickness on the UV ageing degree. Three different wavebands of UV radiation were selected to study the ageing effect of UV radiation in different wavebands. The rheological properties and functional groups of bitumen were tested to evaluate changes of bitumen properties due to ageing.

2. Experiments

2.1. Materials

Base bitumen with 60/80 pen grade (B) was supplied from KOCH Asphalt Co. Ltd (Hubei Province, China). The physical properties of the bitumen used are listed in Table 2.

2.2. Ageing procedure

Bitumen was UV-aged in an oven with an UV lamp of 500 W. The main wavelength of the UV lamp is 365 nm. The UV lamp was equipped with three filters (filter-1, filter-2 and filter-3). The photo of filters' transmittance is shown in Fig. 1. UV radiation in waveband-1 (UV1), waveband-2 (UV2) and waveband-3 (UV3) refer to the UV radiation filtrated through filter-1, filter-2 and filter-3 respectively. UV1 ranges from 260 to 300 nm. UV2 ranges from 300 to 350 nm. UV3 ranges from 350 to 400 nm. The experiment temperature is 30 °C to make sure that the UV ageing procedure won't be affected by thermal oxidation ageing [34]. Two types of bitumen sample were used to evaluate the UV ageing effects with different filters.

- An amount of 20 g melted bitumen was poured into an Ø (140 ± 0.5) mm iron pan and the thickness of sample was about 1.13 mm. Samples were UV aged for 2 d, 4 d, 8 d and 16 d respectively under different UV radiation wavebands and they are abbreviated as such format (B-UV1-2d). The average intensity of the UV radiation on bitumen surface was about 10 W/m^2. After UV ageing, rheological properties and function groups of the aged bitumen were tested.

Table 2
Physical properties of B.

Physical properties	B
Softening point (°C)	49.0
Penetration (25 °C, 0.1 mm)	77.5
Ductility (5 °C, 1 cm/min)	8.9
Viscosity (60 °C, Pa s)	205
Viscosity (135 °C, Pa s)	0.46

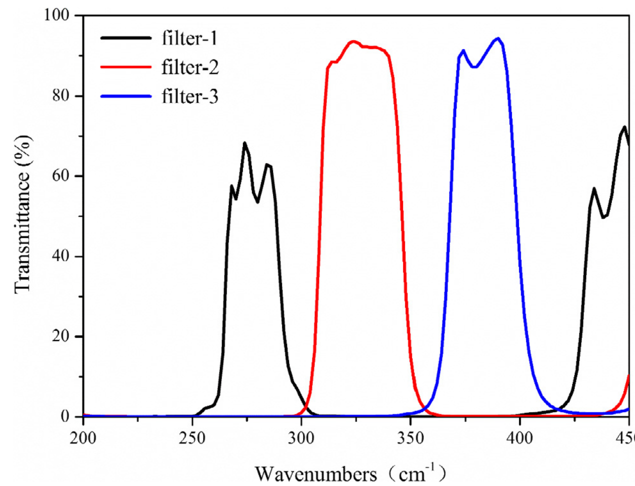

Fig. 1. The transmittance between 200 and 400 nm of different filters.

- A bitumen film was prepared by Pieri's "dry slide" technique [35]. First, bitumen samples were dissolved by carbon disulfide. Then the solutions with concentration of 5 wt% were dropped onto a blankly scanned KBr slide and dried for a moment. Carbon disulfide would be removed and sample would turn into a thin film. Thickness of the thin film is approximately 10 μm. Slides prepared in this way were UV aged for 1 h, 3 h, 5 h, 10 h, 20 h, 30 h, 40 h, 80 h, 120 h and 160 h under different UV radiation wavebands respectively. The average intensity of the UV radiation on bitumen surface was about 0.8 W/m^2. After UV ageing, functions groups of samples were tested by FTIR spectroscopy. Samples aged by UV1, UV2 and UV3 were abbreviated as B-UV1, B-UV2 and B-UV3 respectively. The flowchart of experimental design is exhibited in Fig. 2.

2.3. Characterization methods

2.3.1. Dynamic shear rheometer (DSR)

Rheological properties of base bitumen before and after UV ageing were investigated by DSR (MCR101, Anton Paar Corp., Austria). Temperature sweep tests were adopted under strain-controlled mode with a constant frequency of 10 rad/s. The high temperature sweep tests ranges from 30 °C to 80 °C and the increment of temperature is 2 °C per minute. The diameter of the testing plate is 25 mm and the gap between the plates is 1 mm. The low temperature sweep tests ranges from −10 °C to 30 °C. The diameter of the plate is 8 mm and the gap between the plates is 2 mm. The main parameters which represent the rheological properties of bitumen obtained from the DSR test are complex modulus (G*) and phase angle (δ).

2.3.2. Fourier transform infrared spectroscopy (FTIR)

The spectra of bitumen before and after UV ageing can be obtained from FTIR (Nexus, Thermo Nicolet Corp., America). The chemical structural changes of bitumen can be distinguished from the FTIR test conveniently. Spectra ranging from

Table 1
UV ageing conditions of previous researches.

Author	UV illuminant	Sample thickness	References
Zhengang Feng	UV lamp with main wavelength of 365 nm	Sample thickness: 2 mm	[27]
Song Xu	UV lamp with main wavelength of 365 nm	Sample thickness: 3.2 mm	[28]
Peiliang Cong	UV lamp with main wavelength of 340 nm	Sample thickness: 3 mm	[29]
Virginie Mouillet	Fluorescent lamp	Sample thickness: 10 μm	[30]
Françoise Durrieu	Fluorescent lamp	Sample thickness: 10 μm	[32]
V.F.C. Lins	Xenon arc lamp with main wavelength of 340 nm	Sample thickness: not mentioned	[31]
Katsuyuki Yamaguchi	Xenon arc lamp	Sample thickness: 100 μm	[33]