

Ultraviolet Aging Properties of Bitumen in Ultra-thin Asphalt Pavement

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Abstract. Ultra-thin asphalt pavement is a material commonly used in the preventive maintenance engineering. Despite rather mature technologies at present, the ultraviolet aging problem of bitumen material during usage is often overlooked. To study the changes in the properties of bitumen materials in the ultra-thin asphalt pavement after ultraviolet aging, and to optimize the selection of bitumen, ultraviolet aging tests were carried out at different aging times using three types of bitumen. Penetration gradation indices and infrared spectroscopy were used to analyze the properties of bitumen before and after aging. The results showed that tiny pits and wrinkled textures appeared on the surface of bitumen films after ultraviolet aging. The aging properties of bitumen were remarkable. Different types of bitumen exhibited markedly distinct ultraviolet aging properties from each other. Although the mass of bitumen changed little before and after the ultraviolet aging, the penetration, softening point and ductility of bitumen all reduced significantly after ultraviolet aging, and the bitumen become hardened and more susceptible to fracture at low temperatures. The values of infrared absorption peaks increased significantly after aging for ultraviolet aging-sensitive bitumen materials. Based on this finding, the aging resistance of bitumen can be evaluated. After comprehensive comparison, it is found that bitumen C had the best aging resistance.

1. Introduction

In the preventive maintenance and related projects of asphalt pavements for high-grade highways, ultra-thin asphalt pavement is a commonly used solution [1]. It can well restore the surface function of roads and extend their useful life when the pavement distress is mild and the overall situation is preferable. Moreover, with a thickness of only about 2 cm, it can significantly reduce the cost, which has excellent technological and economical efficiency. Currently, the ultra-thin asphalt pavement technologies commonly used at home and abroad mainly include: BBTM, OGFC [2], Novachip [3], ECA[4], AC[5], etc. Through many years of research, these technologies have become fairly mature, which are applied in large scale in the actual engineering.

The existing research on ultra-thin asphalt pavement are concentrated mainly on the structural design of ultra-thin asphalt pavement, the optimization of gradation composition of bituminous mixture, the research and application of special bitumen, and the integrated paving technology [6-8]. In contrast, aging problem of bitumen materials during usage of ultra-thin asphalt pavement is often overlooked. Due to thin thickness and large gap, ultra-thin asphalt pavement is prone to aging related distresses during usage, especially the photoaging caused by the sun's ultraviolet light is the most significant distress. The ultraviolet aging of bitumen is actually a complex process subject to combined effects of heat, light, oxygen, water, load and other factors [9]. Similar to the thermal aging process, bitumen undergoes multiple changes such as oxidation, volatilization and polymerization during ultraviolet aging, of which oxidation is the dominant change. Therefore, the ultraviolet aging process of bitumen can be approximately considered as a photooxidation process. During this process, the solar ultraviolet energy in the range of 200-400 nm [9] is usually higher than the energy needed to break the chemical bonds in the polymer chain. The ultraviolet light in this range will cause rupture of

the polymer chain in bitumen materials, thereby greatly diminishing their performance and significantly degrading the road performance of bituminous mixtures. Obviously, it is necessary to study the ultraviolet aging properties of bitumen in the ultra-thin asphalt pavement. To study the changes in the properties of bitumen materials in the ultra-thin asphalt pavement after ultraviolet aging; and to optimize the selection of bitumen, ultraviolet aging tests are carried out in this paper for three common types of bitumen at different aging times. Furthermore, properties of bitumen before and after aging are analyzed using the penetration gradation indices and infrared spectroscopy.

2. Experimental design

2.1 Test equipment

In the study, the light source of simulation test equipment in the ultraviolet aging chamber was selected such that it can provide ultraviolet light in the wavelength range of 200-400 nm while ensuring stable control of temperature and humidity. Among a variety of light sources that can simulate ultraviolet radiation, the ultraviolet and visible spectra emitted by xenon lamp are very closed to the sunlight. After filtering the infrared light with the filter glass, the spectral line is closest to the natural light, which can well simulate the natural photoaging. Therefore, xenon lamp was used as the radiation source for the bitumen ultraviolet aging equipment in this paper. Its radiation spectral range was 290-800 nm, average irradiance was $4 \times 10^{-3} \text{W/cm}^2$, and power 3.3 kW; moreover, temperature and humidity were controllable, and cycles were steady, as shown in Fig.1. The bitumen aging times were chosen as 240 h and 360 h. To analyze the changes in the chemical substances and various functional groups in the materials after ultraviolet aging, Fourier transform infrared spectrometer (FT-IR) was used to perform spectral analysis on bitumen, as shown in Fig.2.



Fig.1 Ultraviolet aging test equipment



Fig.2 FT-IR equipment

2.2 Bitumen materials

To compare the effects of different bitumen materials on the performance of ultra-thin asphalt pavement, three types of bitumen commonly used in the ultra-thin asphalt pavements, namely SBS modified bitumen I-D of A origin (A); SBS modified bitumen I-D of B origin (B); and rubber powder modified a bitumen (C), were selected to conduct relevant tests. Performance test results of the three bitumen are listed in Table 1.

Table 1 Bitumen performance test results

Test item	Bitumen A	Bitumen B	Bitumen C
Penetration (25°C, 100 g, 5 s) (0.1mm)	54.6	54.6	45.4
Softening point $T_{R\&B}$ (°C)	86.2	80.8	68.5
Ductility (5°C, 5 cm/min) (cm)	33.3	12.4	8.3
Brookfield viscosity (135°C) (Pa·s)	2.454	6.525	-
Brookfield viscosity (180°C) (Pa·s)	-	-	2.888

3. Results and Analysis

3.1 Changes in surface state of bitumen before and after ultraviolet aging

Fig.3 shows the surface state of bitumen B before ultraviolet aging. Clearly, the bitumen film surface produced an obvious mirror effect. Fig.4 shows the surface state of the specimen after 360 h of ultraviolet aging. As can be seen, after ultraviolet aging, the surface of bitumen film lost its luster, and the mirror effect disappeared. Tiny pits and even significant wrinkled textures appeared on the surface, exhibiting very evident aging characteristics of bitumen.



Fig.3 Bitumen B before aging



Fig.4 Bitumen B after aging for 360 h

3.2 Changes in bitumen performance before and after ultraviolet aging

Performance test results of bitumen A, B and C before and after ultraviolet aging are listed in Tables 2-4.

Table 2 Routine performance test results of bitumen A before and after ultraviolet aging

Test item	Before aging	After aging for 240 h	After aging for 360 h
Mass loss (%)	-	-0.02	0.02
Penetration (25°C, 100 g, 5 s) (0.1mm)	54.6	37.7	38.1
Softening point $T_{R\&B}$ (°C)	86.2	79.1	84.6
Ductility (5°C, 5 cm/min) (cm)	33.3	31.1	26.6
Brookfield viscosity (135°C) (Pa·s)	2.454	-	2.838

Table 3 Routine performance test results of bitumen B before and after ultraviolet aging

Test item	Before aging	After aging for 240 h	After aging for 360 h
Mass loss (%)	-	-0.01	0.01
Penetration (25°C, 100 g, 5 s) (0.1mm)	54.6	42.0	41.2
Softening point $T_{R\&B}$ (°C)	80.8	75.9	64.9
Ductility (5°C, 5 cm/min) (cm)	12.4	10.7	8.7
Brookfield viscosity (135°C) (Pa·s)	6.525	-	1.563

Table 4 Routine performance test results of bitumen C before and after ultraviolet aging

Test item	Before aging	After aging for 240 h	After aging for 360 h
Mass loss (%)	-	0.06	0.08
Penetration (25°C, 100 g, 5 s) (0.1mm)	45.4	36.8	37.3
Softening point $T_{R\&B}$ (°C)	68.5	66.8	65.6
Ductility (5°C, 5 cm/min) (cm)	8.3	8.0	9.2
Brookfield viscosity (135°C) (Pa·s)	2.888	-	1.707

It can be seen from the data in Tables 2-4 that: Mass of bitumen A, B and C changed little before and after ultraviolet aging, which was almost no loss. Penetrability and ductility of bitumen A, B and C decreased significantly after ultraviolet aging, indicating that the bitumen materials became hard and brittle after ultraviolet aging, which were more susceptible to fracture at low temperature (5 °C). Penetration values after 240 h of aging did not differ much from those after 360 h of aging, which tended to stabilize. Ductility of bitumen A and B decreased gradually over the aging time, while bitumen C showed no significant change in ductility. Softening points of bitumen A, B and C all decreased after ultraviolet aging, indicating that the bitumen materials were more susceptible to softening after ultraviolet aging. The softening point did not decrease much over aging time for

bitumen A and C, while rather greatly for bitumen B. After ultraviolet aging, bitumen A increased in viscosity, while bitumen B and C decreased in viscosity. According to the test results, bitumen A and C had less performance degradation than bitumen B, which possessed better anti-ultraviolet aging properties.

3.3 Infrared spectral analysis before and after ultraviolet aging

Fig.5-7 illustrate the FT-IR scan results of bitumen A, B and C before and after aging 360 h of ultraviolet aging.

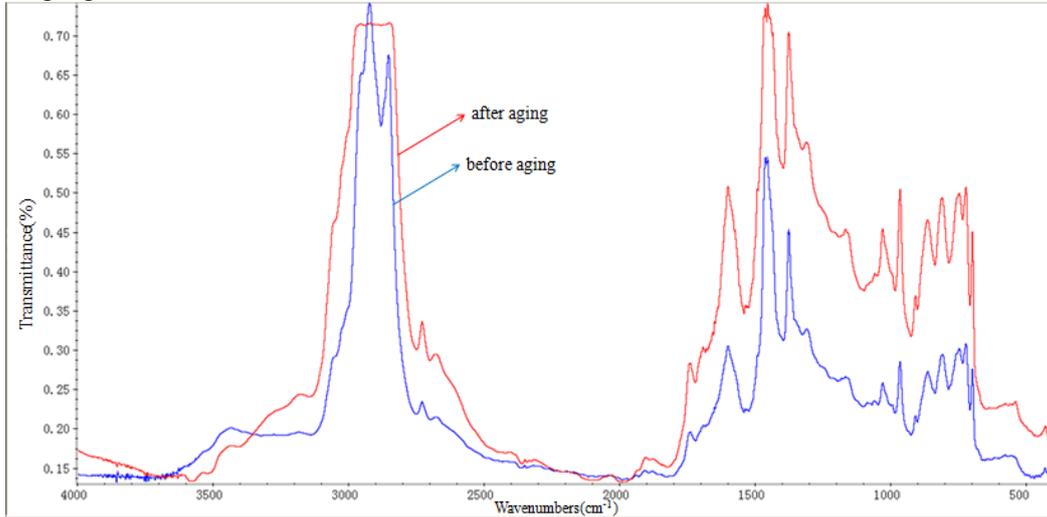


Fig.5 FT-IR absorbance of bitumen A before and after aging

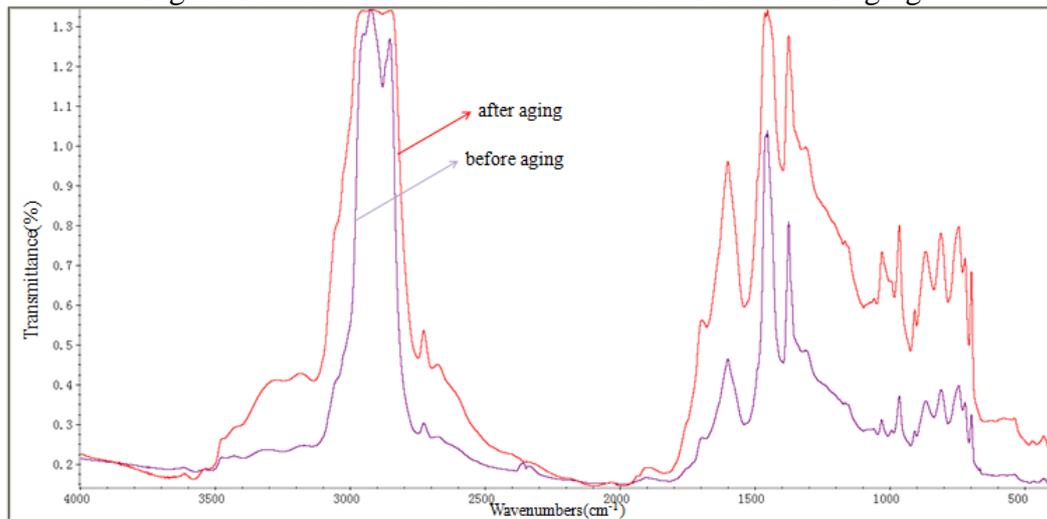


Fig.6 FT-IR absorbance of bitumen B before and after aging

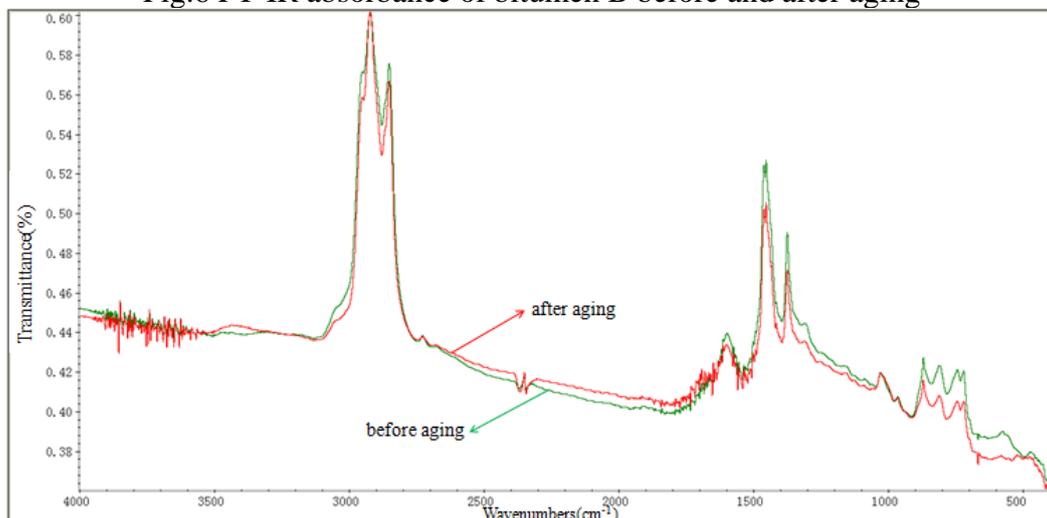


Fig.7 FT-IR absorbance of bitumen C before and after aging

The results in Fig.5-7 showed that:Before aging, bitumen A, B and C presented significant absorption peaks at three positions, which corresponded to the different functional groups, specifically:Primary peak: Methyl (CH_3-) and methylene (CH_2-) groups with wavelengths of $2800-3000\text{cm}^{-1}$;Secondary peak: Carbonyl and carboxyl groups with wavelengths of $1200-1900\text{cm}^{-1}$;Tertiary peak: C-O single bond with wavelengths of $910-1300\text{cm}^{-1}$.

After ultraviolet aging, very obvious numerical changes occurred at these three absorption peak positions for bitumen A and B. This suggested significant increase in the number of corresponding functional groups, which were severely affected by ultraviolet aging.

For bitumen A and B, the values of primary absorption peaks increased over the aging time at wavelengths between $2800-3000\text{cm}^{-1}$ after ultraviolet aging. Since the site was mainly the absorption range of CH_3- and CH_2- , the finding suggested increased content of these two functional groups after the ultraviolet aging. The values of carbonyl and carboxyl secondary peaks at $1200-1900\text{cm}^{-1}$ and the C-O tertiary peaks between $910-1300\text{cm}^{-1}$ also increased over the aging time. This similarly suggested that the contents of these functional groups would increase under ultraviolet aging.

Bitumen C did not show significant change in the absorption peaks before and after ultraviolet aging, which was not sensitive to such aging. Thus, its aging resistance was better than the bitumen A and B.

4. Conclusions

After ultraviolet aging, tiny pits and wrinkled textures appear on the surface of bitumen films, showing very obvious aging characteristics of bitumen.

Different bitumen materials have markedly distinct ultraviolet aging properties. Despite little changes in the mass of bitumen before and after the ultraviolet aging, the penetration, softening point and ductility of bitumen all decrease significantly after aging, and the bitumen hardens to become more susceptible to fracture at low temperatures.

For ultraviolet aging-sensitive bitumen materials, the values of FT-IR absorption peaks increase markedly after aging. The aging resistance of bitumen can be evaluated based on this finding. After comprehensive comparison, bitumen C is found to have the best aging resistance, followed by A, while C has the poorest resistance.

5. References

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