Investigation of AASHTO T 283 To Predict the Stripping Performance of Pavements in Colorado

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Moisture damage to hot-mix asphalt pavements has been a sporadic but persistent problem in Colorado, even though laboratory testing is performed to identify moisture susceptible mixtures. The laboratory conditioning was often less severe than the conditioning the hot-mix pavement encountered in the field. Twenty sites of known field performance with respect to moisture susceptibility, both acceptable and unacceptable, were identified. Materials from these sites were tested using several versions of AASHTO T 283. For this testing, two levels of severity for conditioning laboratory specimens were identified that correlated well with pavement conditions. For mixtures placed under high traffic, high temperatures, high moisture, and possibly freezing conditions, the severe laboratory conditioning defined in the report should be used. The milder laboratory conditioning defined in this report is appropriate for low traffic sites.

Moisture damage, otherwise known as "stripping," to hot-mix asphalt (HMA) pavements has been a sporadic but persistent problem on projects in Colorado. In July 1991 distress attributed to moisture damage was observed on a project on I-70 in eastern Colorado. A joint study between the Colorado Department of Transportation (CDOT) and the Asphalt Institute (AI) investigated the cause of the damage (*1*). One of the perplexing aspects of the investigation was that moisture susceptibility tests performed before and during construction did not identify moisture-susceptible HMA. Among others, the following recommendations were made as part of the joint CDOT/AI study:

- Evaluate HMA of known field performance with several versions of the moisture susceptibility tests used by CDOT, and
- Evaluate HMA of known field performance without lime or liquid antistripping additives.

These recommendations were accepted by the engineering management of CDOT, and a related experiment was designed and conducted during the winter months of 1992 and 1993. All laboratory work was conducted at the CDOT Central Materials Laboratory in Denver. The moisture susceptibility test examined was AASHTO T 283, Resistance of Compacted Bituminous Mixture to Moisture Induced Damage. A detailed report (*2*) presented a thorough analysis of the experiment. This paper presents a brief summary of the results of the experiment.

Twenty pavement sites were selected throughout Colorado with a known history of performance with respect to moisture damage. These sites represent a wide variety of performance characteristics and encompass an equally wide variety of material types used for asphalt paving in Colorado. Performance of the sites was categorized as good, high maintenance, disintegrators, or complete rehabilitation. The sites are listed in Table 1 by county or nearby city. A brief description of the performance categories follows.

"Good" projects were constructed with materials that have a good history of providing pavements that resist moisture damage. These represent the target for engineers at CDOT.

"High Maintenance" projects are still in service after 2 to 5 years, although their performance is considered unacceptable when compared to their design life. The maintenance required to address problems from moisture damage included overlays and significant patching of structural damage. A high maintenance pavement that required an overlay on some sections is shown in Figure 1.

"Complete Rehabilitation" projects required complete rehabilitation when less than 2 years old and often less than 1 year old. The moisture damage was related to a unique pavement design feature, rut-resistant composite pavement, that used a plant mixed seal coat as described and evaluated by Harmelink (*3*). Pavements requiring complete rehabilitation all failed when high levels of precipitation occurred in the hottest part of the summer. Even though all pavements in Colorado are subjected to freeze cycles, the severe moisture damage did not occur during freezing conditions. The instantaneous failures were directly related to a simultaneous combination of high temperature, high moisture, and high traffic. A core from one of these projects is shown in Figure 2.

"Disintegrators" were pavements that failed in less than 6 months. Material sources with a notorious history of severe moisture damage were used for these pavements. A 6-month old pavement that disintegrated is shown in Figure 3.

EXPERIMENTAL DESIGN

A literature review was performed to ascertain testing factors that might influence the predictive ability of moisture susceptibility tests. A thorough summary of the literature review is included in other work by Aschenbrener and McGennis (*2*).

The purpose of the experiment was to ascertain whether any adjustments needed to be made to the standard moisture susceptibility test procedures used by CDOT to make the test more predictive of actual stripping performance.

The original mix design used at each site was identified. Retrieved information included the aggregate sources, percentage of each component, component and combined aggregate gradations, optimum asphalt content, asphalt cement source and grade, and antistripping treatment.

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TABLE 1 Pavement Sites of Known Stripping Performance

Site	Location	Category
1	Glenwood Springs	Good
2	Craig	
3	Delta	
4	Fruita	
5	Grand Junction	
6	Durango	
7	Ft. Collins	
8	Nunn	High Maintenance
9	Denver	
10	Douglas County	
11	Aurora	
12	Jefferson County	
13	Cedar Point	Complete Rehabilitation
14	Agate	
15	Arriba	
16	Limon	
17	Trinidad	Disintegrators
18	Walsenburg	
19	Fleming	
20	Gunnison	

It was not possible to use the exact aggregates and asphalt cements from the original projects placed 2 to 10 years ago. Consequently, virgin aggregates from the original sources used at each site were sampled. Additionally, recently produced asphalt cements and antistripping treatments were obtained from the original suppliers of materials to the sites.

The aggregates from each site were then blended to match the gradation used on the project as closely as possible. A mix design was then performed to validate the optimum asphalt content from each site. When the optimum asphalt content of the new mix design matched the optimum asphalt content of the original mix design, the moisture susceptibility testing proceeded. When the optimum asphalt content of the new mix design did not match the optimum asphalt content of the original mix design, it was assumed the materials had changed, and the new optimum asphalt content was used. No optimum asphalt contents used in this study varied by more than 0.2 percent from the original designs. The aggregate gradations and optimum asphalt contents for the HMA mixtures are shown in Table 2.

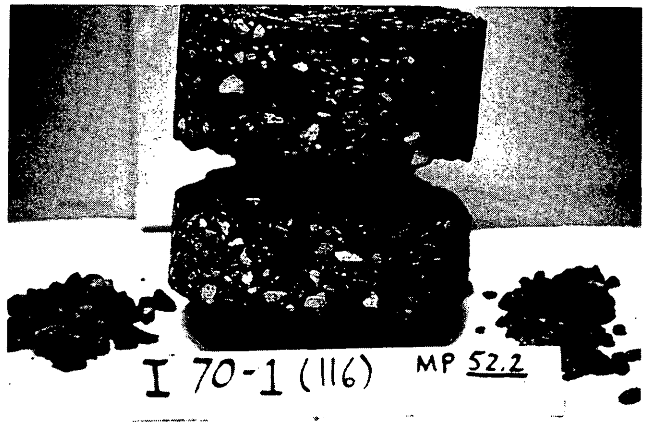

FIGURE 2 Core from complete rehabilitation project.

TEST PROCEDURES

A summary of AASHTO T 283 test procedures is shown in Table 3. The experimental grid of tests performed on samples from the various sites is shown in Table 4. A brief description of the factors evaluated follows.

Standard AASHTO T 283

The materials from all sites were tested with the standard procedure (AASHTO T 283). It includes short-term aging, freezing, and limits on air voids (6 to 8 percent) and saturation (55 to 80 percent). As previously stated, the HMA tested in this group simulated as closely as possible the mixture as originally constructed. This included aggregate, asphalt cement, and the project antistripping treatment.

No Antistripping Treatment

CDOT specified the use of liquid antistripping additives in all mixtures around 1983. Even HMA with liquid antistripping additives had continued problems with moisture damage. CDOT then began

FIGURE 1 High maintenance project.

FIGURE 3 Six-month-old pavement that disintegrated.

TABLE 2 Aggregate Gradation and Optimum Asphalt Contents

		Percent Passing Size Indicated, mm								
Site	Asph, %	19.00	12.50	9.50	4.75	2.36	0.60	0.30	0.15	0.08
1	5.5	100	87	72	51	45	26	18	10	7.0
2	4.5	100	87	74	53	42	24	15	10	6.6
3	5.3	100	93	77	53	37	21	14	9	5.9
4	4.9	100	88	66	50	40	21	14	8	5.1
5	5.0	100	94	80	52	41	31	18	10	7.1
6	6.0	100	100	88	51	37	22	14	10	5.9
7	5.7	100	91	74	49	37	18	12	8	4.7
8	4.8	100	94	77	49	38	24	18	12	8.1
9	5.9	100	100	96	62	41	25	13	10	6.1
10	5.0	100	86	77	55	43	26	18	13	8.6
11	4.9	100	100	97	57	40	21	15	11	7.8
12	5.0	100	86	76	54	42	25	18	13	8.4
13	5.7	100	86	78	60	45	22	15	9	5.7
14	5.3	100	86	78	63	47	25	16	10	7.7
15	5.6	100	85	76	62	49	27	18	13	8.3
16	5.4	100	88	79	61	50	30	20	13	8.3
17	5.6	100	100	95	72	44	24	17	12	7.3
18	5.6	100	100	95	70	39	21	15	11	7.2
19	5.5	100	96	93	83	69	32	20	14	11.7
20	6.5	100	96	80	50	42	26	18	12	8.3

requiring hydrated lime in all mixtures at a concentration of 1 percent by weight of aggregate. The materials in this study were tested with no antistripping treatment, using the standard AASHTO T 283 procedure to determine the baseline moisture susceptibility potential of the untreated HMA.

Lime Modification

Many of the HMA mixtures that exhibited moisture distress were originally constructed using liquid antistripping additives. The potential moisture susceptibility of these materials with 1 percent hydrated lime by weight of aggregate was investigated as part of this study. If materials from one of the sites did not contain hydrated lime when constructed, the AASHTO T 283 procedure was performed on material from the site with hydrated lime.

TABLE 3 Summary of Test Parameters for AASHTO T 283

Test Parameter	Test Requirement
Short-Term Aging	Loose mix: 16 hrs at 60° C Compacted mix: 72-96 hrs at 25° C
Air Voids Compacted Specimens	6 to 8 %
Sample Grouping	Average air voids of two subsets should be equal
Saturation	55 to 80 %
Swell Determination	Not required but determined in this study
Freeze	Minimum 16 hrs at -18° C (optional)
Hot Water Soak	24 hrs at 60° C
Strength Property	Indirect tensile strength
Loading Rate	51 mm/min at 25° C
Precision Statement	None

No Freeze

The materials from all sites were tested without the freeze cycle to determine if the actual pavement performance could be predicted.

30-min Vacuum Saturation

Some investigators (*4–9*) have performed a variation on AASHTO T 283 by vacuum saturating a sample with 7 percent air voids for 30 min. The degree of saturation was not controlled. This procedure was used in this study to ascertain whether the 30-min vacuum saturation technique had better predictive ability.

No Short-Term Aging

The materials from all sites were tested without the short-term aging required in the standard AASHTO T 283 procedure. Standard AASHTO T 283 short-term aging requires 16 hr at 60°C for loose mixture and 72 to 96 hr at 25°C for compacted specimens.

Extra Short-Term Aging

When HMA is produced for a project in Colorado, a loose sample is obtained and delivered to the Central Materials Laboratory for testing. After delivery, the sample is reheated for splitting into the correct specimen size and reheated a second time for compaction. In total, the mixture is reheated approximately 4 to 8 additional hr. The effect of such additional short-term aging was investigated in this study by subjecting loose mixtures to an extra short-term aging period of 5 hr at 121°C.

TEST RESULTS

Results from each variation in the AASHTO T 283 test are presented in the following sections.

TABLE 4 Experimental Grid

	Good Performers							High Maintenance					Complete Rehab				Disintegrators			
Test Factor	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Standard T 283	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
No freeze	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
30 minute saturation	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
No short-term aging	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Extra short-term aging	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
No modification	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Lime Modification	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√

Analysis of Antistripping Treatment Effectiveness

Figure 4 shows tensile strength ratios (TSRs) for mixtures from each site, evaluated using the standard AASHTO T 283 procedure. Mixtures were evaluated with no antistripping treatment, with the antistripping additive used during original construction (either liquid or hydrated lime), and with hydrated lime (if originally constructed with liquid additive).

For the seven sites that performed well, only two (Sites 5 and 7) showed acceptable TSRs with no additive. Site 2 showed a marginal TSR with no additive. Sites 1, 3, 4, and 6 exhibited low TSRs with no additive. In all cases, TSRs improved with addition of antistripping additive, whether liquid or hydrated lime.

For the thirteen sites that performed poorly, only one (Site 10) showed a marginal untreated TSR. The remaining sites exhibited low or very low TSRs.

With the addition of antistripping additives, 7 of 13 poorly performing sites achieved acceptable TSRs. For two of these sites (Sites 8 and 11) hydrated lime was used, and for five (Sites 9, 11, 12, 16, and 18) liquid additives were used. The remaining six poorly performing sites exhibited gains in TSR with treatment, but not enough to achieve the minimum value of 0.80 currently specified by CDOT.

With the exception of Site 19, all sites showed an acceptable TSR with the addition of hydrated lime. It is not clear if the addition of lime would have provided good pavement performance since these pavements were originally constructed using liquid additives. The data in Figure 4 suggest that the use of lime may or may not have resulted in good pavement performance for these sites. For example, Sites 1 and 3 exhibited low untreated TSRs but benefited from the addition of lime, both in TSR and actual field performance. Conversely, Sites 8 and 18 had low untreated TSRs and did benefit from the addition of lime in terms of TSR but did not benefit in terms of actual field performance.

These data clearly show that the use of antistripping agents, whether lime or liquid, as a "cure-all" does not ensure good performance. It is possible that, when these projects were constructed, just enough antistripping additive was used to facilitate a passing TSR but not enough to accommodate good performance under actual project conditions.

A secondary recommendation that resulted from the I-70 investigation (*1*) was that CDOT investigate whether there is a minimum untreated TSR below which antistripping additives should not be allowed merely to facilitate a passing TSR. Rather, if an asphalt aggregate combination has too little inherent resistance to moisture damage, a change in one or more materials should be required. In other words, an antistripping additive would not be used to overcome profound deficiencies in materials. Although the authors still support this concept, the data in Figure 4 do not. For example, Sites 1, 3, and 6 had remarkably low TSRs without treatment. With treatment, the TSRs for these sites were acceptable, as was actual pavement performance.

Analysis of Specimen Conditioning

TSRs for mixtures from each site tested using AASHTO T 283 with a freeze cycle, without a freeze cycle, and 30-min vacuum saturation with freeze are shown in Figure 5. The average TSR for these three conditioning procedures are as follows:

- Freeze, TSR = 0.84,
- No freeze, TSR = 0.81, and
- 30-min vacuum with freeze, TSR = 0.72.

Because of the variability in TSR data, there was no statistically significant difference in TSR among the three conditioning procedures. However, as shown in Figure 5, the 30-min vacuum saturation technique tended to provide a more conservative (i.e., lower) TSR value.

For the sites that performed well (Sites 1–7), no conditioning method showed consistently higher or lower TSRs. All TSR values for the sites with good performance were higher than of 0.80, except for Site 6, which was 0.74 using the 30-min vacuum saturation technique. The data in Figure 5 do not support a reduction in the 0.80 minimum TSR used by CDOT.

There was a strong trend in TSR values for the high maintenance sites (Sites 8–12) with the 30-min vacuum saturation technique consistently showing a lower TSR value. Using CDOT's current specification limit of 0.80, only the 30-min vacuum saturation technique would have largely identified these sites as being moisture susceptible.

For the complete rehabilitation and disintegration sites (Sites 13–20), any of the conditioning techniques would have identified

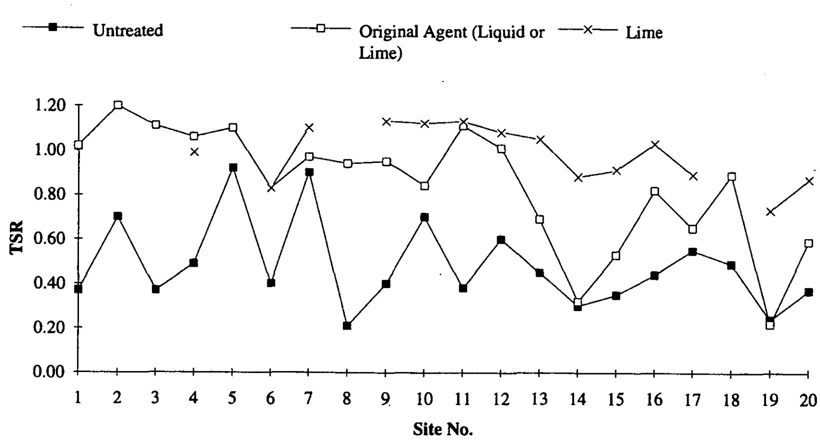

FIGURE 4 Tensile strength ratios for various antistripping treatments.

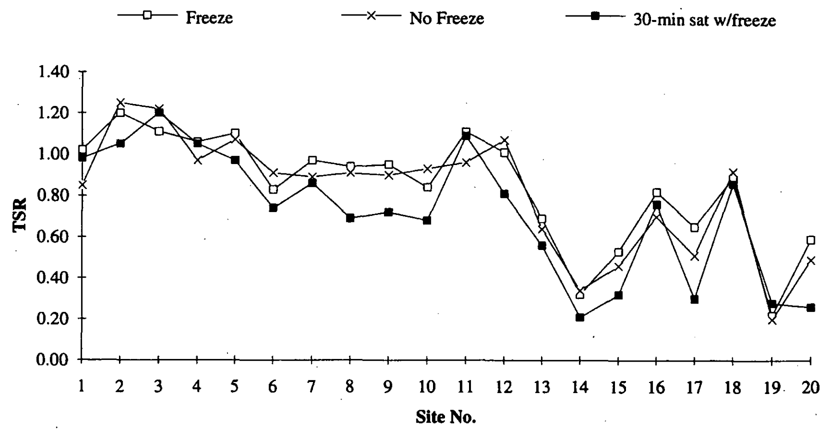

FIGURE 5 Tensile strength ratios for various specimen-conditioning techniques.

moisture-susceptible HMA. Site 18 is the exception since all of the conditioning techniques resulted in TSRs greater than 0.80.

The most obvious conclusion from the comparison in Figure 5 is that for nonmoisture-susceptible and highly moisture-susceptible asphalt mixtures in Colorado, the conditioning technique is unimportant. In other words, all three of the conditioning techniques have the ability to pass good materials and fail bad materials. For marginally moisture-susceptible mixtures such as those from Sites 8–12, the 30-min vacuum saturation technique appears to have the best ability to discriminate between desirable and undesirable performance. Using the 30-min vacuum saturation technique seems to balance "buyer's and seller's risk." That is, only one mixture showing poor performance (Site 11) would have a passing TSR. Only one mixture showing good performance (Site 6) would have a failing TSR.

The literature review conducted as part of this study showed that there is considerable disagreement over the veracity of a constant period of vacuum saturation such as 30 min. AASHTO T 283 and similar protocols such as ASTM D 4867 do not specify a constant vacuum duration. Instead, they suggest a variable duration and vacuum level to achieve saturation in the range from 55 to 80 percent. Both procedures caution that higher levels of saturation indicate specimen damage. ASTM D 4867 states that the degree of saturation is independent of time. Neither of these assertions is consistently true for the 20 sites tested in this study.

Figure 6 shows the saturation achieved using the three conditioning procedures. The 30-min saturation procedure clearly and consistently resulted in higher degrees of saturation in the range from about 85 to 95 percent. The standard AASHTO T 283 saturation procedures (freeze and no freeze) show saturation levels for the same materials with only 5 to 10 min of saturation. In all cases, the vacuum was held constant at 610 mm of mercury. Evidently the degree of saturation achieved for materials in Colorado is sensitive to vacuum duration.

The swell after conditioning for all sites is shown in Figure 7. These data show that the specimen swell is generally insensitive to saturation procedure. For good and high maintenance sites (Sites 1–12), the swell values tend to be clustered around a single swell value. For sites with poor performance there are larger differences in swell among the three saturation procedures. In these cases, the specimens subjected to the 30-min saturation vacuum procedure tended to exhibit higher swell values.

The effect on wet tensile strength of the various conditioning procedures is shown in Figure 8. In this case, there is a tendency for the 30-min vacuum saturation procedure to result in lower wet tensile strength. For 13 sites, specimens subjected to the 30-min vacuum saturation exhibited lower wet tensile strengths. However, this difference was more pronounced for the sites showing undesirable performance (Sites 13–20). For the sites with good performance

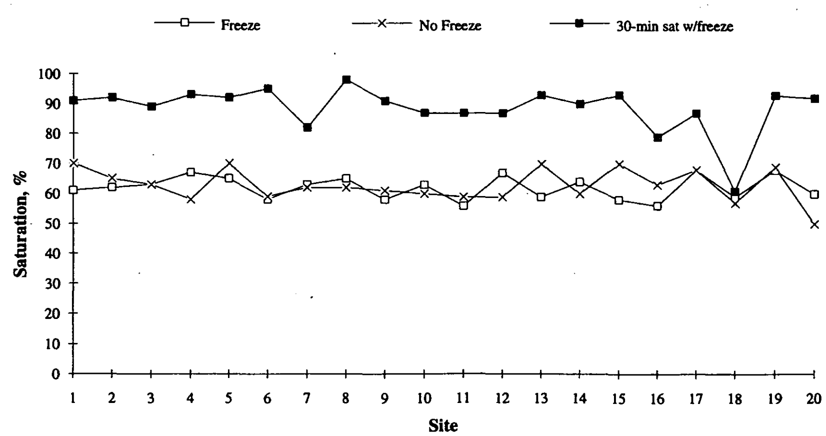

FIGURE 6 Degree of final saturation for various specimen-conditioning techniques.

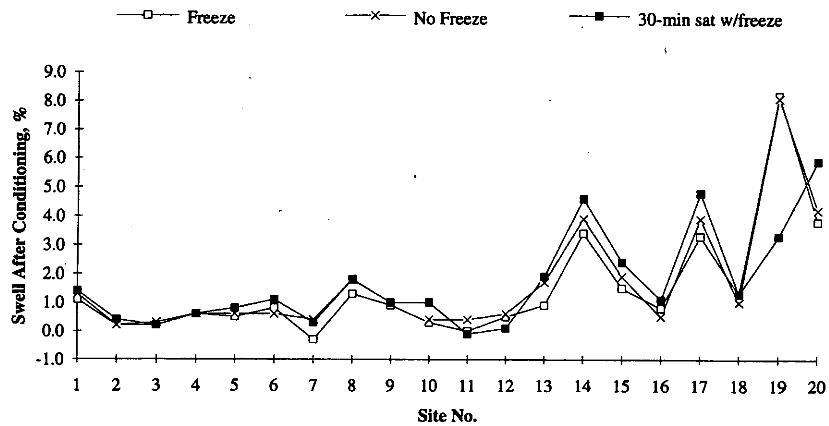

FIGURE 7 **Swell after conditioning for various specimen-conditioning techniques.**

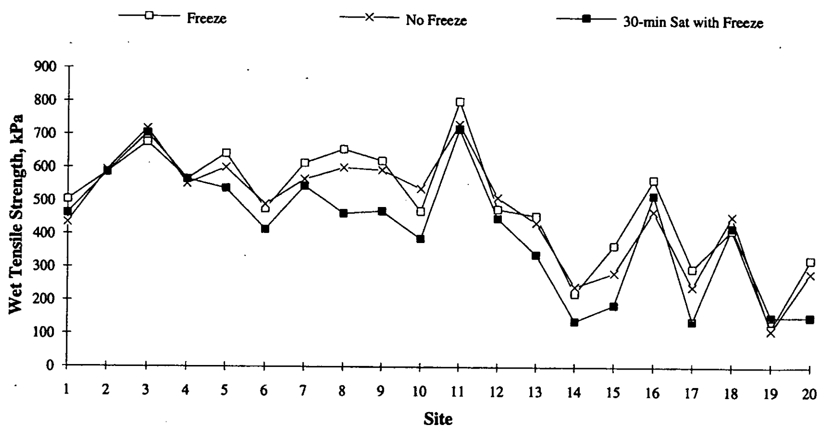

FIGURE 8 **Wet tensile strengths for various specimen-conditioning techniques.**

(Sites 1–7), the difference in wet tensile strength for the different conditioning techniques was less pronounced.

For the 20 sites in this study, whether the high degrees of saturation resulted in damaged test specimens and are thus too conservative is a matter of conjecture. The only specimens that displayed very low wet tensile strengths were those from sites performing very poorly. From these data it appears that for Colorado materials there is an equally small chance that a mixture that performs well will fail and a mixture that performs poorly will pass TSR requirements when evaluated using the 30-min vacuum saturation technique.

Analysis of Mixture Aging

Figure 9 shows the TSR values for each of the sites for the standard short-term aging in AASHTO T 283, no short-term aging, and extra short-term aging. There appears to be no correlation between observed performance and the amount of oven aging to which specimens are subjected. In most cases TSRs remained relatively constant with increases in aging. However, in one case (Site 16), the TSR decreased because the dry tensile strength increased dramatically and the wet tensile strength did not change. The TSR is generally insensitive to the amount of aging. By eliminating short-term aging, the time required for testing could be shortened significantly.

Figures 10 and 11 show wet and dry tensile strengths for each of the sites as a function of mixture aging. A significant component of HMA tensile strength is contributed by asphalt stiffness. Asphalt stiffness increases with the amount of time loose mixture specimens are subjected to oven aging. Consequently, extra short-term aging tends to result in higher tensile strength, which is the trend seen in Figures 10 and 11.

In recent years some agencies have begun specifying minimum wet tensile strengths in addition to TSR. If a minimum tensile strength is specified, the length of short-term aging must also be specified. The data in Figure 10 indicate no justification for minimum tensile strength requirements.

Specifying a TSR appears to be superior to an absolute requirement on tensile strength of a conditioned sample, particularly when AASHTO T 283 is used in an HMA production environment. The influence of aging is negated when a ratio is used. Under plant production conditions, mixture aging is a function of plant type, silo storage time, haul time, and so forth. With all these field variables, it is difficult to simulate the amount of short-term aging HMA receives.

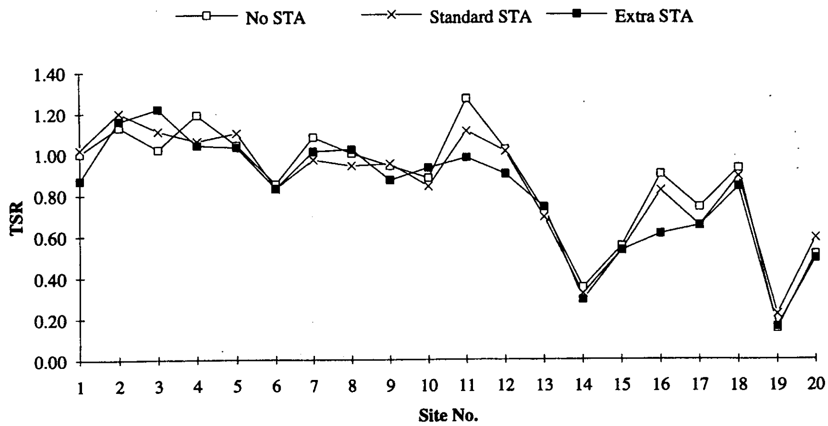

FIGURE 9 Tensile strength ratios for various specimen-aging techniques.

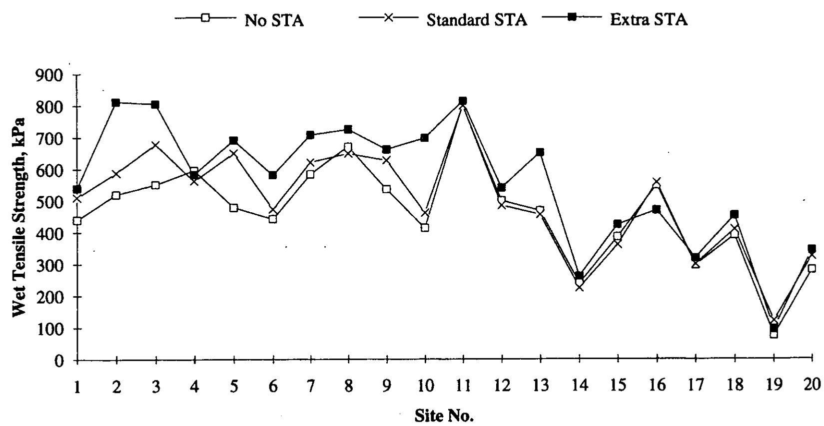

FIGURE 10 Wet tensile strengths for various aging techniques.

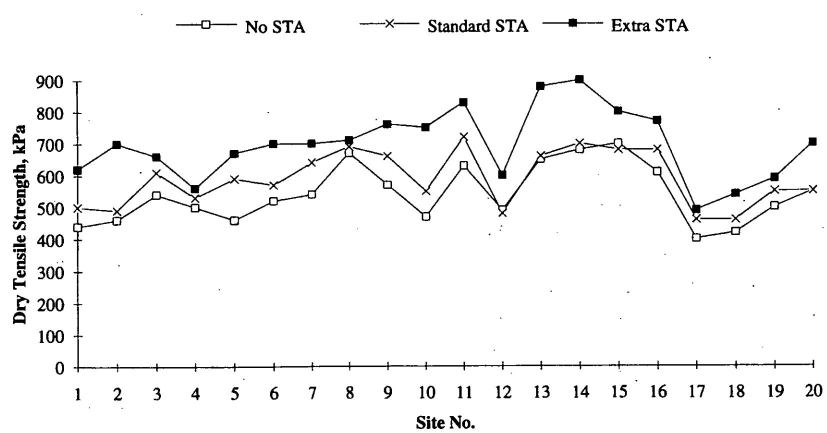

FIGURE 11 Dry tensile strengths for various aging techniques.

CONCLUSIONS

The seven sites exhibiting good performance (Sites 1–7) had mixed results when tested without antistripping treatment. Two of the sites showed high TSR values when untreated, and the remaining five sites showed poor TSR values when untreated.

For the 13 sites with undesirable performance (Sites 8–20), AASHTO T 283 results were very poor when no antistripping treatments were used. These sites suffered moisture damage even though they were originally constructed using antistripping treatments. For 2 of the 13 moisture-susceptible mixtures lime was used as an antistripping treatment; liquid treatment was used for the remainder. Consequently, it is clear that neither lime nor liquid antistripping treatments are a panacea for moisture damage.

This study could not identify a TSR below which antistripping treatment should not be considered. Several of the sites with good performance had remarkably low untreated TSR values. With treatment, these mixtures showed acceptable TSR values and acceptable performance. Without a more detailed study, no minimum untreated TSR can be identified.

In general AASHTO T 283 is a reasonable predictor of moisture susceptibility of asphalt mixtures. Mixtures known to perform well (Sites 1–7) exhibited higher TSRs. Mixtures with poor performance (Sites 13–20) exhibited lower TSRs. For these sites, representing the best and poorest asphalt pavement performance in Colorado, any of the variations in the AASHTO T 283 procedure (i.e., freeze, no freeze, 30-min vacuum saturation with freeze) would have adequately predicted observed moisture susceptibility.

High maintenance mixtures of marginal performance characteristics (Sites 8–12) were not as well identified by the standard AASHTO T 283 procedure, with or without a freeze cycle. The standard AASHTO T 283 procedure modified to include a 30-min vacuum saturation period was the most effective predictor of actual pavement performance for the marginal high maintenance sites. The 30-min vacuum saturation was shown to be a more severe conditioning procedure. However, the results of the more severe conditioning were most pronounced for the materials performing poorly and less pronounced for the materials performing well. This procedure was reasonably balanced in terms of the risk of failing good materials and passing bad materials.

Longer periods of short-term aging resulted in an increase in specimen tensile strength, particularly dry tensile strength. However, the TSR remained fairly constant because the tensile strengths generally increase proportionally. Because the length of short-term aging does not significantly affect TSR, this step could probably be skipped to shorten testing time.

The data from the 20 sites in Colorado do not support the use of a minimum tensile strength requirement. If a minimum tensile strength requirement is used, a tightly controlled short-term aging procedure should be used.

RECOMMENDATIONS

On the basis of the results from this study, the following items have been submitted to managing engineers of CDOT:

- For asphalt pavements that will simultaneously experience high traffic, high temperatures, and high moisture, a Severity Level 1 test should be used. The protocol will include no short-term aging, vacuum saturation for 30 min with 610 mm of mercury, and a freeze cycle. This is a modification of the AASHTO T 283 procedure.
- For asphalt pavements with low traffic or areas without extremely high temperatures, a Severity Level 2 test should be used. The protocol will include no short-term aging and vacuum saturation using a varying duration and level of vacuum to achieve 55 to 80 percent final saturation. This corresponds exactly to the ASTM D 4867 procedure without that procedure's optional freeze cycle.
- A knowledgeable team in Colorado should be assembled to determine traffic and environmental conditions on which to apply the two severity levels.

REFERENCES

1. McGennis, R. B., R. T. Rask, and T. B. Aschenbrener. *Investigation of Premature Distress on IH-70 in Colorado.* Report CDOT-SM-AI-92-15. Colorado Department of Transportation, Denver, 1992.
2. Aschenbrener, T. B. and R. B. McGennis. *Investigation of the Modified Lottman Test to Predict the Stripping Performance of Pavements in Colorado.* Report CDOT-DTD-R-93-3. Colorado Department of Transportation, Denver, 1993.
3. Harmelink, D. S. *Rut-Resistant Composite Pavement Design.* Report CDOT-DTD-R-91-4. Colorado Department of Transportation, Denver, 1991.
4. Lottman, R. P. *NCHRP Report 246: Predicting Moisture-Induced Damage to Asphaltic Concrete—Field Evaluation.* NCHRP, TRB, National Research Council, Washington, D.C., 1982.
5. Jiminez, R. A. *Testing for Debonding of Asphalt from Aggregates.* In *Transportation Research Record 515*, TRB, National Research Council, Washington, D.C., 1974.
6. Coplantz, J. S., and D. E. Newcomb. *Water Sensitivity Test Methods for Asphalt Concrete Mixtures: A Laboratory Comparison.* In *Transportation Research Record 1171*, TRB, National Research Council, Washington, D.C., 1988.
7. Kennedy, T. W., F. L. Roberts, and K. W. Lee. *Evaluation of Moisture Effects on Asphalt Concrete Mixtures.* In *Transportation Research Record 911*, TRB, National Research Council, Washington, D.C., 1983.
8. Stuart, K. D. *Evaluation of Procedures Used to Predict Moisture Damage in Asphalt Mixtures.* FHWA RD-86-090. FHWA, U.S. Department of Transportation, 1986.
9. Dukatz, E. K. The Effect of Air Voids on Tensile Strength Ratio. In *Proc., Association of Asphalt Paving Technologists*, Vol. 56, 1987.