Ranking of HMA Moisture Sensitivity Tests in Iowa

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By
Scott Schram

Iowa Department of Transportation
Office of Materials
800 Lincoln Way
Ames, IA 50010
515-239-1604

Iowa Department
of Transportation

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16 Abstract

Several agencies specify AASHTO T283 as the primary test for field acceptance of moisture susceptibility in hot mix asphalt. When used in this application, logistical difficulties challenge its practicality, while repeatability is routinely scrutinized by contractors. An alternative test is needed which can effectively demonstrate the ability to screen mixtures based on expected performance. The ideal replacement can be validated with field performance, is repeatable, and allows for prompt reporting of results. Dynamic modulus, flow number, AASHTO T283, Hamburg wheel tracking device (HWTD), and the moisture induced sensitivity test (MIST) were performed on plant produced surface mixes in Iowa. Follow-up distress surveys were used to rank the mixes by their performance. The rankings indicate both the quantity of swelling from MIST conditioning and submersed flow number matched the performance ranking of all but one mixture. Hamburg testing parameters also appear effective, namely the stripping inflection point and the ratio between stripping slope and the creep slope. Dynamic modulus testing was ineffective, followed by AASHTO T283 and ratios produced from flow number results of conditioned samples.

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By
Scott Schram
State Bituminous Engineer
Iowa Department of Transportation
Office of Materials
800 Lincoln Way
Ames, Iowa 50010
515-239-1604

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INTRODUCTION

Moisture damage in flexible pavements has long been a concern to owner/agencies and can manifest in many forms of distress within months of construction. The modes of failure (adhesive and cohesion) can be explained by one or more of the following mechanisms: detachment, displacement, spontaneous emulsification, film rupture, pore pressure, hydraulic scouring, and pH instability (Taylor and Khosla, 1983; Kiggundu and Roberts 1988; Terrel and Al-Swailmi, 1994; Scott, 1978).

A 2002 survey showed as many as 44 states routinely test for moisture sensitivity. Over 86% of these state Departments of Transportation (DOT) specify AASHTO T283 as their primary test method for identifying moisture-susceptible asphalt mixtures (Hicks et al., 2002). Both the repeatability of AAHSTO T283 and its relation to performance are often scrutinized (Brown et al. 2001; Solaimanian et al. 2003), partly because the manner in which moisture is introduced into the specimen is not representative of field conditions. Epps et al found the moisture damage potential as identified by the test, did not match observed field performance (Epps et al., 2000). Furthermore, the single user variability in tensile strength ratio (TSR) is 9%, while the multi-lab variability reached as high as 25% (Azari, 2010). When considering the test's repeatability, it is conceivable for laboratories to reach conflicting acceptance decisions. The minimum TSR is often specified at 80%, though some agencies have lowered this requirement (Roberts, et al. 1996). Because the test was initially developed using 100 mm diameter-Marshall specimens (Lottman 1978), the minimum recommended TSR requirement may not be applicable when using other compaction methods and specimen sizes. If the minimum TSR requirement is 80%, the equivalent requirement for 150 mm gyratory specimens was shown to be 87% (Bausano et al. 2006).

Agencies using this test as part of acceptance in production face many logistical challenges. Recognizing these challenges, a 2006 study evaluated alternative test methods for use in Iowa (Williams, 2010). Tensile strength, dynamic modulus, and flow number testing was conducted on both conditioned and unconditioned specimens fabricated from plant produced mixtures. Upon completion of the study, additional mix was retained and stored for future research. In 2011, two additional devices were used to test these same mixtures: the Hamburg wheel tracking device (HWTD) and the moisture induced sensitivity test (MIST). Results from all devices were compared with field performance to identify a suitable alternative.

PROBLEM STATEMENT

Of the 38% of agencies which specify AASHTO T283 for field acceptance, not all district laboratories within the agency are equipped with a compression machine. In Iowa, samples are sent via courrier to a central laboratory where the turn-around time for delivery, testing, and reporting can exceed five days. During this time, the contractor may wait for results, or continue production while assuming the risk of a failing result. An anti-stripping agent may be incorporated to mitigate this risk, which increases costs. Typically, the TSR of plant-produced mix is lower than that from preliminary testing of the job mix formula (JMF), which complicates the decision to include these additives. Anecdotal evidence from the Iowa DOT suggests it is not uncommon for the JMF TSR to drop by as much as 7% when production begins; in some instances even higher.

Further convoluting the matter, the compatibility between project-specific aggregates and liquid anti-stripping agents is often overlooked. Contractors commonly use the same additive for a variety of materials, resulting in cases where liquid agents decrease the unconditioned tensile strength, which misleadingly inflates the tensile strength ratio. For smaller projects, production is often completed before a problem can been identified, which is a major disadvantage to both the contractor and owner/agency.

Given the challenges with logistics and practicality, an alternative moisture sensitivity test is needed for field acceptance. The test should effectively demonstrate the ability to screen poor performing mixtures in the field.

RESEARCH APPROACH

Five test methods were evaluated for identifying moisture-related damage in flexible pavements. Plant-produced loose samples were collected from 13 Iowa projects in 2006. Specimens were fabricated and tested for dynamic modulus, flow number, and indirect tensile strength. In 2011, the remaining loose mix was retrieved from an in-door storage facility and used to fabricate specimens for HWTD and MIST testing. Results were compared to observed field performance.

The mixtures were selected to cover a wide range of material properties. Three traffic levels were considered: less than 3 million equivalent single-axle loads (ESALs), 3 to 10 million ESALs, and greater than 10 million ESALs. Two nominal maximum aggregate sixes (NMAS)—12.5 and 19.0 mm—were used, and three binder performance grades (PG 58-25, PG 64-22, and PG 70-28) were represented. The properties of the mixes are presented in Table 1. The Iowa DOT only conducts pavement distress surveys on its primary system. Performance data is unavailable for seven of the mixtures placed under local jurisdiction. Comparisons to performance were made only to surface mixtures.

TABLE 1 Properties of Sampled Mixtures

Project Name	NMAS (mm)	Binder PG	Traffic Level Million ESALs	Designation	Performance Available?
HWY 330 Base	19.0	64-22	<3	330B	Yes
HWY 218, Tripoli	19.0	64-22	<3	218	Yes
I-80 Intermediate	19.0	64-22	>10	I80I	Yes
I-235 Intermediate	19.0	70-28	>10	235I	Yes
6th St. Nevada	12.5	64-22	<3	6N	No
Dedham	12.5	58-28	<3	Ded	No
Rose Street	12.5	64-22	<3	Rose	No

F-52	12.5	58-28	<3	F52	No
Northwestern Avenue	12.5	64-22	<3	NW	No
HW 4	12.5	58-28	<3	HW4	Yes
HWY 330 Int.	12.5	64-22	3-10	330I	Yes
Jewell	12.5	64-22	3-10	Jewell	No
HWY 330 Surface	12.5	64-22	3-10	330S	Yes
I-80 Surface	12.5	64-22	>10	I80-S	Yes
I-235 Surface	12.5	70-28	>10	235S	Yes
Altoona	12.5	64-22	>10	ALT	No

Experimental Plan

All samples were compacted to 7% ± 1% air voids and split into two groups with equivalent average air voids. The first group served as the control, while the second was subjected to the following modes of moisture conditioning:

1. unconditioned without water submersion testing
2. unconditioned with water submersion testing
3. moisture saturation with freeze/thaw conditioning without water submersion testing
4. moisture saturation with freeze/thaw conditioning and with water submersion testing

With the exception of HWTD and MIST testing, five replicates were tested in each condition for each mix. Because the test protocol dictates the use of external linear variable differential transformers (LVDTs) on the sides of the specimen, dynamic modulus for conditions 2 and 4 was omitted. When fabricating HWTD and MIST specimens, loose samples were brought to 275°F and compacted. Table 2 summarizes the testing plan, where X denotes a replicate was tested (Williams, 2010).

TABLE 2 Test Matrix

Test	Condition 1	Condition 2	Condition 3	Condition 4
Dynamic Modulus	XXXXX		XXXXX XXXXX	
Flow Number	XXXXX	XXXXX	XXXXX	XXXXX
AASHTO T283	XXXXX		XXXXX	
HWTD		XX		
MIST		XX		

Sample Conditioning

For HWTD and MIST testing, the only moisture conditioning used was the test itself. All other tests followed AASHTO T 283, “Resistance of Compacted Bituminous Mixture to Moisture Induced Damage.” Specimens were compacted according to section 4.2.3 in AASHTO T 283 and divided into two subsets so that each subset had the equivalent average air voids. The dry subset (control group) deviated from the standard specification as the samples were placed in an environmental chamber rather than being wrapped with plastic or placed in a heavy-duty, leak-proof plastic bag and stored in a water bath at 25°C ± 0.5°C for two hours ± ten minutes prior to testing. The specimen was vacuum saturated for five to ten minutes at 13–67 kPa and submerged in water bath for an additional five to ten minutes. The degree of saturation was held between 70% and 80%. If the sample required a freeze/thaw cycle, each vacuum saturated specimen was tightly covered with plastic wrap and placed in a plastic bag with approximately 10 ± 0.5 ml of water and sealed. The plastic bags were then placed in a freezer at -18°C ± 3°C for a minimum of 16 hours followed by 24 hours ± 1 hour in a 60°C ± 1°C water bath with 25 mm of water above the specimens. The specimens were then removed and placed in a water bath at 25°C ± 0.5°C for two hours ± ten minutes.

Dynamic Modulus

Dynamic modulus testing was performance in a Nottingham Asphalt Tester; a universal servo-hydraulic testing system with a temperature-controlled environmental chamber. Specimens were subjected to repeated loads at two temperatures (4°C and 21°C) and nine frequencies (0.1, 0.3, 0.5, 1.0, 3.0, 5.0, 10.0, 15.0, and 25.0), where strain was maintained at 80 microstrain (Witczak, 2005).

Flow Number

The number of applications where the onset of tertiary flow occurs (flow number) was found using AASHTO TP-79-09 (Witczak et al., 2002). A deviator stress (600 kPa) was applied for 0.1 second, followed by a 0.9 second rest period, simulating normal trafficking. Testing was performed at 37°C.

AASHTO T283

Specimens are conditioned and loaded in indirect tension. The indirect tensile strength is compared to that of the unconditioned control group. The ratio of conditioned to unconditioned strength is known as the tensile strength ratio (TSR).

Hamburg Wheel Tracking Device (HWTD)

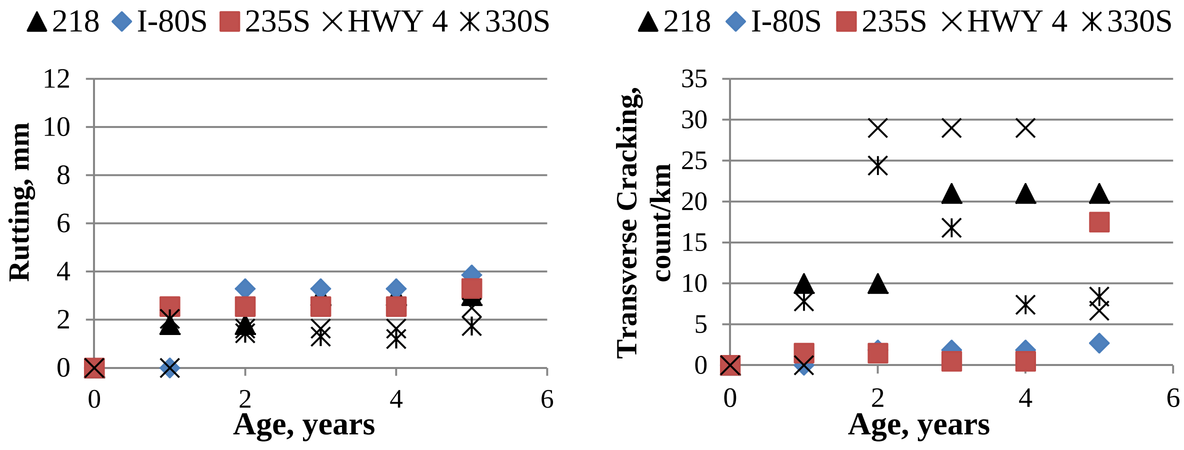
Developed in the 1970s in Hamburg, Germany, this device simultaneously measures a mixture’s susceptibility to rutting and moisture damage by rolling a steel wheel over the submerged specimen in a temperature-controlled water bath (AASHTO T324). The rut depth was measured at eleven positions spaced along the surface of two adjoining cylindrical gyratory specimens. The creep slope represents the rate of rutting in the linear region of the deformation curve after 1,000 passes. The strip slope is the rate of rutting in the linear region of the post tertiary deformation curve to the end of the test. The stripping inflection point (SIP) is the point of intersection of these two slopes (Aschenbrener and Currier, 1993). Results can be reported the same day of testing, which is a major advantage for field acceptance.

Moisture Induced Sensitivity Test (MIST)

Gyratory compacted specimens are placed in the MIST water chamber maintained at 60°C. A bladder inside the chamber inflates, creating a pressure of 40 psi. The inflation is repeated for up to 3,000 cycles. The density of the conditioned specimens is measured with AASHTO T166 and the specimen is loaded in indirect tension. The ratio of MIST conditioned to unconditioned sample strengths is recorded as well as the amount (%) of swelling, measured in percent change in air voids. Results can be reported in as little as three hours. Like the HWTD, the MIST can eliminate the risk to contractors and owner/agencies when production continues before lab results can be reported.

OBSERVED FIELD PERFORMANCE

Distress surveys were compiled from the Iowa DOT pavement management information system (PMIS). Transverse cracking, longitudinal cracking, longitudinal wheel path cracking, alligator (fatigue) cracking, and rutting are considered. Distresses are derived from automated surveys taken bi-annually across the network, where each half of the network is surveyed every other year. The authors recognize the presence of distress in the PMIS does not necessarily imply damage is moisture related, but rather the damage may be explained by the test results included in the study. Figure 1 shows the performance of the five surface mixtures on the primary system. Performance was averaged over the first two years to allow for one bi-annual survey cycle.



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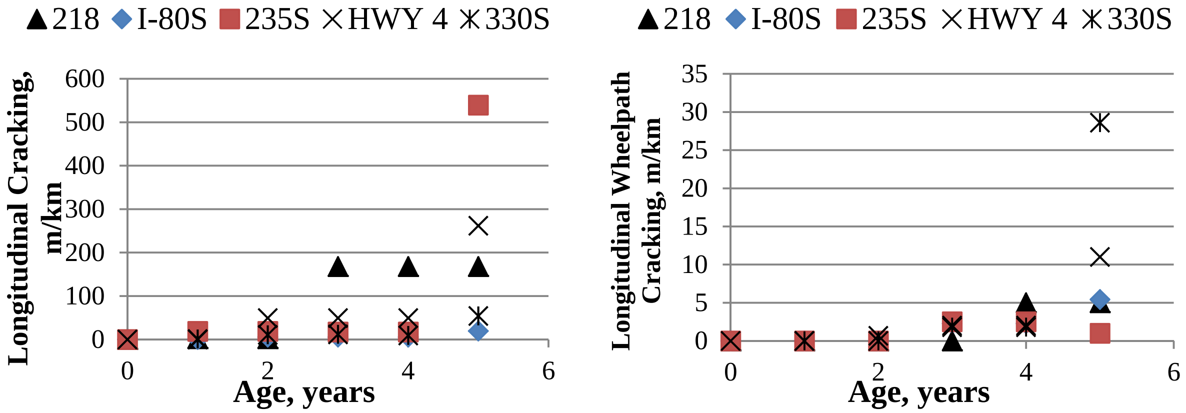

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FIGURE 1 Observed Field Performance

Table 3 shows the average early performance and ranking for each mix. Because no fatigue cracking was observed and early rutting levels are insignificant, these distresses were removed from the overall rankings. While no mix has performed poorly, a clear ranking could be established for comparisons among performance tests. The best performing mixture was I-80S.

TABLE 3 Performance Ranking after 2 Years

Mixture	Rutting[1] (mm)	Alligator Cracking[1] (m^2/km)	Transverse Cracking (count/km)	Longitudinal Wheelpath Cracking (m/km)	Longitudinal Cracking (m/km)	Average Ranking
80S	NA (1.6)	NA (1.0)	1 (0.9)	1 (0.0)	1 (0.1)	1
235S	NA (2.6)	NA (0.0)	2 (1.5)	1 (0.0)	5 (18)	2
330S	NA (1.7)	NA (0.0)	5 (16.1)	3 (0.2)	2 (1.9)	3
218	NA (1.8)	NA (0.0)	3 (10.0)	5 (2.0)	3 (2.0)	4
HW4	NA (0.8)	NA (0.0)	4 (14.5)	4 (1.3)	4 (7.0)	5

[1] *Excluded from average ranking*

RESULTS

The objective of the analysis is to evaluate how well each test ranks a mixture with respect to its field performance.

Dynamic Modulus Results

Figure 2 shows the dynamic modulus master curve for the I80-S mixture. The figure depicts the typical behavior of moisture conditioned specimens. The evidence suggests the mixtures are more susceptible to moisture effects at higher temperatures and/or lower loading frequencies. Only one of the 16 mixtures (330S) did not follow this trend. Results for all dynamic modulus testing are presented in the Phase I report (Williams, 2010).

The area under the master curve was calculated for both conditioned and unconditioned modes. The distinction becomes clear in the high-temperature–low-frequency zone. The following were considered as screening parameters for moisture sensitivity:

1. Ratio of the average conditioned and unconditioned dynamic modulus obtained from the master curve at 37°C
2. Ratio of area under the conditioned master curve to area under the unconditioned master curve

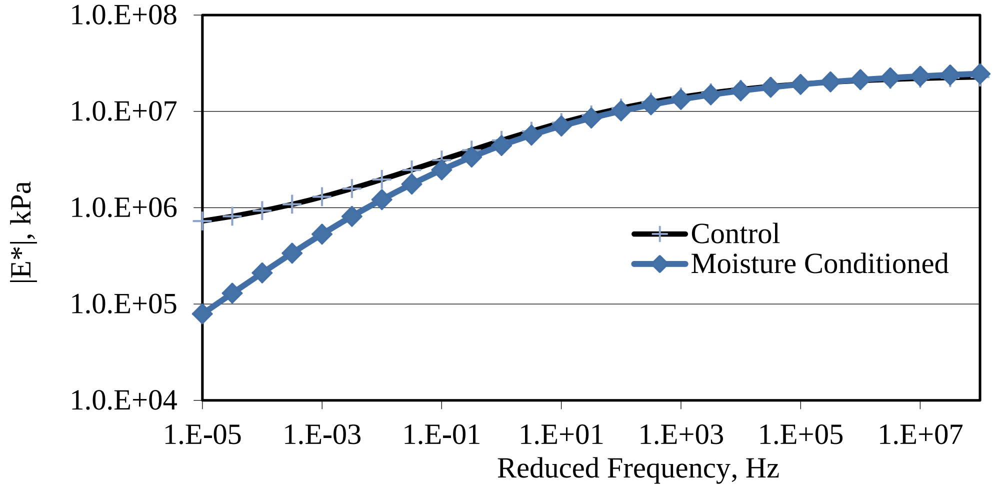


FIGURE 2 Dynamic Modulus Master Curve for I80-S

Table 4 shows the results of the dynamic modulus ratios and their rankings. While, both the E* and the area ratios correctly identified the poorest performance mixture, overall rankings were poor when considering the five mixtures.

TABLE 4 Dynamic Modulus Rankings

Mixture	Performance Ranking	E* Ratio 37°C	Area Ratio
I-80S	1	1.17 (3)	0.9 (4)
235S	2	0.78 (1)	1.3 (1)
330S	3	0.79 (4)	0.8 (3)
218	4	0.86 (2)	1.2 (2)
HW4	5	1.25 (5)	0.6 (5)

Flow Number Results

While flow number has correlated well with field rutting (Zhou and Scullion, 2003), it has not produced similar results for moisture damage prediction (Solaimanian et al., 2007, Williams, 2010). The following were evaluated as a potential screening parameter for moisture sensitivity:

1. FN at Condition 1
2. FN at Condition 2
3. FN at Condition 3
4. FN at Condition 4
5. FN ratio between Condition 2 and Condition 1
6. FN ratio between Condition 3 and Condition 1
7. FN ratio between Condition 4 and Condition 1

Flow number results are shown in Table 5. Test results from moisture conditioned and freeze/thaw conditioned samples agreed well with the field performance ranking. Ranking of the ratios between conditioned and dry modes do not match well with observed performance, particularly for mixtures with low flow numbers.

TABLE 5 Flow Number Rankings

Mixture	Performance Ranking	FN Wet Cycles (Cond. 2)	FN Dry Cycles (Cond. 1)	FN Frozen in Air Cycles (Cond. 3)	FN Frozen in H_2O Cycles (Cond. 4)	FN Wet/Dry	FN Frozen/Dry in H_2O	FN Frozen/Dry in Air
I-80S	1	1,797 (2)	10,912 (3)	4,849 (3)	8,990 (2)	0.2 (3)	0.8 (4)	0.4 (4)
235S	2	13,245 (1)	14,840 (2)	16,603 (1)	13,895 (1)	0.9 (2)	0.9 (3)	1.1 (1)
330S	3	1,150 (3)	19,533 (1)	5,200 (2)	5,420 (3)	0.1 (5)	0.3 (5)	0.3 (5)
218	4	648 (4)	534 (5)	494 (5)	732 (5)	1.2 (1)	1.4 (1)	0.9 (2)
HW4	5	199 (5)	1,941 (4)	1,007 (4)	2,153 (4)	0.1 (4)	1.1 (2)	0.5 (3)

AASHTO T283 Results

The indirect tensile (IDT) strength and TSR were evaluated a potential screening parameters. Results from T283 testing appear in Table 6. The TSR rankings poorly match field performance. The best performing mixture among the five failed the minimum 80% requirement. Dukatz and Phillips suggest the minimum TSR requirement be supplemented with a minimum conditioned IDT strength (Dukatz and Phillips, 1987). This approach appears to be appropriate for the mixtures included in this study.

TABLE 6 AASHTO T283 Rankings

Mixture	Performance Ranking	T283 Wet IDT (psi)	T283 TSR (%)
I-80S	1	142.3 (3)	78.9 (4)
235S	2	175.0 (2)	102.7 (1)
330S	3	181.1 (1)	98.6 (2)
218	4	124.6 (5)	71.2 (5)
HW4	5	132.0 (4)	80.1 (3)

Hamburg Wheel Tracking Device (HWTD) Results

Parameters evaluated for the HWTD included:

1. Stripping inflection point (SIP)
2. Strip slope
3. Creep Slope
4. Ratio between strip slope and creep slope

Table 7 gives the results from the HWTD testing. All mixes performed very well in the Hamburg, which is consistent with the observed performance in the field. All HWTD parameters appear to effectively rank the mixtures by performance. The ratio between the stripping slope and creep slope serves as an effective measure of confirming the stripping inflection point. Quality assurance testing by the Iowa DOT indicates a ratio of 2.0 or greater is needed to validate the SIP. Ratios less than 1.0 may signify the SIP was found mathematically, but no clear stripping behaviour was observed.

TABLE 7 HWTD Rankings

Mixture	Performance Ranking	SIP (Passes)	Strip Slope (mm/1K Passes)	Creep Slope (mm/1K Passes)	Strip/Creep Ratio
I-80S	1	18,025 (2)	0.1032 (2)	0.0781 (2)	1.3 (1)
235S	2	18,513 (1)	0.0632 (1)	0.0475 (1)	1.3 (1)
330S	3	17,189 (4)	0.2106 (4)	0.1194 (4)	1.8 (4)

218	4	17,828 (3)	0.1298 (3)	0.0921 (3)	1.4 (3)
HW4	5	16,083 (5)	0.9152 (5)	0.1678 (5)	5.4 (5)

Moisture Induced Sensitivity Test (MIST) Results

MIST parameters evaluated included the following:

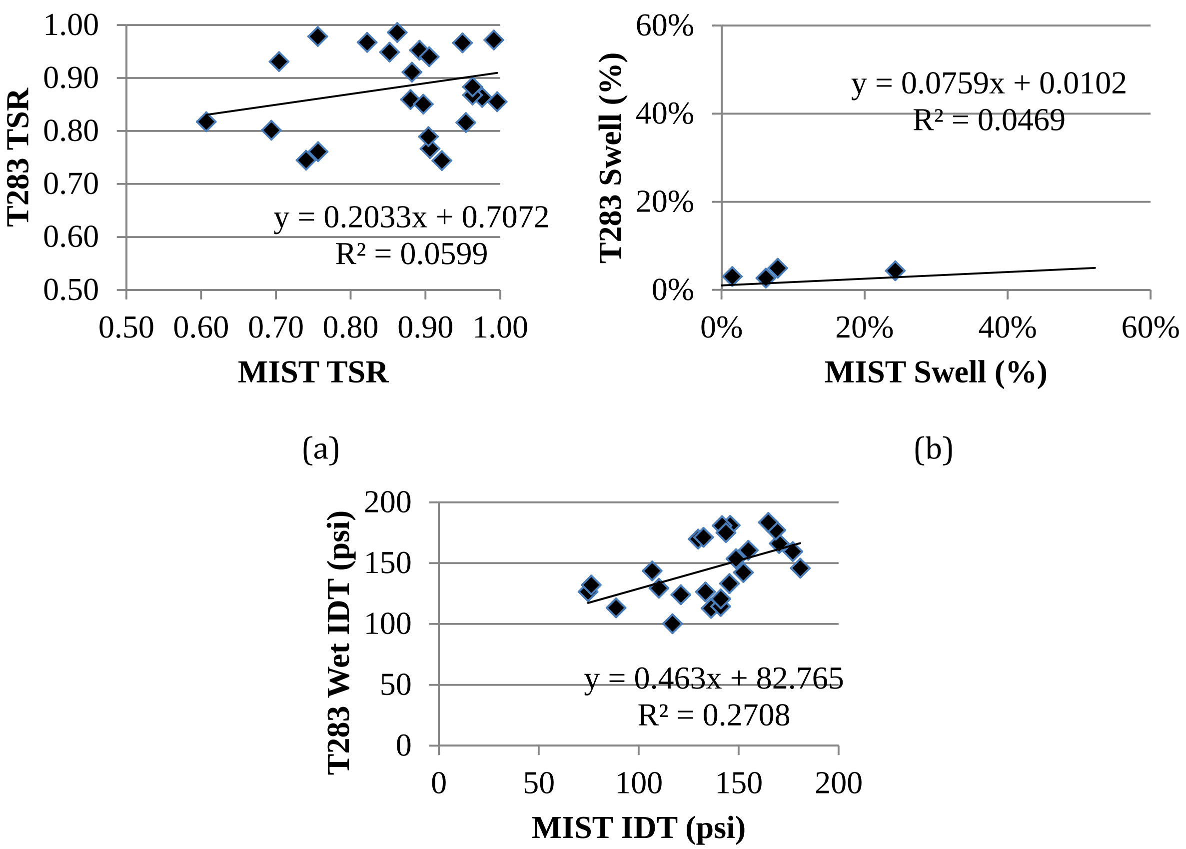
1. Indirect tensile strength of MIST conditioned sample
2. Ratio between indirect tensile strength of MIST sample to that of an unconditioned sample
3. Change in air voids after MIST conditioning (swell)

Results are reported in Table 8. Unlike AASHTO T283, the MIST TSR indicates an acceptable result for the I-80S mix. IDT strengths are high for all mixtures with the exception of HW4, which showed the poorest performance among the five sections. MIST swelling appears to be very effective in identifying high and low rankings of field performance. In cases such as HW4, the degree of swelling can be severe enough that adjustments to the clearance of the compression machine become necessary.

TABLE 8 MIST Rankings

Mixture	Performance Ranking	MIST TSR (%)	MIST Wet IDT (psi)	MIST Swell (%)
I-80S	1	90.4 (2)	152.3 (2)	0.6 (1)
235S	2	96.8 (1)	143.6 (4)	0.7 (2)
330S	3	86.2 (4)	145.8 (3)	5.9 (4)
218	4	89.2 (3)	170.3 (1)	2.8 (3)
HW4	5	69.4 (5)	76.2 (5)	45.0 (5)

A comparison of the MIST and AASHTO T283 is presented in Figure 3. As part of an ongoing evaluation, more samples are included in the comparison. Correlation between TSR values is very poor. Tthere are cases where the two tests give conflicting pass/fail results with respect to the 80% minimum TSR. It can be seen from the swelling results, that the MIST is a much harsher conditioning process due to the hydraulic scouring that occurs from the induced pressures. While IDT strengths did not correlate well, most conditioning protocols produce strengths of similar magnitude.



(a) (b)

(c)

FIGURE 3 Comparison of MIST and AASHTO T283 Conditioning

SUMMARY AND CONCLUSIONS

Agencies specifying AASHTO T283 for field acceptance face logistic and practical challenges that are both inherent and difficult to avoid. An alternative test for identifying moisture sensitivity is needed. This study evaluated five tests for their capacity to effectively demonstrate the ability to screen mixtures based on their observed performance. Dynamic modulus, flow number, AASHTO T283, Hamburg wheel tracking device, and the moisture induced sensitivity test were performed on plant produced surface mixes. Follow up distress surveys were used to rank the mixes by their performance. Though it was beyond the scope of this project, more forensic evaluation is needed to determine whether distresses were moisture-related.

Parameters derived from the test measurements were ranked from high to low and contrasted against the corresponding ranking of the field performance for each mix. The following equation was used to quantify the effectiveness of each test parameter:

$$Performance\ Rank\ Error = \sum_{i=1}^{5} (TestRank_i - PerformRank_i)^2$$

Parameters are ranked according to the lowest total error across the five mixtures. The overall rankings are given in Table 9. The rankings of both the MIST swell and submersed flow number matched the performance ranking of all but one mixture. However, the best performing mix in the submersed flow number test (235S) was not the best performing mix in the field (I-80S). Hamburg testing parameters also appear effective, namely strip/creep ratio and SIP. These two parameters can be used in parallel to confirm stripping behaviour that has been mathematically identified as the SIP. Dynamic modulus testing was ineffective, followed by AASHTO T283 TSR and ratios produced from flow number results.

TABLE 9 Overall Test Rankings

Test	Test Parameter	Performance Rank Error	Ranking
MIST	MIST Swell	2	1
Flow Number	FN Wet	2	1
HWTD	Strip/Creep Ratio	3	3
HWTD	SIP	4	4
HWTD	Strip Slope (mm/1K passes)	4	4
HWTD	Creep Slope (mm/1K passes)	4	4
MIST	MIST TSR	4	4
Flow Number	FN Frozen in H2O	4	4
Flow Number	FN Frozen in Air	8	9
Flow Number	FN Dry	10	10
Dynamic Modulus	E* Ratio 37°C	10	10
AASHTO T283	T283 Wet IDT (psi)	10	10
MIST	MIST Wet IDT	14	13
Dynamic Modulus	Area Ratio	14	13
AASHTO T283	T283 TSR	16	15
Flow Number	FN Wet/Dry	18	16
Flow Number	FN Frozen/Dry in Air	22	17
Flow Number	FN Frozen/Dry in H2O	32	18

Considering turn-around time and simplicity, the MIST and Hamburg should be considered for further evaluation as viable alternatives to AASHTO T283, particularly for field acceptance. A larger sample size would strengthen the validity of the rankings and provide guidance for quantifying testing thresholds used for specifications.

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