Using Dynamic Modulus Test as a Tool to Determine Resistance of Asphalt Concrete to Moisture Damage

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ABSTRACT: Modulus of asphalt concrete mixes has been considered among the most important properties measured for this material. Results from dynamic modulus (DM) testing provide the fundamental material properties used with the newly developed Mechanistic Empirical Pavement Design Guide. This study was conducted to evaluate potential of DM test in discriminating the behavior of poorly performing mixes from well-performing mixes in regard to moisture damage. Two different siliceous gravel aggregate sources were utilized to prepare asphalt concrete mixes. The specimens were first tested for dynamic modulus under dry conditions. They were subsequently exposed to vacuum saturation while submerged in water, followed by one freeze-thaw cycle with a total duration of 40 hours. These conditioned specimens were tested for dynamic modulus and then were placed under a second round of freeze-thaw conditioning. The specimens were tested again for dynamic modulus. This sequence of testing and conditioning was repeated three times. Testing was conducted at 25°C and loading frequencies of 10, 5, 2, and 1 Hz. Testing results showed damaging effect on modulus of both kinds of tested specimens after experiencing cycles of freeze-thaw conditioning process. Furthermore, when assessing the resistance of the mixes to moisture damage, the results based on ratio of moduli did not match those from the tensile strength ratio (TSR). Dynamic modulus testing with repeated freeze-thaw cycles maybe a better predictor of moisture damage susceptibility than tensile strength ratio and its potential to do so could only be evaluated through field comparisons, which was not part of this study.

KEY WORDS: Asphalt concrete, moisture damage, dynamic modulus test.

1 INTRODUCTION

Moisture-induced damage in asphalt concrete generally results from the loss of adhesive bonding force between asphalt binder and aggregates, also known as “stripping,” from the loss of cohesive property within the binder, or from the loss of both. Moisture-related problems are believed to occur under the influence of water and traffic loading. Various test methods have been proposed through years in an attempt to investigate moisture damage susceptibility of asphalt concrete. Among these tests, the American Association of State Highway and Transportation Officials (AASHTO) T283, also known as Modified Lottman test, has been recommended to determine potential moisture susceptibility of asphalt concrete. It is also adopted by Superpave mix design as the final step to evaluate sensitivity of the design mixture to moisture induced damage. The test uses the indirect tensile strength ratio, TSR, which is defined by dividing tensile strength of conditioned specimen by tensile strength of unconditioned specimen, to obtain the percent strength loss and thus to evaluate the potential for moisture susceptibility.

However, AASHTO T283 has been criticized for its accuracy of moisture damage prediction due to the lack of considering in-situ repeated traffic loading. In addition, it was found that TSR is sensitive to other minor changes in voids, moisture conditioning, saturation level, aggregate orientation and temperature (Bahia and Ahmad 1999), making the results biased and unreliable for moisture damage determination. Kanitpong and Bahia (2008) studied results from Tensile Strength Ratio Tests based on ASTM D4867 (equivalent to AASHOT T283) for a large number of constructed pavements and found no relationship between TSR and specific pavement distresses related to moisture damage.

For the purpose of better predicting moisture damage in asphalt pavements, Solaimanian et al. (2006) investigated the dynamic modulus test integrated with the environmental conditioning system (ECS). Later studies also pointed out that the dynamic modulus test, compared with AASHTO T283, may potentially be a better approach to predict field moisture damage in asphalt concrete (Bausano et al. 2006 and Nadkarni et al. 2009). Furthermore, test results of the dynamic modulus testing can be used as an input in the Mechanistic Empirical Pavement Design Guide (MEPDG). MEPDG is the new guide for pavement design and utilizes existing mechanistic models and current pavement design procedures and considers the influence of factors like climate and aging on material properties.

This research was focused on assessment of mechanical tests for evaluation of moisture damage. There have been a number of research studies in the past investigating fundamental material properties responsible for moisture damage. A prominent example is surface free energy of asphalts and aggregates that has been investigated with great interest in recent years. The work by Bhasin et al. (2007), for example, shows how surface free energy is used to derive energy parameters for quantifying the moisture sensitivity of various mixes. The objective of the research presented in this paper was to evaluate the potential of dynamic modulus test in discriminating the behavior of poorly performing from well-performing asphalt mixes in regard to moisture damage.

2 EXPERIMENTAL DESIGN

Two siliceous gravel aggregates from northwest of Pennsylvania, here referred to as TRC and CLA, were used for this research. One of the aggregates (TRC) had a high level of water absorption and high sodium sulfate soundness loss. The other (CLA) could be classified as an aggregate with low water absorption and sodium sulfate soundness loss. Mix designs for these aggregates were available and were used to prepare specimens. The test specimens, 100-mm-diameter (3.9-inches) by 150-mm-high (5.9-inches), were prepared by coring and sawing from the middle of gyratory compacted specimens that were 150-mm-diameter (5.9-inches) by 165-mm-high (6.5-inches). Tests were first conducted under dry conditions. The specimens were subsequently exposed to one freeze-thaw conditioning cycle. The procedure outlined under AASHTO T283 with modification to vacuum saturation time was followed to condition specimens. These conditioned specimens were tested for dynamic modulus and then were subject to a second round of freeze-thaw conditioning. The specimens were tested again for dynamic modulus. This conditioning procedure was repeated three times.

2.1 Mix Design

The two coarse aggregates were AASHTO designation #8. A fine #3 aggregate from only one source was used in the study and was blended with the #8 aggregates to deliver the asphalt mixes needed for the study. The binder for all mixes was a neat PG 64-22 asphalt binder.

The blend required 54 percent of #3 aggregate and 46 percent of AASHTO #8 aggregate. For the #8 aggregates, sizes from 9.5 mm to #16 were used and for the #3 aggregates, sizes ranged from #4 sieve to material passing #200 sieve. The final gradation satisfied requirements for a Superpave 9.5 mm nominal maximum size aggregate.

2.2 Dynamic Modulus Test Protocol

The dynamic modulus testing was conducted with a uniaxial sinusoidal load. Dynamic modulus tests were conducted on the same specimen four times. The first test was on the dry unconditioned specimen, followed by a second test after the specimen was exposed to one complete cycle of water conditioning, a third test after a 2nd cycle of water conditioning, and a fourth test after a 3rd cycle of water conditioning.

Table 1 shows details of major testing parameters. All dynamic modulus tests were conducted at 25°C. Selection of the 25°C test temperature was based on findings from the research under NCHRP 9-29 (Bonaquist et al. 2003), which concluded that dynamic modulus testing at moderate temperatures close to 25°C produced less variability in results compared with tests at extreme temperatures such as -10°C or 40°C, respectively. Specimen setup and temperature control were also more easily managed at moderate temperatures. Hence, testing at other temperature was not included in this research. The loading frequencies for each specimen were 10, 5, 2, and 1 Hz applied in decreasing order. The number of loading cycles for 10, 5, 2, and 1 Hz were 100, 50, 20, and 10 cycles, respectively. Furthermore, attempts were made to apply a load level which would induce a strain level between 30 to 70 microstrains to minimize specimen permanent deformation.

Table1: Description of parameters for dynamic modulus testing.

Parameter	**Value/Type**
Temperature	25 °C
Load Pattern	Sinusoidal
Frequencies	10, 5, 2, and 1 Hz
Load Level	Variable
Displacement Measurement	3 LVDTs @ 120 ^{o} Axial Direction
Measurement Span in Axial Direction	70 mm
Strain Level	50 ± 20 microstrain
Number of Loading Cycles	100 Cycles for 10 Hz 50 Cycles for 5 Hz 20 Cycles for 2 Hz 10 Cycles for 1 Hz

2.3 Conditioning Approach

The idea behind this testing was to conduct the same conditioning approach which was used in AASHTO T 283 test method with the exception of conditioning time, i.e., using 30-minute conditioning time instead of targeting a specified level of degree of saturation. The combined conditioning-DM tests were conducted to determine the impact of the water conditioning on dynamic modulus of the mix. After each specimen was tested for dynamic modulus at four frequencies, it was exposed to water conditioning as follows.

- 30 minutes of vacuum at partial pressure of 26 inches of Hg.
- 16 hours of -18°C freeze.
- 24 hours of 60°C water bath.
- 2 hours of conditioning at 25°C

The preceding sequence completes one cycle of conditioning. Afterwards, the specimen was subject to a second set of dynamic modulus tests at four frequencies. This was followed by the second cycle of water conditioning for 2 days and the second set of dynamic modulus tests, as explained above, before the final round of conditioning and dynamic modulus testing were conducted.

3 TEST RESULTS AND ANALYSIS

3.1 Test Results

The summary of test results is provided in Table 2. The shaded areas indicate unreasonable results or outliers which were not included in computation of averages. Figure 1 and 2 show the average modulus for different frequencies and different conditioning levels for both TRC and CLA mixes. It can be observed that the modulus decreases when loading frequency decreases. For TRC mix, the modulus at 10 Hz is approximately 4200 MPa (600,000 psi) while it is approximately 1900 MPa (270,000 psi) at a loading frequency of 1 Hz. More importantly, in general, a drop in modulus is observed for all specimens and at all frequencies after water conditioning. For example, at 10 Hz frequency for TRC mix, the specimen modulus drops from approximately 4200 MPa to 3000 MPa once it goes through a complete cycle of water conditioning. Figures 1 and 2 also show the level of modulus drop for different conditioning cycles. It is quite obvious that as the number of conditioning cycle increases, the modulus decreases.

Table2: Summary of dynamic modulus test results.

Mix	Frequency	Dynamic Modulus, Mpa				Moduli Ratio		
	Hz	Mod. 1	Mod. 2	Mod. 3	Mod.4	DMR-1	DMR-2	DMR-3
TRC-1	10	4195.6	2724.5	2402.8	NA	0.65	0.57	NA
	5	3148.5	1986.0	1703.6		0.63	0.54	
	2	2243.2	1447.0	1246.9		0.65	0.56	
	1	1635.4	1263.1	999.7		0.77	0.61	
TRC-2	10	NA	3416.9	2843.6	2948.0	NA	NA	NA
	5		2696.5	2482.3	2034.9			
	2		2232.4	1713.2	1478.0			
	1		1610.7	1318.0	1256.8			
TRC-3	10	4265.2	2813.5	3495.1	2331.2	0.66	0.82	0.55
	5	3103.7	1994.6	2729.8	2400.4	0.64	0.88	0.77
	2	2155.8	2279.9	2368.5	1798.5	1.06	1.10	0.83
	1	2104.8	1443.1	1959.8	1598.2	0.69	0.93	0.76
AVERAGE of All 3 for TRC	**10**	**4230.4**	**2985.0**	**2623.2**	**2639.6**	**0.65**	**0.57**	0.55
	5	**3126.1**	**2225.7**	**2092.9**	**2217.6**	**0.64**	**0.54**	0.77
	2	**2199.5**	**1986.4**	**1480.1**	**1638.2**	**0.65**	**0.56**	0.83
	1	**1870.1**	**1439.0**	**1158.8**	**1427.5**	**0.73**	**0.61**	0.76
CLA-1	10	3211.4	2948.0	2108.6	NA	0.92	0.66	NA
	5	2692.4	2024.4	1648.3		0.75	0.61	
	2	2018.9	1557.8	1210.2		0.77	0.60	
	1	1833.4	1385.0	1263.1		0.76	0.69	
CLA-2	10	3491.1	2745.9	2916.4	2461.8	0.79	0.84	0.71
	5	2877.4	2543.5	2391.0	1869.8	0.88	0.83	0.65
	2	2176.5	2084.4	1980.4	1371.0	0.96	0.91	0.63
	1	1953.0	1851.1	1400.4	1005.7	0.95	0.72	0.51
CLA-3	10	4276.5	3258.2	2701.4	2396.3	0.76	0.63	0.56
	5	2936.5	2594.4	2142.7	1913.2	0.88	0.73	0.65
	2	2359.9	2045.4	1695.4	1364.7	0.87	0.72	0.58
	1	2149.2	1981.9	1488.7	1118.1	0.92	0.69	0.52
AVERAGE of All 3 for CLA	**10**	**3659.7**	**2984.1**	**2512.5**	**2429.0**	**0.82**	**0.66**	**0.63**
	5	**2835.5**	**2387.4**	**2019.6**	**1891.5**	**0.84**	**0.61**	**0.65**
	2	**2185.1**	**1895.9**	**1595.3**	**1367.9**	**0.77**	**0.60**	**0.60**
	1	**1978.5**	**1739.3**	**1331.8**	**1061.9**	**0.88**	**0.69**	**0.52**

DMR-1: Ratio of Modulus after 1st Cycle Conditioning to Unconditioned Modulus.
DMR-2: Ratio of Modulus after 2nd Cycle Conditioning to Unconditioned Modulus.
DMR-3: Ratio of Modulus after 3rd Cycle Conditioning to Unconditioned Modulus.
Shaded cells contain outliers or unreliable data and were not included in calculation of averages.
MOD1, MOD2, and MOD3 refer to modulus of specimen at dry condition, after 1st cycle, after 2nd cycle, and after 3rd cycle conditioning.

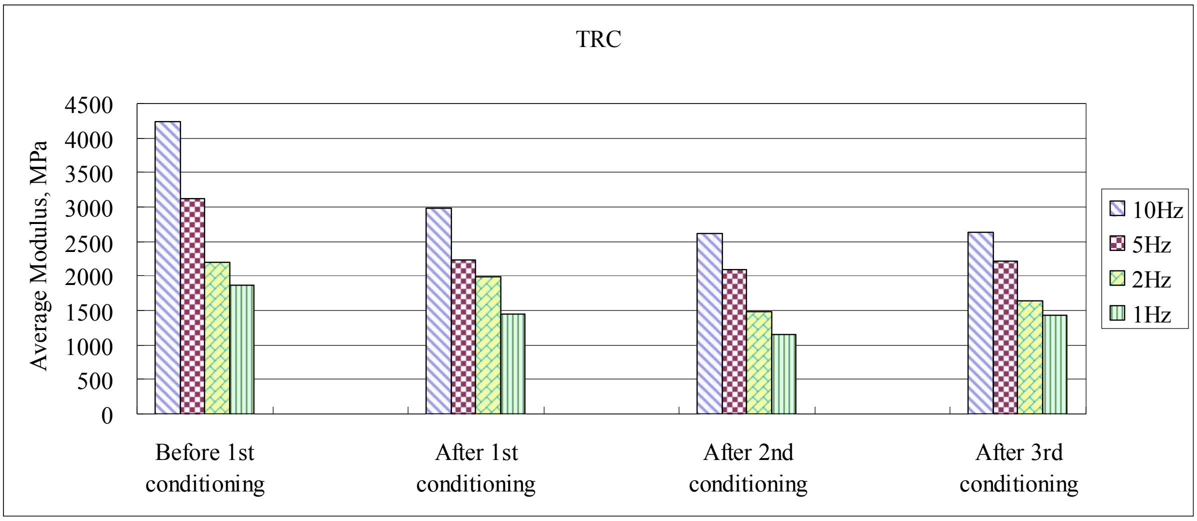

Figure1: Average modulus for different frequencies and different conditioning levels for the TRC mix.

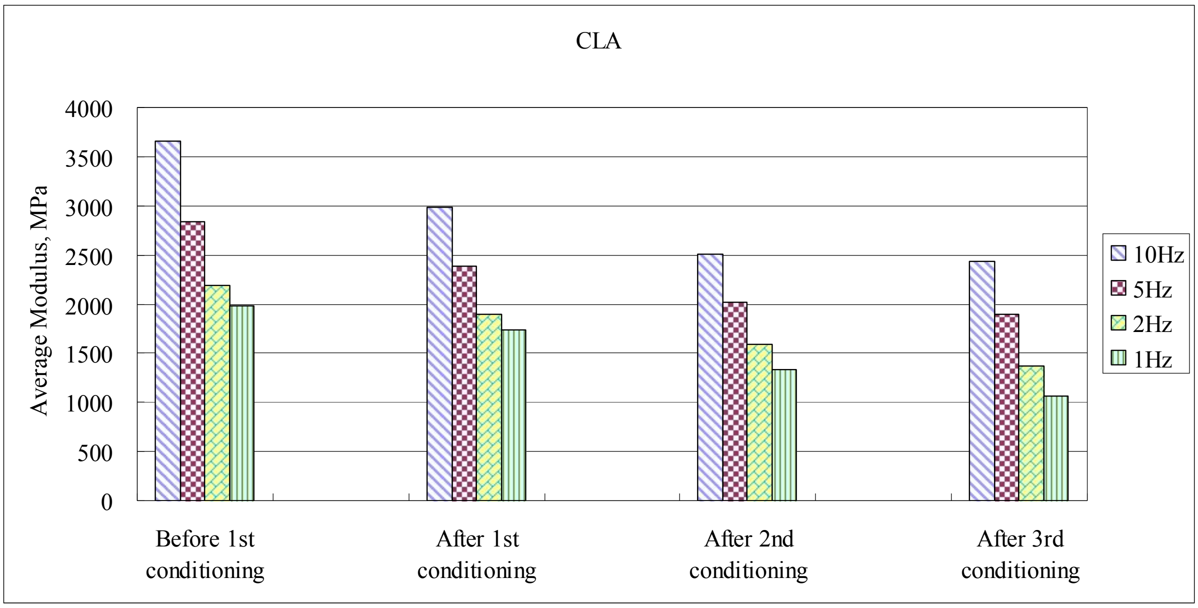

Figure2: Average modulus for different frequencies and different conditioning levels for the CLA mix.

3.2 Analysis on Ratio of Moduli

Figures 3 and 4 show the ratio of the modulus of a fully conditioned specimen to the modulus of that specimen in dry condition for TRC and CLA mixes, respectively. Figure 5 shows ratio of moduli at different frequencies for both mixes after first and second conditioning. The ratio was calculated according to Equation (1).

$$\text{Ratio of Moduli} = \frac{\text{Dynamic Modulus After Conditioning}}{\text{Dynamic Modulus Before Conditioning}} \tag{1}$$

For TRC mix, the specimen retained approximately 65 percent to 73 percent of its original modulus after the first conditioning cycle at testing frequency of 10 Hz. For CLA, the retained modulus after the first conditioning cycle was around 77 percent to 88 percent of its original value at 10 Hz frequency, showing a better moisture damage resistance after one conditioning cycle. However, the results indicate that after two cycles of water conditioning, there is a significant drop of modulus for both mixes, indicating susceptibility of the mixes to moisture damage. It should be noted that the results presented here for dynamic modulus are for mixes without any liquid antistripping agent, lime, or any other modifications.

Another noticeable point is, although 3rd cycles of conditioning were applied to both mixes, some of the specimens failed (disintegrated) during the 24-hour hot-water bath of the 3rd conditioning cycle or specimens were conditioned to a level that made measurement of dynamic modulus unreliable. As a result, in some cases, the data of modulus from specimens experiencing the 3rd conditioning cycle were not available and were excluded from further analysis.

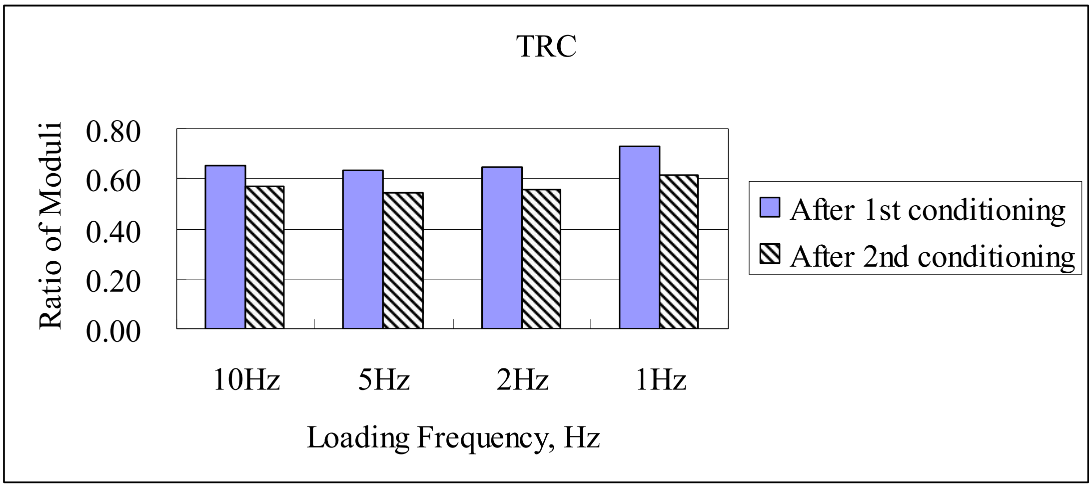

Figure3: Ratio of moduli for different frequencies for TRC mix.

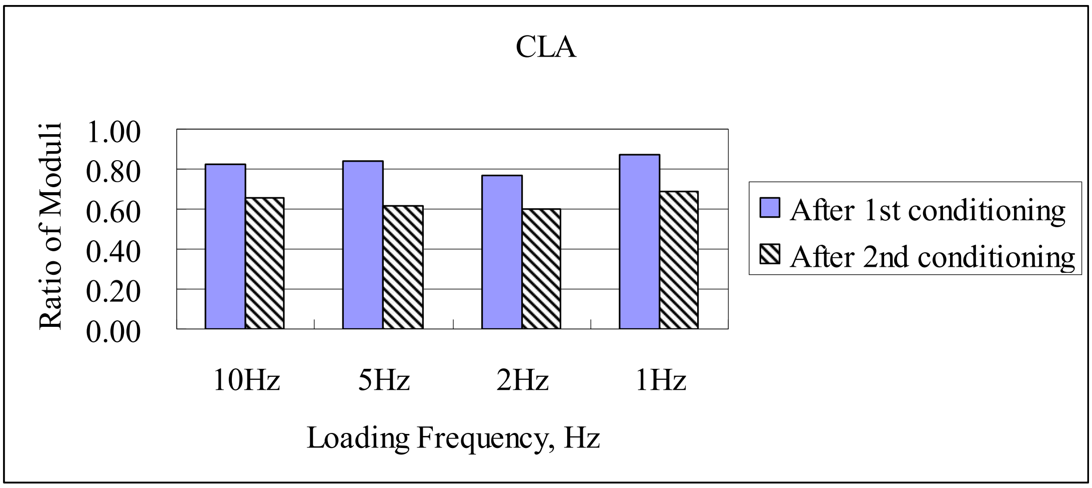

Figure4: Ratio of moduli for different frequencies for CLA mix.

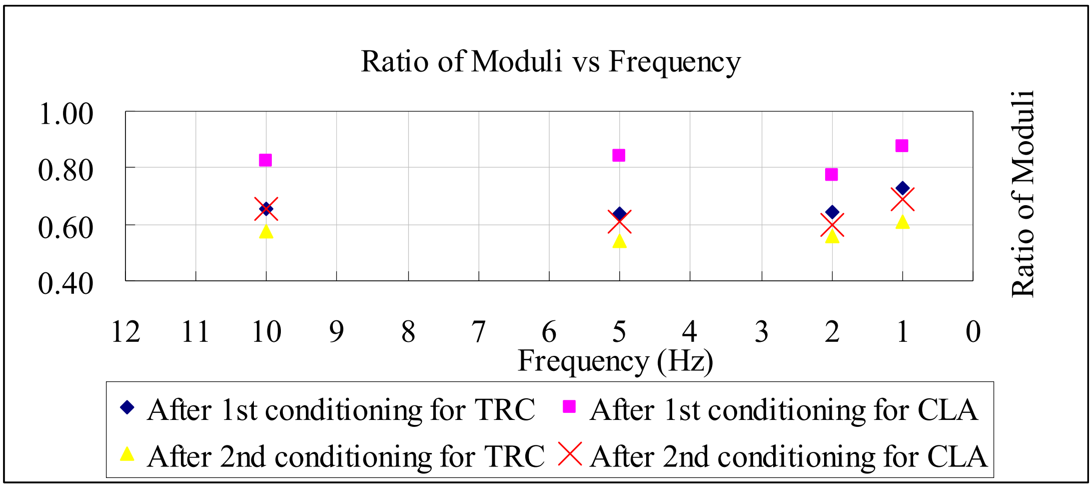

Figure5: Ratio of moduli at different frequencies.

3.3 Comparison between Ratio of Moduli and Tensile Strength Ratio (TSR)

Indirect tensile strength ratio (TSR) for mixes was obtained from tests according to AASHO Test method T 283. The only modification to the procedure was for the conditioning time. A fixed vacuum saturation period of 30 minutes was utilized rather than targeting a specified degree of saturation. Figures 6 and 7 show the comparison of TSR and average ratio of moduli after the first conditioning cycle at frequencies of 10 Hz and 5 Hz for both TRC and CLA mixes. The tensile strength ratio of TRC mix is 0.94 and tensile strength ratio of CLA mix is 0.80. For TRC mix, TSR is higher than TSR for CLA mix. TSR of both mixes meet or pass 0.80, the minimum TSR value required by AASHTO T 283 for a mix to be called as resistant to moisture damage. The ratio of moduli for TRC mix at both frequencies is less than ratio of moduli for CLA mix. It can be concluded that ratio of moduli does not provide the same ranking as the tensile strength ratio for the two mixes tested under this study. In addition, a suitable threshold value of ratio of moduli to discriminate passed or failed mix could be established with more number of testing and more data related to field performance of the mixes. Dynamic modulus testing with repeated freeze-thaw cycles may be a better predictor of moisture damage susceptibility than tensile strength ratio and its potential to do so could only be evaluated through field comparisons, which was not part of this study.

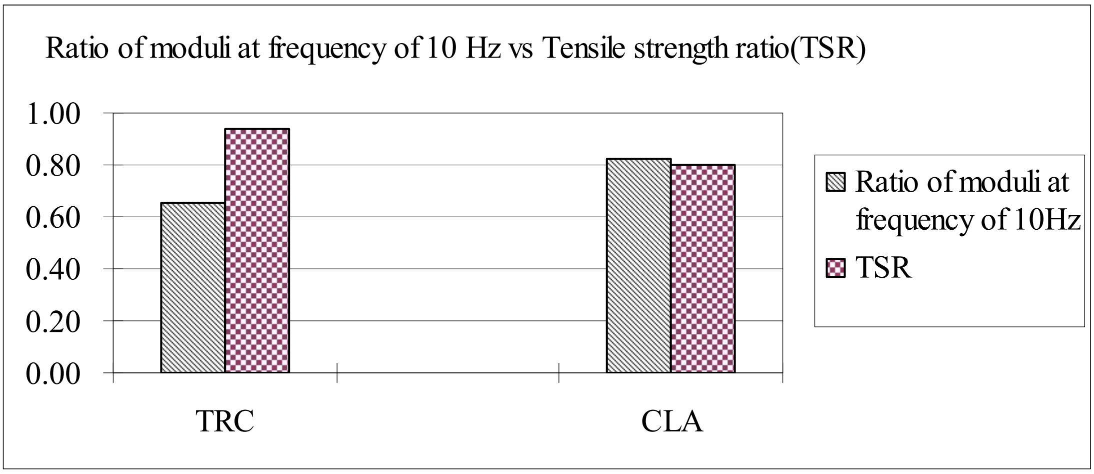

Figure6: Ratio of moduli at frequency of 10 Hz versus tensile strength ratio (TSR).

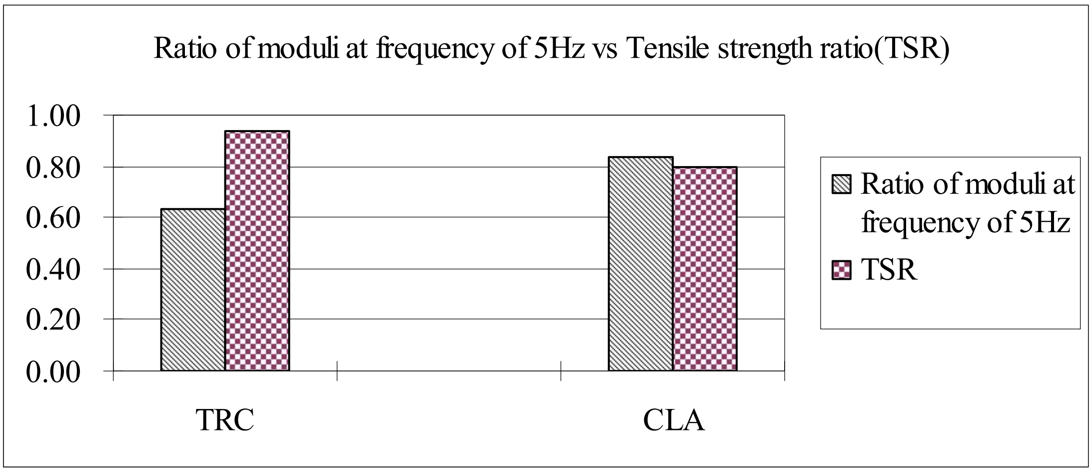

Figure7: Ratio of moduli at frequency of 5Hz versus tensile strength ratio (TSR).

4 CONCLUSIONS

Dynamic modulus tests were conducted on specimens of two mixes without any treatment (TRC and CLA). Dynamic modulus tests were conducted on dry specimens followed by further testing on the same specimen after exposure to three cycles of conditioning. Testing results of this research showed damaging effect on modulus of both types of tested mixtures after experiencing cycles of freeze-thaw conditioning process. Significant drop in modulus was observed for the TRC mix after the first cycle of conditioning. Significant drop in modulus was observed for both mixes after the second cycle of conditioning, indicating susceptibility of both mixes to moisture damage. Results indicated that moisture damage assessed based on ratio of moduli does not correlate well with the results from tensile strength ratio tests (TSR). TRC mix, with higher TSR value, exhibits less ratio of moduli than CLA mix does, implying more modulus loss after conditioning process for TRC mix. It seems that the retained modulus of the mixture after the first and second cycles of conditioning process could be used as the criteria to determine resistance of asphalt concrete to moisture damage when considering traffic loading.

Compared to AASHTO T283, dynamic modulus testing on moisture conditioned specimens may be a better method to evaluate moisture damage susceptibility of asphalt pavements but such assessment is only possible through field comparison which was not considered under this study. Due to the limit number of tested specimens, future validation will be necessary by conducting tests on a larger number of specimens. Testing is also needed on a larger number of asphalt mixes to ensure that the procedure is reliable in discriminating between poorly performing and well performing mixes in regard to moisture damage.

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