Effects of Moisture on Properties of Asphalt Mixes in a Wet Tropical Climate: A Laboratory Study

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A moisture treatment designed to simulate the condition that pavements are exposed to in the wet tropical climate of Singapore is described. A weathering chamber was specially fabricated to introduce simultaneous wetting-drying and thermal cycles. The experimental program subjected four different asphalt mixtures—an open-graded, a gap-graded, and two dense-graded mixes—to the moisture treatment. Results indicate that the treatment was able to induce bleeding, stripping, and softening (loss of strength) in test specimens. The extent and severity of the resultant moisture damage varied with the mixture type and with the length of the treatment cycle period and the number of treatment cycles. On the basis of the test results, a procedure consisting of 150 4-hr cycles of simultaneous wetting-drying and thermal cycles was recommended. The treatment procedure shows significant potential as a research and development tool for studying the moisture damage resistance of new asphalt mixtures and the effect of modified binders in a wet tropical climate.

Aggregates of crushed natural rock and bituminous binder are the two principal constituents in asphalt paving mixtures. Although the proportion of binder in the mixtures, usually between 5 and 8 percent by weight, is very much less than that of the aggregates, the property of the bituminous binder has a marked influence on the performance of pavement mixtures. The common defects found on highway and airfield pavements, including cracks, rutting, surface distortion, and stripping, are closely related to binder behavior under weather and traffic loading.

Moisture-induced damage of asphalt mixtures is probably one of the most important factors that affect the in-service performance of asphalt pavements (*1–3*). Unfortunately, the action of water in an asphalt mixture is highly complicated, and no single theory or distress mechanism can fully explain the various facets of moisture-induced damage. As a result, a large number of laboratory simulation tests have been proposed by researchers to study and evaluate the effects of moisture on various asphalt mixtures under different climatic conditions (*1,4–6*, ASTM D1664). This paper describes a laboratory study in which test specimens were subjected to repeated wetting and drying to simulate the conditions of the wet tropical climate of Singapore. The study was conducted with the aim of achieving a better understanding of the influence of moisture on the performance of asphalt pavements in Singapore.

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SELECTION OF MOISTURE TREATMENT METHOD

Common Laboratory Moisture Treatment Methods

In laboratory studies of moisture-induced damage, a number of methods have been used to introduce moisture into the asphalt-aggregate system. The most direct means is to soak loose asphalt mix in water, such as in the Nicholson test (*6*) and ASTM D1664, to wash the loose mix as proposed by Tyler (*7*) and Winterkorn (*8*), or to boil the mix for a specified time as described by the Texas Boiling Test (*9*) and ASTM D3625. Because these tests are performed on loose mix, one of their main drawbacks is difficulty in relating the test results to the performance of compacted asphalt mixtures.

Tests conducted on compacted specimens can be classified into two broad categories: retained-strength tests and endurance tests. A retained-strength test assesses the moisture-damage resistance of compacted asphalt mixtures by determining the loss in selected measures of mechanical property after a certain moisture treatment. An endurance test refers to one in which specimens are subjected repeatedly to a certain moisture treatment, with or without simultaneous simulated traffic loading, until a failure state is reached.

Two basic procedures have been used by researchers to generate moisture damage in retained-strength tests. These are the water-immersion procedure (*9–11*; ASTM D1075) in which specimens are soaked for an extended period and the freeze-thaw cycle procedure (*2, 12–14*) in which specimens are subjected to alternating freezing and thawing. In both procedures, it is common to vacuum saturate test specimens first before the water treatment program; this is carried out to rapidly draw water into the test specimens.

Endurance tests are used less commonly by researchers than the retained-strength tests. An example is the Texas freeze-thaw pedestal test (*9*), which measures the number of freeze-thaw cycles that an asphalt specimen can endure before cracking. Another example is the British immersed-wheel tracking test (*15*), in which immersed specimens are subjected to a reciprocating motion of a wheel 8 in. in diameter and 2 in. wide until the asphalt mixture disintegrates.

Basis for Selecting Moisture Treatment Method

Because the main objective of the present study was to obtain some understanding of the manner in which moisture affects asphalt pavements under the prevailing local climatic condition in Singapore, preference was given to moisture treatment methods that closely reflect this condition. The wet tropical climate of Singapore is characterized by an abundance of rainfall as well as bright sunshine and a relatively uniform temperature accompanied by high humidity throughout the year (*16*). There is no distinct wet or dry season because rain falls during every month of the year, with an annual rainfall of about 2,200 mm (86 in.). The region is also exposed to sunshine extensively all year long. The annual average number of hours each day under bright sunshine is more than 5 hr. The direct result of this climatic condition is that road and airfield pavements in Singapore are experiencing a relatively large number of wetting and drying cycles.

It is apparent that none of the moisture treatment procedures described in the preceding section could be used directly for the purpose of the present study. Treatments involving freeze-thaw cycles are not suitable; neither are those calling for long duration of continuous soaking. The major characteristics of the Singapore climate suggest that a fair understanding of the effect of moisture might be gained in laboratory studies if the wetting-drying process together with the daily temperature variation experienced by the pavements could be simulated. On the basis of this reasoning, a treatment that exposed asphalt specimens to alternate wetting and drying as well as cyclic temperature changes was adopted in this study.

Experimental Setup for Moisture Treatment

A "weathering chamber" was specially fabricated to provide the desired moisture treatment that combined the wetting and drying of test specimens with simultaneous heating and drying thermal cycles. The weathering chamber was a concrete tank with an enclosed space that measured 915 mm (36 in.) in height and 940 × 1,420 mm (37 × 56 in.) in plane cross section. Wetting of test specimens was achieved by spraying tap water at about 28°C through eight well-positioned shower heads that were fitted on the interior walls of the tank. The number of shower heads was more than sufficient to keep specimens wet throughout the wetting phase.

The thermal cycle of the treatment was kept in phase with the wetting-drying cycle by means of a single timing device that activated the heater control the moment spraying of water was cut off. Heating was provided by four 500-W ceramic heaters located at the underside of the ceiling of the tank. The heaters were positioned such that a near uniform temperature distribution was achieved at the specimen platform level near the floor of the chamber.

Figure 1 shows the time histories of temperatures at the top surface and middepth of a specimen 63 mm (2.5 in.) tall and 102 mm (4 in.) in diameter in three different treatment conditions, namely 2-hr (1-hr wetting and 1-hr drying), 4-hr (2-hr wetting and 2-hr drying), and 6-hr (3-hr wetting and 3-hr drying) treatment cycles, respectively. Each specimen was seated on a 102-mm (4-in.) concrete cube. As can be seen from Figure 1, the temperature at the top face of a typical specimen in the three treatments varied from about 34°C to 55°C, 35°C to 62°C, and 38°C to 65°C, respectively. These thermal variations provided a reasonable approximation to the daily temperature variation in Singapore. On a typical day in Singapore, the surface temperature of bituminous pavements usually ranges from around 25°C in the early morning to more than 60°C on a hot afternoon.

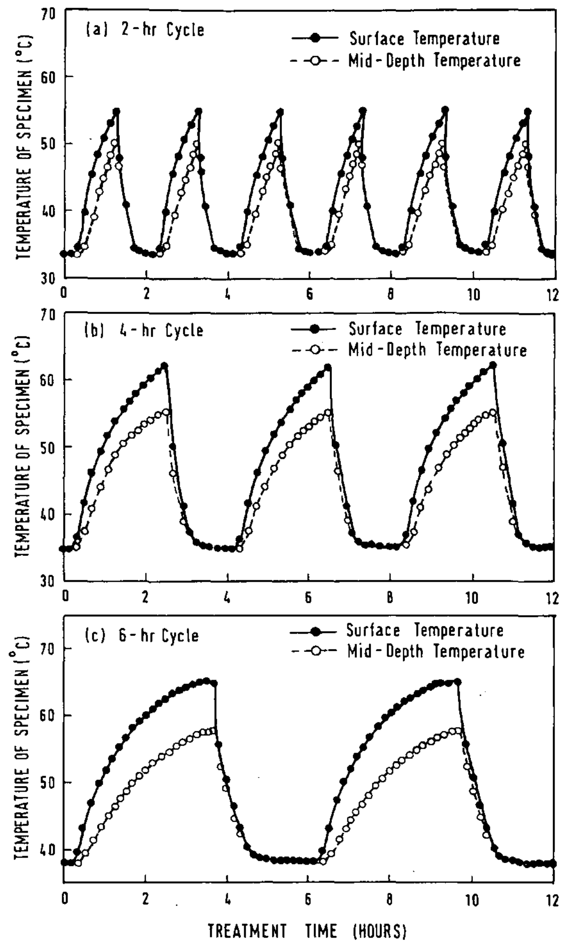


FIGURE 1 Specimen temperature variations during moisture treatment.

EXPERIMENTAL PROGRAM

Asphalt Mixtures Studied

Four asphalt mixtures that have been used as a wearing course for road pavements in Singapore were tested in the study. The mix proportions and aggregate gradations for the four mixtures, designated as W1, W3, W6, and WR, are shown in Table 1. Asphalt cement of 60/70 penetration grade and granite aggregates, the only type of aggregate available in Singapore, was used. The binder content of each mixture was the optimum asphalt content by weight of total mix determined by using the Marshall method of mix design (*17*). W1 and W3 were dense-graded mixes with a nominal top size of 19

TABLE 1 Mix Proportions and Aggregate Gradations

Mix Type	Binder Content	% Air Void	% VMA	Aggregate size distribution (% passing) 25 mm	19 mm	13 mm	9.5 mm	6.4 mm	3.2 mm	1.2 mm	0.3 mm	0.075 mm
W1	6.1%	5.2%	19.0%	100	100	100	100	95	74	47	27	6
W3	5.8%	3.9%	16.9%	100	100	95	87	77	58	37	19	6
W6	4.2%	10.9%	19.8%	100	95	60	41	35	20	12	8	4
WR	6.2%	2.4%	16.5%	100	100	90	67	64	58	43	17	8

Note: VMA = voids in mineral aggregate

mm (0.75 in.) and 9.5 mm (0.375 in.), respectively, W6 was an open-grade mix with a nominal top size of 25 mm (1 in.), and WR was a gap-graded mix having a nominal top-size aggregate of 19 mm (0.75 in.) with deficiencies in sizes between 9.5 and 3.2 mm (0.375 and 0.125 in.). These differences are shown in Figure 2.

Moisture Treatment Program

There were two major experimental variables in the moisture treatment program, namely the length of the cycle period and the total number of cycles applied in the treatment. The test program included the following three cycle periods: a 2-hr cycle, a 4-hr cycle, and a 6-hr cycle. In each case, a cycle consisted of a wetting phase followed by a drying phase of equal duration, as explained earlier with respect to Figure 1. For each of the cycle periods selected, specimens were tested for two treatment lengths: 150 cycles and 300 cycles. There were therefore six treatment types altogether.

In the selection of the number of treatment cycles, the average number of rainy days in a year was used as a guide. An examination of the meteorological data in the past 5 years in Singapore (*16*) showed that there were, on the average, approximately 150 days with rain each year. Although it may be true that a pavement in the field would experience about 150 wetting and drying cycles in a year, it is unlikely that the 150 cycles in the field would be as severe as 150 cycles in the weathering chamber. This difference is because not all rains would fall during a hot afternoon after pavements had been heated up by sunlight, and not all rains would be followed by intense heating from hot afternoon sun. Compared with the weathering chamber treatment cycles, most field cycles are likely to have longer drying periods and a more gradual rate of temperature change. The weathering chamber treatment therefore accelerated (and likely also intensified) the moisture damage process for the purpose of laboratory study.

Vacuum saturation was not included as part of the moisture treatment program. This decision was based on two considerations. First, it was thought that the rapid forced introduction of moisture into an asphalt mixture by means of vacuum saturation may not be a good representation of the actual process of moisture intrusion in the field. Second, because it was not an aim of this study to develop a quick laboratory procedure for routine testing, the time-saving speedy method of introducing moisture was not necessary.

Specimen Preparation

All specimens were prepared in accordance with the Marshall method described in ASTM D1559. A total of 75 compaction blows were applied to the top and bottom faces of each specimen. The final compacted specimens measured 102 mm (4 in.) in diameter and approximately 63 mm (2.5 in.) in height. For each of the four mixture types, a total of 35 specimens were prepared: 5 control specimens plus 6 sets of 5 specimens for 6 treatment types.

Evaluation of Moisture Damage

Moisture damage was evaluated by determining the changes in the condition of specimens after moisture treatment. Two

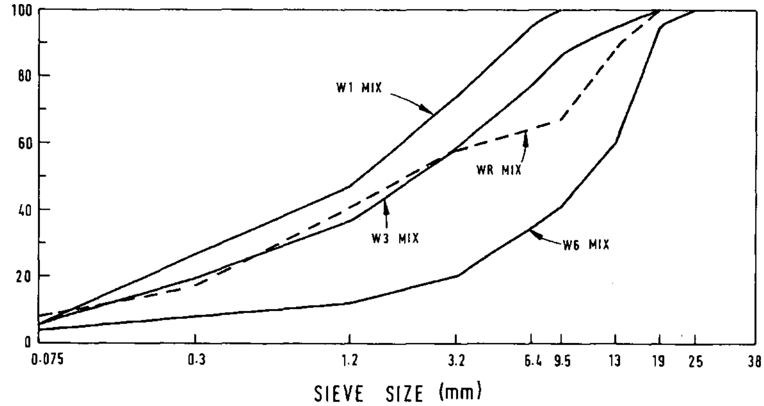


FIGURE 2 Aggregate gradations of asphalt mixtures studied.

forms of evaluation were performed: one on the basis of visual assessment of changes in mixture appearance and another on the basis of engineering tests of mechanical properties before and after moisture treatment.

Visual assessment was carried out mainly to estimate the extent of moisture damage with respect to stripping and displacement of asphalt binder. The degree of stripping in a moisture-treated specimen was estimated by inspecting a diametrical cross section of the specimen and determining the total area of aggregate affected. Figure 3 shows how this measurement was used to calculate the percentage area of stripping. Displacement of binder in a treated specimen was described by the extent of asphalt bleeding or flushing on its surface, as well as by movements of binder observed within a diametrical cross-section area of the specimen.

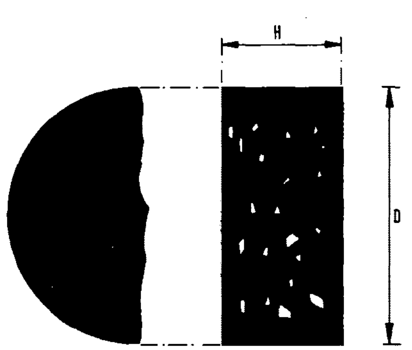
Two tests of mechanical properties, namely the resilient modulus determination and the indirect tensile strength test, were adopted as the basis of assessing moisture damage in moisture-treated specimens. The resilient modulus test was conducted according to the procedure outlined in ASTM D4123 using a load of 1.6 kN (0.36 kip) applied at a frequency of 1 Hz with a loading duration equal to 400 msec. In the indirect tensile strength test, the rate of loading adopted was 50.8 mm/min (2 in./min).

Employing the concept of retained strength, the degree of moisture damage in a treated specimen was expressed as the percentage of the original strength that was retained after the moisture treatment. In the case of resilient modulus, the percentage retained [$R(M)$] was obtained by comparing the moduli determined before and after moisture treatment, that is,

$$R(M) = \frac{\text{resilient modulus of specimen after moisture treatment}}{\text{resilient modulus of specimen before moisture treatment}} \times 100 \qquad (1)$$

For each moisture treatment performed on a mixture type, the average of five $R(M)$ values calculated according to Equation 1 was reported as the percentage resilient modulus retained. As for indirect tensile strength, the retaining percentage [$R(T)$] was computed from strength measurements of five control specimens and five treated specimens as follows:

$$R(T) = \frac{\text{average indirect tensile strength of 5 treated specimens}}{\text{average indirect tensile strength of 5 control specimens}} \times 100 \qquad (2)$$



Percentage Area Stripped = Projected Plan Area of Aggregates Stripped / Diametrical Cross Area (H x D)

FIGURE 3 Computation of percentage area stripped.

ANALYSIS OF TEST RESULTS

Visual Assessment of Treatment Effects

Both bleeding and stripping were observed in all the specimens tested, although their severity and extent varied among the four mixture types and differed from treatment type to treatment type. This is an important feature of the moisture treatment devised in this study because it is able to produce a distress form that has been observed in Singapore. This form of moisture damage also has been found in Texas by Kennedy (*18*), who made an excellent description of the distress mechanism:

> Preliminary evidence of stripping of asphalt pavement mixtures often occurs as localized instability and patch flushing or bleeding, that is, localized shiny areas. Flushing occurs when a portion of the stripped asphalt cement rises to the surface of the pavement, producing localized shiny areas of asphalt. This bleeding is not necessarily confined to the wheel paths but rather is often distributed across the pavement surface. Deformations in the form of shoving and rutting may also develop because of the loss of structural strength and stiffness and because of instability caused by the excessive amounts of asphalt near the surface.

Table 2 presents a summary of the results of visual inspection of moisture-treated specimens, and Figure 4 plots the percentage area stripped against treatment type. In general, more and more severe bleeding and stripping occurred as the specimens were subjected to either a higher number of treatment cycles or longer treatment cycle periods. For example, Treatment A2 produced more severe conditions than did Treatment A1 regardless of the type of mixture tested. The same was also true between Treatments B1 and B2, and between Treatments C1 and C2. As for the effects of treatment cycle period, the trend of increasing moisture damage with the use of longer cycle period was distinctly demonstrated by the results in Table 2 and Figure 4.

On the basis of the results of visual assessment, specimens of mixtures W1, W3, and W6 appeared to have about the same degree of moisture damage. The specimens of rolled asphalt mixtures (WR) had the most severe bleeding and stripping. Cracks were found to appear on the surface of some of the WR specimens, especially those exposed to Treatments C1 and C2. Cracking was not seen in specimens of other mixture types.

Assessment Based on Resilient Modulus

The computed results of percentage resilient modulus retained, $R(M)$, are presented in Figures 5 and 6. Each data point represents the average of five test values, each computed according to Equation 1. Figure 5 is plotted to highlight the effects of the number of treatment cycles and length of cycle periods. Figure 6 combines all test results in a single plot where the six treatment types are arranged on

TABLE 2 Visual Assessment of Moisture Damage

(a) Moisture Treatment A1 — 150 cycles of 2-hr period

Mix Type	Bleeding Assessment	% Diametral Area Stripped	Other Observation
W1 mix	No noticeable bleeding	About 5 to 10%	—
W3 mix	No noticeable bleeding	About 5%	—
W6 mix	A few beads of asphalt seen between coarse aggregates	About 5 to 10%	—
WR mix	Shiny patches of asphalt on specimen surface covering about 20% surface area	About 20%	—

(b) Moisture Treatment A2 — 300 cycles of 2-hr period

Mix Type	Bleeding Assessment	% Diametral Area Stripped	Other Observation
W1 mix	A few beads of asphalt on surface	About 10%	—
W3 mix	A few beads of asphalt on surface	About 10%	—
W6 mix	Scattered small beads of asphalt between coarse aggregates	About 10%	—
WR mix	Shiny patches of asphalt on specimen surface covering about 50% surface area	About 40%	—

(c) Moisture Treatment B1 -- 150 cycles of 4-hr period

Mix Type	Bleeding Assessment	% Diametral Area Stripped	Other Observation
W1 mix	Scattered small beads of asphalt on specimen surface	About 20%	—
W3 mix	Scattered small beads of asphalt on specimen surface	About 20%	—
W6 mix	Scattered beads of asphalt between coarse aggregates	About 15%	—
WR mix	Shiny patches of asphalt on specimen surface covering about 70% surface area	About 60%	A few minor cracks on surface

(d) Moisture Treatment B2 -- 300 cycles of 4-hr period

Mix Type	Bleeding Assessment	% Diametral Area Stripped	Other Observation
W1 mix	Scattered asphalt of about 2 mm diameter on specimen surface	About 35%	—
W3 mix	Scattered asphalt of about 1 mm diameter on specimen surface	About 25%	—
W6 mix	Concentration of asphalt between coarse aggregates	About 20%	—
WR mix	Shiny patches of asphalt on specimen surface covering about 80% surface area	About 70%	A few cracks on specimen surface

(continued on next page)

the horizontal axis according to the severity of moisture damage they produced.

The test results confirm the following two trends observed in the visual assessment presented in the preceding section: (a) moisture damage increased with the number of treatment cycles regardless of the treatment cycle period and mixture type, and (b) moisture damage increased when longer treatment cycle periods were used. However, Figures 5 and 6 also clearly indicate that the rate of increase of moisture damage with either number of treatment cycles or length of cycle period varied from treatment to treatment, as well as from mixture type to mixture type.

Figure 6 offers a way to compare the relative resistance of the four mixture types of moisture damage. Judging from the percentage resilient modulus retained, the gap-graded mixture WR was affected most by the moisture treatment. There were few differences among the other three mixture types, although the W3 mixture appeared to be marginally more resistant to moisture damage.

Assessment Based on Indirect Tensile Strength

Figures 7 and 8 show the results of indirect tensile tests. Each data point was calculated from five sets of tests using Equation 2. These two figures present the $R(T)$ data in a fashion similar to those for $R(M)$ in Figures 5 and 6. The general trends of moisture damage displayed by the test results in Figure 5 can

TABLE 2 *(continued)*

(e) Moisture Treatment C1 — 150 cycles of 6-hr period

Mix Type	Bleeding Assessment	% Diametral Area Stripped	Other Observation
W1 mix	Scattered beads of asphalt on specimen surface	About 35%	—
W3 mix	Scattered beads of asphalt on specimen surface	About 25%	—
W6 mix	Concentration of asphalt between coarse aggregates	About 30%	—
WR mix	A thick layer of asphalt on specimen surface covering about 90% surface area	About 80%	Diametral crack on surface

(f) Moisture Treatment C2 — 300 cycles of 6-hr period

Mix Type	Bleeding Assessment	% Diametral Area Stripped	Other Observation
W1 mix	Scattered beads of asphalt on specimen surface	About 50%	—
W3 mix	Scattered beads of asphalt on specimen surface	About 40%	—
W6 mix	Concentration of asphalt between coarse aggregates	About 40%	—
WR mix	A thick layer of asphalt on specimen surface covering about 90% surface area	About 85%	Diametral crack on surface

be seen in Figure 7. The same can also be said for Figures 6 and 8. The conclusions drawn in the preceding section on the basis of Figures 5 and 6 would therefore also hold true for Figures 7 and 8.

Effect of Mixture Type

The same source of aggregates and identical grade of asphalt binder were used for all test specimens of the four mixture types studied. The test results, however, indicated that the degree of moisture damage differed among the four mixture

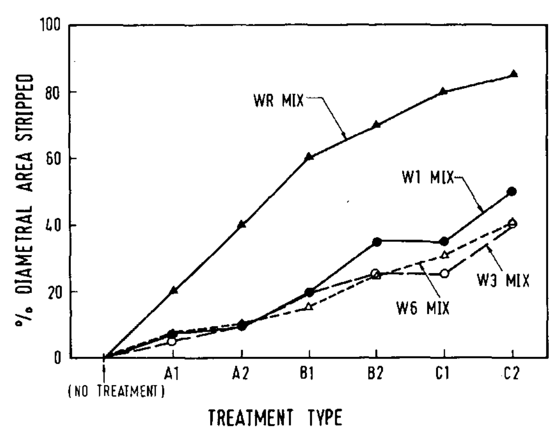


FIGURE 4 Comparison of the effects of various treatment types on the basis of percentage area stripped.

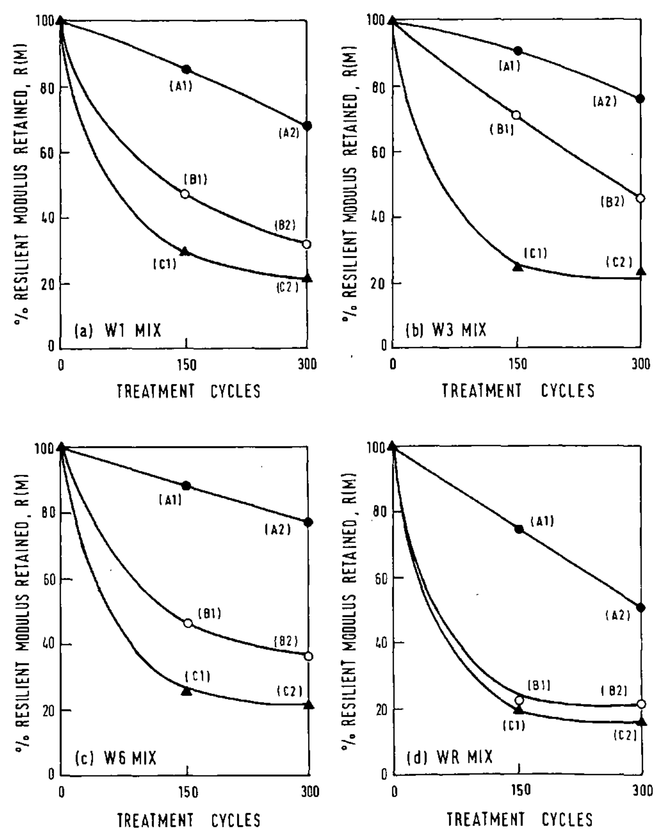


FIGURE 5 Effect of treatment cycles on resilient modulus.

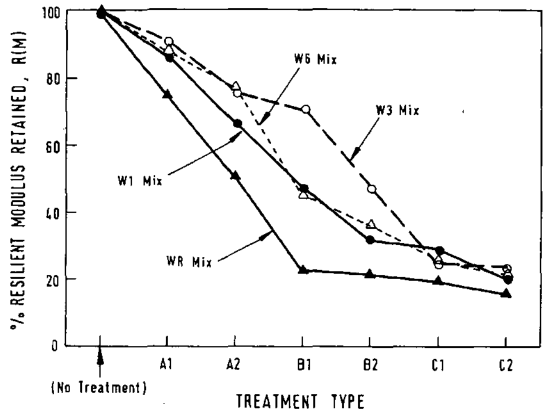


FIGURE 6 Comparison of the effects of various treatment types on the basis of resilient modulus tests.

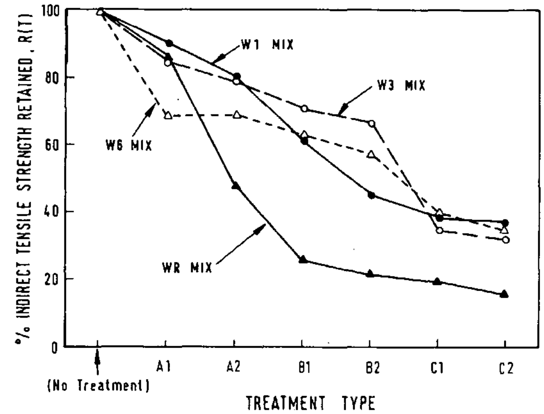
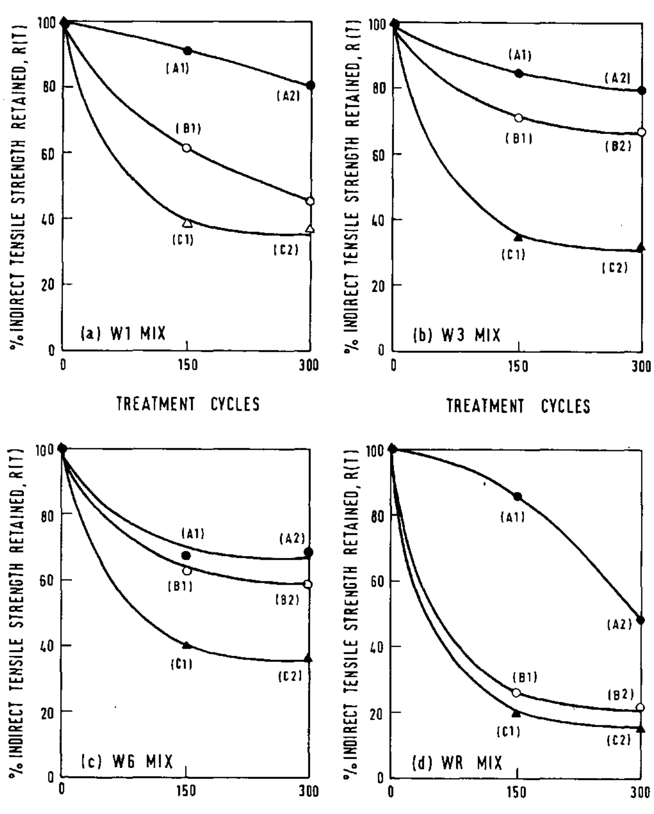


FIGURE 8 Comparison of the effects of various treatment types on the basis of indirect tensile strength tests.

types. These differences could not be explained statistically by the use of percent air void or percent voids in mineral aggregate (VMA) of the mixes. Because the only other major difference among the mixture types was in their aggregate gradations, the test results suggest that in addition to the common emphasis of improving aggregate-binder interfacial properties, it is possible to increase the moisture damage resistance of an asphalt mixture by changing its aggregate gradation.



Note : A1, A2, B1, B2, C1 and C2 are treatment types defined in Table 2

FIGURE 7 Effect of treatment cycles on indirect tensile strength.

Effect of Moisture Treatment

Figures 6 and 8 provide a very useful basis for the choice of moisture treatment duration for future studies adopting the same weathering chamber. Both figures indicate that Treatments A1 and A2 were not severe enough to create sufficiently big differences among the various mixture types for evaluation purposes. On the other hand, Treatments C1 and C2 were so severe that all the specimens tested suffered heavy moisture damage, resulting again in small differences in moisture damage measures among the various mixtures. Treatments B1 and B2 appeared to be the most suitable choices as far as the four mixture types were concerned. Although it yielded 150 more treatment cycles than Treatment B1, Treatment B2 gave no additional information on moisture damage. It is therefore logical to recommend Treatment B1 for use in future work.

Choice of Evaluation Test

The two measures of moisture damage, namely percentage resilient modulus retained $R(M)$ (*3,10,13*) and percentage indirect tensile strength retained $R(T)$ (*2,9,14*), both have been widely used for evaluating effects of moisture on asphalt mixtures. In this study, the test results allow one to compare the relative ability of the two measures to distinguish among asphalt mixtures with different moisture damage resistance. A visual comparison between Figures 5 and 7 or between Figures 6 and 8 suggests that there was not much difference between the two measures.

A quantitative statistical analysis based on the coefficient of correlation, r, also arrived at the same conclusion. This analysis is summarized in Table 3. The bottom row of r values shows that $R(T)$ and $R(M)$ were equally capable of differentiating the effects of various moisture treatments on any given mixture type. The values of r in the last column present some interesting results. Each r value gives a measure of how well $R(T)$ and $R(M)$ correlate in evaluating the moisture dam-

TABLE 3 Comparison of *R(M)* and *R(T)* as Measures of Moisture Damage

Treatment	W1 Mix		W3 Mix		W6 Mix		WR MIx		r
	R(M)	R(T)	R(M)	R(T)	R(M)	R(T)	R(M)	R(T)	
A1	85.6%	90.8%	90.3%	84.7%	88.4%	68.0%	74.3%	85.5%	-0.31
A2	66.1%	80.3%	75.7%	79.7%	76.9%	69.8%	50.3%	47.6%	0.79
B1	46.2%	61.5%	70.6%	70.7%	45.3%	62.5%	22.5%	25.3%	0.91
B2	31.5%	45.1%	45.5%	66.4%	35.2%	58.3%	21.5%	21.6%	0.96
C1	29.0%	38.9%	24.3%	34.0%	25.0%	39.3%	18.6%	19.6%	0.92
C2	20.5%	37.7%	23.6%	31.9%	20.9%	35.1%	15.7%	15.6%	0.79
r	0.99		0.96		0.87		0.99		—

age resistance of various asphalt mixtures. Very good correlations were found for Treatments B1, B2, and C1, relatively poorer correlations for Treatments C2 and A2, and negative correlation for Treatment A1. These results provide an indirect confirmation of the conclusion reached in the preceding section concerning the choice of mixture treatment type. That is, Treatments A1 and A2 were too mild to produce significant differences in the responses from different mixtures, where Treatment C2 was so severe that it was not suitable for comparing the moisture damage resistance of different mixtures.

CONCLUSIONS

This paper has demonstrated the application of a laboratory moisture-treatment procedure designed to study the effect of moisture on asphalt pavements under the climatic conditions of Singapore. On the basis of the findings and results of the analyses presented in this paper, the following conclusions may be drawn:

- Without introducing vacuum saturation, a laboratory treatment combining wetting-drying and thermal cycles was able to produce three effects of moisture damage observed in asphalt pavements in the field, namely stripping, bleeding, and softening (or loss in strength).
- Bleeding and stripping induced in the tests can be evaluated on the basis of visual assessment. Bleeding can be assessed by measuring the surface area covered by flushed asphalt and displacement of asphalt in a diametrical cross-sectional area. Stripping can be measured in terms of the percentage area stripped in a diametrical cross-sectional area.
- The two measures of moisture-induced softening, percentage resilient modulus retained and percentage indirect tensile strength retained, were found to be equally sensitive to changes caused by moisture damage.
- The degree of moisture damage achieved in the laboratory moisture treatment was a function of the number of treatment cycles applied and the length of the cycle period. It varied positively with the two treatment parameters.
- The study was able to show that different levels of moisture damage could be induced through appropriate combinations of treatment cycle number and cycle period. For the four mixture types examined in this study, a treatment that consisted of 150 cycles of 4 hr was the most suitable for evaluating the relative moisture-damage resistance of the mixture types. The validity of this recommendation has yet to be verified by field studies.
- Four mixture types prepared using the same source of asphalt and aggregate were studied. A gap-graded mix was found to have the least resistance to moisture damage. The resistances of the other three, two dense-graded mixtures and one open-graded mixture, were higher with slight differences among them. This finding suggests that changing the aggregate gradation could be used as a means to alter the moisture-damage resistance of an asphalt mixture.
- A moisture treatment consisting of 150 cycles of 4 hr would last 25 days. The procedure is therefore too long to be practical for routine laboratory tests. However, it shows significant potential as a research and development tool to study and compare the moisture-damage resistance of new asphalt mixtures and the effect of modified binders in a wet tropical climate.

ACKNOWLEDGMENT

The research reported in this paper was funded by the National University of Singapore.

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The views presented in this paper are the sole responsibility of the authors.

Publication of this paper sponsored by Committee on Characteristics of Bituminous Paving Mixtures To Meet Structural Requirements.