Evaluation of Asphalt Deterioration Behavior Based on Ultraviolet ray Climate and Prediction in Accelerated Weathering Test

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ABSTRACT: Asphalt deterioration is primarily the result of fatigue caused by repetitive traffic loadings and oxidation caused by solar heat and ultraviolet (UV) radiation. Damage from UV rays is especially significant because such radiation acts directly on the chemical linkage of the material, resulting in bond cutting and crosslinking that weakens the material. As a result, UV radiation is considered the primary cause of the top-down cracking and aggregate stripping of asphalt pavement. Despite this, there have been studies related to weather-based asphalt deterioration and it was not clear previously how meteorology-related deterioration influences pavement performance.

In this study, the authors measured field climate conditions as part of efforts to understand UV related deterioration behavior. Asphalt mixtures exposed at the same period (from Oct. 2007 to Sep. 2008.) were evaluated physically and chemically. However, long-term examination periods were considered necessary to fully understand how asphalt properties are altered by UV radiation, and that factor was seen as an obstacle to this research. Because of this, an accelerated weather meter was used as part of a forecast procedure for predicting long-term deterioration. Accelerated weathering test conditions were set based on actual meteorological observation data.

After adjusting UV irradiation and temperatures, good correlations between field exposure specimens and accelerated weathering specimens were obtained. Meteorology-related deterioration influences between UV radiation and asphalt oxidation levels, bending tests were clarified. Furthermore, it was confirmed that oxidation caused by UV radiation significantly influences the cracking and aggregate stripping of asphalt pavement.

KEY WORDS: Oxidation, field climate conditions, accelerated weathering test, infrared spectroscopy, SBS modified asphalt.

1 INTRODUCTION

Asphalt, the binding agent in asphalt pavements, is the component in road surfacing materials that suffers embrittlement, so top-down cracks (reduction in flexibility) and aggregate stripping (reduction of the holding force on aggregates) are thought to be the basic causes of these problems. However, few reports have concentrated on UV radiation, and it remains unclear how much influence this really has on pavement functionality.

The authors have performed a year-long meteorological survey (UV irradiation, environmental temperature, rainfall) to elucidate the process by which asphalt is weakened by exposure to UV radiation; at the same time, we conducted physical and chemical evaluations of asphalt samples exposed to actual field climate conditions. The long time required to observe trends in the changes of asphalt due to UV radiation is an obstacle to this kind of research. Therefore, an accelerated weathering test conducted to make predictions of UV-induced deterioration.

2 METEOROLOGICAL LOADS DURING SERVICE

Asphalt mixtures were placed outside in order to examine the effect of the meteorological load on asphalt conditions during their service lives. Meteorology conditions were also observed during the exposure test. The exposure stand and samples are shown in Photo 1.

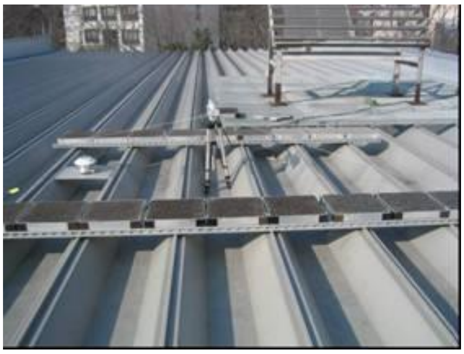

Photo 1: Placement of asphalt mixture specimens and meteorological instruments.
The location is Tsukuba city in Ibaraki pref., Japan

2.1 Specimens

The materials used in the exposure test are described in Table 1. The specimens were 30 × 30 × 5cm and were installed in aluminum frames for the exposure test.

Table1: Binder performance and Sorts of mixture.

Type of Binder	BINDER		ASPHALT MIXTURE	
	Penetration Index (1/10mm)	Softening Point (°C)	Mixture Type	Compaction Ratio (%)
Straight-Asphalt	67	45	Dense Graded	99
PMA- II	47	80	Dense Graded	98.5
PMA-H	53	91	Porous Graded	99.7

2.2 Meteorological Observations

Meteorology conditions were observed with a thermometer, a precipitation gauge, and a radiometer that monitored the UV-A spectrum (315 – 400 nm). The monthly UV radiation data from October 2007 to September 2008 are shown in Figure 1. These observations indicated an annual UV insolation of 314 MJ/m^2, a mean annual temperature of 17°C and an annual rainfall of 1348 mm.

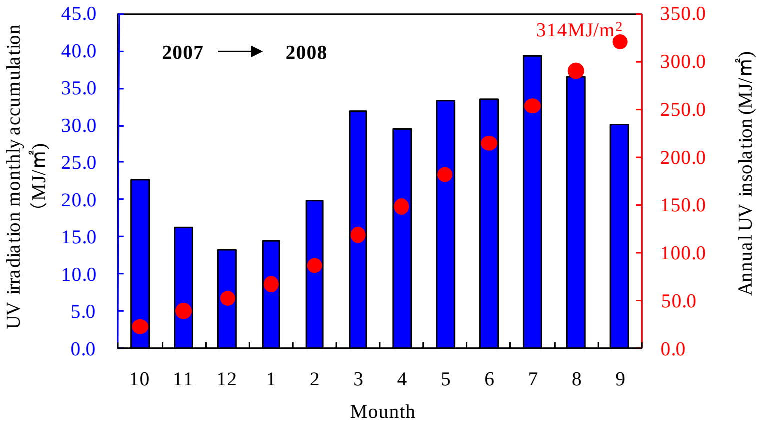

Figure 1: The monthly and annual UV insolation data fromOct.2007 to Sep.2008.

3 PREDICTION IN ACCELERATED WEATHERING TEST

An accelerated weathering meter was employed to conduct short-term examinations of the influence of weather load on asphalt (Photo 2).

Photo 2: Accelerated weathering meter

3.1 Selection of Accelerated Weathering Test Conditions

The conditions for the accelerated weathering test were set on the basis of observed meteorology data. The conditions used are listed in Table 2. The intensity of the light source was adjusted to provide 324 MJ/m^2 of annual UV insolation, equivalent to a year's exposure (UV insolation observed data; 314MJ/m^2) under the sun, within 200 hours.

Table 2: Accelerated weathering test conditions.

Items	Specification
A Source of Light	High Intensity Discharge lamp
Test Temperature	20°C
Rainfall	100 mL/hr
Irradiance	450 W/m^2
Accumulated UV insolation	1.62 MJ/m^2/hr

3.2 Specimens

The asphalt mixture samples described in Table 1 were used in the accelerated weathering test.

4 EVALUATION METHOD

Bending and wheel-tracking fatigue tests were conducted and binder samples recovered from the mixtures were examined under infrared spectroscopy to obtain physical and chemical evaluates of the influence of meteorological load on the condition of the asphalt mixture. The changes in flexibility characteristics of the mixture due to meteorological load were measured by the bending test. The bending test conditions are listed in Table 3.

Tensile loads from automobile tires, as shown in Figure3, are thought to cause cracking in the pavement surfaces (top-down cracking). A test causing tensile stresses at the asphalt mixture surface was conceived, and the occurrence and conditions during progress of cracking at the mixture surface around the time of weathering were observed. The conditions for the wheel-tracking fatigue test are listed in Table 4. The test instrument is shown in Photo 3.

The infrared spectroscopy using an FT-IR spectrometer indicated changes in the asphalt molecular structure around the time of weathering test. Observations were mainly of absorption in the vicinity of 1700 cm^{-1}, which is an index of oxidation degradation of materials.

Table 3: Bending test conditions.

Items	Conditions
Specimen size	30×10×5cm
Test temperature	20 °C
Curing time	5hours
Loading speed	50 mm/min

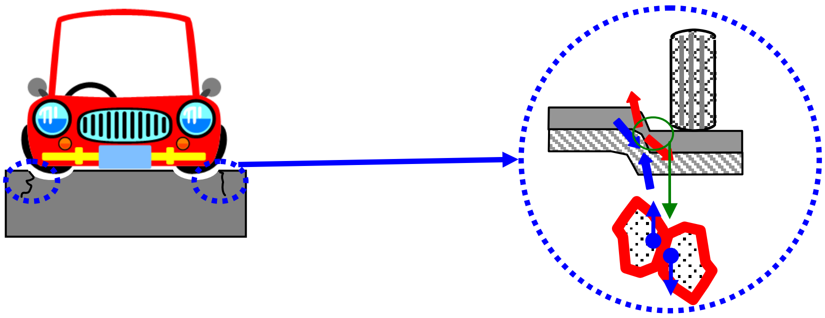

Figure 3: Tensile stress caused on surface of pavement at loading.

Table 4: Wheel-tracking fatigue test conditions.

Items	Conditions
Test temperature	20 °C
Wheel load	833.5 N
Wheel contact pressure	0.77 MPa
Rubber hardness	60
Specimen size	30×10×5cm

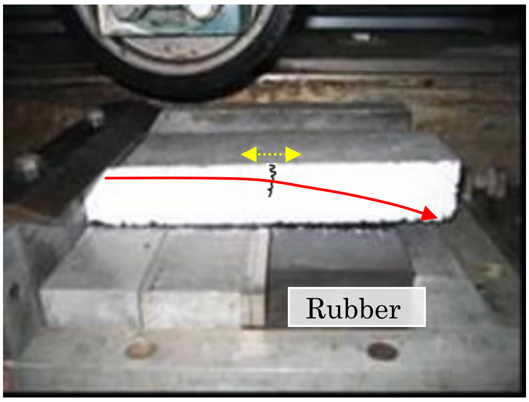

Photo 3: Wheel-tracking fatigue test.

5 TEST RESULTS

5.1 Bending Test of Mixtures

The results of the bending tests are shown in Figure4. Changes in the maximum load and displacement at maximum bending load were found in the exposed and accelerated specimens. Specimens exposed to field climate conditions and subjected to the accelerated weathering test showed identical trends in flexibility, even when their maximum strengths differed.

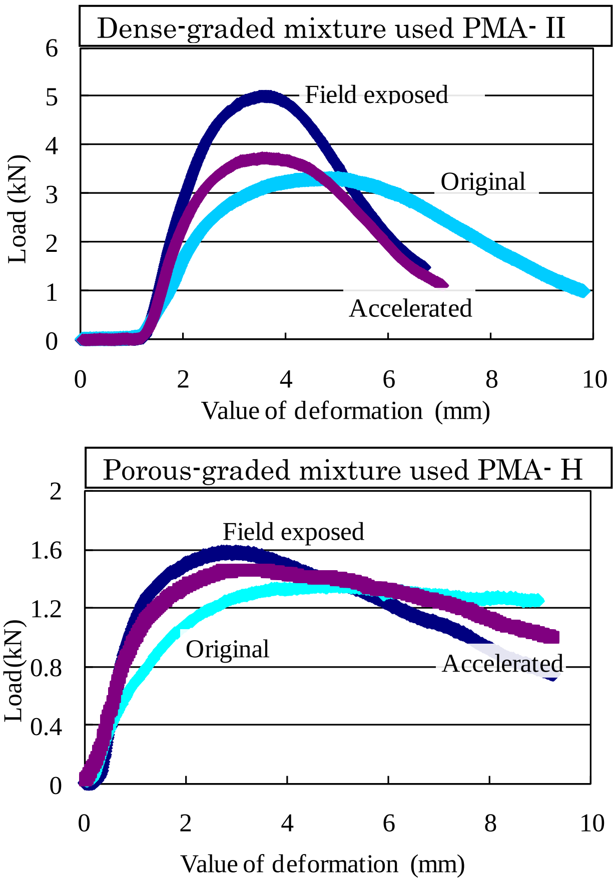

Figure 4: The results of bending test (Dense-graded and Porous-graded mixture).

5.2 Wheel Tracking Fatigue Test of Mixtures

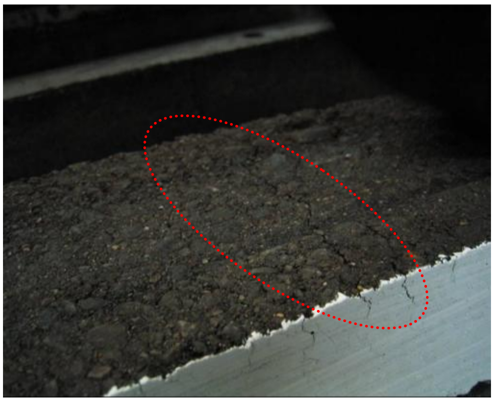

Photo 4: Cracking occurred in mixture surface (Dense-graded mixture used PMA- II).

The results of observations made during the wheel-tracking fatigue tests are shown in Photo 4. Cracking occurred in locations that developed a grainy texture due to the meteorological load just after the wheel-tracking test and in places where the mortar had flaked away. The cracks subsequently increased to depths of 1cm. Meanwhile, almost no cracks developed in the new mixture. These results indicate that a change had occurred in the condition of the asphalt mixture at the surface due to the meteorological load.

5.3 Infrared Spectroscopy of Recovered Asphalt

The Bending and wheel-tracking fatigue test results suggest that the asphalt deteriorates in the vicinity of the surface, so a 1.5cm thick portion of the surface recovered asphalt.
The results of infrared spectroscopy on recovered asphalt are shown in Figure 5. There were some differences between the samples exposed to field climate conditions and the samples subjected to accelerated weathering test, but, overall, oxidation degradation was noted to progress with increased UV irradiation. These findings confirm that we can determine their serviceability in shorter periods of time compared to natural degradation.

The signature of the oxidation degradation of asphalt appears to 1700cm^{-1} as shown in Figure 6. The peak that appears to 1700cm^{-1} shows the thing where the carbonyl group exists in asphalt.

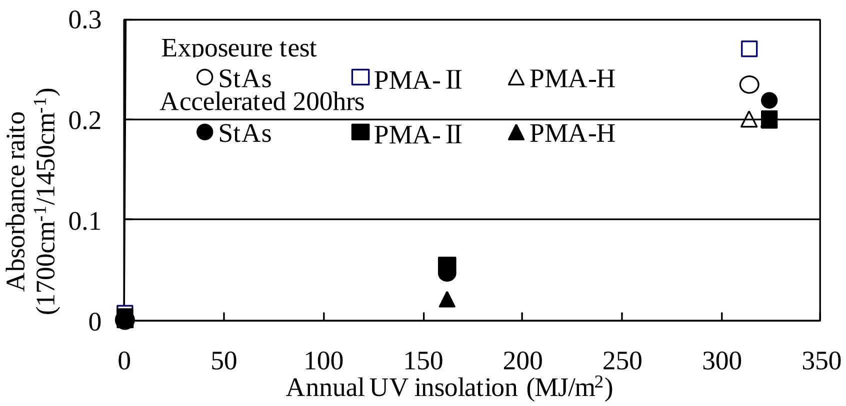

Figure 5: Infrared spectroscopy results of the carbonyl absorbance ratio (1700cm^{-1}/1450cm^{-1}).

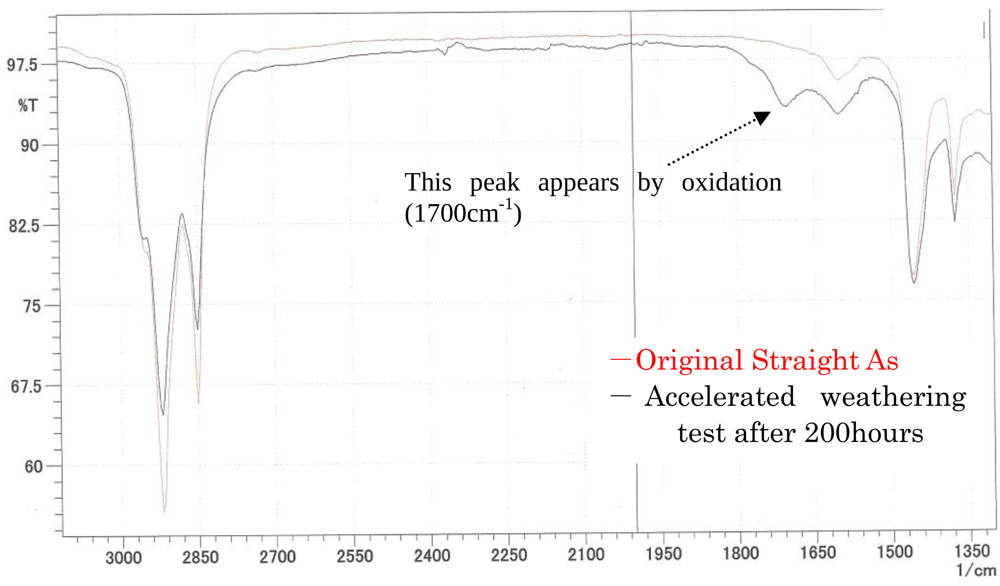

Figure 6: Absorbance of the carbonyl peak.

6 INVESTIGATION OF A SIMPLE LABORATORY TEST METHOD

The previous test showed that the progression of oxidation of the asphalt binder causes degradation of flexibility and cracking resistance. However, the asphalt in the mixture must be recovered with solvents in order to evaluate its condition. Recently, some issues were suggested to deteriorate in the accurate recovery by the diversification of the modification materials.

Therefore, an accelerated weathering test was conducted on specimens of binder and the specimens were subsequently analyzed with the objectives of shortening the time needed for the test as well as improving its precision.

6.1 Accelerated Weathering Test Conditions for Binder

The conditions for the accelerated weathering test of binder were the same as those listed in Table 2.

6.2 Specimens

Specimens were made from each of the binders shown in Table 1 measuring 2 × 2 × 12cm and subjected to the accelerated weathering test. The test setup is shown in Photo 5.

Moreover, in order to obtain a quantitative evaluation of the influence of weather on Styrene-Butadiene-Styrene (SBS) copolymer, a commonly used additive for asphalt, specimens of SBS-modified asphalt were prepared simultaneously with binder specimens. The SBS fractions used were 5, 7 and 9%.

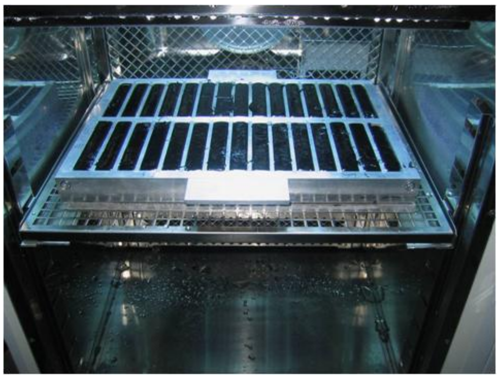

Photo 5: Binder specimen for accelerated weathering test.

6.3 Evaluation Method

The conditions of binder specimens were evaluated by bending tests and infrared spectroscopy. The conditions for the bending tests of the binder specimens are listed in Table 5. After bending test, sections of the surfaces of the specimens (0.5mm thick) were peeled for infrared spectroscopy. Absorbances of the carbonyl peak at 1700 cm^{-1} and of the butadiene double bond at 965 cm^{-1} were observed. The latter was analyzed for its value as estimation of serviceability in comparison with SBS-modified asphalt after the general RTFO/PAV conformed AASHTO test method.

Table 5: Binder bending test condition.

Items	Conditions
Curing Temperature	-30 ~ 15 °C
Curing Time	5 hrs
Loading Speed	100 mm/min
Test number	n = 3

7 TEST RESULTS

7.1 Bending Tests of Binder

The bending test results are shown in Figure7.

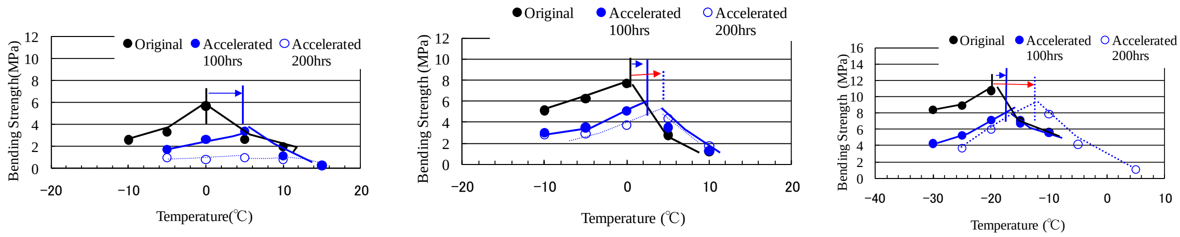

Figure 7: The result of binder bending test (Straight-Asphalt, PMA- II and PMA-H from left side).

Reductions in maximum bending strength were found to diminish with the length of exposure to the accelerated weathering conditions. The maximum value shifts found by all binders. Maximum bending strength of PMA-II and PMA-H were shifted over +2 ~ 3°C at 100 hours and +5 ~ 8°C at 200 hours. Meanwhile, in straight asphalt, the stresses were constant after 200 hours, showing no dependence on temperature. The specimens fractured at 15°C, as they had at other temperatures.

The above results indicate that asphalt binders shows embrittlement due to accelerated weakening (weathering); and subsequently predict that cracking resistance will be decreased.

7.2 Infrared Spectroscopy

Oxidation

Infrared spectroscopy results for binder specimens are shown in Figure 8.

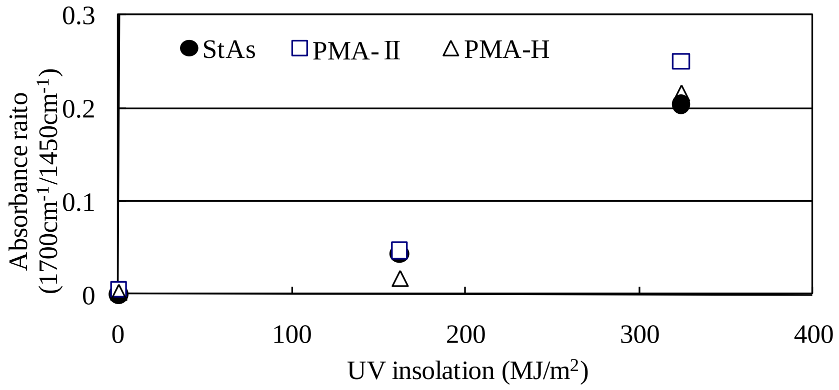

Figure 8: Infrared spectroscopy results of the carbonyl absorbance ratio.

As already seen in the mixture, an increase in the carbonyl peak was found with respect to the amount of UV irradiation. This is similar to the results found in recovered asphalt 1.5 cm beneath the surface of the mixture following UV exposure of 314 MJ/m^2, an amount equivalent to annual UV irradiation.

Butadiene double bond (SBS modified asphalt)

Working Curve, results of SBS-modified asphalt are shown in Figure 9.

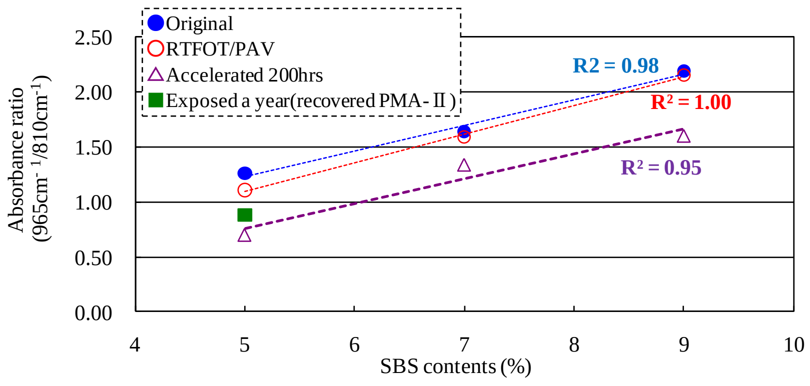

Figure 9: Working curves of butadiene double-bond absorbance by Infrared spectroscopy.

A large drop in the absorbance ratio was found from the initially detected value in SBS-modified asphalt that had been subjected to accelerated weathering. There was almost no difference between these observations and observations of specimens prepared with RTFO/PAV. Therefore, it is sure that SBS molecular structures are greatly affected by the meteorological load, especially UV radiation. Since these findings showed a trend resembling the results from PMA-II recovered from the surfaces of specimens exposed to field climate conditions, it is possible to predict binder weathering using short and simple accelerated weathering tests.

8 CONCLUSIONS

The following conclusions can be drawn from this study.

1) In Tsukuba city, meteorological observations revealed that the annual UV irradiation was 314 MJ/m^2, the annual mean temperature was 17°C, and the annual rainfall was 1348 mm.
2) Accelerated weathering test conditions were set on the basis of these field climate observations, and allowed speedy predictions of the weathering of materials.
3) UV irradiation causes progressive oxidation of asphalt, resulting in embrittlement and a reduction in cracking resistance. Therefore, it is thought that cracking is predictable if the oxidation degradation is appreciable.
4) SBS, used as a modifier for asphalt, shows structural degradation due to UV exposure. As a result, it can be expected that peculiar elasticity of the butadiene will be lost.

The authors will research to validate the relationships between results in asphalt binder and the rate of aggregate stripping from asphalt mixtures exposed to meteorological conditions in future studies.

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