Comparative Evaluation of Laboratory Moisture Susceptibility Tests for Asphalt Mixtures

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ABSTRACT

Moisture damage in asphalt mixtures, caused by the loss of adhesion between the asphalt mastic and aggregate surface, loss of cohesion within the mastic phase itself, and/or breakdown of aggregates, is a common and challenging distress for asphalt pavements. There are additives and material selection alternatives to treat asphalt mixtures so that they are less susceptible to premature moisture damage. However, an effective laboratory test and conditioning method is ultimately needed to identify susceptible mixtures as well as to assess effectiveness of any treatments. The objective of this study is to evaluate the ability of three conditioning and testing procedures to identify poor performing mixtures and the effectiveness of treatments. The procedures evaluated include: modified Lottman and moisture induced stress tester (MIST) conditioning paired with indirect tensile strength testing, MIST conditioning paired with dynamic modulus testing, and the saturated aging tensile stiffness (SATS) test. The results from the various procedures are assessed to identify the key differences between each conditioning procedure in terms of its effect on asphalt mixtures as well as to determine which procedure is most effective and practical as a moisture susceptibility test for routine usage during asphalt mixture design as well as for purposes of material acceptance during production.

Keywords: Moisture-induced damage, Moisture susceptibility, MIST, Dynamic Modulus, SATS, TSR

1. INTRODUCTION

Moisture-induced damage in asphalt pavements, typically considered to be caused by either a loss of adhesion between the binder and aggregate phases or a loss of cohesion within the binder phase itself, is a common and challenging distress in areas of wet weather climates. Severe amounts of moisture-induced damage can reduce the useful life of asphalt pavements, leading to significant costs for transportation agencies. To combat this issue, various test methods have been developed to evaluate the moisture susceptibility of asphalt mixtures, which can be defined as the extent to which a mixture is prone to moisture-induced damage. Most of these approaches compare the stiffness or strength of mixtures that have been moisture conditioned to those that are unconditioned. The moisture conditioning is intended to create moisture-induced damage in the test specimens that would then affect the measured material properties. The comparison of the conditioned and unconditioned properties gives an understanding the moisture susceptibility of the mixture. Among transportation agencies in the United States, the most common test procedure is the modified Lottman procedure (specified by AASHTO T-283) or some variant of this procedure [1]. However, AASHTO T-283 has received much criticism as a moisture-susceptibility testing procedure [2-6]. This has lead researchers and agencies to investigate alternate testing and conditioning methods with the goal of developing a more reliable asphalt mixture moisture susceptibility testing procedure.

2. MATERIALS AND METHODS

Three surface course asphalt mixtures were chosen for evaluation in this study. The three mixtures are from the state of Vermont and were produced during the summer of 2017. These three mixtures were chosen from recommendations by representatives from the Vermont Agency of Transportation. One mixture has historically shown good field performance with respect to moisture damage, while the other two have historically shown poor field performance. The two poor performing mixtures are identical except one was treated with a warm mix additive (which is also marketed to function as an anti-strip additive). Table 1 summarizes key parameters associated with the three mixtures. All three of these mixtures were sampled at the plant and then loose mixture was reheated and compacted into test specimens in the laboratory. All test specimens were compacted to 7% air voids.

TABLE 1: Mixture Information

Mixture	Good Performer	Poor Performer with Additive	Poor Performer without Additive
Historical Performance	Good	Poor	Poor
Primary Aggregate Type	Dolomite	Granite	Granite
Superpave Binder Grade	PG 70-28	PG 58-28	PG 58-28
Binder Content (%)	4.9	6.0	6.0
RAP Content (%)	15	20	20
NMAS (mm)	12.5	9.5	9.5
Additive	None	0.5% by weight of binder	None

One of the test methods applied in this research was the modified Lottman procedure. This procedure, primarily used in the United Sates, specifies that two sets of three specimens are made from each mixture. Three of these specimens are tested until failure in an indirect tensile mode. The other three specimens are then conditioned by first vacuum saturating the specimens so that they are between 70-80 percent saturated. Once saturated, the specimens are placed in an environmental chamber at -18°C for a minimum of 16 hours. After this freeze cycle, the specimens are placed in a 60°C water bath for 24 hours. After this conditioning is finished, the samples are tested for indirect tensile strength (ITS). The primary result from this testing is the tensile strength ratio (TSR) of the average conditioned strength to the average unconditioned strength. Typically, mixtures that achieve TSR values over 0.80 are considered good performers.

In addition to the typical Lottman/AASHTO T-283 procedure, a modified version of this procedure was conducted by replacing the standard conditioning procedure with Moisture Induced Stress Tester (MIST) conditioning, specified as ASTM D7870. MIST conditioning involves vacuum saturating specimens to 70-80 percent saturation and submerging the saturated specimens inside a MIST device at 60°C. The MIST device will then apply alternating pressure and vacuum cycles, which is intended to simulate the effects of traffic forcing water into and out of the pores of saturated asphalt pavements [5-8]. This produces scouring, considered one of the most common forms of moisture damage in asphalt pavements.

Similar to the Lottman/AASHTO T-283 procedure, the MIST conditioned subset of specimens are tested for ITS. The primary result is the TSR between the MIST conditioned specimens and the unconditioned specimens.

Another mechanical test conducted was dynamic modulus on the AMPT as specified by AASHTO T-342. Dynamic modulus tests allow the effect of moisture conditioning on linear viscoelastic properties of asphalt mixtures to be determined. Dynamic modulus tests were conducted on three replicates of both unconditioned and MIST conditioned specimens. The test was conducted at three temperatures (4.4, 21.1, and 37.8°C) and six loading frequencies (25, 10, 5, 1, 0.5, and 0.1 Hz). The data from these tests is then used to construct a dynamic modulus master curve at a reference temperature of 21.1°C. The master curves are both compared visually and dynamic modulus stiffness ratios (DMR) are calculated at specific frequencies along the master curve to assess the moisture susceptibility of the mixtures. The DMR is calculated similar to TSR where the MIST conditioned stiffness is divided by the unconditioned stiffness.

The last mechanical test conducted with these mixtures was the saturated aging tensile stiffness (SATS) procedure. The SATS procedure, developed at the Nottingham Transportation Engineering Centre, was originally conceived as a test to evaluate the moisture susceptibility of high modulus base materials [8]. This procedure uses a conditioning protocol that combines both oxidative aging and moisture conditioning into one procedure. Five specimens from each mix are initially tested for stiffness in indirect tensile mode at 20°C. Next, the specimens are vacuum saturated for 30 minutes at an absolute pressure of 33 kPa. The saturated specimens are then placed on a vertical rack inside a conditioning chamber (very similar to a PAV vessel). Since significantly softer surface mixtures were used in this study, the conditioning procedure was modified to use a temperature of 85°C under a pressure of 0.5 MPa for a duration of 24 hours on the basis of recommendations by Grenfell et al [8]. After conditioning, the percent saturation is determined for the specimens (referred to as retained saturation). The conditioned specimens are retested for stiffness, and the retained stiffness value is determined by finding the ratio in stiffness results between the conditioned and unconditioned specimens. A benefit of the SATS test is that the five specimens undergo conditioning at different saturation levels as they rest at different heights in the conditioning vessel. This variance in saturation gives insight into the effect of variable moisture levels on the performance of the mixture. A summary of conditioning methods and mechanical tests used in this study is presented in Table 2.

TABLE 2: Summary of Testing

Conditioning Processes	Indirect Tensile Strength	Dynamic Modulus	Indirect Tensile Stiffness
Modified Lottman Procedure	Yes	No	No
Moisture Induced Stress Tester (MIST)	Yes	Yes	No
Saturated Aging Tensile Stiffness Procedure (SATS)	No	No	Yes

3. RESULTS

The average ITS results are presented below in Figure 1. Both the AASHTO T-283 and MIST TSR values are presented as points corresponding to the right vertical axis, while the average strength values are plotted on the left vertical axis. The error bars displayed represent the standard deviation of the three strength values.

The tensile strength ratios are similar for the three mixtures and all are above 0.80, indicating good performance according to the AASHTO T-283 standard. Ranking the TSR values does not conclusively differentiate the good and poor performing mixtures either, as the good performer has the highest AASHTO T-283 TSR while the poor performer without additives has the highest MIST TSR. The TSR values also did not capture any effect of the additive as there are no significant differences in results between the two poor performing mixtures.

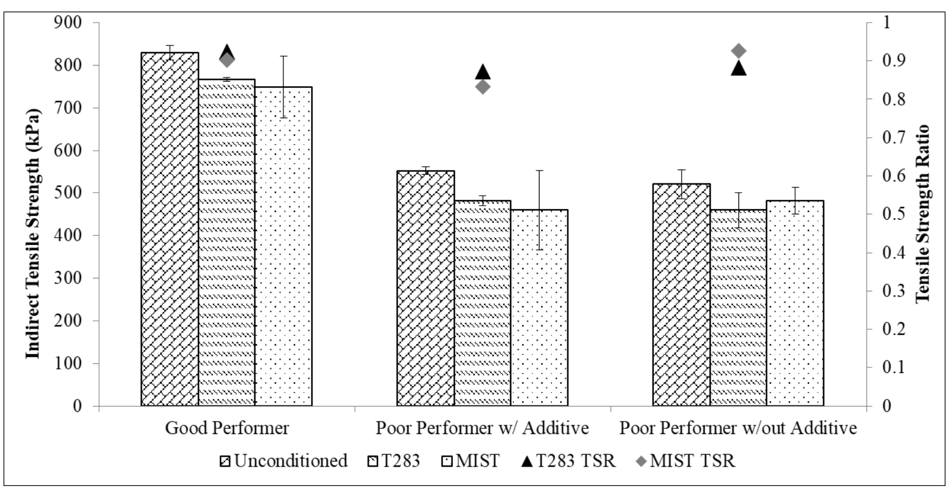

FIGURE 1: Indirect Tensile Strength Results

The dynamic modulus master curves (plotted at a reference temperature of 21.1°C) and dynamic modulus ratios for the three mixtures are shown in Figures 2. The MIST conditioning combined with dynamic modulus testing distinguishes the good and poor performing mixtures as a greater decrease in stiffness is observed in the poor mixtures. The DMR values also show differences between the two poor mixtures at low frequencies; suggesting that the additive may improve the mixture's moisture damage resistance.

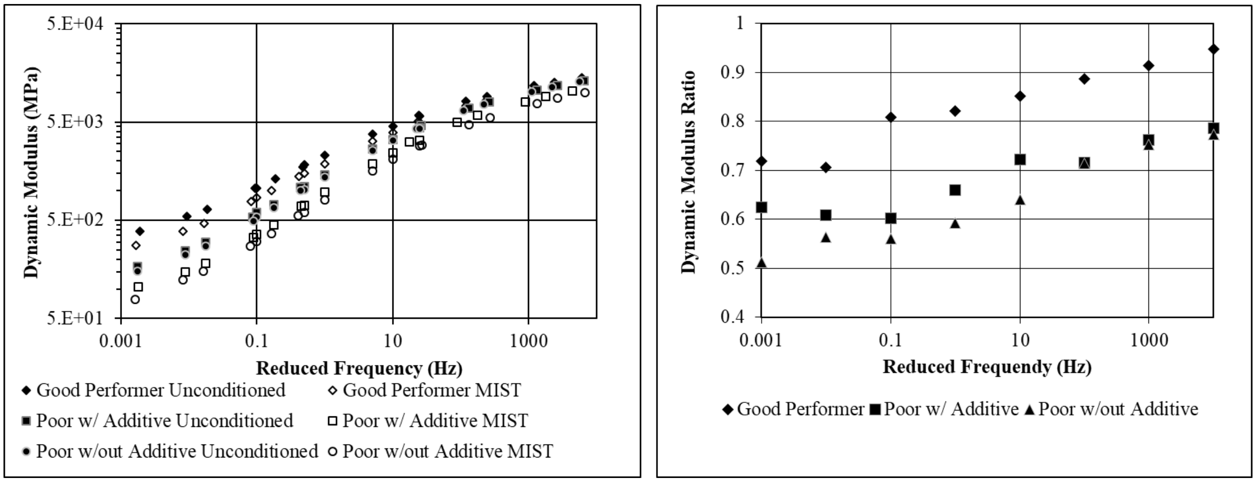

FIGURE 2: Dynamic Modulus Master Curves (reference temperature = 21.1°C) (left); Dynamic Modulus Ratio Results after MIST Conditioning (right)

Figure 3 shows the SATS test results. The SATS procedure was able to clearly distinguish the good performing mixture (which stayed above 0.80 retained stiffness) from the two poor performers (which never exceeded 0.65 retained stiffness). However, the procedure was not able to distinguish any difference due to the presence of the additive. The saturation levels for all specimens were similar, with the exception of the one that was submerged (corresponding to the points in the 80-90 percent range). This is likely due to the relatively low permeability of these dense graded surface mixtures as compared to the base materials for which the test was designed. Allowing more time for saturation to occur or increasing the conditioning time may produce a wider range of retained saturation values and will be investigated in future work.

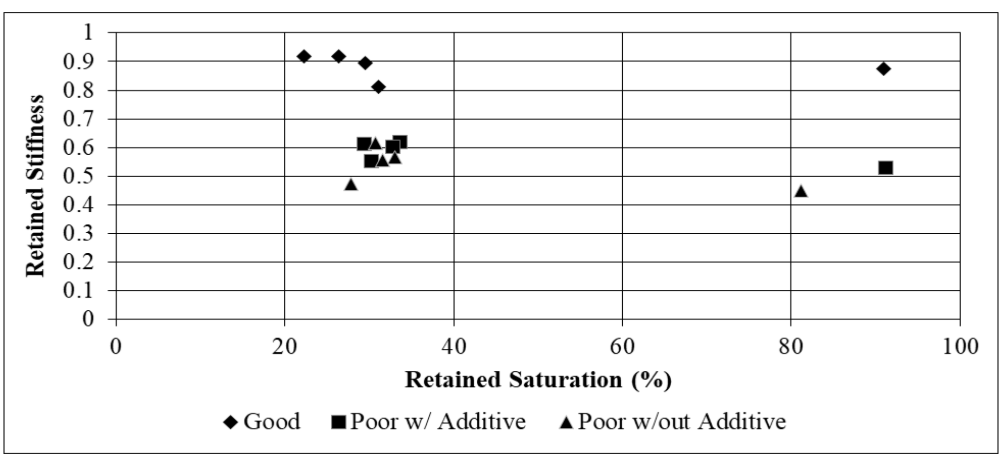

FIGURE 4: SATS Retained Stiffness Results

4. SUMMARY AND CONCLUSIONS

The primary goal of this study was to evaluate various laboratory moisture conditioning methods and mechanical tests in terms of their ability to distinguish good and poor performing mixtures. Three dense graded surface mixtures, two that historically have poor field performance and one that has good historical field performance, were evaluated. The indirect tensile strength with Lottman/AASHTO T-283 and MIST conditioning, dynamic modulus with MIST conditioning, and the SATS test procedure were performed. The testing results and analysis allow the following conclusions to be drawn.

- Indirect tensile strength ratio does not distinguish the good and poor performing mixtures in this study with either AASHTO T-283 or MIST conditioning.
- Stiffness measurements obtained via dynamic modulus testing paired with MIST conditioning or the SATS test effectively distinguished the good and poor performing mixtures evaluated in this study.
- None of the procedures evaluated were able to clearly distinguish the effect of the additive in the poor performing mixture. This could be due to the additive having a minor effect on performance or the inability of the procedures to distinguish small differences in performance.
- These results indicate that the dynamic modulus paired with MIST conditioning or SATS procedures hold promise as effective screening tools during mixture design and production.

5. FUTURE/ONGOING WORK

The results presented in this paper are part of a much larger study on moisture susceptibility of asphalt mixtures. The following points summarize the additional work that will be carried out in the future.

- Seven additional mixtures have been sampled (including good and poor performers with various additives) and are currently being tested in the same manner as the three presented here.
- Additional test procedures, such as the semi-circular bend test and the Hamburg wheel tracking test, as well as two additional conditioning procedures (multiple cycle freeze-thaw and a modified MIST) will be evaluated.
- Pavement life cycle analysis will be conducted to determine the life cycle impacts of good and poor performing mixtures.

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