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Effect of ultraviolet radiation on bitumen by different ageing procedures

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HIGHLIGHTS

- Performing TFOT procedure firstly is significant in UV ageing method.
- UV ageing degree of bitumen sample is closely related to sample thickness.
- UV radiation has a severer effect on low temperature properties of bitumen.
- TFOT has a severer effect than UV radiation when bitumen thickness is 3 mm.

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ABSTRACT

Many researchers have conducted the Thin Film Oven Test (TFOT) before ultraviolet (UV) ageing to simulate the thermal-oxidation ageing process of bitumen, but the effect of TFOT procedure on UV ageing is still unknown. In this research, three ageing procedures were used to investigate the influence of TFOT procedure on UV ageing. Test results indicated that TFOT has a severer effect than UV radiation when bitumen thickness is 3 mm and bitumen thickness has a great influence on the ageing degree. Results of different ageing procedures shows that performing TFOT firstly is more appropriate for experimental analysis in UV ageing method.

1. Introduction

Bitumen is a viscoelastic material and possesses waterproofing and adhesive properties. It is either obtained by refinery processes from petroleum or is found as a natural deposit or as a component of naturally occurring asphalt, in which it is associated with mineral matter [1–3]. The properties of the bitumen are significant in deciding road performance. Appropriate bitumen can provide longer service life as well as ensure better usability of the pavement [4]. For example, the bitumen should be flexible enough to ensure cracking resistance ability at low temperature. Also, the bitumen should be stiff enough to ensure permanent deformation resistance ability at high temperature. However, asphalt pavement containing conventional bitumen do not always perform as expected due to external environment effects and internal material degradation. Therefore, properties of bitumen should be improved to ensure better performance, such as permanent deformation resistance, low temperature cracking resistance and ageing resistance [5–7]. A better arrangement of aggregate, void content and bitumen are the basis to guarantee excellent asphalt pavement, although it is not enough, because the character of asphalt itself is temporal and properties of bitumen would be degraded due to ageing during mixing and application in service life.

Bitumen becomes harder and more brittle because of ageing. The physical and mechanical properties of asphalt pavement generate a series of complex changes, which results in fatigue cracking and low temperature cracking [5,8,9]. The main reason for ageing during the service life of bitumen is the oxidation. In the process of oxidation, more highly polar and strongly interacting oxygen function groups, change the composition and properties of the bitumen [10].

Bitumen ageing is a very complex process and the complexity increase when UV ageing is involved. UV radiation wavelength is in the range of 10–400 nm and cannot be seen by human eye [11]. In terms of biological effects on organism, UV radiation was divided in three ranges by researchers according to wavelength: UVC short-wave 10–280 nm, UVB 280–320 nm, and UVA 320–400 nm. Organisms are potentially apt to be damaged by UVR with shorter wavelength [12], but not the whole UV radiation radiated

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from the sun can pass through the ozone layer (O_3) and reach the earth; Most UVC cannot make it because of the ozone layer filtration. Unfortunately UV ageing have got few attention until recent years and the method of UV ageing on bitumen is still immature [13].

Before UV ageing, bitumen is aged because of thermal-oxidation effect during the mixing and construction process. During these thermal oxidation processes, bitumen attaches on the aggregate and becomes a thin bitumen film, so previous researches about UV ageing almost focused on bitumen film ageing effect and the samples were TFOT or RTFOT aged firstly to simulate the thermal-oxidation ageing process before UV ageing.

Some references including different UV ageing conditions were shown in Table 1. Zhengang Feng [14] applied two types of UV absorber modified bitumen (octabenzone and bumetrizole) to investigate about UV ageing resistance. The thicknesses of bitumen samples were about 2 mm and the TFOT was firstly performed. Peiliang Cong [15] applied UV absorbers to modify the Styrene-butadiene-styrene copolymer (SBS) modified bitumen and studied its UV ageing resistance property. The thicknesses of bitumen samples were about 3 mm and the TFOT was firstly tested. Henglong Zhang [16] used three inorganic nanoparticles to improve the UV ageing property of bitumen and investigated the UV ageing effect. The samples were conducted TFOT and then UV aged for 12 days. M.D.F.A. de Sá Araujo [17] studied the degradation of different asphalt binders when exposed to UV radiation. In order to simulate the ageing of the hot mixing, the samples were submitted to RTFOT test firstly with sample thickness of 0.6 mm. But the effect of TFOT procedure on UV ageing is still unknown. It remains research about the UV ageing that results after TFOT with regard to thickness and UV ageing time.

In this paper, bitumen samples were UV aged in different ways to contrast the TFOT and UV ageing effect. Two types of thicknesses were used to study the necessity of ensuring the thickness of samples. Rheological properties and functional groups of bitumen before and after ageing were used to evaluate the UV ageing degree of bitumen.

2. Experimental

2.1. Materials

Base bitumen with 60/80 pen grade (A) and 80/100 pen grade (B) bitumen were supplied from KOCH Asphalt Co. Ltd (Hubei Province, China). The main physical properties of the used bitumen are presented in Table 2.

2.2. Ageing procedure

In the experiment, melted bitumen was put in a Φ (140 ± 0.5) mm iron pan to form sample film. Four groups were established in order to better analyze the UV ageing effect:

- A-T (TFOT) and B-T: The first group was samples aged by TFOT (made by Huanan Laboratory Apparatus Co., Ltd., China) according to ASTM D1754. The oven was kept at 163 °C and pans were rotated in the oven at a rate of 5.5 rpm for 5 h. The quantity of samples was (50 ± 0.5) g and the thickness of samples was 3 mm.
- A-UV and B-UV: The second group was UV aged for 0 d, 4 d, 8 d and 16 d respectively at a temperature of 60 °C on the surface of the sample. The quantity and thickness of samples were (50 ± 0.5) g and 3 mm respectively.
- A-T + UV1 and B-T + UV1: The third group was samples treated first with TFOT to simulate the thermal-oxidation ageing process before UV ageing.
  After TFOT samples were UV aged at 60 °C, with three ageing times (4 d, 8 d, 16 d), (50 ± 0.5) g was the quantity of the bitumen used and the sample thickness was about 3 mm.
- A-T + UV2 and B-T + UV2: The fourth and last group was treated with TFOT firstly to simulate the thermal-oxidation ageing process before UV ageing, then 30 g bitumen were taken out from the sample and the residue was UV aged at 60 °C with different ageing times (4 d, 8 d, 16 d). The quantity of the bitumen in the sample was (20 ± 0.5) g with a thickness of 1.13 mm.

Specimens were UV aged in an oven with four UV lamps (250 W). The UV average intensity on specimen surface was about 10 W/m^2.

Table 2
Physical properties of 60/80 and 80/100 pen grade bitumen.

Physical properties	A	B
Softening point (°C)	46.9	45.4
Penetration (25 °C, 0.1 mm)	68.3	96.0
Ductility (5 °C, 1 cm)	8.9	8.6
Viscosity (60 °C, Pa·s)	205	204
Viscosity (135 °C, Pa·s)	0.4	0.3

2.3. Characterization method

2.3.1. Dynamic shear rheometer (DSR) test

DSR test was used to measure the rheological properties of bitumen after different ageing procedures. With DSR test, the primary rheological parameters such as phase angle (δ) and complex modulus (G^*) can be obtained; this parameters are very important for the evaluation index of UV ageing of bitumen.

- Strain sweep test was performed from 30 °C to 80 °C. Strain amplitude was applied to the specimen in a range of 0.005% to high level where nonlinearity appears. Test was performed under the strain-controlled mode.
- During the low temperature sweep test, temperature increased from −10 °C to 30 °C. Diameter plate of 8 mm and gap of 2 mm between parallel plates were used. The constant load frequency was 10 rad/s and the temperature increment was 2 °C/min. The strain amplitude was 0.05%.
- For the high temperature sweep test, temperature increased from 30 °C to 80 °C. The test used a plate with a diameter of 25 mm with a gap between parallel plates of 1 mm. The strain amplitude was 0.5%.

Table 1
Ageing parameters adopted by previous researchers.

Author	UV average intensity	UV ageing time	Ageing temperature	References
Zhengang Feng	0.8 W/m^2	6 d	60 °C	[14]
Peiliang Cong	0.45 W/m^2	7 d	60 °C	[15]
Henglong Zhang	8 W/m^2	12 d	60 °C	[16]
M.D.F.A. de Sá Araujo	0.35 W/m^2	200 h	60 °C	[17]