PROPOSED APPROACH FOR EVALUATION OF COHESIVE AND ADHESIVE PROPERTIES OF ASPHALT MIXTURES FOR DETERMINATION OF MOISTURE SENSITIVITY

Dr. Andrew LaCroix
(Corresponding author)
InstroTek, Inc.
5908 Triangle Dr., Raleigh, NC 27617
Tel: 919-875-8371 Fax: 919-875-8328; Email: alacroix@instrotek.com

Mr. Ali Regimand
InstroTek, Inc.
5908 Triangle Dr., Raleigh, NC 27617
Tel: 919-875-8371 Fax: 919-875-8328; Email: aregimand@instrotek.com

Dr. Lawrence James
InstroTek, Inc.
5908 Triangle Dr., Raleigh, NC 27617
Tel: 919-875-8371 Fax: 919-875-8328; Email: ljames@instrotek.com

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ABSTRACT
Moisture damage to asphalt pavements continues to be a major concern after decades of research. Two of the most common moisture failure modes in asphalt mixtures are adhesive failures between the aggregate and binder and cohesive failures in the binder or mastic. The challenge in conditioning asphalt mixtures for moisture sensitivity is developing a test method that is capable of evaluating both adhesive and cohesive failure properties while remaining repeatable, accurate and practical. Currently, there are three methods for conditioning asphalt mixture for determination of moisture sensitivity: AASHTO T283, ASTM D4867and ASTM D7870. T283 is the most common method for evaluating moisture damage. The conditioning involves saturating, followed by freezing-thawing conditioning of specimens to induce pore pressure. D7870 is the moisture-induced stress test (MIST), which dynamically induces pore pressure into the specimen. In this study, both these conditioning methods were evaluated using a known moisture resistant mixture and known moisture sensitive mixture. The different conditioning methods were evaluated using the tensile strength ratio (TSR), change in density, and visual inspection. The results of this study show that the most effective method of conditioning to capture moisture sensitive mixtures is a combination of T283 and D7870. T283 accentuates adhesive failures while D7870 accentuates cohesive failure in the mixtures. The proposed conditioning method uses the MIST unit to effectively identify cohesive and adhesive moisture sensitive mixtures during mixture design and quality control of asphalt pavements.

Keywords: moisture damage, MIST, adhesion, cohesion, moisture conditioning

INTRODUCTION

Moisture damage is a complicated phenomenon since the term encompasses a variety of physical properties such as adhesive and cohesive failure. It is generally agreed that moisture damage, defined as the reduction in strength and durability of the mixture, is a result of two different mechanisms: 1) loss of adhesion between the binder and aggregate and 2) reduction of cohesion within the binder (*1-3*). Little and Jones (*4*) provide a list of mechanisms of stripping that include detachment, displacement, spontaneous emulsification, pore pressure-induced damage, hydraulic scour, pH instability, and climatic effects on the asphalt-aggregate system. Multiple theories exist to explain the mechanisms that occur during cohesive or adhesive failure. The conclusion is it is not easy to determine which mechanisms occur in a given mixture with moisture damage, but the overall result is a reduction in bond strength.

The challenge with evaluating moisture sensitivity in mixture design and quality control has been to find a laboratory test that is accurate, repeatable, and practical. The AASHTO T283 method (*5)* has been used for several decades with mixed results by many state highway agencies (38 of 55 use it for moisture damage testing) (*2*). The procedure generally identifies moisture sensitive specimens, but there are a number of cases where the test produced either a false positive, i.e., a mixture that passed the lab test but failed in the field, or false negative where the mixture failed the lab test but performed well in the field (*6*). Therefore, major concerns still exist about this test because the low repeatability and questionable accuracy in detecting moisture sensitive mixtures (*7*). The poor repeatability is seen in the precision estimates of 9% coefficient of variation (COV) for single-users and 25% for multi-lab users (*8*). The large multi-lab variability along with several operational steps such as saturation level and techniques used in the labs, time in the temperature bath and accuracy of the temperature bath are concerns for quality assurance testing. Therefore, a method is needed to reduce the variability between tests and evaluate the influence of moisture on both the adhesive and cohesive properties of asphalt mixtures.

A conditioning method that shows promise is a method that uses hydrostatic pore pressure to test the bonding within asphalt mixtures. Jimenez (*9*) used the concept to evaluate the effect of pore water pressure and saturation on debonding of asphalt mixtures. Jimenez initially vacuum saturated the specimens and then conditioned them by cycling the pore pressure at 10 Hz. He found that volume change induced by cyclically varying water pressure provided a good indication of moisture damage. Mallick et al., (*10*) developed Jimenez's concept into a self-contained conditioning system consisting of a pressure chamber that is pressurized using a bladder that is filled with air using a piston to generate hydrostatic pressure within the specimens submerged in water. The conditioning procedure is called the moisture-induced stress test (MIST) conditioning method, which is the basis of the ASTM D7870-13 standard (*11*). The goal of MIST conditioning is to simulate the repeated stresses developed in a saturated asphalt mixture by passing vehicle tires (*10*). This method has been evaluated by several researchers (*12-16*) and they found MIST conditioning enhanced identification of moisture sensitive mixtures.

Some studies have evaluated combining these two methods. Varveri et al., (*16*) state that moisture damage has both long and short time components. The long time component is the gradual saturation of a specimen that sits in water; this saturation allows water to diffuse into the mixture and can weaken the bonds between the aggregate and binder. The short-term damage occurs during cyclic pore pressure activated by a wheel passing over the pavement. Therefore, Varveri et al., soaked the specimens in hot water without vacuum saturation for up to 8 weeks and then performed MIST conditioning on them to evaluate the different components. The results show that these two components are relatively independent from each other. Based on the general consensus that adhesion and cohesion affect the moisture damage and the relative independence of these two behaviors/processes, this study proposes combining the AASHTO T283 conditioning protocol without freeze/thaw cycles (T283-M) with the ASTM D7870 (MIST) conditioning to evaluate adhesive and cohesive failures. The conditioning method proposed in this paper combines the strengths of both conditioning methods such that adhesive and cohesive failures in a mixture are detected before placement in the field.

PURPOSE

The goal of this study is to present a conditioning and testing method that captures the effects of moisture on both the adhesive and cohesive properties of asphalt mixtures. The benefits of an improved method would be capturing more mixtures that demonstrate moisture sensitivity while reducing the variability between tests due to differences in operators performing the procedure.

EXPERIMENTAL PLAN

The experimental plan consists of testing a mixture that has a known history of stripping problems (bad mixture) and comparing the results with the same mixture with improved performance because of a liquid antistrip additive (good mixture). This comparison provides an evaluation of whether different moisture conditioning methods can differentiate between good and bad mixtures. The mixture will be conditioned by several different procedures described in this paper. In this study, different conditioning methods were evaluated side-by-side using visual inspection, tensile strength ratio (TSR), and change in density.

Materials and Specimen Fabrication

For a majority of the testing, a mixture with a known history of moisture sensitivity was used. The mixture was a 19 mm dense-graded mixture composed of granite sourced in central North Carolina. The mixture had 5.2% asphalt content by weight of the total mixture. The binder graded as a PG 64-22. The specimens were lab-prepared and lab-compacted using a gyratory compactor. The specimens used in the testing were standard sized specimens with a height of 95.0 mm and a diameter of 150.0 mm. Four specimens were tested for each moisture conditioning case: dry, T283, D7870, and proposed method. The mixture was prepared with and without antistrip. The antistrip used was a surfactant-based additive at a dosage of 0.5% weight of the binder. Other mixtures were used to verify the results of the reference mixture. The specimens were cured for at least two weeks at room temperature to reduce variability between specimens since all the moisture conditioning methods could not be performed at the same time.

Testing Procedure

Moisture Conditioning

As previously mentioned, the most common method for conditioning specimens to evaluate moisture damage is AASHTO T283. The method involves compacting specimens to 7.0 ± 0.5% air voids, saturating the specimens between 70 and 80% complete saturation, freezing the specimens for at least 16 hours, and soaking the specimens in a hot water bath (like Figure 1(a)) at 60°C for 24.0 ± 1.0 hours. In this study, the AASHTO T283 method (hereafter referred to as freeze-thaw (F-T)) was performed).

Another method, used by some highway agencies, utilizes the F-T protocol but excludes the optional freeze portion of the testing. For this study, this method will be referred to as the T283-M (modified) conditioning since the specimens are saturated between 70 and 80% and immediately placed in the hot water bath without freezing beforehand. This method is used in some states because the NCHRP 444 report showed that there was no significant difference in the TSR results between the F-T and soak conditionings for 18 of 20 mixtures (*6*). This result appears to contradict the theory proposed by Lottman that the freezing/thawing of the water was designed to induce pore pressure. Note that T283 was never intended to simulate F-T cycles experienced in colder climates.

A third conditioning method is MIST conditioning (ASTM D7870). The goal of MIST conditioning is to simulate the stresses developed in a saturated asphalt mixture by a passing vehicle tire (*10*). The MIST device (Figure 1(b)) works by generating hydrostatic pressure in a chamber with a specimen submerged in water. The water temperature is elevated to 60°C to accelerate the conditioning process. The specimens are subjected to 3500 cycles of pressurization with a half peak width of approximately 1 second at 276 kPa (40 psi). The pressure is generated using a bladder that is cyclically filled with air using an air piston driven by a hydraulic actuator that generates hydrostatic pressure within the specimen submerged in water. The specimens are not saturated beforehand but are allowed to reach a saturation that depends on the surface- and inter-connected voids of the specimens. This step removes the variability that occurs during the vacuum saturation process of T283 in which the saturation depends on a subjective SSD weight to determine if the specimen is within the range of 70 to 80 percent saturation; in the MIST conditioning, the saturation reaches a natural saturation because of the permeable voids of the specimen. After the specimens are placed in the chamber, the operator starts the MIST program and it runs automatically for approximately 4 hours. Once the test is done, the machine automatically drains the water from the tank to prevent excessive time in the hot water, which may further reduce the strength of the mixture.

FIGURE 1 Equipment used for (a) T283-M and F-T conditioning; (b) MIST and proposed conditioning; and (c) test frame for testing indirect strength of asphalt mixtures.

Strength Testing

According to the AASHTO T283 standard, the specimens are tested in the indirect tensile (IDT) mode at a constant actuator displacement of 50.8 mm/minute (2.00 inches/minute) using a load frame (Figure 1(c)) after moisture conditioning in a water bath at 25°C (77°F) for 2 hours. The peak load was measured using the load frame software. After testing, visual stripping of the specimens is evaluated. The visual stripping evaluation is based on a scale of none/minor, moderate, and severe.

RESULTS

The results of this study will show that it is important to evaluate both adhesive and cohesive properties when determining if a mixture is moisture susceptible. The most effective method of conditioning for moisture sensitivity is to incorporate elements of both AASHTO T283 and ASTM D7870. The proposed conditioning method, which was developed based on this research, uses the combination of these two established moisture conditioning methods in the MIST unit to effectively identify a moisture sensitive mixture during design and quality control of asphalt mixtures. These conclusions are based on evaluating the test specimens in three categories, visual observations, TSR, and density change, and comparing the results of the samples without antistrip to the samples with antistrip.

Visual Observations

Loss of adhesion is evaluated visually. The AASTHO T283 standard requires a visual observation of the fractured surface and a rating of the visual stripping. Figure 2(a) and (b) shows the results for T283-M saturated specimens with and without antistrip, respectively. Figure 2(a) shows minimal visual stripping. Figure 2(b) shows that the mixture without antistrip experienced severe stripping, which means antistrip was effective at reducing visual stripping. In Figure 2(c) and (d), the visual results for MIST specimens show that there is not much difference with or without antistrip. When comparing the specimens without antistrip from the T283-M and MIST conditioning, Figure 2(b) and Figure 2(d), respectively, the stripping is much less severe for Figure 2(d), yet both specimens fail; the TSR for both set of specimens is less than 85%, which is the local state highway agency TSR failure criterion for this mixture. The visual difference strongly indicates that different mechanisms are activated by the MIST and T283-M conditionings. Adhesion is the separation of the binder and aggregate, which is easily seen in Figure 2(b) for the saturated specimens as bare aggregates. Therefore, extended soaking for 24 hours accentuates the damage to the adhesive strength of the binder-aggregate interface. The reduced stripping for the MIST specimens (Figure 2(d)) suggests that the conditioning time in the MIST conditioning may not be long enough to fully activate adhesion. Since the reduced strength is not caused by adhesive failure, the other option is cohesive failure. On closer examination, the smaller aggregates and mastic have stripped. This suggests that the MIST conditioning caused cohesive damage in the binder and failure in the mastic, which has a much higher percentage of binder than the whole mixture. This idea is strengthened by the observation that the MIST conditioning reduces the strength for specimens with antistrip even though the antistrip completely removes the adhesive problems (as seen in the TSR values listed in Figure 3(a) for the proposed method). This observation supports the conclusion of Little and Jones *(4)* that it is necessary to consider both adhesive and cohesive failure. They report that failures of thin and thick asphalt films are controlled by adhesive and cohesive failures, respectively. Since mixtures have a combination of both thick and thin films, it is necessary to test both conditions.

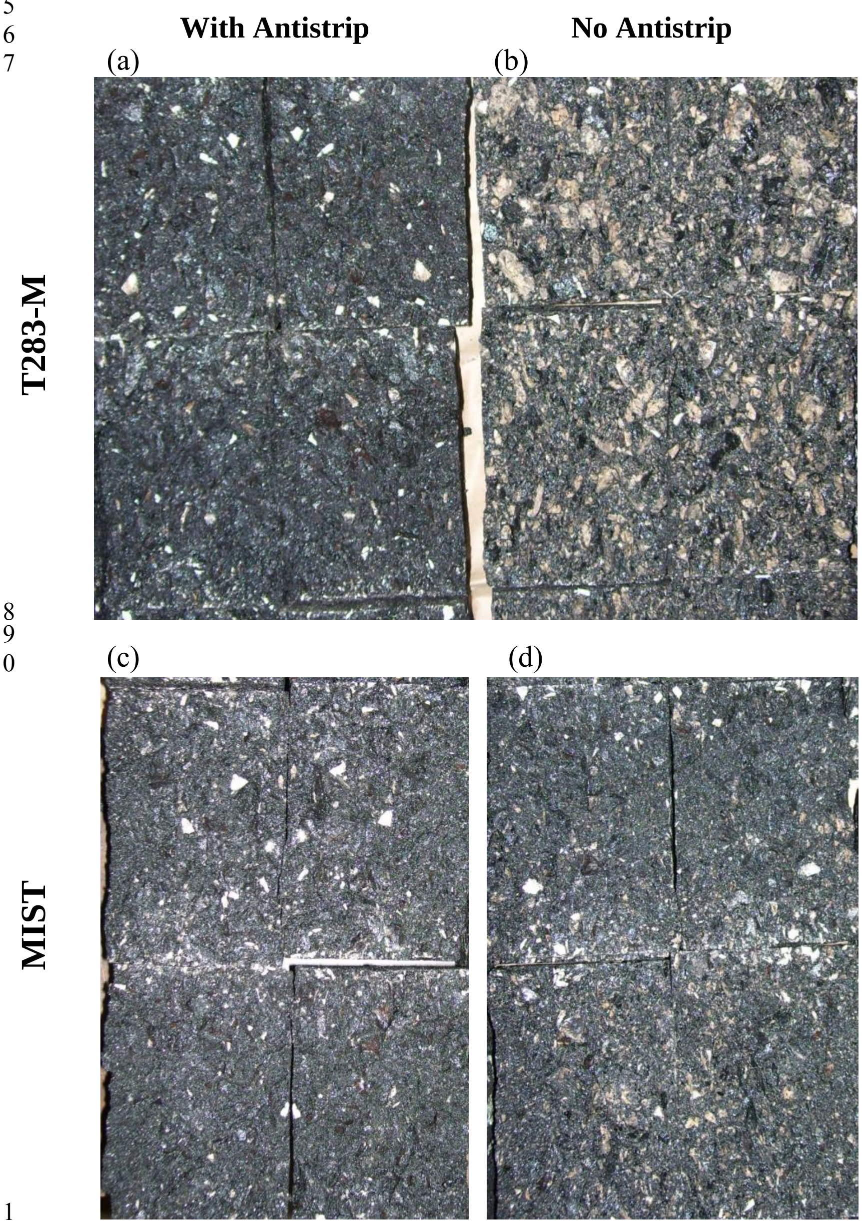

FIGURE 2 Pictures of specimens: T283-M-conditioned (a) with and (b) without antistrip and MIST-conditioned (c) with and (d) without antistrip after TSR testing.

Tensile Strength Ratio (TSR)

The TSR is the most common method for evaluating moisture damage. An advantage of using TSR is the ratio normalizes the results for different mixtures. A potential disadvantage is variability is reported to be a problem with indirect strength tests (*7, 8*) though results below suggest that TSR variability is generally less than 5%.

Conditioning Method

The TSR results from the reference mixture are shown in Figure 3(a). For all the conditions, the specimens without antistrip had much lower TSRs than the specimens with antistrip. This shows that antistrip benefits the tensile strength of this mixture significantly. The T283-M and F-T specimens with antistrip had TSR values greater than 100%. A possible explanation is the 24 hours soaking in the hot water stiffens the binder (after the initial 2 week wait period before testing) and thereby the mixture. For the same conditions without antistrip, the strength decreased more than 40 percentage points. The reduction in strength during the T283-M conditioning must be caused by a chemical process because no other mechanical dynamic is involved except forcing water into the specimen during vacuum saturation. It appears that chemical interaction of the antistrip with the aggregate and binder improves the adhesion. The TSR values from T283-M and F-T specimens confirm the results from the NCHRP 444 report (*6*) that the difference between these two methods is negligible based on a t-test with 95% reliability. All three MIST conditions have similar TSRs of approximately 90% for the specimens with antistrip in comparison to greater than 100% for T283-M. The results with MIST and the proposed conditioning show that application of pore pressure to the specimen promotes a different damage mechanism, i.e., cohesion, because there is a change in the TSR even though the antistrip addressed the adhesion problem based on visual observations. These observations concur with results presented by Varveri et al. (*16*) that soaking and cyclic pore pressure activate different mechanisms.

The effect of combining T283-M and MIST conditioning or the proposed conditioning can be seen in Figure 3(a). The proposed conditioning TSR appears to be the summation of the effects from MIST and T283-M conditioning. For the specimens with antistrip, the average of the two saturation conditions (T283-M and F/T) is approximately 100%. The MIST conditioning reduces the strength by approximately 10 percentage points. The proposed conditioning also has a strength reduction of 10 percentage points. For the specimens without antistrip, the reduction from the T283-M conditioning is approximately 40 percentage points. The reduction due to the MIST conditioning is approximately 25 percentage points. The combined reduction of these two conditionings is 65 percentage points, close to the value for the proposed conditioning, which has a reduction of approximately 60 percentage points. This result agrees with the results presented in other studies in which the effect of MIST conditioning was generally a constant reduction in strength regardless the time of soaking (*16*). Therefore, the two different conditioning methods appear to capture damage from extended soaking that accentuates adhesive failure (chemical) and damage from pore pressure (mechanical) that can occur in asphalt mixtures due to the presence of water and traffic loading.

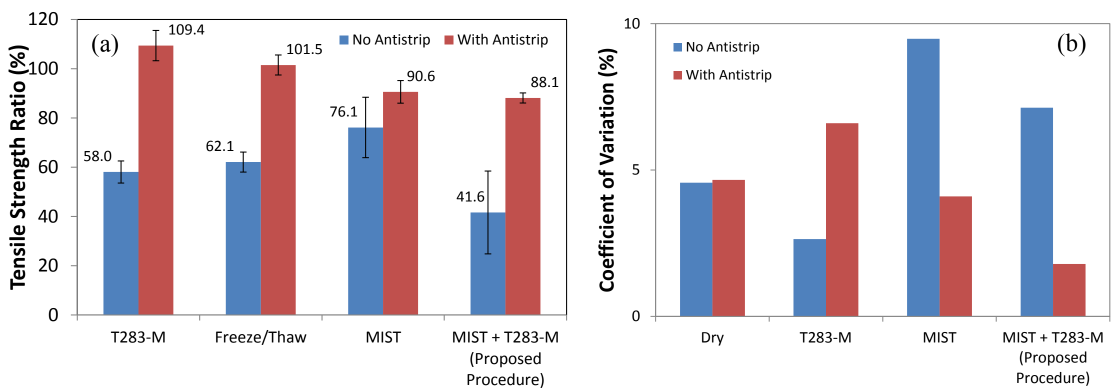

FIGURE 3 (a) TSR and (b) coefficient of variation (COV) results for the reference mixture with and without antistrip for different moisture conditioning procedures.

Figure 3(b) shows the coefficient of variation (COV) of specimens for different conditions. The COV was calculated by dividing the standard deviation for a given conditioning method by the dry strength to normalize the standard deviation. The specimens that have antistrip generally have a lower COV. For the specimens without antistrip, the COV varies more. The COV for the saturated specimens is relatively low (5%), lower than the 9% reported by Azari (*8*), while the MIST variability is high (~10%), which is mostly sample related. The increased variability is because MIST conditioning forces water into the open pores through repeated pressurization cycles, which for an unstable mixture like the mix without the antistrip would result in a change in volume and increased variability in tensile strength. The variability in this bad mix is not caused by the indirect tensile strength test. In fact, the COV for TSR values for good mixes for this study is approximately 5%, which we believe is very good for any type of cracking/splitting test. The repeated pore pressure breaks the bond between the weakened aggregate particles causing an increase in sample volume. Depending on the accessibility of air voids to water, the damage to the sample can be more or less severe, which is an advantage of dynamically conditioning the mixture because damage ultimately affects the strength.

Conditioning Time

In Figure 3(a), solely saturating the specimen and soaking it in a water bath produces a greater drop in strength than the MIST conditioning for specimens without antistrip (i.e. T283-M vs. MIST). This difference is because the loss in adhesive strength is a chemical process, instead of a mechanical process. The biggest challenge to understanding whether cohesion or adhesion is responsible for a reduction in strength is separating the effects of repeated pore pressure (MIST) from the soaking in hot water since both conditioning methods are performed in water at the same temperature (60°C) for different lengths of time (4 or 24 hours, respectively). To evaluate the effect of conditioning time, a small study was performed by saturating and testing specimens at different times in a 60°C water bath. Two specimens were tested for each condition. The mixture is the reference mixture without antistrip except the binder source changed because a limited availability of resources. The TSR was 76.3, 71.6, 66.6, and 64.8 after 4, 8, 12, and 24 hours soaking, which shows that the TSR decreases as the soaking time increases. The TSR decreased by 10 percentage points when the soaking was increased from 4 to 24 hours. The MIST conditioning TSR was 61.3, so the TSR was reduced by 15 percentage points when comparing MIST and 4 hour soaking, which shows that the MIST is causing additional damage to the specimen besides the chemical reaction that occurs in the hot water for the same amount of time. T283-M for 24 hours and MIST at 4 hours resulted in similar reductions in strength for this mixture, but the visual stripping did not occur until 24 hours of soaking. The TSR and visual results suggest that the specimens should be soaked 24 hours to achieve results consistent with the results reported in AASHTO T283.

Change in Density (Swell)

To further evaluate the performance of the two conditioning methods, the change in density is evaluated. In the MIST operation manual (*17*), 1.5% change in density after conditioning is used to delineate good and bad mixes. According to a study by Schramm and Williams (*15*), the swell or change in air voids is one of the best ways to predict whether a mixture is moisture sensitive. For this study, the swell will be defined as the percentage change in density, calculated in this study by the following equation:

$$\Delta Density\ (\%) = \frac{Gmb_{inital} - Gmb_{final}}{Gmb_{initial}} * 100$$

Change in density is preferable to change in air voids because the relative range of the denominator is smaller when using density compared to air voids, which can range from 2 – 10+ % for field cores. The density of the specimens was determined using the SSD method (AASHTO T166) since the mixture was a dense-graded mixture and had air voids less than 8%. The dry, submerged, and SSD weights were measured for the specimens. These measurements allow for calculating the volume and density of the specimens as follows:

$$Volume\ (cm^3) = SSD\ Weight - Submerged\ Weight$$

$$Density\ (g/cm^3) = \frac{Dry\ Weight}{Volume}$$

The submerged and SSD weights of the specimens were measured after moisture conditioning to determine the change in density. The volume measurements were confirmed by measuring the diameter and thickness of the specimens to calculate the volume before and after conditioning.

The results for the average density change for different conditionings are displayed in Figure 4. The change in densities ranges from slightly negative numbers, because of consolidation or losing some small pieces of specimens during handling, to greater than 3.0%. Both the saturated and F-T specimens have a volume change less than 0.5% because there is no cyclic pore pressure to open up the structure. The F-T specimens actually had lower volume changes even though the freeze cycle was intended to create pore pressure. Most of the MIST conditioned specimens are greater than 1.5% without antistrip but less than 1.0% with antistrip, which confirms the recommended threshold of 1.5% to distinguish moisture sensitive mixtures. This result also shows the benefit of antistrip for this mixture by strengthening and reducing the density change below the recommended criterion.

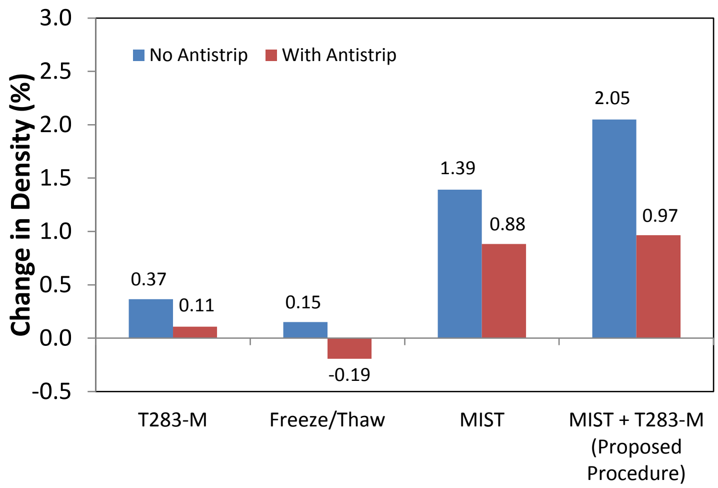

FIGURE 4 Average percent density change versus peak strength for specimens (a) without and (b) with antistrip.

PROPOSED CONDITIONING AND EVALUATION PROTOCOL

The proceeding results of this study show the necessity of incorporating elements of both AASHTO T283 and ASTM D7870 to accurately characterize moisture sensitivity for asphalt mixtures. Using different approaches with reference mixtures showed that AASHTO T283 accentuates adhesive failures while ASTM D7870 accentuates cohesive failure in the mixtures. To evaluate moisture sensitivity of asphalt mixtures, two main steps are necessary: conditioning the specimen and evaluating the specimens. The proposed method is shown in Figure 5. The proposed moisture conditioning is performed in the MIST to simulate cyclic pressure from a passing wheel and maintain the testing temperature for an additional 20 hours to activate the chemical process that causes stripping. The first portion of the conditioning is the MIST conditioning described in ASTM D7870. Then, the specimens continue to soak in hot water an additional 20 hours such that the total soaking time at 60°C is 24 hours. The two main benefits of this test are consistency in the testing process across different labs and improved accuracy in identifying moisture sensitive mixtures. The consistency is improved because the specimen does not have to be saturated manually, which will ensure that specimens will reach a percent saturation during the MIST portion of the test that is representative of the permeable structure of the mixture. Also, the specimens are conditioned for the same length of time, which further improves consistency. The current AASHTO T283 standard requires 24 ± 1 hours of soaking, while the MIST device can drain the water after the same amount of soaking time every time. Given that visual stripping can change after just a few hours in the hot water for sensitive mixtures, this consistency is important.

AASHTO T283 has two criteria for determining whether a specimen is moisture sensitive: tensile strength ratio and visual inspection. The proposed method has an additional criterion of percent change in density. Visual inspection is a good method for evaluating adhesion. Percent change in density is a good method for evaluating the cohesion and stability of the mixture. These two effects are combined and affect the strength of the mixture in the pavement, so they should be evaluated in the mixture before placement. Even though TSR has been reported to have high variability, from this study it appears that mixture instability due to moisture sensitivity caused more variability than the strength evaluation. A mixture is considered moisture resistant if it passes 2 of 3 criteria. Another advantage of 3 criteria is the ability to interpret whether the problem is an adhesive or cohesion problem. If visual stripping is observed, then the adhesive problem should be addressed using different additives appropriate for the aggregate and aggregate structure in the mix. If the mixture has little to no visual stripping but the TSR is low, the cause could be a cohesive problem, which means the issue may be with the binder.

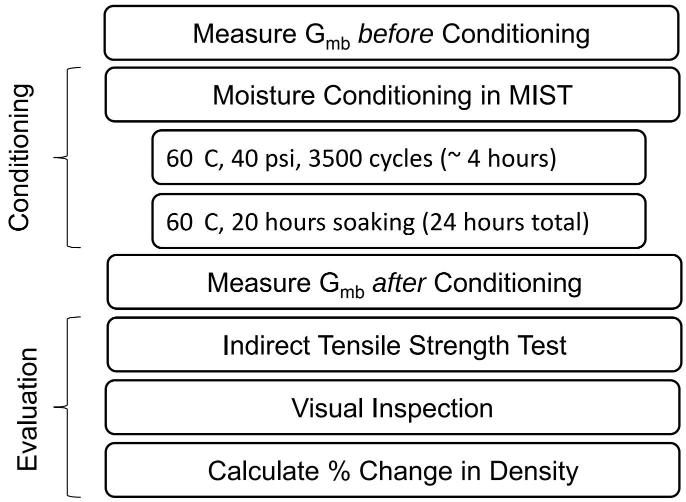

FIGURE 5 Proposed conditioning and evaluation procedure to evaluate moisture sensitivity of asphalt mixtures.

Verification of Proposed Protocol

In Table 1, the TSR results for T283-M and the proposed moisture conditioning methods for multiple mixtures are presented as a verification of the proposed conditioning method. The density change is the average density change for the specimens. The reference mixture is described in the Materials and Specimen Fabrication section. The other mixtures are a variety of mixtures sampled by the North Carolina Department of Transportation (NCDOT) for a variety of traffic levels. The mixtures labeled ‘Surface’, ‘Intermediate’, and ‘Base’ were field mixed, lab compacted mixtures with 9.5, 19, and 25 mm nominal maximum sized aggregates, respectively. The highlighted cells indicate a failing result. As discussed before, the reference mixture without antistrip fails all three criteria (listed below Table 1), but passes all criteria with antistrip. For most of the mixtures, whether the specimens were conditioned with the proposed method or T283-M, the pass/fail status of the mixture was the same.

There are several cases that demonstrate the benefit of the proposed method for identifying whether the moisture sensitivity is a function of cohesion or adhesion. Surface 1 may pass the TSR test after the T283-M conditioning because it is close to the 85% threshold with no visual stripping, but fail the proposed conditioning test because of a lower TSR value and higher percent density change. This result indicates that the cohesive properties are an important component of the moisture susceptibility for this mixture. Conversely, the Intermediate 1 mixture has similar failing TSR values for T283-M and the proposed method. When only the MIST conditioning was performed, the TSR value was 84%, a potentially passing mixture because of minimal visual stripping and no density change. This is a case in which adhesion was the dominant problem, so the 24 hours soaking was important. Other mixtures have similar results between the proposed and T283-M conditioning tests and low density changes; therefore, they are sensitive to adhesive properties because the added cyclic pressure does not change the TSR. The Surface-2 and Surface-2-retest are the same mixture sampled at different times because the initial sample failed the 85% TSR criterion. For the Surface 2 mixture, it failed all the criteria, but passed when resampled. Since the mixture design and aggregate source did not change, the binder and/or additives probably affected the mixture behavior. This significant change in strength may suggest the need to test more frequently since binder sources change frequently, especially when purchased on the spot market. Intermediate 4 and its retest show small changes in the TSR with a small density change both times, which indicates the mixture had a minor adhesion problem that was improved during the second sampling.

Since the proposed method incorporates both cohesion and adhesion, the TSR threshold may need to be changed to 80% to account for the extra damage. For Intermediate 3 and 5, the mixture passed the T283-M, but failed the proposed method TSR value. If the TSR criterion was 80%, the results would be consistent with T283-M. Even if the TSR threshold is relaxed, moisture sensitive mixtures will be limited because of the density change criterion. For example, the percent density change for the Surface 2-Retest was greatly reduced, which shows the mixture is more moisture resistant than before. In another case, the proposed method seems to improve the TSR of the Intermediate 2 mixture. In this case, the cyclic pressure may help consolidate the specimen. Overall, a modification of the TSR threshold is worth considering.

Based on the dataset in Table 1 for a variety of mixtures, if the T283-M conditioning method is performed instead of the proposed conditioning, the error rate would be 3 out of 11 or 27%. Therefore, approximately 18% of the mixes tested by the T283-M conditioning methods could potentially pass yet fail in the field because cohesion was not evaluated (Intermediate 3 and 5) and another 9% fail in the lab and pass in the field (Intermediate 2). Using the proposed conditioning method provides additional information about a mixture beyond what is available in T283. Using the density change value provides guidance whether the mixture has a stability and/or cohesion problem. If the density change is below 1.5%, most of the reduction in strength can be contributed to adhesion. This provides guidance on whether antistrip or different binder and aggregate sources are necessary to reduce the moisture sensitivity.

Table 1 TSR Results for Lab-Produced and Field-Produced Mixtures

Mixture	T283-M	Proposed Conditioning	Density Change	Visual
Reference - No Antistrip	58.0	41.6	2.05	Severe
Reference – Antistrip	109.4	88.1	0.97	Minor
Surface – 1	84.3	72.5	1.13	Minor
Surface – 2	69.9	40.5	3.30	N/A
Surface - 2 – Retest	90.5	87.2	0.45	Minor
Surface – 3	87.5	96.4	-0.11	Minor
Intermediate – 1	71.9	74.9	0.55	Minor
Intermediate – 2	82.2	86.8	-0.03	Minor
Intermediate – 3	92.5	81.8	0.15	Minor
Intermediate – 4	77.6	69.4	0.88	Minor
Intermediate - 4 – Retest	84.3	81.1	0.16	Minor
Intermediate – 5	86.6	81.2	0.00	Minor
Base – 1	76.7	68.2	-0.04	Minor

Passing Criteria: TSR > 85%, Density Change < 1.5%, and Visual – Minor/None.

CONCLUSIONS

Moisture damage is a complicated phenomenon since the term encompasses a variety of physical properties that can be observed as adhesive and cohesive failures. The challenge has been to find a laboratory test that is accurate, repeatable, and practical. The AASHTO T283 method has been used for several decades with mixed results with problems that are well documented. Based on the results of this research, it appears that AASHTO T283 performs well for determination of adhesive failure of the mixture, while ASTM D7870 (MIST) protocol captures cohesive failures. The proposed conditioning method combines the strengths of both conditioning methods such that adhesive and cohesive failures in the field are prevented. The following conclusions can be drawn from the results in this study:

1. The current AASHTO T283 protocol, which involves saturating and soaking specimens in hot water, affects the adhesive strength of the binder to the aggregate. This is proven by visual observations of severe stripping that corresponds to a significant decrease in the strength.
2. ASTM D7870 conditioning primarily affects the cohesive strength of the mixture as shown by the reference mixture with antistrip having no reduction in strength or visual stripping for T283-M, but a 10 percent point reduction in strength with the D7870 conditioning, which is attributed to a reduction in the cohesive strength component.
3. Combining the T283-M and D7870 conditioning methods together in the MIST unit ensures that both adhesion and cohesion properties are tested for moisture susceptibility. Based on the dataset in this study, the new method would fail approximately 20% of the mixtures that would have otherwise passed if only the T283-M conditioning method was used and the TSR criterion is not adjusted.

4. Variability is an indicator of mixture structural integrity. When the reference mixture had antistrip, the COV in TSR was less than 5% for the new combined conditioning testing, but increased up to 10% when the antistrip was not included. This shows that for the samples used in this study, antistrip improves the adhesive properties and structural integrity of the mixture. Further testing should be performed to determine this variability for other mixtures.
5. Density change, along with the TSR, is an important way to distinguish mixtures that are moisture susceptible. Density change is a good indicator of the structural integrity and if it has been disturbed. The recommended criterion of 1.5% change in density was confirmed. It is determined that mixes with a change greater than 1.5% in density have weak cohesive bonding and should be evaluated and modified to ensure mixture stability in the field. D7870 conditioning is necessary to determine density change.

Based on these conclusions, the new conditioning method (D7870 and extended soak) should be used to ensure mixtures are not moisture susceptible. ASTM D7870 is being modified to incorporate the additional soaking time and evaluation method. This would reduce the chance of poor mixtures being used on roadways. For additional reliability, it may be prudent for state highway agencies to consider using a minimum wet tensile strength as an additional criterion to prevent utilization of moisture sensitive mixtures.

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