Research on the Asphalt Aging Properties under Ultraviolet Radiation and its Modification

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ABSTRACT**:** As there is intensive ultraviolet(UV) radiation in high-altitude areas in China, the UV resistance should be considered in analyzing the durability of asphalt mixture. Firstly, Field UV radiation intensity was also conducted in Galitai, national highway 213, Sichuan province, which is at an altitude of 2992 meters. Based on the test results, as well as the laboratory UV light source intensity, the equivalent time of laboratory and field UV radiation aging was determined. Then, based on the laboratory test results on the penetration, softening point, ductility and viscosity of the binders under the different aging processes by thin film oven test and the UV aging system test, it can be seen that the UV radiation has significant influence on the property of the binders, especially the SBR modified asphalt with good low temperature properties, which is also proved by the testing results of field UV aging test specimens. On the other hand, authors selected six UV absorbents and made an evaluation on the UV resistance effects of these absorbents, and recommended two UV absorbents which have better UV resistance and better low temperature properties. One of the two absorbents was used in field test section in national highway 213, Sichuan province and a control section was also constructed to compare their long-term UV resistance.

KEY WORDS**:** UV radiation, asphalt aging, UV absorbent, low temperature properties

1 INTRODUCTION

While the asphalt pavement is exposed to the natural environment, its performance also depends on the impact of traffic loads and the influence of the elements like rainfall, temperature and UV radiation, especially in the cold high-altitude areas where the asphalt pavement is exposed to severe test of the natural environment. Low temperature, plus strong UV radiation, will markedly impair the deformation capacity of the asphalt covering and increase its brittleness. Thus, the low temperature properties and fatigue resistance of the pavement decline and the asphalt pavement tends to prematurely crack or peel, or to be damaged in other ways, which can significantly affect the performance and shorten the service life of asphalt pavement. Therefore, it is of great importance in both theory and actual application for constructing asphalt pavement in cold high-altitude areas to study the UV aging property and aging extent and to take certain measures to improve its aging property.

With the method of UV aging test, this contribution has conducted thin film oven tests on 3 types of asphalt with better low temperature properties, as well as laboratory UV aging tests of different durations, to investigate the extent of the impact of UV radiation on the property of different types of asphalt. For the asphalt which does not have sound UV resistance, UV absorbents were adopted to improve its UV resistance, and field test sections were built to evaluate their effectiveness.

2 UV AGING TEST

2.1 Instruments for UV Aging Test

Under natural conditions, as the UV aging period of asphalt is long, plus the complex field environment, there are many factors affecting the test results. Therefore, this research adopted the UV aging simulation system (Fen, 2005[1])developed by Tongji University to simulate the field UV aging process. This system simulates the natural conditions in artificial environment, with high-voltage mercury lamp as the UV radiation source, to make the UV radiation intensity in the test box more than 10 times of that under field sunshine condition, thus reducing the aging period of asphalt. This simulation system consists of 5 parts – strong UV light source environment box, light source system (including reflecting black-light high-voltage mercury lamp and stabilizer), temperature control system, safety control system, and time control system.

2.2 Determining the Duration of Laboratory Strong UV Radiation

We have conducted measurement on the field UV radiation intensity in Chuanzhusi Town, Abazhou, Sichuan Province at an altitude of 2992m. The results of the field measurement showed that the maximum solar UV radiation intensity was 3610μW/cm^2 and the average intensity was 2500μW/cm^2; considering such reduction factors as season, cloudy or rainy days, the annual sunshine hours was preliminarily determined as 2400 h; the average radiation intensity of the artificial UV light source adopted by the laboratory aging test was 34000μW/cm^2. Based on the equivalent relation of radiation level, the field UV radiation under sunshine condition (at the altitude of 2992m) can be converted to laboratory strong UV radiation duration through field measurement and calculation, and the conversion results are listed in Table1 below.

Table1: Scaled time table of laboratory and field UV radiation

Field UV radiation time (months)	3	6	9	12	15
Laboratory UV radiation time (h)	40	80	120	160	200

In accordance with the time equivalents in Table 1, the UV aging tests were undertaken using exposure times of 32h, 80h and 160h to simulate field UV exposure of 2.5, 6 and 12 months. The samples were exposed for 16h UV radiation each day with a non exposure interval of 8h.

2.3 Laboratory UV Aging Test Procedures

First, Thin Film Oven Test (TFOT) was conducted on asphalt specimens to simulate the short-term aging during the construction; then the asphalt specimens having undergone TFOT were placed in several pans separately with the asphalt film at about 1mm thick; then the specimens were placed in the artificial UV light source environment box to suffer strong UV radiation for a specified duration (2, 5, 10 d); when the specimens were taken out, the 3 key conventional indexes - penetration, softening point, ductility (especially low-temperature ductility; here at 5, 10 ℃), as well as the viscosity at 60 ℃, were tested in accordance with *Test Specifications of Asphalt and Bitumen in Highway Engineering* (JTJ052-2000). During aging process, the temperature of the artificial strong UV light source environment box (below 20℃ in winter, below 40 ℃ in summer) should be controlled, and the total UV radiation duration in the artificial strong UV light source environment for each day should be controlled at 16h (i.e. AM5:00~PM9:00), with an interval of 8h.

3 ASPHALT TYPES FOR TEST

The tests used 3 types of asphalt: Shell AH-90 asphalt, SBR modified asphalt, and Shell SBS modified asphalt. The conventional indexes of the three types of asphalt are listed in Table 2.

Table 2: Conventional indexes of asphalt

Type of asphalt	Penetration, 25 ℃ (0.1 mm)	Softening point(℃)	Ductility(cm)		Viscosity （Pa•s）
			5 ℃	10 ℃	
AH-90	84	46	-	>150	134(60℃)
SBR	74	53	>150	>150	0.3(135℃)
SBS	56	67	34	80	0.1(135℃)

4 IMPACT OF UV AGING ON ASPHALT PROPERTIES

4.1 Laboratory Testing Results and Analysis

In order to determine the impact of UV aging on asphalt property indexes, we first conducted Thin Film Oven Tests (TFOT) on three types of asphalt; on the basis of TFOT, laboratory UV aging tests of different durations were conducted; then, the property indexes of the asphalt specimens after TFOT and after UV aging test were measured respectively. The test results are listed in Table 3 and Table 4 respectively. Figure 1 shows the asphalt specimens after UV aging and we can see that the surfaces of all the specimens are obviously carbonized.

Table 3: Results of performance indexes about three types of asphalt before and after TFOT test

Type of asphalt		Penetration, 25 ℃(0.1 mm)	Softening point(℃)	Ductility(cm)		Viscosity, 135℃ （Pa•s）
				5 ℃	10 ℃	
AH-90	Before TFOT	84	45.5	-	>175	134(60℃)
	After TFOT	63	48.5	-	19	253(60℃)
SBR	Before TFOT	74.3	53	＞150	＞150	0.3
	After TFOT	56.0	59	＞150	＞150	0.6
SBS	Before TFOT	62.6	67	34	79.5	0.1
	After TFOT	42.3	67	23	57.0	0.8

From Table 3, we can see that: (1) after TFOT, all the 3 types of asphalt had reduced penetration but increased viscosity; (2) SBR modified asphalt had sound low temperature ductility, and its ductility at 5 and 10 ℃ before and after TFOT both exceeded 150cm; the ductility of SBS modified asphalt at 5 and 10 ℃ before and after TFOT both did not exceed 80cm, and the post-aging ductility at both 5 and 10 ℃ was reduced to a certain extent; the ductility of Shell AH-90 asphalt at 10 ℃ declined sharply. (3) After TFOT, the softening point of SBR modified asphalt rose, but that of SBS modified asphalt did not change.

Table 4: Results of performance indexes about three types of asphalt after UV radiation aging test

Type of asphalt	UV radiation aging(d)	Penetration, 25℃(0.1 mm)	Softening point(℃)	Ductility(cm)		Viscosity,135 ℃（Pa•s）
				5 ℃	10 ℃	
AH-90	2	48	52	-	12.5	276(60℃)
	5	48	52	-	9.5	284(60℃)
	10	43	52	-	8.5	328(60℃)
SBR	2	54.0	60.0	7.8	16.7	0.6
	5	54.0	61.0	7.7	16.0	1.3
	10	48.0	63.5	6.9	12.5	1.8
SBS	2	39.0	67.0	22.0	28.0	1.3
	5	37.0	67.0	18.7	25.0	1.3
	10	37.0	67.0	17.9	22.5	1.5

As shown in Table 4: (1) As the period of UV radiation aging increases, reduction in penetration and ductility and increment in viscosity happened to all the three types of asphalt, but with small variation amplitude; (2) SBR modified asphalt showed an upward trend in its softening point, while the softening points of AH-90 asphalt and SBS modified asphalt remained unchanged after the UV radiation aging test.

As can be seen from the related data about low temperature ductility in Table 3 and 4: (1)

AH-90 asphalt received more impacts from TFOT test than from the UV radiation aging test, while it was just the opposite with SBR modified asphalt, which was less impacted by TFOT test, but had a sharp drop in its ductility at 5 and 10 ℃ from 150cm to 7.8 cm and 16.7 cm respectively after experiencing the laboratory UV radiation aging for 2 days; slightly differently, the ductility of SBS modified asphalt at 5 ℃ declined fast after TFOT test, compared with the small variation magnitude before and after UV radiation aging test, while its ductility at 10 ℃ had a similar decline magnitude after experiencing the TFOT test and UV radiation aging test; (2) All the three types of asphalt experienced the largest decline magnitude in their ductility after 2d of laboratory UV radiation. Then, as the aging period increased, there were quite small variation magnitudes in their ductility; (3) Although the original specimen of SBS modified asphalt possessed a small low temperature ductility than the original specimen of SBR modified asphalt, the decline magnitude of the former was far smaller than that of the latter after experiencing the UV radiation, hence leading to a bigger ductility of SBS modified asphalt at 5 ℃and 10℃ than those of SBR modified asphalt after the UV radiation aging. Thus, after experiencing the same conditions of UV radiation aging, SBS modified asphalt has a better resistance to UV aging than SBR modified asphalt.

As can be seen from above, impacts on the SBR modified asphalt by UV in areas with high altitude and high UV intensity cannot be ignored. When selecting asphalt materials, SBS may be adopted by taking into account of pavement damages resulted from both low temperature cracking and UV radiation aging cracking. Of course, the practice of adding UV absorbent to SBR modified asphalt may be tried as well, so as to improve its UV resistance.

Figure 1: The asphalt specimen after UV radiation aging test

4.2 Field UV Aging Test and Analysis

In order to evaluate the impact of field UV aging on the properties of asphalt and asphalt mixture, we exposed some asphalt specimens to natural UV in the field (see Figure 2 and Figure 3). After being exposed for 7 months and 1 year, some specimens were taken back to the laboratory for testing and analysis. See Table 5 and Table 6 for the results.


Figure 2: Before field UV aging   Figure 3: Seven months after field UV aging

Table 5: Comparison of asphalt properties after UV exposure in the laboratory and in the field

Asphalt specimen		Penetration ,25℃ (0.1 mm)	Softening point(℃)	Ductility,10℃(cm)
AH—90 asphalt	As-received	84	46	＞150
	Post-TFOT aging	63	49	19
	Laboratory UV aging for 80h	48	52	9.5
	Field UV aging for 7 months	57	52	10.5

As shown in Table 5, in respect of softening point and ductility, the laboratory UV aging for 80h is equivalent to field UV aging for 7 months, which illustrates that the laboratory UV aging equivalent time listed in Table 1 is applicable. Certainly, it still requires further attestation or revision with more tests.

Table 6: Low-temperature Splitting Strength of Marshall Specimens at −10℃ after different aging durations (MPa)

Adhesives of mixture	Specimen prior to UV aging	Specimen after 7 months	Specimen after 1 year
SBS modified asphalt	2.25	2.97	2.88
SBR modified asphalt	2.80	2.11	2.03
AH-90 asphalt	1.80	2.27	1.77

As shown in Table 6, with the extension of aging duration, the low temperature splitting strength of the Marshall specimens of both SBS modified asphalt and AH-90 asphalt register the tendency of increase followed by decline, while the Marshall specimen of SBR modified asphalt, which first featured high strength, declines all the way and its low-temperature splitting strength is even poorer than Marshall specimens of AH-90 asphalt. This again illustrates that the UV aging resistance of SBR modified asphalt needs to be improved.

5 MODIFICATION FOR ASPHALT AGING PROPERTIES AND EFFECT ANALYSES

In accordance with the test results above, the UV radiation aging has significant impacts on asphalt properties, especially the performance of SBR modified asphalt, hence having to taking measures (such as adding UV absorbent) to improve their UV resistance, so as to achieve a longer service life of asphalt pavement. Through extensive literature search, this study has selected six types of UV resistance additives, namely, two kinds of nano-materials (FU1 and FU2) and four kinds of UV absorbents (D1, D2, D3, and Y1), with the respective dosage of 0.3%, 0.8%, 1.3% and 1.8%. During the test, required dose of additive was first spread evenly in the adopted Shell AH-90 asphalt by using the high speed shearing machine. Then, the TFOT test and UV radiation aging test were conducted on the prepared speicimens as described above, together with other technical index tests as well. The results show that UV absorbent can play a certain role in improving the UV resistanceof asphalt, with improvement degrees specific to the doses applied, especially true with the doses of 0.8% and 1.3% (See Table 5). Therefore, studies are carried out by referring to these doses' effects in improving UV resistance of SBR modified asphalt, whose technical indexes from TFOT test and 2-day laboratory accelerated UV radiation aging test after various additives are applied are listed in Table 7.

Table 7: Test results of SBR modified asphalt with additive after laboratory UV aging

Type of Asphalt		Penetration, 25℃, (0.1mm)	Softening Point(℃)	Ductility,10℃(cm)	135℃Viscosity (Pa·s)
Additive	Dose				
FU1	0.8%	44	58	45	1.1
FU2	0.8%	41	59	12.5	1.0
D1	1.3%	35	61	19.6	1.1
D2	1.3%	37	62	18.5	1.3
D3	1.3%	34	65	8.5	1.7
Y1	1.3%	40	60	44	1.4
SBR Modified Asphalt		54	60	16.7	0.6

It can be seen from above table that after additive is added, compared with SBR modified asphalt without additive, penetration declines and viscosity increases, but the softening point and ductility vary irregularly, which illustrates that different additives have different impacts on the UV aging resistance of SBR modified asphalt. The additives 0.8%FU1 and 1.3%Y1can significantly improve low temperature ductility of SBR modified asphalt after UV aging.

However, in view of the fact that the price of FU1 is three times of Y1, this study finally recommends that Y1 be added in the surface course of asphalt pavements as a UV aging resistant additive, with a mixture dose of 13%.

6 TEST SECTION SCHEME AND IMPLEMENTATION

This study relies on the highway reconstruction project from Langmusi to Chuanzhusi on National Highway 213, located on the eastern edge of Tibetan Plateau, the western end of Qinling Mountain and Northwest Sichuan Plateau, with average elevation at 2900～3850m. Construction standard of the whole route is technical standard for Class II highway in plain lightly undulate area, traveling speed calculated at 80km/h, width of subgrade at 12m, and width of pavement at 9m. The average temperature of years in this region is 1.1℃, extreme maximum temperature 24.4℃, and extreme minimum temperature -33℃. The section in Songpan County is selected as the test road section. It is 600m long, and is divided into three options as shown in Table 8. Study has indicated that UV aging in asphalt binder only takes place at 1mm on surface course of the asphalt(Fen, 2005[2]). Therefore, consideration for UV aging is only limited to the upper surface course.

Table 8: Option of AC13 Asphalt Binder on the Upper Surface Course

Test Section Option	1	2	3
Asphalt Binder	SBR Modified Asphalt	SBS Modified Asphalt	SBR Modified Asphalt + UV Absorbent

Figure 4 and Figure 5 are photos of the construction site. At present the overall condition of the test sections is good. Since the duration is short, it is very difficult to identify the difference between the three binders. Therefore, the test section shall be observed in long term to investigate difference in UV aging resistance performance of the three binders.

Figure 4: Adding additives into asphalt

Figure 5: Roller compaction site

7 CONCLUSIONS

1) Technical indices of Shell AH-90 asphalt are more influenced by film oven aging than by UV aging.
2) Film oven aging does not have much influence on technical indices of SBR modified asphalt, especial low temperature ductility. However, after UV radiation, its low temperature ductility drops sharply, indicating that UV aging has very significant influence on its low temperature ductility.
3) After thermal aging in film oven test and UV aging, ductility of SBS modified asphalt drops by an equivalent margin, indicating that UV aging has equivalent influence on SBS modified asphalt as thermal aging in film oven.
4) Low temperature ductility of SBR modified asphalt is significantly better than that of SBS modified asphalt when it is in original state and after it is aged in film oven. However, after UV radiation for some time, low temperature ductility of SBR modified asphalt drops sharply. Its ductility is worse than that of SBS modified asphalt under the same temperature. This indicates that UV aging resistance performance of SBS modified asphalt is better than that of SBR modified asphalt. This provides new reference for selection of asphalt pavement modifier in alpine and high altitude regions.
5) UV absorbent can improve UV aging resistance performance of asphalt to some extent, and the extent of improvement varies with different dose. Among the 6 additives selected, 2 improve UV aging resistance performance of SBR modified asphalt significantly, and one of these two is recommended for the project in the test section.

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