EVALUATING MOISTURE SUSCEPTIBILITY OF ASPHALT CONCRETE MIXTURES THROUGH SIMPLE PERFORMANCE TESTS

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ABSTRACT

Moisture damage is one of the major causes of premature failure in asphalt concrete mixtures.Proper evaluation of moisture susceptibility is essential for preventing the deterioration of field mixtures. The AASHTO T283 Test Method, also known as the Modified Lottman Indirect Tension Test Procedure, was adopted by the Superpave system as the required test for determination of moisture damage and is currently the most widely used procedure for measuring moisture damage potential. However, this test method has two limitations: 1) its conditioning procedure does not include dynamic loading, which is different from actual field conditions, and 2) it uses strength, a parameter that is not directly used in pavement design, to determine whether unacceptable moisture damage will occur in the field. The objective of this study was to evaluate the moisture susceptibility of different asphalt mixtures using simple performance tests in conjunction with environmental conditioning procedures.AASHTO T283 was conducted for conditioning levels of 0, 1, 3 and 6 freeze/thaw cycles and compared to results obtained from the dynamic modulus (E*) and flow number tests for the same conditioning levels. The results showed that modifications to AASHTO T283 or the use of simple performance tests are a valid alternative for the evaluation of moisture susceptibility and may represent expected field performance better than the Modified Lottman Indirect Tension Test. The advantages and disadvantages of each method need to be carefully considered before implementing a new testing protocol.

INTRODUCTION

Moisture damage is one of the major causes of premature failure in asphalt concrete mixtures. This type of damage can be described as the progressive deterioration of asphalt mixes due to adhesive failure (stripping of the asphalt film from the aggregate surface) and/or cohesive failure (loss of mixture stiffness primarily due to the action of water) (*1*-*3*).

Proper evaluation of moisture susceptibility is essential for preventing the deterioration of field mixtures. The AASHTO T283 Test Method (*4*), also known as the Modified Lottman Indirect Tension Test Procedure, was adopted by the Superpave system as the required test for determination of moisture damage and is currently the most widely used procedure for evaluating moisture damage potential (*5*).However, this test method has two limitations: 1) its conditioning procedure does not include dynamic loading, which is different from actual field conditions, and 2) it uses strength, a parameter that is not directly used in pavement design, to determine whether unacceptable moisture damage will occur in the field (*3*).

In addition, although several “fixes” have been applied to deal with the method’s shortcomings, the test remains empirical and liable to give either false positives or false negatives in the prediction of moisturesusceptibility. Major concerns with this test are its reproducibility and its ability to predictmoisture susceptibility with reasonable confidence (*5*).

The use of simple performance test (SPTs) to evaluate moisture susceptibility of asphalt mixtures has shown promising results (*6*-*8*). These tests appear to correlate better to observed field performance and could provide an improvement to moisture damage assessment.

OBJECTIVES AND SCOPE OF WORK

The objective of this study was to evaluate the moisture susceptibility of different asphalt mixtures using simple performance tests in conjunction with environmental conditioning procedures. This was accomplished by performing the Modified Lottman Indirect Tension Test Procedure (AASHTO T283) with different conditioning levels and comparing the results to those obtained using the dynamic modulus and flow number tests for the same conditioning levels.

METHODOLOGY

Mixture Designs

Ten different mixtures were designed and produced in the laboratory using an aggregate source known for showing moisture related deterioration in the field. Five of the mixtures had a nominal maximum aggregate size (NMAS) of 9.5 mm and the other five had a NMAS of 12.5 mm. Each of the selected NMAS sizes included a control mix, as well as the following variations: 2% SBS modified mix by total weight of binder, mixtures that contained 0.5% liquid antistrip (LAS) by total weight of binder and 1% hydrated lime by total weight of aggregate, and a mixture that combined 2% SBS and 1% lime. All mixtures used the same PG 70-22 binder source. Table 1 shows the gradations for the two aggregate sizes and Table 2 shows the volumetric properties of all the mixtures used in this study.

TABLE 1Mixture Gradations

Sieve Size	% Passing	
	9.5 NMAS	12.5 NMAS
3/4"	100	100
1/2"	100	95.4
3/8"	95.0	78.3
N° 4	60.0	43.3
N° 8	40.0	28.9
N° 16	25.0	20.0
N° 30	17.0	14.8
N° 50	10.0	10.9
N° 100	7.0	8.0
N° 200	5.0	5.8

TABLE 2 Mixture Volumetric Properties

Mixture	% Design AC	%VMA	% VFA	DustRatio
9.5 Control	6.5	15.5	73.7	1.0
9.5 SBS	6.5	15.8	74.3	1.0
9.5 LAS	6.5	15.9	72.7	1.0
9.5 Lime	6.7	16.3	74.4	0.9
9.5 SBS+Lime	6.6	16.0	74.4	1.0
12.5 Control	7.0	15.8	74.5	1.1
12.5 SBS	6.5	15.1	73.3	1.2
12.5 LAS	6.5	14.7	72.7	1.2
12.5 Lime	6.0	14.0	71.5	1.3
12.5 SBS+Lime	6.3	14.3	72.0	1.3

Laboratory Testing

For each of the mixtures, the Modified Lottman Indirect Tension Test was conducted for conditioning levels of 0, 1, 3 and 6 freeze/thaw cycles. The results were used to calculate the tensile strength ratio (TSR) at each level, which is used as an acceptance criteria for moisture damage performance. A minimum TSR of 0.80 was defined as the required value for acceptance of a mixture.

In addition, dynamic modulus (E*) and flow number tests were performed in accordance to AASHTO TP79 (9) for the same conditioning levels.For the dynamic modulus, an E* ratio (ER) was calculated as the ratio of conditioned to dry specimens for the measurements made at 20°C and 10 Hz (typical pavement operating conditions) and used as the parameter to evaluate moisture sensitivity of the mixtures. For the flow number test, a flow number ratio (FNR) was calculated in the same manner for all conditioning levels.

For all tests, one cycle of conditioning consisted of keeping vacuum-saturated specimens in a freezer at -18°C for 16 hours, followed by a 60°C water bath for 24 hours. The use of multiple conditioning cycles allowed for an increased deterioration of the mixture, simulating more aggressive field conditions.

RESULTS AND DISCUSSION

Modified Lottman Indirect Tension Test (AASHTO T283)

Figure 1 shows the TSR of all mixtures for each of the conditioning levels. It can be observed that if the test is performed for the standard procedure using one cycle of conditioning, all mixtures pass the minimum criteria, even though this particular aggregate source is known for exhibiting moisture related damage in the field. As the number of freeze-thaw cycles is increased, only mixtures that contain some type of antistripping agent (LAS or hydrated lime) are considered satisfactory.

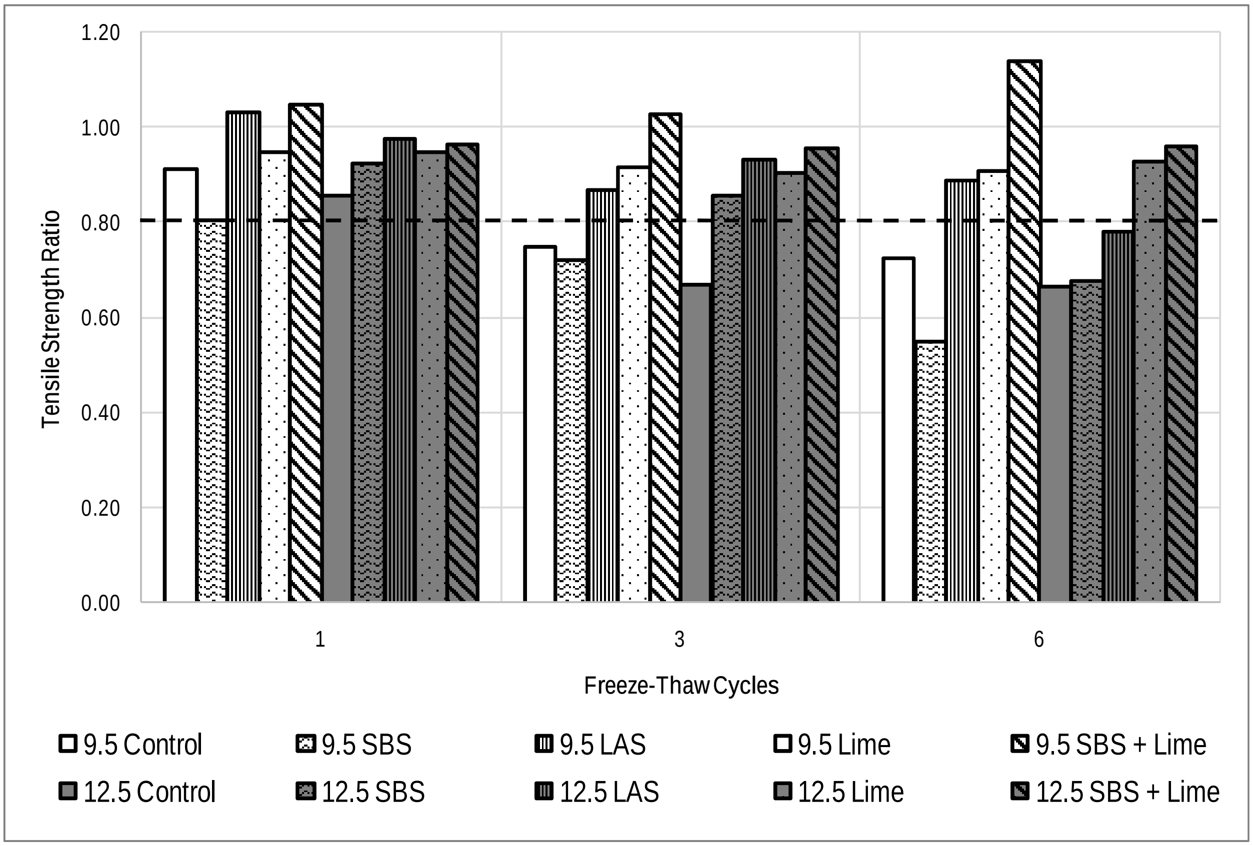


FIGURE 1 TSR Results at All Conditioning Levels.

Dynamic Modulus

Figure 2 shows the ER results for all conditioning levels. In this case, it can be seen that if the same minimum criteria of 0.80 is used, some of the mixtures fail even with a single conditioning cycle. As with the TSRs, when the number of conditioning cycles is increased, mixtures are more likely to require an antistripping aid to resist moisture induced damage.

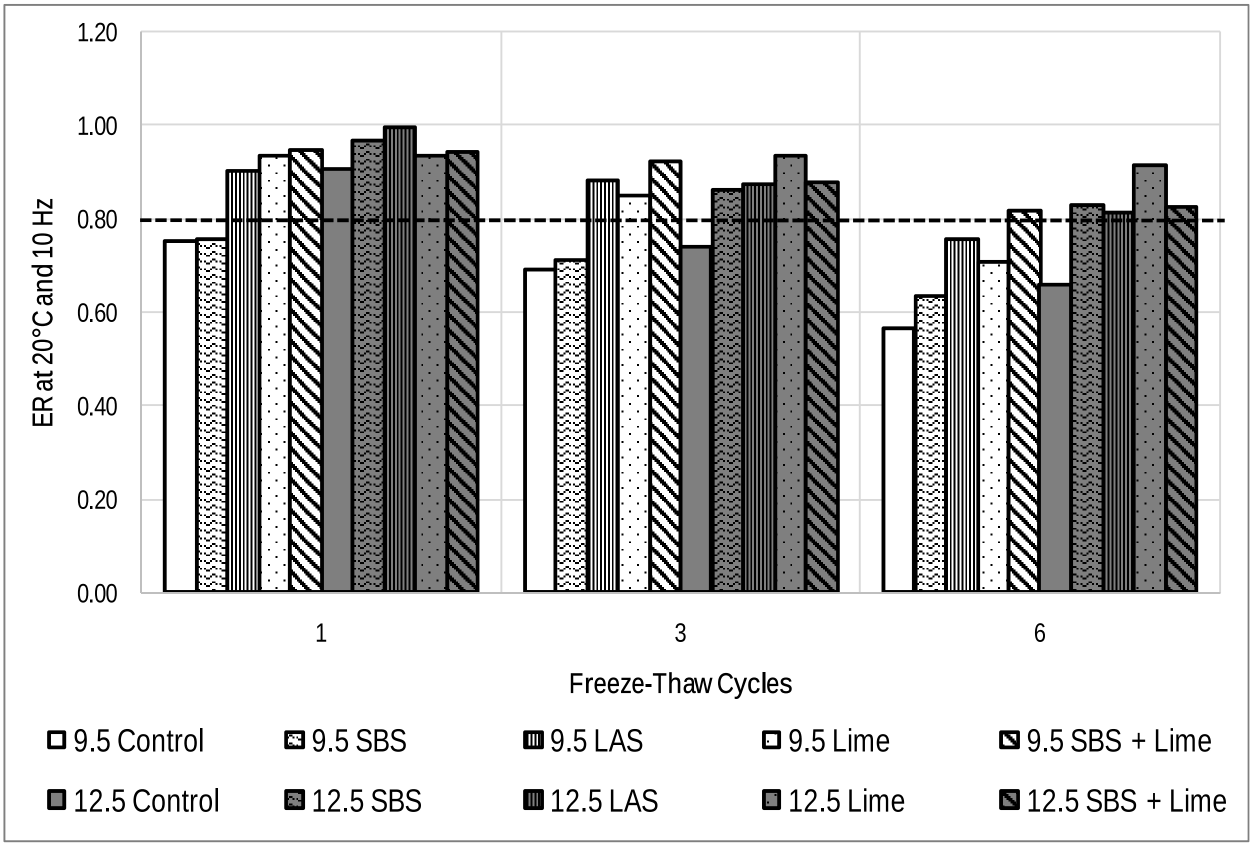
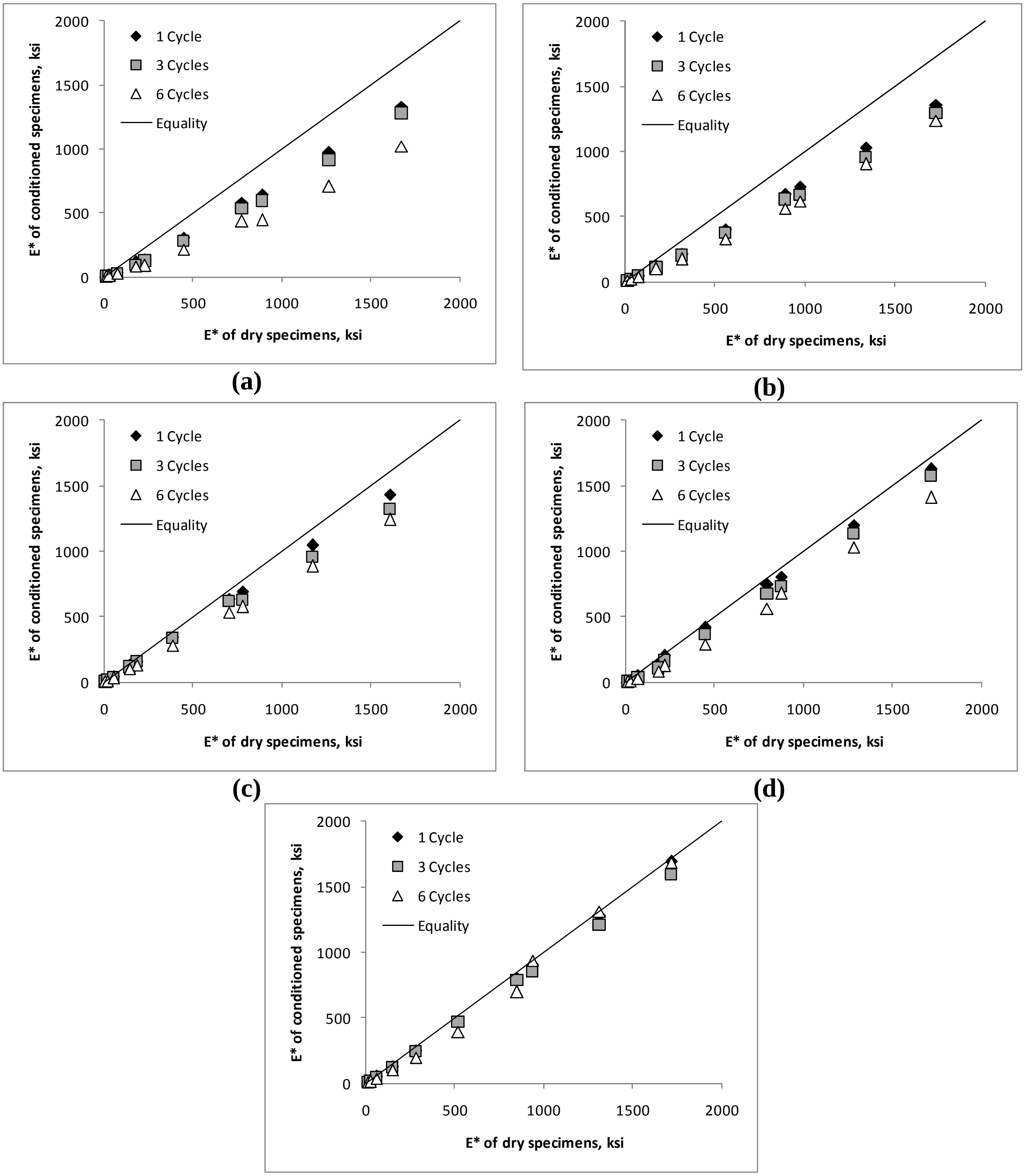


FIGURE 2 ER Results at All Conditioning Levels.

The ER shown in Figure 2 was calculated at 20°C and 10 Hz because these conditions represent typical pavement operating conditions. However, testing was conducted over a wide range of temperatures and frequencies, as required by AASHTO TP79. Figures 3 and 4 present all dynamic modulus measurements made for 9.5 and 12.5 NMAS mixtures, respectively. It is evident that mixtures that do not contain any kind of antistripping agents exhibit a more significant reduction in dynamic modulus for conditioned specimens, compared to dry specimens.

In general, the majority of modulus reduction (i.e. mixture deterioration due to moisture) occurs after the first conditioning cycle. The E* values for conditioned specimens tend to stabilize after six conditioning cycles, which suggests this is an appropriate number of cycles to be used as part of the testing protocol.

Figure 5 illustrates the average ER of the mixtures (including all temperatures and frequencies). It can be observed that some of the mixtures exhibit more variability due to increased moisture susceptibility at certain combinations of testing temperature and frequency.



(a)

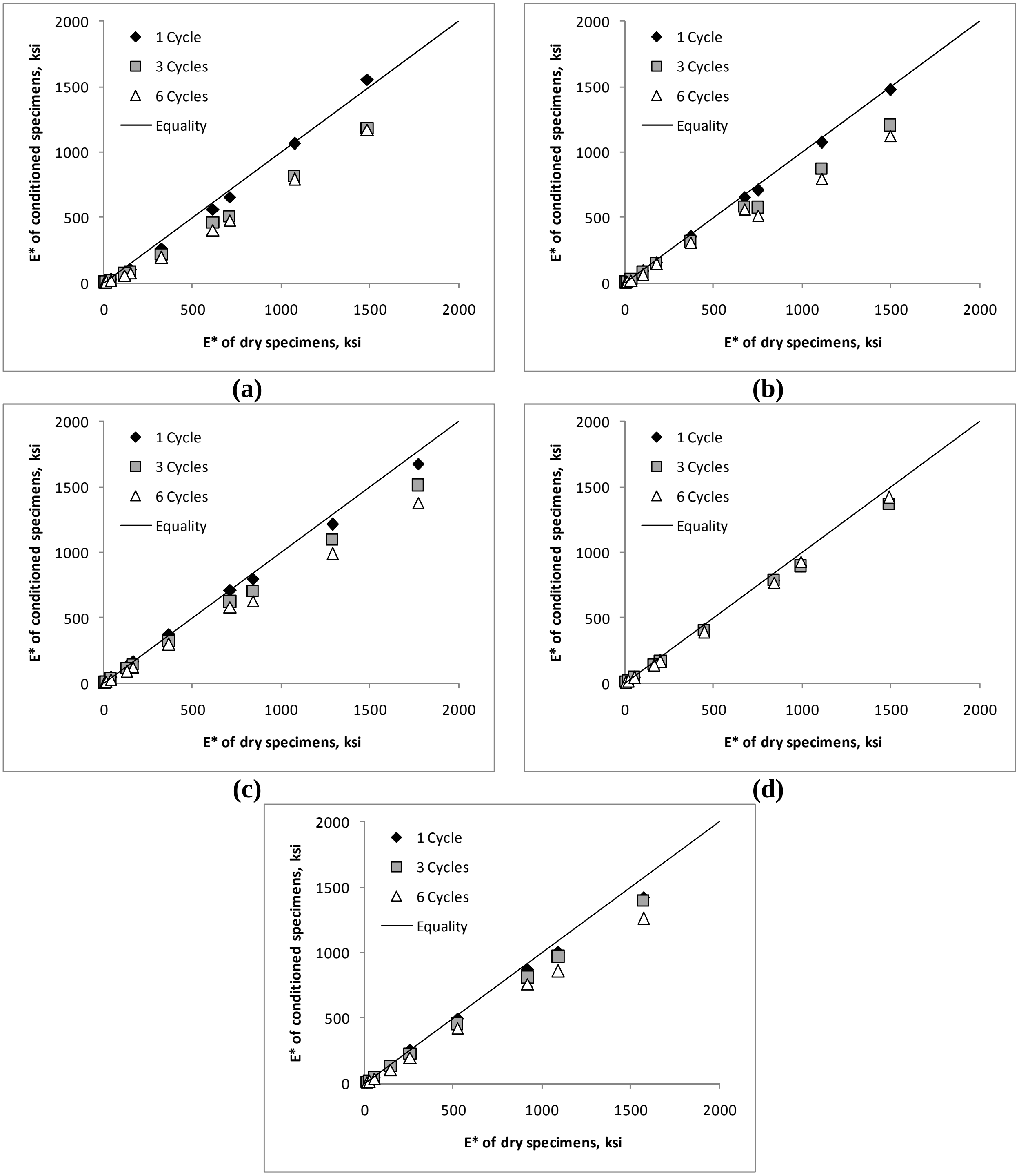
(b)

(c)

(d)

(e)

FIGURE 3Measured Dynamic Modulus at All Testing Conditions for 9.5 mm NMAS Mixtures: a) Control, b) SBS, c) LAS, d) Hydrated Lime and e) SBS + Hydrated Lime.



(a) (b) (c) (d) (e)

FIGURE 4 Measured Dynamic Modulus at All Testing Conditions for 12.5 mm NMAS Mixtures: a) Control, b) SBS, c) LAS, d) Hydrated Lime and e) SBS + Hydrated Lime.

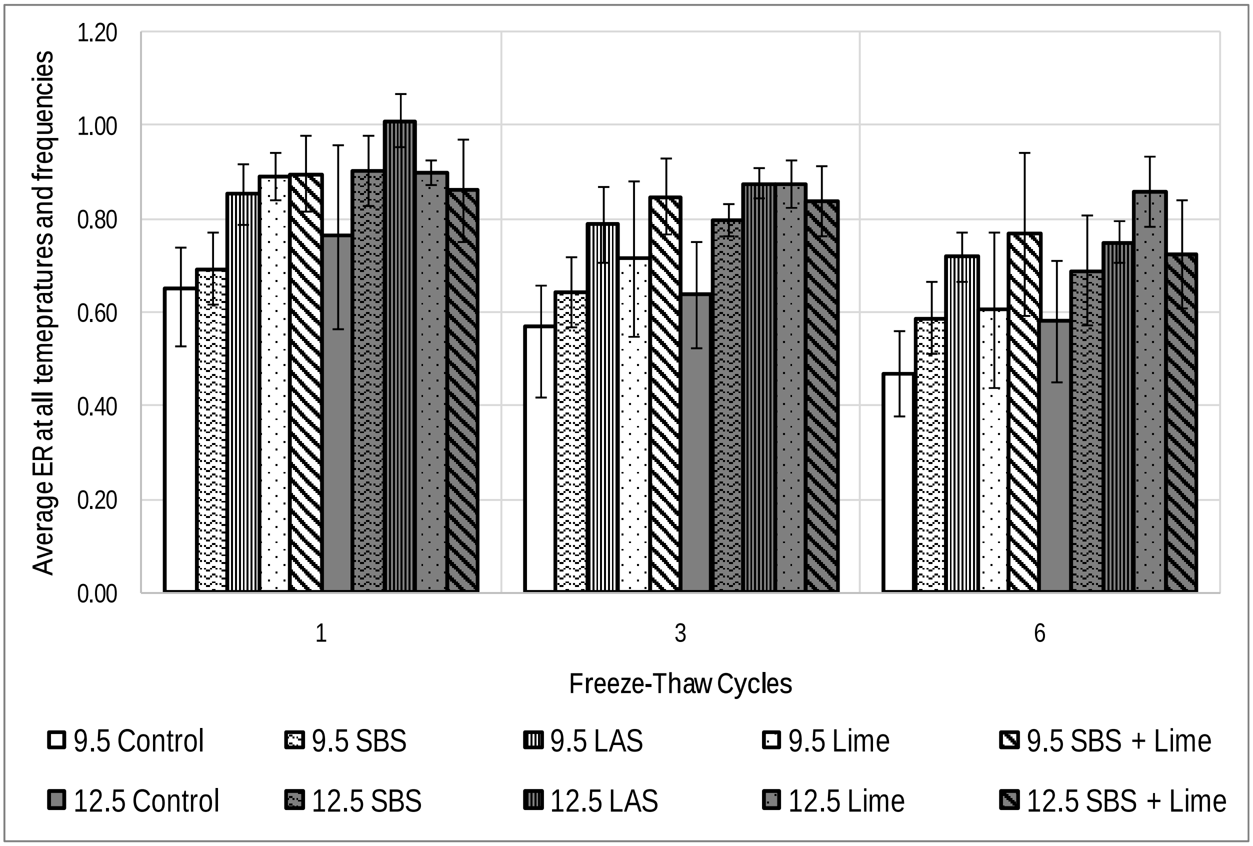


FIGURE 5 Average ER of the Mixtures at All Conditioning Levels.

Table 3 shows the ER values for the entire range of evaluated temperatures and frequencies. Depending on the mixture, the reduction in modulus varies drastically for certain testing conditions. In general, this reduction is greater for measurements made at high temperatures and low frequencies, while conditioning produces less deterioration at low temperatures and high frequencies.

TABLE 3Dynamic Modulus Reduction as a Function of Conditioning Levels

Mixture	**% Dynamic Modulus Compared to Dry Specimens**		
	1 Cycle	**3 Cycles**	**6 Cycles**
9.5 Control	44.5% - 79.8%	35.9% - 76.6%	35.4% - 61.1%
9.5 SBS	56.2% - 78.9%	52.1% - 74.8%	48.3% - 71.6%
9.5 LAS	70.8% - 90.5%	62.7% - 88.2%	62.7% - 77.4%
9.5 Lime	82.1% - 94.7%	49.4% - 91.6%	39.4% - 82.1%
9.5 SBS+Lime	73.4% - 98.7%	72.6% - 92.9%	54.3% - 100%
12.5 Control	51.8% - 1.05%	49.6% - 79.8%	41.3% - 78.8%
12.5 SBS	76.6% - 98.7%	76.0% - 86.4%	53.5% - 83.3%
12.5 LAS	94.3% - 1.11%	84.0% - 94.7%	68.6% - 81.5%
12.5 Lime	85.2% - 93.5%	79.7% - 93.5%	75.9% - 95.4%
12.5 SBS+Lime	62.1% - 96.0%	67.6% - 89.3%	49.5% - 82.8%

An analysis of variance was performed to determine the effect of three factors on the average ER of the mixtures: nominal maximum aggregate size (9.5 or 12.5 mm), use of antistripping agents ("Treated" for mixtures containing LAS or hydrated lime, "Untreated" otherwise) and number of conditioning cycles (1, 3 or 6). Table 4 shows the results of the analysis.

TABLE 4 Analysis of Variance for ER

Source	Degrees of freedom	Sums of squares	F-statistic	p-value	% contribution	Significant?
NMAS	1	0.679	52.89	0.000	9.0%	Yes
AS Agent	1	1.752	136.40	0.000	23.2%	Yes
Cycles	2	1.338	52.08	0.000	17.7%	Yes
NMAS*AS Agent	1	0.062	4.82	0.029	0.8%	Yes
NMAS*Cycles	2	0.001	0.05	0.955	0.01%	No
AS Agent*Cycles	2	0.002	0.06	0.941	0.03%	No
NMAS*AS Agent*Cycles	2	0.031	1.21	0.299	0.4%	No
Error	288	3.699				
Total	299	7.564				

The results indicated that for a significance level of 0.05 all three factors have a significant effect on the ER. As shown if Figure 6, in general, 12.5 mm mixtures exhibited better resistance to moisture damage than 9.5 mm mixes. As expected, the use of antistripping agents increased the average ER of the mixtures, making them more resistant to moisture induced damage. Finally, the application of multiple conditioning cycles accelerated the deterioration of the mixture and may be necessary to better simulate field conditions.

In addition, the interaction between the nominal maximum aggregate size and the use of antistripping agent was also significant at the 0.05 significance level. Figure 7 shows how the addition of liquid antistrip agent or hydrated lime increased the average ER of the mixtures, but this improvement was more pronounced for 9.5 mm mixtures. All other interactions were not found to be statistically significant.

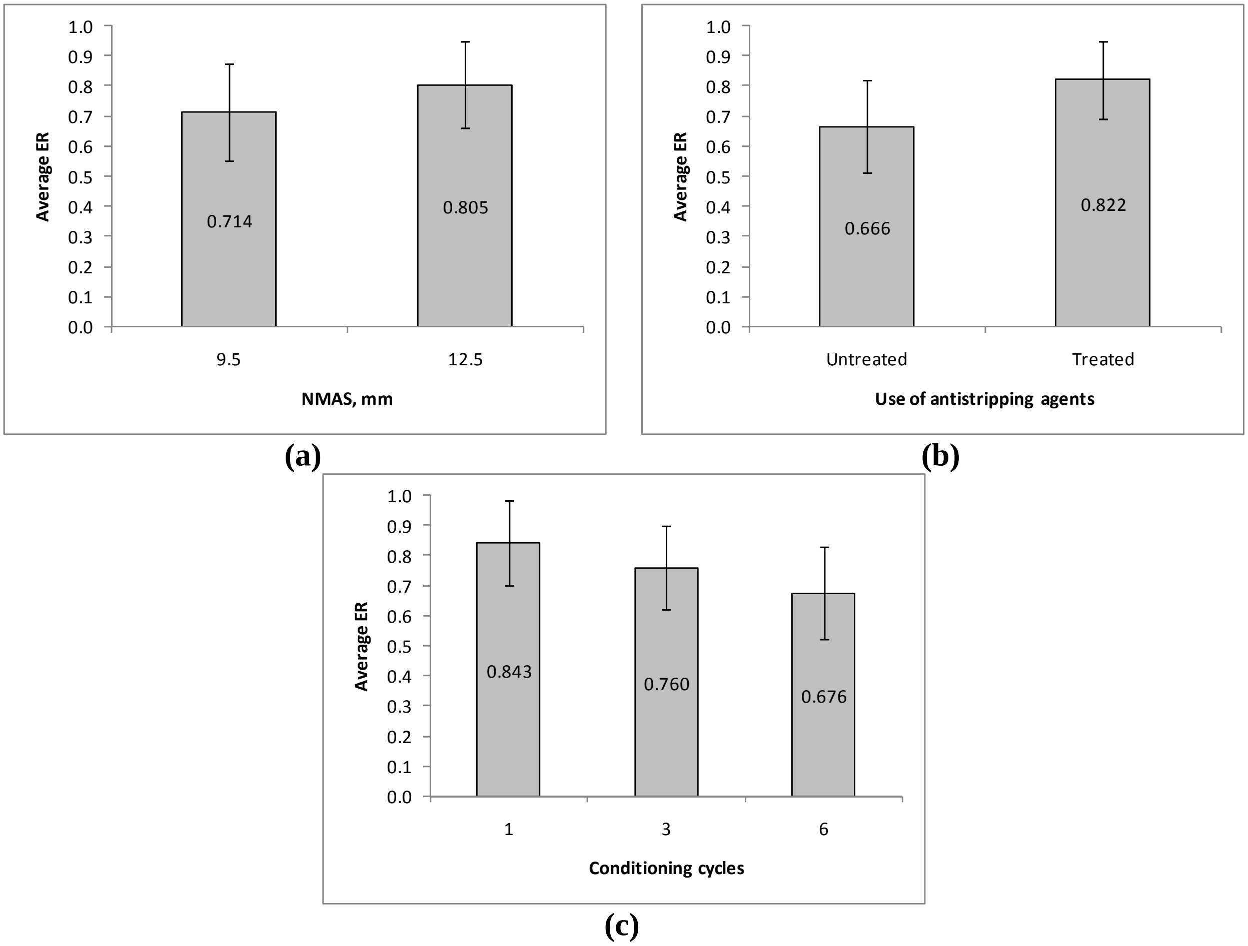


FIGURE 6 Effect of Main Factors on Average ER.

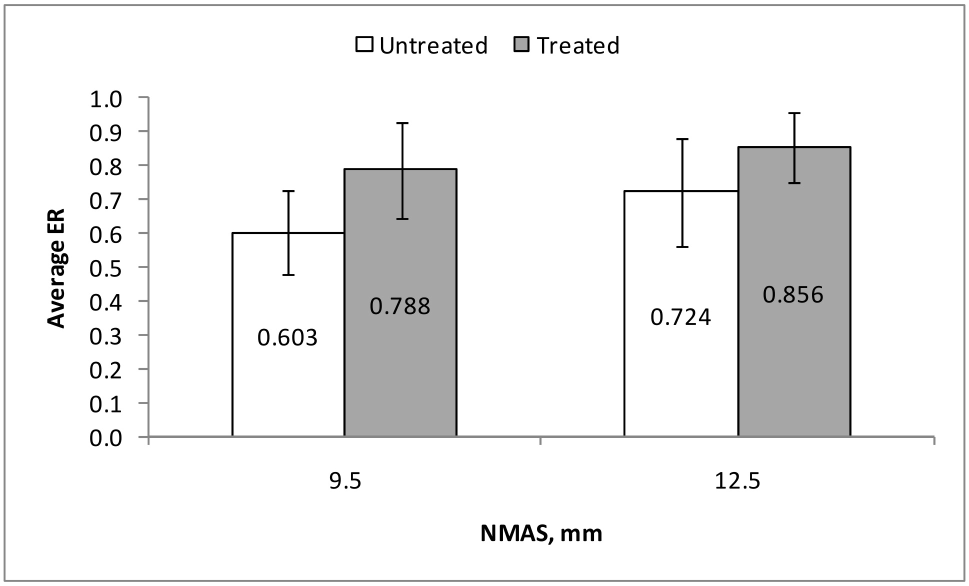


FIGURE 7 Combined Effect of NMAS and Use of Antistripping Agents.

Flow Number

When using the FNR as the parameter to evaluate moisture susceptibility, mixtures are being subjected to the combined effect of permanent deformation and moisture damage. As observed in Figure 8, only mixtures containing antistripping agents pass the minimum criteria of 0.80, even with one conditioning cycle. The downside of the flow number test is its high variability; however, the results obtained in this study follow the expected trend: untreated mixtures fail to meet the required criteria at any of the conditioning levels.

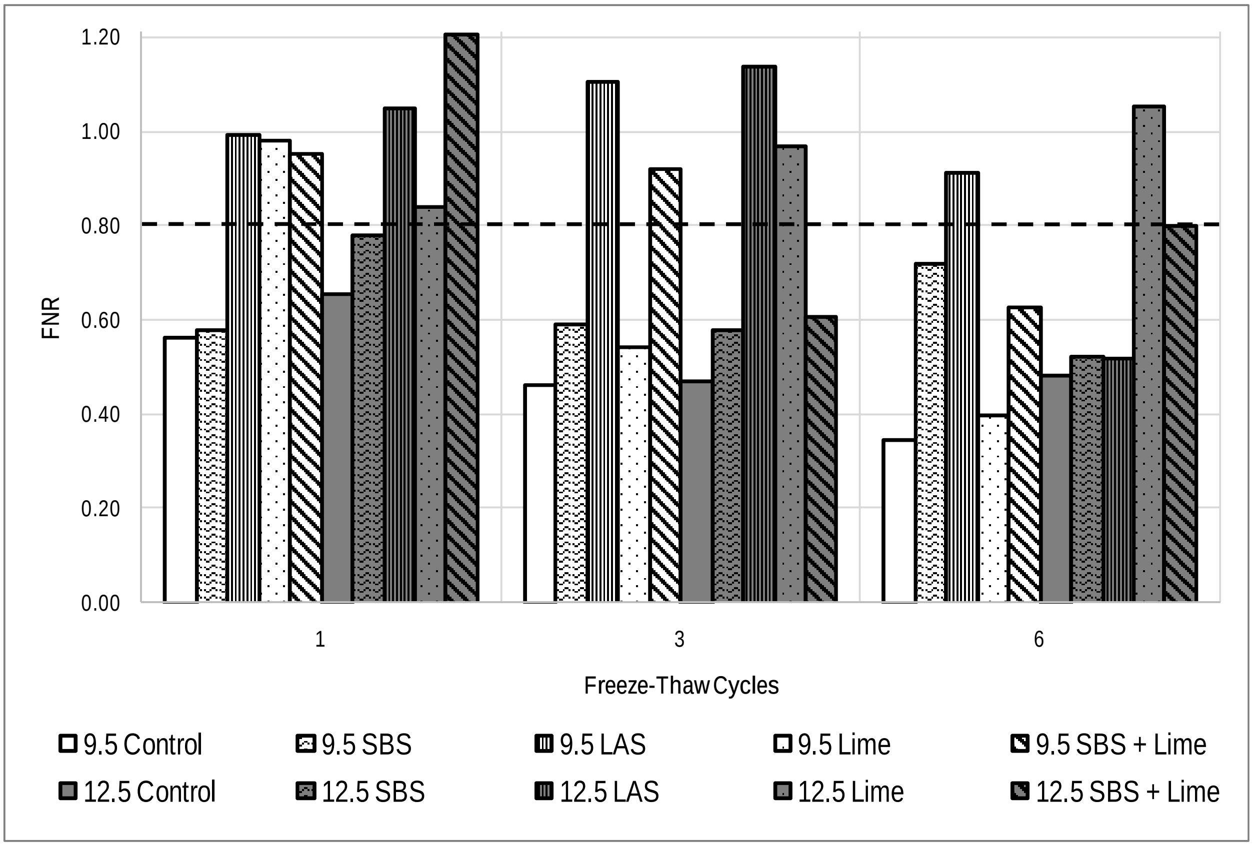


FIGURE 8FNR Results at All Conditioning Levels.

SUMMARY

Table 5 presents a summary of the different parameters used in this study to evaluate moisture susceptibility. Figure 9 shows the average TSR, ER (at 20°C and 10 Hz) and FNR of all mixtures at each of the conditioning levels. These results indicate that the standard AASHTO T283 procedure yields high TSR values, making it easy for the mixtures to meet the required criteria, even when field experience has shown a potential for moisture related damage. Increasing the number of conditioning cycles from one to six may offer a better simulation of field performance. However, this modification can be time consuming.

TABLE 5 Ratio of Conditioned to Dry Specimens for all Tests Performed

Mixture	TSR			ER			FNR		
	1 Cycle	3 Cycles	6 Cycles	1 Cycle	3 Cycles	6 Cycles	1 Cycle	3 Cycles	6 Cycles
9.5 Control	0.91	0.75	0.73	0.75	0.69	0.56	0.56	0.46	0.35
9.5 SBS	0.81	0.72	0.55	0.76	0.71	0.64	0.58	0.59	0.72
9.5 LAS	1.03	0.87	0.89	0.90	0.88	0.76	0.99	1.10	0.91
9.5 Lime	0.95	0.92	0.91	0.94	0.85	0.71	0.98	0.54	0.40
9.5 SBS+Lime	1.05	1.03	1.14	0.95	0.92	0.82	0.95	0.92	0.63
12.5 Control	0.86	0.67	0.67	0.91	0.74	0.66	0.65	0.47	0.48
12.5 SBS	0.92	0.86	0.68	0.97	0.86	0.83	0.78	0.58	0.52
12.5 LAS	0.98	0.93	0.78	1.00	0.88	0.81	1.05	1.14	0.52
12.5 Lime	0.95	0.91	0.93	0.94	0.94	0.92	0.84	0.97	1.05
12.5 SBS+Lime	0.96	0.96	0.96	0.94	0.88	0.83	1.20	0.60	0.80
Mean	*0.94*	*0.86*	*0.82*	*0.91*	*0.84*	*0.75*	*0.86*	*0.74*	*0.64*
St. Dev.	*0.07*	*0.11*	*0.17*	*0.08*	*0.09*	*0.11*	*0.21*	*0.26*	*0.23*

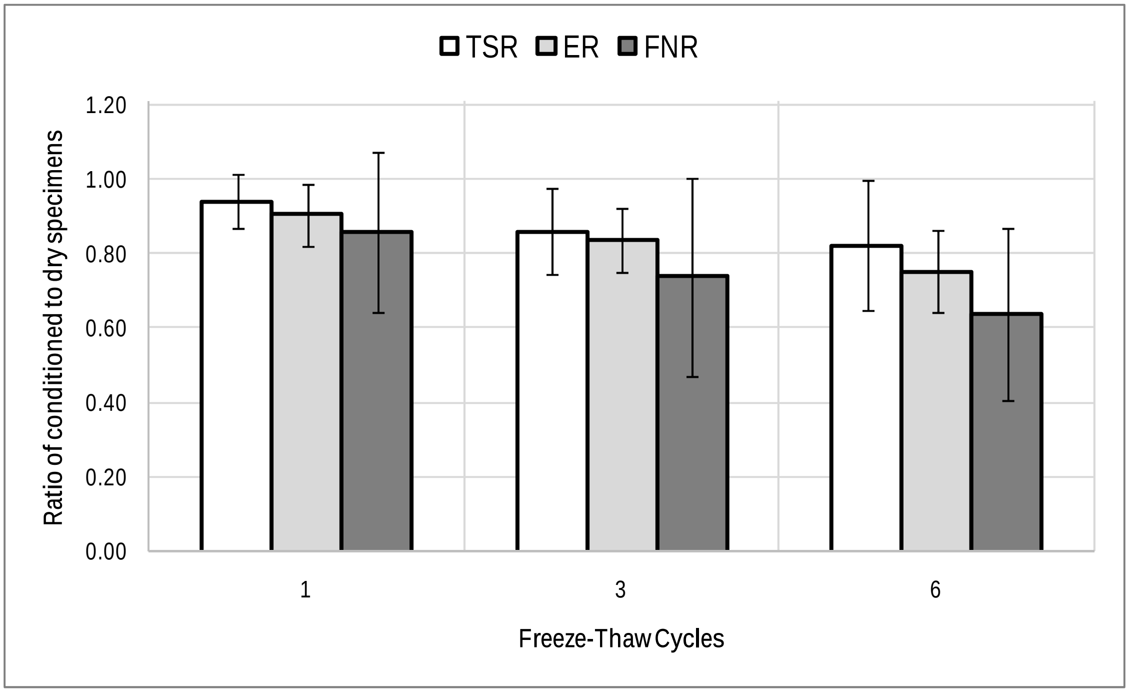


FIGURE 9 Average Ratio of Conditioned to Dry Specimens.

Using the dynamic modulus test to evaluate moisture susceptibility is a less empirical approach, since E* is a main input in the mechanistic-empirical design method for flexible pavements and is an indicator of mixture performance at different ranges of temperature and speed. The ER is a more severe parameter than the TSR, but is highly dependent on testing conditions. This study focused on ERs calculated at 20°C and 10 Hz, but as discussed earlier, higher reductions in dynamic modulus can be expected for high temperatures and low frequencies.

Finally, as observed in Table 5 and Figure 9, the average FNR results had the lowest values of all the parameters studied. Mixtures with expected poor field performance were easier to screen out, without the need to apply multiple conditioning levels. The higher standard deviations observed in Figure 9 for the FNR are caused by the differences in the values of untreated and treated mixtures, which were not as easily identified with the Modified Lottman indirect tension and dynamic modulus tests.

CONCLUSIONS

The objective of this study was to evaluate the moisture susceptibility of different asphalt mixtures using simple performance tests for various levels of environmental conditioning. Based on the data presented above, the following conclusions are made:

- The current test adopted by the Superpave design method to assess moisture susceptibility (known as the modified Lottman indirect tension test) remains empirical and may not identify mixtures that are likely to exhibit poor performance in the field. An increased number of conditioning cycles may be required to accurately simulate observed field performance.
- The use of simple performance tests offers an alternative for the evaluation of moisture damage in asphalt concrete mixtures. Similar to AASHTO T283, test parameters can be calculated by comparing the results of conditioned specimens to those of dry specimens.
- The dynamic modulus test could be a preferred option than indirect tension because E* is a main input in the mechanistic-empirical design method for flexible pavements and is an indicator of mixture performance at different ranges of temperature and speed. However, it should be noted that the reduction in dynamic modulus caused by sample conditioning is highly dependent on testing conditions and lower ER values can be expected for high temperatures and low frequencies.
- For the entire range of testing temperatures and frequencies performed according to AASHTO TP79, the ER was affected by three factors: nominal maximum aggregate size, use of antistripping agents and number of conditioning cycles. The interaction between the nominal maximum aggregate size and the use of antistripping agent was also significant, as the addition of liquid antistrip agent or hydrated lime increased the average ER of the mixtures, but this improvement was more pronounced for 9.5 mm mixtures.
- The flow number test, typically used to evaluate permanent deformation, also provided moisture susceptibility results that better reflected the expected trend without the need to apply multiple conditioning levels. However, caution must be taken as this test has a higher variability.

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