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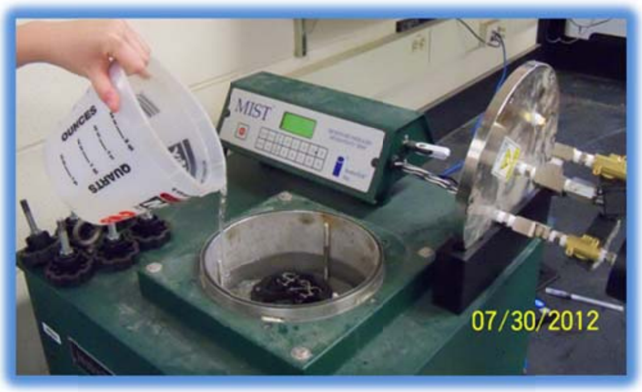

Technical Report 12-08

USE OF MOISTURE INDUCED STRESS TESTING TO EVALUATE STRIPPING POTENTIAL OF HOT MIX ASPHALT (HMA)

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16. Abstract (Limit 200 words)

Stripping of hot mix asphalt (HMA) in the field is an ongoing issue for many Departments of Transportation (DOTs). A leading cause of stripping is hydraulic scouring. The Moisture Induced Stress Tester (MIST) is a recently developed technology that applies alternating pressure and vacuum cycles to submerged asphalt samples to mimic hydraulic scouring. The objective of this study was to differentiate six HMA mixes used by Maine DOT in terms of their moisture susceptibility using the latest MIST technology and field cores. Half of the field cores were conditioned in the MIST. Before and after conditioning visual observations were made, and the bulk specific gravity and resilient modulus were determined using the CoreLok and ASTM D4123, respectively. All conditioned and unconditioned samples were tested for indirect tensile strength (ITS) in accordance with ASTM D 6931. Values from before and after conditioning were compared by HMA mix. It was determined that the MIST conditioning process does cause moisture damage to the samples in a manner that mimics hydraulic scouring. It is recommended that further research be carried out to investigate the effect of the MIST on HMA cores, and that parameters be developed for characterizing the results of the MIST conditioning process. These results would also help in the development of standard specifications for the use of MIST.

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USE OF MOISTURE INDUCED STRESS TESTING TO EVALUATE STRIPPING POTENTIAL OF HOT MIX ASPHALT (HMA)

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USE OF MOISTURE INDUCED STRESS TESTING TO EVALUATE STRIPPING POTENTIAL OF HOT MIX ASPHALT (HMA)

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ABSTRACT

Stripping of hot mix asphalt (HMA) in the field is an ongoing issue for many Departments of Transportation (DOTs). A leading cause of stripping is hydraulic scouring. The Moisture Induced Stress Tester (MIST) is a recently developed technology that applies alternating pressure and vacuum cycles to submerged asphalt samples to mimic hydraulic scouring. The objective of this study was to differentiate six HMA mixes used by Maine DOT in terms of their moisture susceptibility using the latest MIST technology and field cores. Half of the field cores were conditioned in the MIST. Before and after conditioning visual observations were made, and the bulk specific gravity and resilient modulus were determined using the CoreLok and ASTM D4123, respectively. All conditioned and unconditioned samples were tested for indirect tensile strength (ITS) in accordance with ASTM D 6931. Values from before and after conditioning were compared by HMA mix. It was determined that the MIST conditioning process does cause moisture damage to the samples in a manner that mimics hydraulic scouring. It is recommended that further research be carried out to investigate the effect of the MIST on HMA cores, and that parameters be developed for characterizing the results of the MIST conditioning process. These results would also help in the development of standard specifications for the use of MIST.

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USE OF MOISTURE INDUCED STRESS TESTING TO EVALUATE STRIPPING POTENTIAL OF HOT MIX ASPHALT (HMA)

INTRODUCTION

Stripping of Hot Mix Asphalt (HMA) mixes is a widespread problem. The Maine Department of Transportation (MDOT) has been observing aggregate loss at various project sites in the state of Maine and is investigating causes and methods to detect moisture-susceptible HMA mixes in the laboratory.

Different methods have been used to determine the moisture susceptibility of mixes. In the AASHTO T283 method, the tensile strength ratio (TSR) of unconditioned and conditioned (freeze-thaw, for example) is used to determine the moisture susceptibility of the mixes. Another method is the Hamburg Wheel Tracking Test (HWT), in which HMA samples are placed in a water bath and a steel wheel makes a specified number of passes over the samples and the resulting rut depth is measured.

Hydraulic scouring, the effect caused by repeated generation of pore water pressure due to traffic loading, is considered to be the leading cause of stripping in asphalt paving mixes (*1*).

In an effort to address this issue, the Moisture Induced Stress Tester (MIST) has been developed (*1*). The MIST is used to condition compacted HMA samples and determine the moisture susceptibility of mixes. It uses a hydraulic system to create alternative pressure and vacuum cycles inside the test chamber of the equipment, thereby forcing water into and out of the pores of the HMA sample. This process is intended to mimic the effect of hydraulic scouring (*1*). Preconditioned values for bulk specific gravity and indirect tensile strength (ITS) of compacted samples as well as visual inspection of the sample can be compared with post-conditioned values to determine the susceptibility of the HMA mix.

A study by Huang and Chen (*2*) used the previous version of the MIST to condition laboratory compacted samples with and without anti-strip additives and with various gradations. They compared results from the MIST with those from traditional freeze-thaw conditioning, and determined that the MIST is effective to determine the moisture-susceptibility of HMA mixes in the laboratory.

OBJECTIVE

The objective of this study was to utilize the concept of moisture induced stress testing to differentiate six HMA mixes that are used by Maine DOT, in terms of their moisture susceptibility. Field cores, and the latest model of the MIST equipment were utilized in this study.

SCOPE

Eight field cores were provided from each of the six different project locations by MDOT. Four samples from each set were used as control samples for the indirect tensile strength test. The other four samples from each set were conditioned in the MIST. Each sample was visually inspected before and after conditioning. The bulk specific gravity of each sample was determined before and after conditioning using the CoreLok method. The resilient modulus was determined before and after conditioning according to ASTM D 4123. The indirect tensile strength was determined according to ASTM D 6931. The visual observations, bulk specific gravity, resilient modulus and indirect tensile strength were compared for each project location to determine the effect of the MIST.

MATERIALS AND METHODS

Samples

Samples for MIST testing were provided by the Maine Department of Transportation (MDOT). The samples were four-inch field cores taken from six different projects throughout the state. At each site four cores were taken from each side of the roadway. As indicated in Table 1, the cores had been present in the field for varying lengths of time, and the projects were either overlays, mill and fill, or full construction. Additionally, each project had different aggregate and asphalt binder sources and PG grades.

TABLE 1 Properties of Field Cores Provided by MDOT

Project Name	Aggregate Source	Asphalt Source	PG Grade	Construction Type	Age at Coring, days
Abbot-Monson	Sidney Quarry-Sidney (9.5/washed stone)	Refiner-Irving-St John, Canada	64-28	Overlay	461
	Gerrish Pit-Milo (washed sand)				
	Davis-Glidden Pit-Sangerville (sand)	Supplier-Irving Oil Corporation-Searsport			
	RAP-various locations				
Dover-Foxcroft	Odlin Rd Quarry-Hermon Quarry-Bangor (12.5/9.5 minus/washed ledge sand)	Refiner-Irving-St John, Canada	64-28	Mill & Fill	454
	Presque Isle Quarry-Presque Isle (12.5)				
	Stockton Springs Pit-Stockton Springs (sand)	Supplier-Irving Oil Corporation-S Portland			
	RAP-various locations				
Ellsworth	MacQuinn Quarry-Hancock (19.0/12.5/9.5/crushed sand)	Refiner-United-Warren, PA	58-28	Reconstruction	439
	Camber Pit- Ellsworth (sand)				
	RAP-various locations	Supplier-Downeast Emulsions-Bangor			

Harrison	Pike Quarry-Poland (9.5/dry stone screenings/washed stone screenings) Porthland S & G Pit (sand)	Refiner-Bitumar-Montreal, Canada Supplier-Irving-St John, Canada	64-28	Overlay	535
Turner	Christian Hill Quarry (aka airport)-Auburn (1/2 stone/ 3/8 stone) Gracelawn/Christain-Auburn (dust/sand blend)	Refiner-Nustar-Paulsboro, NJ Supplier-Pike Industries-Newington, NH	64-28	Reconstruction	459
South Portland	Brickyard Quarry-Gorham (12.5/9.5) I Pit-Dayton (sand/dust) RAP-various locations	Refiner-Irving-St John, Canada Supplier-Irving Oil Corporation-S Portland	64-28	Mill & Fill	474

MIST Testing Procedures and Guidelines

Procedure

To carry out MIST testing, the lid was removed to expose the conditioning chamber. Water was added until the chamber was filled to one inch above the support plate. The first sample was then added, along with spacers on the vertical supports. After placing the first sample in the chamber and spacers on the vertical supports, water was added until the chamber was filled to one inch above the top of the spacers. The next support plate was then added, followed by the sample above it, as shown in Figure 1. After the chamber was filled to capacity with water, the lid was fastened, and water was added through the valves to fill any remaining air voids. The cyclic process of filling with water and adding supports and samples ensured that there were no air voids in the chamber.

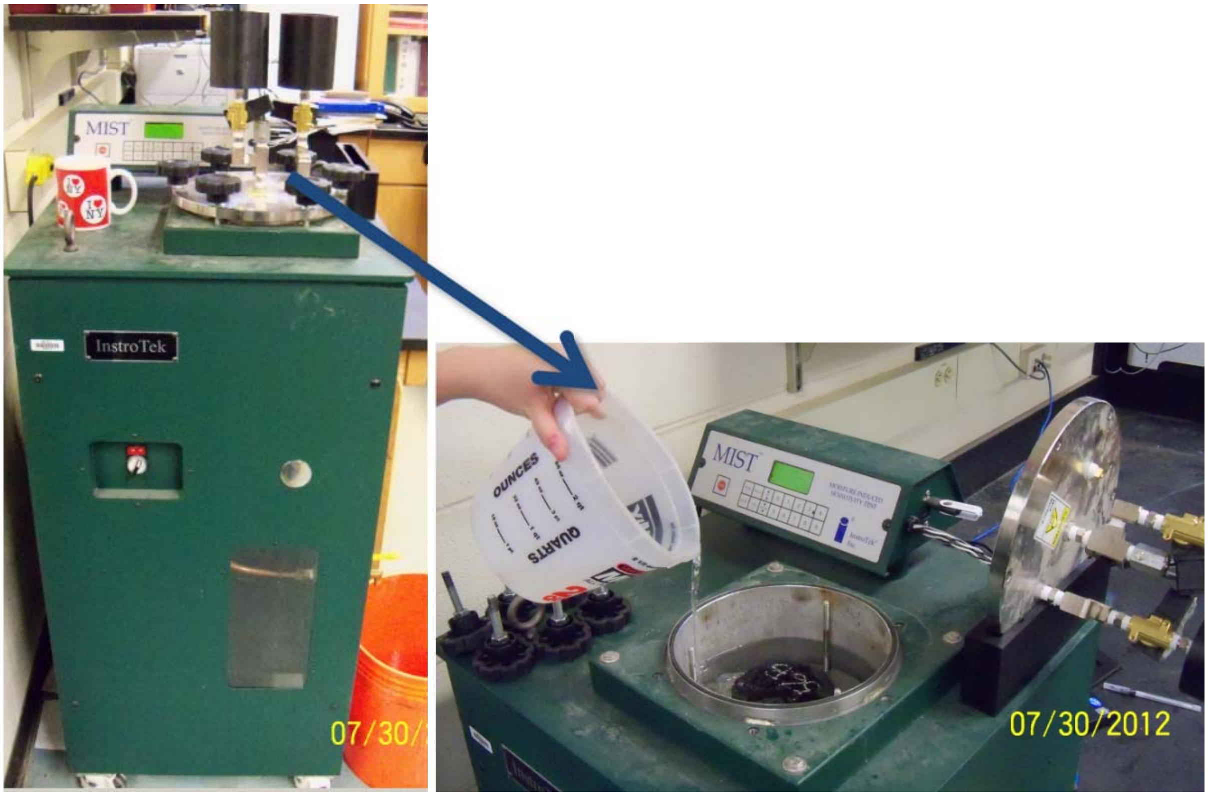

FIGURE 1 Filling of MIST conditioning chamber.

After appropriate test settings were entered in the MIST, the conditioning process was initiated. The MIST raises the water temperature to 10 C below the target temperature before beginning the pressure cycles. A bladder below the lowest sample support plate is expanded by air, forcing water upwards past the support plates and pressurizing the entire chamber. Therefore, each sample in the chamber experiences water pressure on all faces except that contacting the support plate. The bladder then deflates, releasing the pressure in the chamber and completing the pressure cycle. Each cycle requires approximately three seconds. When the specified number of cycles was completed, the warm testing water was drained from the chamber. The chamber was refilled with cool water for 2-3 minutes, after which the samples were removed to a room-temperature water bath for further cooling.

MIST Settings

Default settings of 3500 pressure cycles, 60 C (for PG 64 and above – 50 degrees Celsius is recommended for PG58 and PG52) and pressure of 40 psi are usually recommended by the manufacturer. Additionally, caution is recommended in selecting thicknesses of samples as a very thin sample may disintegrate under the MIST pressure cycles.

This study used less harsh settings than the default settings because the cores had experienced 14-18 months of prior "conditioning" in the field, and it was feared that the samples may disintegrate or show an unusually high response to conditioning if the full default values were used. Standard MIST settings as recommended by the manufacturer, as well as the ones used in this study can be seen in Table 2.

TABLE 2 MIST Settings for Study

Parameter	Recommendation	WPI Study
Number of Cycles	3500	2000
Pressure (psi)	40	30
Temperature	60C (or 50 if using PG 58 binder)	60C (or 50 if using PG 58 binder)

Failure Criteria

Currently three failure criteria are utilized:

- Significant visual degradation of samples
- Change in BSG > 1.25%
- TSR < 0.80

If a mixture fails two or more of the criteria, the mix is considered susceptible to moisture.

Sample Testing

Sample Preparation

The samples were first cataloged, which included pictures, dimensions, bulk specific gravity and observations regarding aggregate loss for each sample. In an effort to maintain consistency in spite of the subjective nature of observations, one person made all sample observations throughout the study.

Testing Procedure

The procedure for testing is outlined in Figure 2. Ideally, only the surface layer of each sample would have been tested. However, the surface layers of the mixes were approximately 1.5 inches thick, which is too thin to guarantee survival through MIST conditioning as mentioned in *MIST Settings*. It was decided that a sample thickness of 3-inches would allow similar ratios of surface layer to second layer thicknesses, and ensure the samples would not disintegrate in the MIST chamber. A wet saw was used to cut the samples to the 3-inch height, while retaining the original surface of the roadway. The samples were then placed in front of a fan at room temperature for 2-5 days, until completely dry.

There were some difficulties in preparing the South Portland samples according to this plan. During transportation and storage, the surface layer of the cores got separated from the second layer. As the surface layers were too thin to condition in the MIST equipment, a thin layer of epoxy was used to join the surface layer to the second layer to create a 3-inch thick sample. Two of the South Portland samples were damaged beyond repair when the layers separated, therefore four samples were conditioned and only two were left unconditioned.

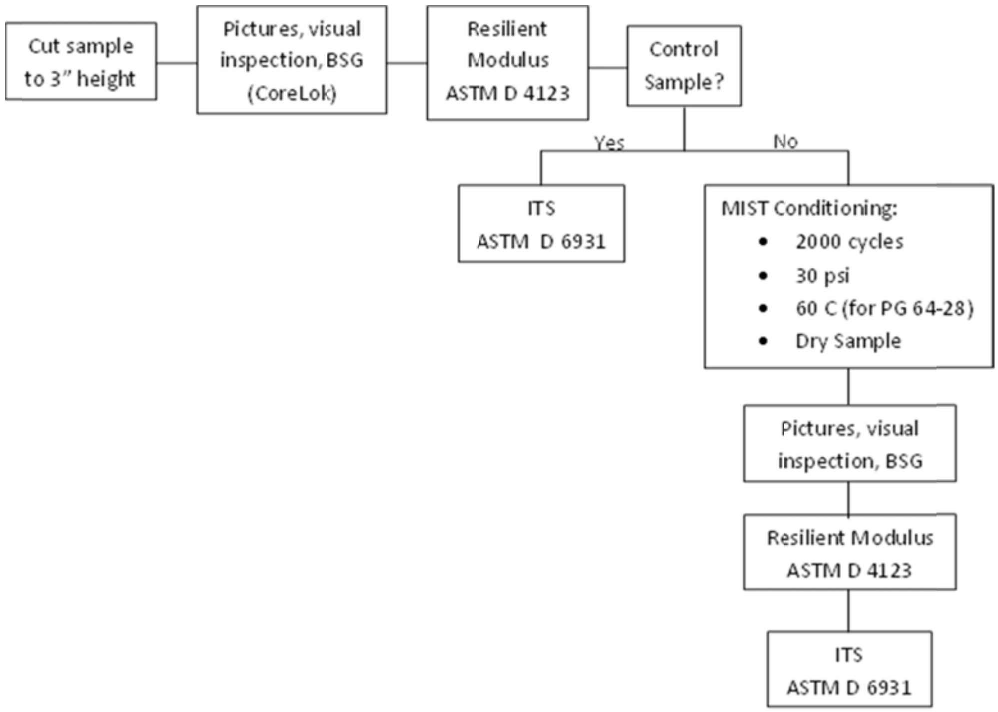

FIGURE 2 Flow chart of sample preparation and testing.

To comply with MIST guidelines, the bulk specific gravity of the samples were determined using the CoreLok method. It was impossible to calculate the air voids of the samples because they consisted of two layers, and the theoretical maximum density of the second layer was unknown in each case.

Observations were made regarding the extent of visible aggregate loss and chipping on each specimen. This study added resilient modulus as another indicator of susceptibility to MIST conditioning; therefore each sample was tested according to ASTM D 4123 to determine the pre-conditioned resilient modulus of each mix at 25C. Peak loads ranged between 200 and 250 pounds.

The eight samples from each project were equally divided into an unconditioned control group and a group that was conditioned in the MIST. Each group contained two cores from either side of the road. The cores selected for conditioning were then conditioned through the MIST using the settings shown in Table 2.

When the MIST conditioning of the samples was complete, the samples were removed to a room-temperature (25C) water bath and allowed to cool for 2-3 hours before handling. Following the MIST conditioning, the samples needed to be thoroughly dried. The approximate time required for this was two weeks. For the first week, the samples were placed on a counter at room temperature under a fan. After this, the samples were vacuum-sealed for two hours using the CoreLok, to extract remaining moisture from the samples. The samples were then removed and placed back under the fan. This process was repeated for all conditioned samples four times over the course of two days. The samples remained under the fan for approximately four more days until completely dry.

The completely dry conditioned samples were inspected again for signs of aggregate loss or sample degradation, before the bulk specific gravity and resilient modulus tests were repeated as outlined above.

Once all non-destructive testing was complete, the indirect tensile strength (ITS) of each sample was determined by loading the sample diametrically, as outlined in ASTM D 6931. These ITS values were used to calculate the tensile strength ratio (TSR) of each mix.

Analysis of Results

To determine the effects of MIST conditioning on HMA samples, values of the four parameters mentioned above (visual degradation, bulk specific gravity, tensile strength ratio and resilient modulus) were compared before and after MIST conditioning. Calculations were performed to determine whether there was a statistically significant difference between the values before and after conditioning using paired comparisons to determine the difference between population means with 95% confidence.

RESULTS AND ANALYSIS

As discussed in *Materials and Methodology*, 3 parameters are currently in use to determine the moisture susceptibility of an asphalt mixture subjected to MIST conditioning:

- Extent of visual sample degradation before and after conditioning
- Tensile strength ratio
- Change in bulk specific gravity.

This study also included the determination of the change in the modulus of resilience before and after conditioning as an indicator of the effect of MIST conditioning. This study investigated the effect of MIST conditioning on these four parameters for the six mixes provided by MDOT, by comparing average values before and after conditioning.

Results of Testing

The average values for each parameter tested are shown in Table 3. Some of the samples showed severe aggregate loss or cracking after MIST conditioning, as can be seen in Figure 3.

TABLE 3 Average Values of Testing Parameters before and after MIST Conditioning

Project Name	Average Value before Conditioning			Sample Observations After Conditioning	Average Value after Conditioning		
	BSG (pre)	MR, psi (pre)	ITS, psi(pre)		BSG (post)	MR, psi (post)	ITS, psi (post)
Abbot-Monson	2.340	253,428	88.7	One sample shows severe aggregate loss[a]; the other samples have minor aggregate loss	2.359	145,061	78.7
Dover-Foxcroft	2.225	378,726	95.3	All samples show minor chipping and aggregate loss	2.204	331,579	85.3
Ellsworth	2.305	259,981	81.9	All samples show minor chipping and aggregate loss	2.316	300,439	89.0

Harrison	2.192	189,375	76.0	Very minor chipping or no noticeable chipping or aggregate loss on most samples[b]	2.194	222,830	73.5
South Portland	2.320	219,573	81.5	Asphalt binder cracking in surface layer with minor to moderate aggregate loss	2.315	163,757	74.6
Turner	2.284	255,873	65.9	Very minor chipping or no noticeable chipping or aggregate loss on most samples	2.306	161,252	69.6

[a] see Figure 3.
[b] see Figure 4.
NOTE: 1 psi = 6.89 kPa

FIGURE 3 Sample that shows significant degradation after MIST conditioning.

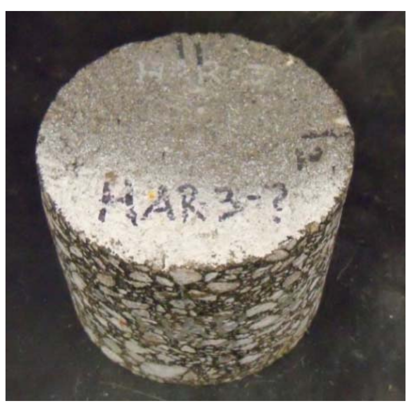

FIGURE 4 Sample that does not show significant degradation after MIST conditioning.

The percent changes of the parameters are shown in Table 4. The absolute value of the change in bulk specific gravity was calculated for each mix, rather than the directional change in the bulk specific gravity, because both increases and decreases were observed in bulk specific gravity and both indicate an effect from the MIST. However, it is very clear that a high tensile strength ratio and high resilient modulus are preferable after conditioning. Therefore average changes in these values included the direction of the change.

TABLE 4 Visual Sample Degradation, Tensile Strength Ratio, Absolute Change in Bulk Specific Gravity and Net Change in Resilient Modulus after MIST Conditioning for Each Project Location

Project Name	Visual Sample Degradation*	TSR	BSG (Absolute percent change)	Resilient Modulus (Net percent change)
Abbot Monson	Severe	0.89	1.71	-43.1
Dover Foxcroft	Minor	0.9	0.95	-11.9
Ellsworth	Minor	1.09	0.5	9.7
Harrison	Very Minor	0.97	0.57	14.3
South Portland	Moderate	0.92	0.54	-25.0
Turner	Very Minor	1.06	0.94	-36.7

*Visual sample degradation refers to aggregate loss or visible cracking in the asphalt binder

As is presented in the above table, the Abbot-Monson samples showed the greatest response to MIST conditioning, with a 43.1% decrease in resilient modulus due to conditioning, a 1.71% change in bulk specific gravity, and severe sample degradation. South Portland also showed some notable changes with a 25.0% decrease in resilient modulus and moderate sample degradation. Turner also showed a large decrease – 36.7% - in resilient modulus, and a moderate change in bulk specific gravity without showing much change in indirect tensile strength or sample degradation. The other three projects, Dover-Foxcroft, Ellsworth and Harrison, showed very little change in any of the four parameters. However, Ellsworth and Harrison both experienced increases in resilient modulus, with minor changes in bulk specific gravity with Ellsworth also indicating an increase in indirect tensile strength after conditioning.

Analysis of Results

The results show that the MIST conditioning procedure does impact the samples. The aggregate loss and asphalt binder cracking visible in the Abbot-Monson and South Portland sample do suggest that the MIST equipment recreates the conditions leading to stripping in the field. The decrease in the resilient modulus of four of the six projects supports this theory. Three of the four projects exhibiting a decrease in resilient modulus also displayed an accompanying decrease in indirect tensile strength. However, as can be observed in the table, the indirect tensile strength of the Turner samples increased while the resilient modulus decreased. One likely reason for this is that the change in resilient modulus was calculated from pre- and post-conditioning values solely of those samples which were conditioned. The tensile strength ratio was calculated using values from unconditioned and conditioned samples, leading to a greater number of variables.

Two of the projects, Dover-Foxcroft and Ellsworth, showed only a small change in bulk specific gravity, an increase in resilient modulus and a negligible or positive change in indirect tensile strength. As was discussed in *Materials and Methods* it was impossible to calculate the air voids of the samples. Past research has indicated that samples with high air voids subjected to moisture conditioning will show a subsequent increase in resilient modulus (*3*). It is possible that these samples had high air voids, leading to this increase.

As discussed in *Materials and Methods*, the MIST settings were conservative for this research, as was the selected sample thickness, due to the pre-conditioning the cores experienced in the field. However, the amount of pre-conditioning experienced by the cores is unknown. The six projects experience different amounts of traffic and it is unclear whether some cores came from the shoulder or the lane. It is possible that the cores of some of the projects have experienced much more conditioning than others.

Statistical Analysis of Results

Table 5 shows which of the three quantitative parameters showed a statistically significant change in the mean value due to MIST conditioning based on a 95% confidence paired comparison. As can be seen in the table, five out of the 17 categories showed a statistically significant change in the value.

TABLE 5 Statistical Significance of Changes in Parameters

Project Name	MR	BSG	ITS
Abbot-Monson	S*	S	NS
Dover-Foxcroft	NS	NS	NS
Ellsworth	NS	NS	NS
Harrison	NS	NS	NS
South Portland	S	S	N/A
Turner	S	NS	NS

* S indicates “statistically significant”. NS indicates “not statistically significant”.
Complications with South Portland samples resulted in having only 2 unconditioned samples.

Based on the results presented above, Abbot-Monson, South Portland and Turner all exhibited significant responses to MIST conditioning. Dover-Foxcroft, Ellsworth and Harrison did not. However, the authors believe that this should not lead to the conclusion that MIST conditioning does not significantly impact the samples, for several reasons.

Firstly, the sample sizes were small. In each calculation, very large changes in the measured values were required to achieve statistical significance because each population consisted of only four sample pairs.

Secondly, there were numerous, uncontrolled variables with the provided samples. It is unclear whether some samples came from the shoulder of the roadway or the lane, and how much traffic and pre-conditioning the projects and individual field cores experienced.

Finally, the volumetric properties of the samples were not well controlled. Some of the projects were overlays, while others were full construction. The thickness of the surface layer changed depending on which side of the roadway the sample was taken from, and the theoretical maximum density of the second layer is unknown, making it impossible to calculate the air voids of the samples.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results obtained, the following conclusions and recommendations have been made:

1. MIST impacts samples and has the potential to indicate sensitivity of a mixture to pressure cycles and stripping.
2. The effects of MIST conditioning should be studied further with the intent of developing thorough standards for evaluating the moisture sensitivity of hot mix asphalt mix
3. The researchers recommend further research using laboratory prepared mix-design samples with controlled air voids for the purpose of better understanding the MIST equipment and its effects on HMA.

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DISCLAIMER

The contents of this report reflect the views of the authors and do not necessarily reflect the official policy of the Maine Department of Transportation.

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