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A Study on Moisture Susceptibility of Asphalt Concrete Mixtures Modified with Ethylene–propylene Residual

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Moisture damage is one of the common distresses found in asphalt pavements. Polymer additives to asphalt not only decrease temperature susceptibility, but can also improve adhesion and cohesion and resistance to moisture-induced damage. Ethylene propylene diene monomer (EPDM) is a polymer waste and is found abundantly in Louisiana. Earlier studies have shown that chemically treated EPDM could be used as a viable modifier in asphalt cement and when incorporated in asphalt concrete mixes showed enhanced stiffness and creep properties. The objective of this study was to examine the moisture susceptibility behavior of conventional and EPDM modified asphalt concrete mixes. A dense graded mix incorporating three-control asphalt cements and two EPDM modified asphalt cements were studied. The results of the study show that the EPDM modified asphalt concrete mixes are prone to moisture damage and the use of an antistripping additive is very effective.

Keywords: EPDM; Stripping; Tensile strength ratio (TSR); Retained resilient modulus (RRM); Marshall retained index (MRI); Asphalt; Moisture susceptibility

INTRODUCTION AND BACKGROUND

Stripping is defined as "breaking of the adhesive bond between the aggregate surface and asphalt cement" in an asphalt pavement or mixture (Taylor and Khosla, 1983). Moisture damage to asphalt pavements as a result of stripping is a complex problem dependent on many variables, including the type and use of mix, asphalt characteristics, aggregate characteristics, environment, traffic, construction practice and the use of antistripping additives (Jimenez, 1974; Taylor and Khosla, 1983; Kandhal *et al.*, 1998).

The need to improve the performance of asphalt concrete mixes for heavier traffic loads has led to many experiments with rubber polymers to improve asphalt cements. Polymer additives to asphalt

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materials are being advocated as having high potential for improving long-term pavement performance through their ability to improve the properties of the asphalt binder and the resulting asphalt concrete mix (Rogge *et al.*, 1990). The primary benefits associated with the addition of polymers to asphalt cements include decreased temperature susceptibility, and increased resistance to fatigue and rutting (Terrel and Walter, 1986; Khosla and Zahran, 1989; Romine *et al.*, 1992). Polymer additives to asphalt can also improve adhesion and cohesion and resistance to moisture-induced damage and age hardening (Rogge *et al.*, 1990).

In recent years, polymer wastes, which pose a threat to the environment in terms of disposal, have caught the attention of highway engineers and asphalt paving technologists. Ethylene propylene diene monomer (EPDM) is one such polymer waste and a laboratory study of its potential as a modifier of asphalt cements was initiated in 1997 (Metcalf and Waters, 1997). The results indicated that hot mix asphalt concrete (HMAC) mixes containing EPDM modified asphalt cements showed significant improvement in terms of engineering properties such as Marshall stability, indirect tensile strength, indirect tensile resilient modulus and creep stiffness when compared to conventional HMAC mixes. One of the major recommendations of that study was to investigate the stripping characteristics of HMAC mixes containing conventional and EPDM modified asphalt cements and hence the current study was undertaken.

OBJECTIVE AND SCOPE

The primary objective of this research was to study the moisture susceptibility behavior of conventional and EPDM modified HMAC mixes and evaluate the relative effectiveness of different antistripping additives in these mixes. A typical Louisiana Type 8 mixture was used. Five types of asphalt cements (AC-10, AC-30, PAC-40 HG, EPDM modified AC-10 and EPDM modified AC-30) and three types of commercial liquid antistripping additives were used. Modified Lottman test, Louisiana ten minute boil test, indirect tensile (retained) resilient modulus test and, Marshall (retained) stability tests were conducted to study the mositure susceptibility of these mixes.

MATERIALS

Asphalt

A total of five asphalt cements were used in this study: AC-10, AC-30 and PAC-40 HG were designated as control asphalt cements, and, EPDM modified AC-10 and EPDM modified AC-30 as experimental asphalt cements. The experimental asphalt cements were produced by modifying conventional AC-10 and AC-30 each with 3% EPDM by weight of asphalt. The maleated EPDM material (containing 1% poly vinyl alcohol (PVA)) was cut into very small pieces (approximately $2 \times 5 \times 5\,\mathrm{mm}^3$) prior to mixing with the heated asphalt cement. A high shear mixer was used for blending these EPDM particles into the asphalt cement. An acceptable EPDM particle dispersion was achieved by operating the high shear mixer at 175°C and 1500–2000 rpm. Table I presents the Superpave binder specification test results for all the five asphalt cements used in this study.

Aggregates

The aggregate composition was selected from an actual Job mix formula (JMF) and consisted of a blend of #78 limestone, #11 limestone, coarse natural sand and fine natural sand.

Antistripping Additives

Three commercial liquid antistripping additives (all amines) were used in this study. They were Permatac-99® (AS# 1), Pavebond T-Lite® (AS# 2), and Adhere HP-Plus® (AS# 3). A dosage rate of one half percent by weight of asphalt was used for all three antistripping additives according to the Louisiana Department of Transportation and Development's (LADOTD) specification (LADOTD, 1992).

TABLE I Superpave™ binder specification test results

Test	Property	Asphalt cement/blend					Criteria
		AC-10	EPDM/AC-10	AC-30	EPDM/AC-30	PAC 40-HG	
			Original binder				
Flash point	N/a	N/a	N/a	N/a	N/a	N/a	230°C Min
Rotational viscosity	135°C	0.305	0.575	0.448	1.485	0.92	3 Pa. S. Max
Dynamic shear rheometer	G*/sin*	1.90 at 58°C	2.54 at 70°C	1.54 at 64°C	1.39 at 76°C	1.02 at 70°C	1.00 kPa Min
			RTFO aged binder				
Mass Loss	N/a	<1.00%	<1.00%	<1.00%	<1.00%	<1.00%	1.00% Max
Rotational viscosity	135°C	0.348	0.625	0.560	1.685	N/a	N/a
Dynamic shear rheometer	G*/sin*	3.06 at 58°C	2.30 at 70°C	3.35 at 64°C	3.03 at 76°C	2.47 at 70°C	2.20 kPa Min
			PAV aged binder				
Rotational viscosity	135°C	0.535	0.715	0.873	1.940	N/a	N/a
Dynamic shear rheometer	G*sin* at 25°C	3212	1464	2836	3821	3403	5000 kPa Max
Bending beam rheometer	Stiffness at −12°C	243	111	198	185	99	300 MPa Max
Bending beam rheometer	*m* value at −12°C	0.48	0.39	0.33	0.35	0.452	0.30 Min
PG grading		58–22	70–22	64–22	76–22	70–22	

Notes: RTFO = Rolling thin-film oven; PAV = Pressure aging vessel; N/a = Not available

Mixture Design

A dense graded mix of limestone, coarse and fine sands to meet the 1992 LADOTD specification criteria for a Type 8 surface course mix (LADOTD, 1992) was considered. The selected aggregate combination consists of 40% #78 limestone, 39% SLS limestone, 16% coarse natural sand, and 5% fine natural sand. Table II presents the JMF for the Type 8 limestone/natural sand surface course mix used in this study. The following mixture identification codes were used:

A10-HMAC mix containing conventional AC-10
E10-HMAC mix containing EPDM modified AC-10
A30-HMAC mix containing conventional AC-30
E30-HMAC mix containing EPDM modified AC-30
P40-HMAC mix containing PAC-40 HG

EXPERIMENTAL PROGRAM

The experimental program consisted of subjecting Marshall specimens (101.6 mm dia. by 63.5 mm thick) in the air void range of 6.0–8.0% to the modified Lottman test (AASHTO T283), an indirect tensile resilient modulus test (ASTM D4123), and the Marshall stability test (LADOTD TR 305M/305-96). The Louisiana ten minute boil test (LADOTD TR 322M/322-97) was conducted on loose asphalt mixtures.

Modified Lottman Test

The modified Lottman test is widely accepted and used by most highway agencies in the USA. This test is used to measure the effect of moisture on the tensile strength of the mixture. In this test, six Marshall specimens (101.6 mm dia. by 63.5 mm thick) are prepared such that all of them have air voids in the range of 6.0–8.0%. The six specimens are then divided into two sets of three samples, one set to be used as a control and the other for moisture-conditioning. The average percent air void between the two sets are kept as close to equal as possible. Moisture-conditioning starts by saturating the specimens between 55–80% after which they are placed in a freezer for a minimum of 15 h at 18 ± 5°C. The specimens are then placed in a hot water bath at 60 ± 0.5°C for 24 ± 0.5 h. The moisture-conditioned specimens are ready for testing after they are removed from the hot water bath and are placed in a 25 ± 0.5°C water bath for 40 ± 5 min.

The indirect tensile strength of both the control set and conditioned set of specimens is determined at 25°C by placing each specimen in a splitting tensile mold and applying a load at a rate of 50.8 mm/min

TABLE II JMF for Type 8 limestone/natural sand mix

Sieve size mm (in.)	Mix ID				
	A10	E10	A30	E30	P40
19 (3/4″)	100.0	100.0	100.0	100.0	100.0
12.5 (1/2″)	98.0	98.0	98.0	98.0	98.0
9.5 (3/8″)	85.7	85.7	85.7	85.7	85.7
4.75 (No. 4)	60.7	60.7	60.7	60.7	60.7
2.0 (No. 10)	41.6	41.6	41.6	41.6	41.6
0.425 (No. 40)	21.9	21.9	21.9	21.9	21.9
0.180 (No. 80)	11.1	11.1	11.1	11.1	11.1
0.075 (No. 200)	7.5	7.5	7.5	7.5	7.5
Mixture components					
Asphalt type	AC-10 (%)	EPDM/AC-10 (%)	AC-30 (%)	EPDM/AC-30 (%)	PAC-40 HG (%)
Asphalt content (% by wt.of mix)	4.0	4.2	4.0	4.2	3.9
EPDM content (% by wt.of asphalt)	–	3.0	–	3.0	–

until failure. The potential for moisture damage is indicated by the Tensile strength ratio (TSR) expressed as

$$\mathrm{TSR} = (\mathrm{Avg.}\, S_{\mathrm{tm}}/\mathrm{Avg.}\, S_{\mathrm{tc}}) \times 100$$

where Avg. S_{tm} is the average tensile strength of the moisture-conditioned set (kPa) and Avg. S_{tc} is the average tensile strength of the control set (kPa).

Louisiana Ten Minute Boil Test

The Louisiana ten minute boil test is a subjective test used for evaluating the water susceptibility of a JMF combination of asphalt cement, antistripping additive and coarse aggregate. It is also used for qualifying the antistripping additives to be incorporated into the asphalt cement to be used in asphalt mixtures. In this test, a loose asphalt–aggregate mixture (passing a 9.5 mm sieve and retained on a 4.75 mm sieve) was placed in boiling water and was allowed to boil for 10 min. The supernatant liquid was then poured off and the remaining mixture was emptied onto a paper towel. It was allowed to cool to room temperature. Three laboratory personnel estimated visually the "percent retained coating" on the dried mixture.

Indirect Tensile Resilient Modulus Test on Lottman Conditioned Samples

The indirect tensile resilient modulus test has become one of the more popular methods among highway agencies for measuring the stiffness modulus of HMAC mixes. This test method (ASTM D4123) was used in determining the effect of moisture on the resilient modulus values of the HMAC mixtures. The test involved measuring the resilient modulus values of both Lottman conditioned set and control set of specimens at 25°C using the repeated load indirect tension test. Loading pulses on the HMAC specimen involved a repeated triangular-wave load of 0.1 s followed by a 0.4 s rest period, thereby generating two load cycles per second. Assuming a Poisson's ratio (μ) of 0.35 for all HMAC specimens at 25°C, the total resilient modulus was calculated according to the following equation (Roberts *et al.*, 1991):

$$M_{\mathrm{R}} = \frac{P}{Ht}(0.27 + \mu)$$

where, M_{R} is the total resilient modulus of elasticity, psi (Pa); P is the maximum applied load, lbs (N); H is the total recoverable horizontal deformation, inches (m); t is the specimen thickness, inches (m) and μ is the Poisson's ratio (assumed as 0.35 at 25°C).

The total M_{R} was determined for each specimen at two orientations (0 and 45°), as required by ASTM 4123. The potential for moisture damage is indicated by the retained resilient modulus (RRM), expressed as a ratio of mean resilient modulus of conditioned set of specimens to that of the control set of specimens.

Marshall Stability Test on Lottman Conditioned Samples

The Marshall stability test was used in assessing the effect of moisture on the bonding strength of HMAC mixtures. Although the Marshall stability and flow values are not considered to be fundamental engineering parameters, they are still widely used and have been implemented by much of the United States and many other countries as specification parameters in quality control. The indirect tensile resilient modulus testing was non-destructive and hence the same Lottman conditioned samples were subjected to the Marshall stability test. The test was performed at 60°C and a loading rate of 50.8 mm/min was used until failure according to LA DOTD TR 305M/305-96 procedure. The ratio of the mean Marshall stability of the conditioned set of specimens to that of the control set of specimens, designated as the Marshall retained index (MRI), is an indicator of the potential for moisture damage.

DISCUSSION OF RESULTS

The one way analysis of variance test, ANOVA, was performed on all the test results at 95% confidence level using pairwise t-tests. A statistical analysis was not performed on the boil test results, as they are subjective in nature. The ANOVA analysis differentiates each group mean that is statistically different from other group means by use of categorical labels (A, B, AB, etc.). For example, a group mean that has a ranking "A" is significantly higher than the group mean that has a ranking "B". A designation of "AB" shows that the group mean can be placed into either statistical group "A" or "B". Group means with the same rankings are not statistically different.

Modified Lottman Test Results

Tables III and IV show the results of modified Lottman tests performed on all the five mixes. In Table III, the response of five mix types for each antistripping additive is compared and in Table IV, a comparison by antistripping additive is presented. The TSR value in the modified Lottman test is an indication of the potential for moisture damage. Higher TSR value indicates greater resistance of the mix to moisture damage. Based on his correlation studies, Lottman suggested a minimum TSR value of 70% to pass the test (Lottman, 1982). However, the LADOTD uses a minimum TSR value of 80%.

From Table III, it can be seen that the P40 mix has the highest TSR value and highest statistical ranking whereas the E10 and E30 mixes show the lowest without any antistripping additive. The TSRs of A10 and A30 mixes are statistically similar. Also, all the five mixes failed to meet the LADOTD's minimum TSR requirement of 80% when performed without any antistripping additive. Thus, all these five mixes require an antistripping additive to meet the minimum LADOTD TSR requirement. Addition of the antistripping additive, AS# 1, improved the TSRs of all five mixes, though the E30 mix fails to meet the minimum TSR requirement. When the test was performed with the antistripping additive AS# 2, all mixes except A10 failed the test. Using the antistripping additive, AS# 3, all the mixes except E30 have passed the test. The addition of AS# 1 and AS# 3 improved the stripping resistance of all five mixes as measured by the TSR.

From Table IV, it is clearly seen that all three antistripping additives: AS# 1, AS# 2 and AS# 3, enable the A10 mix to meet the minimum LADOTD TSR requirement. In case of the E10 and A30 mixes, AS# 1 and AS# 3 are equally effective. All three additives have the same effect on the E30 mix but fail marginally to make it pass the test. The P40 mix passes the test with both AS# 1 and AS# 3.

It is seen that AS# 1 is the only antistripping additive that has improved the TSR of all five mixes without causing a reduction in the control tensile strength. Though AS# 3 is equally effective, the control tensile strengths of mixes have reduced on using this antistripping additive.

Louisiana Ten Minute Boil Test Results

The results of Louisiana ten minute boil tests are reported in Table V. The current LADOTD specification requires a minimum of 90% retained coating, using one half percent antistripping additive, to pass the test. Based on this criterion, the results are reported as either "Pass" (P) or "Fail" (F).

When the test was performed without any antistripping additive, all the mixes failed the test, which is a trend similar to that of the modified Lottman test. With the antistripping additive AS# 1, it can be seen that all mixes passed the test. Using the antistripping additive, AS# 2, all five mixes failed the test. When the test was performed with antistripping additive AS# 3, all mixes except E30 and P40 mixes failed the test. Thus, AS# 2 is not an effective antistripping additive according to the results shown by the Louisiana ten minute boil test. The use of AS# 3 is effective only in E30 and P40 mixes whereas the use of AS# 1 is effective in all the five mixes.

Indirect Tensile Resilient Modulus Test Results

Tables VI and VII show the results of indirect tensile resilient modulus tests performed on all five mixes. Similar to the TSR value in the modified Lottman test,

TABLE III Results of modified Lottman test (comparison by mix type)

Mix ID	Antistripping additive															
	No antistrip				AS# 1				AS# 2				AS# 3			
	Ctrl. str. (kPa)	Cond. str. (kPa)	TSR (%)	Group	Ctrl. str. (kPa)	Cond. str. (kPa)	TSR (%)	Group	Ctrl. str. (kPa)	Cond. str. (kPa)	TSR (%)	Group	Ctrl. str (kPa)	Cond. str. (kPa)	TSR (%)	Group
A10	744	434	58	AB	641	544	85	A	434	400	92	A	296	248	85	AB
E10	703	296	42	B	710	634	89	A	462	324	70	B	420	379	90	AB
A30	1337	772	58	AB	1075	958	89	A	765	517	68	B	510	413	81	B
E30	1474	620	42	B	1075	834	78	A	882	620	70	B	524	413	79	B
P40	1309	1006	77	A	1075	1000	93	A	792	565	71	B	531	496	94	A

Notes: Ctrl. str.-control mean indirect tensile strength, kPa; Cond. str.-moisture conditioned mean indirect tensile strength, kPa

TABLE IV Results of modified Lottman test (comparison by antistripping additive)

Antistripping additive	Mix ID																			
	A10				E10				A30				E30				P40			
	Ctrl. str. (kPa)	Cond. str. (kPa)	TSR (%)	Group	Ctrl. str. (kPa)	Cond. str. (kPa)	TSR (%)	Group	Ctrl. str. (kPa)	Cond. str. (kPa)	TSR (%)	Group	Ctrl. str. (kPa)	Cond. str. (kPa)	TSR (%)	Group	Ctrl. str. (kPa)	Cond. str. (kPa)	TSR (%)	Group
No antistrip	744	434	58	B	703	296	42	C	1337	772	58	C	1474	620	42	B	1309	1006	77	AB
AS# 1	641	544	85	A	710	634	89	A	1075	958	89	A	1075	834	78	A	1075	1000	93	A
AS# 2	434	400	92	A	462	324	70	B	765	517	68	BC	882	620	70	A	792	565	71	B
AS# 3	296	248	85	A	420	379	90	A	510	413	81	AB	524	413	79	A	531	496	94	A

Notes: Ctrl. str.-control mean indirect tensile strength, kPa; Cond. str.-moisture conditioned mean indirect tensile strength, kPa

TABLE V Results of Louisiana ten minute boil test

Mix ID	Antistripping additive			
	No antistrip Pass/Fail	AS# 1 Pass/Fail	AS# 2 Pass/Fail	AS# 3 Pass/Fail
A10	F	P	F	F
E10	F	P	F	F
A30	F	P	F	F
E30	F	P	F	P
P40	F	P	F	P

the RRM is an indication of the potential for moisture damage. Schmidt and Graf have suggested a minimum value of 70% to pass the test (Schmidt and Graf, 1972).

A trend similar to the modified Lottman test could be seen in Table VI except that the RRM values of A10 and A30 mixes are significantly lower compared to the rest when the test was performed without an antistripping additive. The A10 and A30 mixes fail to meet the minimum RRM requirement of 70%. The RRM value of P40 mix is significantly higher compared to the others and it can be concluded that the effect of moisture on the resilient modulus of the P40 mix is small. The use of AS# 1 has once again improved the RRM values of all five mixes significantly and all five mixes meet the minimum RRM requirement. Using AS# 2, the E10 and E30 mixes fail the minimum RRM requirement. The use of AS# 3 is effective on all five mixes and is most effective on the P40 mix.

From Table VII, it can be seen that all antistripping additives improved the RRM value of the A10 mix by more than 30% with AS# 2 being the most effective, which is a trend similar to that with the modified Lottman test. The use of AS# 1 has improved the RRM value of the E10 mix by more than 30% whereas the use of AS# 2 reduced the RRM value by more than 20%. In the case of the E30 mix, AS# 3 additive improved the RRM value by more than 50%, with AS# 2, the mix did not meet the minimum RRM requirement. In the case of P40 mix, the RRM value met the minimum requirement without an antistripping additive.

TABLE VI Results of indirect tensile resilient modulus test on Lottman conditioned samples (comparison by mix type)

Mix ID	Antistripping additive															
	No antistrip				AS# 1				AS# 2				AS# 3			
	Ctrl. res. mod. (MPa)	Cond. res. mod. (MPa)	RRM (%)	Group	Ctrl. res. mod. (MPa)	Cond. res. mod. (MPa)	RRM (%)	Group	Ctrl. res. mod. (MPa)	Cond. res. mod. (MPa)	RRM (%)	Group	Ctrl. res. mod. (MPa)	Cond. res. mod. (MPa)	RRM (%)	Group
A10	1573	963	61	B	1251	1124	90	A	924	907	98	A	930	742	80	AB
E10	1923	1391	72	AB	1447	1409	97	A	1553	847	55	C	976	741	76	B
A30	3123	1861	60	B	1860	1769	95	A	1916	1548	81	AB	1265	1013	80	AB
E30	2603	1904	73	AB	2402	1805	75	A	2232	1039	47	C	1687	1386	82	AB
P40	1898	1800	95	A	1721	1605	93	A	1402	1093	78	B	1075	972	90	A

Notes: Ctrl. res. mod.-control mean indirect tensile resilient Modulus, MPa; Cond. res. mod.-moisture conditioned mean indirect tensile resilient modulus, MPa

TABLE VII Results of indirect tensile resilient modulus test on Lottman conditioned samples (comparison by antistripping additive)

Antistripping additive	Mix ID																			
	A10				E10				A30				E30				P40			
	Ctrl. res. mod. (MPa)	Cond. res. mod. (MPa)	RRM (%)	Group	Ctrl. res. mod. (MPa)	Cond. res. mod. (MPa)	RRM (%)	Group	Ctrl. res. mod. (MPa)	Cond. res. mod. (MPa)	RRM (%)	Group	Ctrl. res. mod. (MPa)	Cond. res. mod. (MPa)	RRM (%)	Group	Ctrl. res. mod. (MPa)	Cond. res. mod. (MPa)	RRM (%)	Group
No antistrip	1573	963	61	C	1923	1391	72	B	3123	1861	60	B	2603	1904	73	AB	1898	1800	95	A
AS# 1	1251	1124	90	AB	1447	1409	97	A	1860	1769	95	A	2402	1805	75	AB	1721	1605	93	A
AS# 2	924	907	98	A	1553	847	55	C	1916	1548	81	AB	2232	1039	47	B	1402	1093	78	A
AS# 3	930	742	80	B	976	741	76	B	1265	1013	80	AB	1687	1386	82	A	1075	972	90	A

Notes: Ctrl. res. mod.-control mean indirect tensile resilient modulus, MPa; Cond. res. mod.-moisture conditioned mean indirect tensile resilient modulus, MPa

TABLE VIII Results of Marshall stability test on Lottman conditioned samples (comparison by mix type)

Mix ID	Antistripping additive															
	No antistrip				AS# 1				AS# 2				AS# 3			
	Ctrl. stab. (MPa)	Cond. stab. (Mpa)	MRI (%)	Group	Ctrl. stab. (MPa)	Cond. stab. (Mpa)	MRI (%)	Group	Ctrl. stab. (MPa)	Cond. stab. (MPa)	MRI (%)	Group	Ctrl. stab. (MPa)	Cond. stab. (MPa)	MRI (%)	Group
A10	6.0	5.3	88	A	5.6	5.0	89	A	6.3	5.5	87	AB	4.6	4.2	91	A
E10	6.8	5.6	82	A	6.2	5.5	89	A	5.8	4.8	83	AB	7.2	6.3	88	A
A30	7.3	6.6	90	A	7.3	7.0	96	A	6.8	5.7	84	AB	6.4	5.4	84	A
E30	8.2	5.9	72	A	7.4	6.8	92	A	8.1	6.3	77	B	8.1	7.6	94	A
P40	8.0	6.4	80	A	7.4	7.1	96	A	9.5	8.8	93	A	10.3	8.8	85	A

Notes: Ctrl. stab.-control mean Marshall stability, MPa; Cond. stab.-moisture conditioned mean Marshall stability, MPa

TABLE IX Results of Marshall stability test on Lottman samples (comparison by antistripping additive)

Antistripping additive	Mix ID A10 Ctrl. stab. (MPa)	A10 Cond. stab. (MPa)	A10 MRI (%)	A10 Group	E10 Ctrl. stab. (MPa)	E10 Cond. stab. (MPa)	E10 MRI (%)	E10 Group	A30 Ctrl. stab. (MPa)	A30 Cond. stab. (MPa)	A30 MRI (%)	A30 Group	E30 Ctrl. stab. (MPa)	E30 Cond. stab. (MPa)	E30 MRI (%)	E30 Group	P40 Ctrl. stab. (MPa)	P40 Cond. stab. (MPa)	P40 MRI (%)	P40 Group
No antistrip	6.0	5.3	88	A	6.8	5.6	82	A	7.3	6.6	90	A	8.2	5.9	72	B	8.0	6.4	80	A
AS# 1	5.6	5.0	89	A	6.2	5.5	89	A	7.3	7.0	96	A	7.4	6.8	92	A	7.4	7.1	96	A
AS# 2	6.3	5.5	87	A	5.8	4.8	83	A	6.8	5.7	84	A	8.1	6.3	77	B	9.5	8.8	93	A
AS# 3	4.6	4.2	91	A	7.2	6.3	88	A	6.4	5.4	84	A	8.1	7.6	94	A	10.3	8.8	85	A

Notes: Ctrl. stab.-control mean Marshall stability, MPa; Cond. stab.-moisture conditioned mean Marshall stability, MPa

Marshall Stability Test Results

In this test, the MRI is an indication of the effect of moisture on the bonding strength of the mixes. Though it is not a widely used test in assessing the moisture damage of the mixes, it was conducted to see if there were any significant differences in the stability values of the mixes. Tables VIII and IX display the results of the Marshall stability tests and their comparison by mix type and by antistripping additive respectively. From both the tables, it can be concluded that the Marshall stability and flow test is not very effective in identifying the moisture susceptible mixes. It is also interesting to note from Table VIII that the test did not show any significant difference in the MRI values of the five mixes.

CONCLUSIONS

The primary objective of this research was to study the moisture susceptibility behavior of conventional and EPDM modified HMAC mixes and evaluate the effectiveness of different antistripping additives in these mixes. A typical Louisiana Type 8 mixture was used and five types of asphalt cements (AC-10, AC-30, PAC-40 HG, EPDM modified AC-10 and EPDM modified AC-30) were considered. The modified Lottman test, the Louisiana ten minute boil test, the indirect tensile resilient modulus test and the Marshall stability test on Lottman conditioned samples were conducted with and without antistripping additives. The results of the study can be summarized as:

(1) The modified Lottman test was very effective in identifying the moisture susceptible mixes. The test results showed that the HMAC mixes containing EPDM modified AC-10 and EPDM modified AC-30 are prone to moisture damage. The introduction of AS# 1 significantly improved the TSR values of all five mixes.

(2) The Louisiana ten minute boil test favored the use of AS# 1 as all five mixes passed the test using this additive.

(3) The results of indirect tensile resilient modulus tests showed a similar trend to that of modified

Lottman test. EPDM modified HMAC mixes showed more resistance to moisture-induced damage in terms of RRM than in terms of TSR. The use of AS# 1 has proved effective.

(4) In both the modified Lottman test and the indirect tensile resilient modulus test, the P40 mix showed significant resistance to moisture damage even without an antistripping additive.

(5) The Marshall stability test was not effective in identifying the moisture susceptible mixes and in assessing the effectiveness of the antistripping additives.

The results of the study have validated the use of an antistripping additive in these mixes and among the three antistripping additives used in this study, AS# 1 proved to be the most effective in increasing the stripping resistance of these mixes.

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