COMPATIBILITY OF AGGREGATE, ASPHALT CEMENT AND ANTISTRIP MATERIALS

FINAL REPORT

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ABSTRACT

Studies undertaken for the FHWA revealed a significant moisture damage problem in Louisiana hot mix pavements. At that time an antistrip additive from a qualified products list was required at the set rate of 0.5 percent weight of asphalt cement. The additives were qualified with the subjective ten minute boil test. No provision was made to test the actual aggregate used on state projects. This study was initiated to further understand the stripping phenomenon using Louisiana specific materials and to develop an objective test procedure for field testing.

The Louisiana ten minute boil test, indirect tension test (Lottman) and the freeze-thaw pedestal test (Texas) were identified for investigation. A test factorial which included thirteen aggregates, five asphalt cements and eleven additive treatments was developed. The additives included four high efficiency liquid antistrips, four low efficiency liquid antistrips, one "super" antistrip, hydrated lime in both slurry and dry forms, and with no additive. The aggregates were chosen as representative of the predominant sources used at the time. In addition, 22 field projects which used these sources were cored to determine field experience with stripping.

The results indicated that all three tests identified field moisture susceptibility problems. A specific implementation plan was provided which provides for the use of the boil test to establish minimum antistrip additive dosage rates and the use of the ITT for job mix approval. Subsequently, all three tests have been successfully used to identify field moisture problems.

IMPLEMENTATION STATEMENT

A specific plan for the implementation of the test methods evaluated herein was proposed. The use of the ITT method for job mix approval and the use of the boil test to establish the minimum quantity of antistrip additive to use was implemented in the specifications in 1991. Its implementation followed the use of these tests along with the pedestal test to determine that stripping problems encountered on I-10, Ramah to Westover, were caused by each individual aggregate material used in those mixes.

Recently, since 1996, strong consideration has been given to eliminate the use of the boil test to determine minimum antistrip additive dosage rates. The findings of this report would indicate that the elimination of the boil test for that purpose would not be prudent. The ITT was not capable of discriminating between antistrip additives and has not been tested with respect to its effect on dosage rate.

The pedestal test has and continues to be a good diagnostic tool to determine forensic moisture damage on in-service pavements.

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INTRODUCTION

LOUISIANA EXPERIENCE

In 1982 at a joint FHWA/Georgia DOT workshop on stripping, department engineers reported that Louisiana was not believed to experience a large stripping problem (1). In the early 1960s some stripping, identified as loss of adhesion, had been noted in asphalt overlays of Portland cement concrete pavements at joint reflection cracks. Where previously poured crack sealer remained in good condition, the asphalt cement in the binder or leveling course was observed to have washed away leaving loose sand and gravel; where the joint sealer had opened up or failed, no washout was observed. This resulted in a joint repair and crack pouring policy which left these reflected joints open so that water could escape the system.

In the late 1960s scattered instances of mix instability and raveled and pitted riding surfaces prompted a research study to evaluate newly marketed "antistrip additives." This study (2) examined seven antistrip additives in the laboratory using a static immersion test and Marshall immersion properties. A standard mix requiring mineral filler was used as the control to evaluate the same mixture with the antistrip additives in lieu of the mineral filler. None of the antistrip additives demonstrated improved performance over the standard mix using the mineral filler. A field construction project using one of these additives demonstrated similar results.

By the early 1970s Louisiana had constructed over 2000 lane miles of open graded friction courses. While department policy with respect to dense graded mixes did not change (no antistrip, 2-3 percent mineral filler required), it was recognized that the open nature of the friction courses provided potential problems with stripping. A policy requiring the use of 0.5 percent by weight of asphalt cement was adopted for all friction course mixes. The static immersion test was used to qualify antistrip additives. Shortly thereafter, severe stripping problems were observed in binder and leveling course layers. A study was initiated which examined eleven gravel sources with up to seven asphalt cement sources according to typical job mixes (3). It was found that the static immersion test did not predict the stripping observed in the field. The immersion test was modified to compare asphalt cement retention after boiling for ten minutes. The results of this test indicated various combinations of aggregate and asphalt cement sources can be susceptible to moisture and that the use of the antistrip additives reduced or eliminated the stripping. The department adopted specifications requiring the use of antistrip additives in all dense graded hot mix using gravel as the coarse aggregate. The ten minute boil test was instituted for antistrip approval in lieu of the immersion test; each antistrip was tested with one standard uncrushed aggregate and asphalt cement source requiring 70 percent retainage for approval.

At this time the addition point for antistrip was the asphalt cement storage or working tank with circulation required for 24 hours prior to use. The observation of crusting and possible separation of the additive because of prolonged storage at elevated temperature, the verification of the 24 hour circulation and, indeed, even the addition of the additive, led to the policy requiring the direct feed of the antistrip into the asphalt cement feed line to the plant. Verification was determined through calibration and the use of a totalizing meter.

The department was aware that a potential shortcoming existed in both the procedure used for antistrip product qualification and its policy which allowed a contractor to select any approved additive from the qualified product list; the shortcoming was that all additives were qualified with a standard aggregate so that compatibility of materials which were project specific to field mixtures was not established. A 1982-84 task order study for the FHWA (4, 5) established that this problem was more extensive than originally anticipated. Four of ten construction projects studied exhibited signs of stripping ranging from slight to severe. These pavements were between nine and sixty months of age at the time of sampling. Each of these projects met specifications and used qualified antistrip additives. The Louisiana ten-minute boil test was used to evaluate the materials used on these construction projects. It was found that those combinations which stripped in the field failed the boil test, while those which did not strip in the field performed well.

A limited scope laboratory study using four of these aggregate sources (three which stripped, one which did not strip), two asphalt cement sources and fourteen antistrip products considered to be the manufacturer's best products, was initiated (6). The results indicated that materials compatibility for specific mix designs should be examined; significant differences in boil test performance was found to be dependent on each source material. Only five of the antistrip products performed better than using no antistrip additive while some products appeared to increase stripping. Hydrated lime used in a slurry form demonstrated excellent performance where the antistrip additives were ineffective. Newly crushed aggregate was found to provide a more severe test than uncrushed aggregate or aggregate which had been stockpiled for long periods of time. Finally, heat storage beyond 24 hours was found to adversely impact the effectiveness of the antistrip additives. On this basis, the qualified products list was reduced to five products, storage of hot mix in silos was limited to 24 hours maximum and major revisions were made to the boil test procedure which included: the use of several aggregate sources, several asphalt cement sources, crushed aggregate, 24 hour heat stability and an increase in the retention of asphalt in the boil test to 90 percent over the range of materials used to reduce subjectivity. Also, the boil test use for job mix approval was instituted so that project specific materials combinations would be tested for performance.

A review of the literature demonstrates that the stripping phenomenon is a complex problem. The chemical characteristics and surface area of the aggregate and the chemical composition of the asphalt cement and antistrip additive contribute to this problem. The boil test is one of many tests which have attempted to relate one or all of these facets to the stripping phenomenon. Although the boil test appeared to correlate with field performance on the limited scale presented above, the nature of the test is subjective and as such presents difficulties in implementing its use in field or district laboratories for job mix formula approval. There were, however, several objective test procedures being developed at the initiation of this study which appeared promising: the pedestal water susceptibility test examined by the Laramie Energy Technology Center and modified by Texas and the indirect tensile test as developed by Lottman and modified by others. The development of one or both of these tests for Louisiana use would provide the objectiveness necessary for full implementation of water susceptibility testing.

OTHER EXPERIENCE

As with most forms of mix and pavement distress, moisture susceptibility of asphalt mixtures has been reported in a cyclical nature beginning in the 1920s. The most recent cycle has drawn the attention of states and researchers circa the late 1970s through the early 1980s as reported in the predominant publications and journals. Two state-of-the-art reviews in 1982 and 1983 (7, 8) fully discuss the stripping phenomenon, use of additives and test methods. Tunnicliff and Root (7) contrast a 1958 survey showing 20 states who use some from of additive for stripping at least some of the time to a 1981 survey documenting only 20 states who rarely or never use antistripping additives. The data indicates that "some states using additives in 1981 were not in 1958 and vice versa." They indicated that the pattern is perhaps changing because of the complexity of the problem.

A basic definition of stripping comes from the Asphalt Institute (9) stating that stripping is "the breaking of the adhesive bond between the aggregate surface and the asphalt cement in a pavement or mixture." Majidzadeh and Brovold fully discussed the fundamentals and theory of adhesion and the rheology of the binder-aggregate bond in a previous state-of-the-art report (10) and identified the major stripping mechanisms of detachment (separation of asphalt from aggregate by a thin film of water), displacement (penetration of water through a break in the asphalt film) and pore pressure (circulation of water through interconnected voids in a high void mix).

The Taylor and Khosla report (8) identified two additional mechanisms (9, 11) as spontaneous emulsification (water and asphalt forming an inverted emulsion) and hydraulic scour (action of tires on a saturated pavement). In addition, they identified 34 specific tests developed over the years to predict moisture susceptibility which they grouped into the following ten general categories: static immersion, dynamic immersion, boiling, chemical immersion, quantitative coating, abrasion, simulated traffic, immersion-mechanical, nondestructive and miscellaneous. Of these, two tests, the pedestal test and the indirect tension test predominated the research of the early 1980s and appeared to provide reasonable laboratory correlations to field performance.

The pedestal test originally developed as the water susceptibility test (WST) by the Laramie Energy Technology Center (now Western Research Institute) was designed to maximize the effect of bond while minimizing the effect of mechanical properties of the mixture (12). A one size (passing No. 20, retained on No. 35) aggregate-asphalt mix was compacted into a briquette which was then placed on a pedestal in a jar, covered with water and subjected to repeated freeze-thaw cycles. A specimen was considered failed when a crack developed because of thermal stressing. They reported good repeatability and response in identification of moisture susceptible materials combinations. Kennedy, et. al. (13, 14) following the Laramie work modified the quantity of asphalt used to facilitate fabrication of the specimen, evaluated additional one sized gradations to facilitate testing individual aggregate components, and changed the freezing temperature and length of the freeze-thaw cycle. These changes became known as the Texas Pedestal Test. A number of subsequent field case studies by these researchers demonstrated good correlation between number of cycles to failure and performance with materials experiencing over 20 cycles having no moisture problems, less than 10 cycles having moisture problems and between 10 and 20 cycles undetermined. Because of the ability to test individual aggregate materials, this test was included in the current study.

In references 15 and 16, Lottman developed the indirect tensile test (splitting tensile) and resilient modulus for use as a moisture susceptibility test. Using Marshall type specimens, he saturated two sets of specimens, further freeze-thaw conditioned one of the saturated sets and compared each to the indirect tensile strength or modulus to a set of dry specimens. The ratio of saturated strength to dry strength was considered as short-term moisture susceptibility and the ratio of saturated and freeze-thaw conditioned to dry strength provided long-term moisture susceptibility. His initial findings in these works indicated high ratios and low ratios corresponded to good moisture susceptibility and poor moisture susceptibility, respectively. However, ratios in the middle were not conclusive moisture damage indicators. Tunnicliff and Root (17) used the "Lottman" procedure in a study to investigate the use of antistrip additives, as it provided an appropriate simulation and relationship to field conditions. As part of their program, they evaluated the test procedure itself providing some major improvements and modifications which included rapid cooling and saturation of specimen, use of a saturation range of 55-80 percent and a target air void content of 7 percent with an allowable range of 6-8 percent. They believed the freeze-thaw cycle to be too severe and too long and therefore modified the conditioning to a 24-hour soak at 60C. They found good correlation with Lottman results. The current ASTM procedure incorporates these changes and permits either the freeze-thaw or 24-hour soak for conditioning. It was decided that this test would be included in the study to evaluate its effectiveness for Louisiana materials.

OBJECTIVES AND SCOPE

The long-term objective of this study was to further understand the stripping phenomenon with Louisiana specific materials through the development of an objective moisture susceptibility test(s) correlated to the boil test and field experience, which could be used for materials compatibility testing in the field. Specific aims included:

- expand the materials compatibility data base of the boil test by examining the most prevalent combinations of materials used throughout the state;
- develop the pedestal test for use with Louisiana materials and determine possible correlation with the boil test; and,
- develop the indirect tension test (Lottman procedure or a modification thereof) for use with Louisiana materials and determine possible correlation with the boil test.

Thirteen aggregate sources representative of all districts, five asphalt cement sources and eight antistrip additives (4 high efficiency, 4 low efficiency) and one "super" antistrip additive were used in various combinations. Also, hydrated lime in both a slurry and dry condition was evaluated.

METHODOLOGY

MATERIALS

The Materials Test System, MATT, data base was used to identify the three most used aggregate sources in each district. The objective was to identify those sources both currently being used and which had previously been used to construct field projects. In this manner, materials and job mix formulas from ongoing projects could be used in the laboratory portion of the study and the previously constructed projects could be used to correlate lab results to field identified moisture problems. A total of thirteen aggregate sources were identified and sampled for use in this study. Ten gravel sources, two limestone sources and one syenitic granite source were included. Job mix formulas (JMF) for the field projects were also obtained from the MATT data base.

Five AC-30 asphalt cements representative of those supplied to the state were selected for use. All asphalt cements reported in the JMFs were included in this group.

Four of the antistrip manufacturers were requested to submit both their best product (high efficiency) from the approved qualified products list (QPL) and another product (low efficiency) which had previously been on the QPL but deleted after the work reported in reference 6. In addition, a relatively new "super" antistrip was included. A total of nine antistrip additives were submitted. Hydrated lime was also included as a moisture damage inhibitor. The lime was used both dry and in a slurry form.

TEST PROCEDURES

Louisiana Ten-Minute Boil Test

Louisiana's standard test procedure TR 317-77 was modified to incorporate revisions recommended in reference 6. These modifications were consistent with the current TR 317-87 test procedure. According to this procedure only the coarse aggregate was tested. A full factorial using thirteen aggregate sources, five asphalt cement sources and ten antistrip treatments (including none) was evaluated by a minimum of 4 asphalt laboratory personnel. The dosage rate of antistrip additive was 0.5 percent by asphalt weight according to the department's existing specification.

In addition, partial replicate factorials were evaluated using three aggregate sources to determine reproducibility and to evaluate differences between the antistrip additives and hydrated lime in both a slurry and dry condition.. Also, the effect of increasing antistrip dosage to 1.25 percent by asphalt weight was evaluated in a partial factorial using three aggregate sources.

Indirect Tensile Test

The test procedure from reference 17 was used which included the modifications to the original Lottman procedure limiting saturation to 55-80 percent and a target air void of 7 percent with a limiting range of 6-8 percent. Because of Louisiana's high annual rainfall and the amount of stripping found in the previous study (5), the more severe freeze-thaw conditioning rather than the 24 hour soak was used. The length of the cycle was modified to 16 hours freeze and 8 hours thaw to accommodate standard work hours.

Mixtures were prepared according to the job mixes for each of twelve aggregate sources (one of the limestone sources was not used in this analysis). Three asphalt cement sources and seven antistrip treatments were evaluated including four antistrip additives (two high efficiency, two low efficiency), none, lime slurry and lime dry.

Freeze-Thaw Pedestal Test

The Texas modified pedestal test as provided in reference 13 was used in this study. Unlike the boil test which evaluates only the coarse aggregate and the indirect tensile test which evaluates the total mixture, the pedestal test was used to examine both full aggregate mixtures proportioned according to job mixes and individual aggregate components which were believed to contribute to moisture problems in either the boil or indirect tensile tests. Duplicate pedestal tests were conducted on either full mix gradation, coarse aggregate only, coarse sand only or fine sand only in a partial factorial. For each individual aggregate material or combination, two asphalt cements and seven additive treatments including four antistrip additives (two high efficiency, two low efficiency), none, lime slurry and lime dry were evaluated.

FIELD EVALUATION

The MATT system was searched to identify field projects which were constructed using the coarse aggregate sources used this study. Two field projects were selected for each aggregate source, one project constructed during the conduct of the study and an older project if possible. Site visits were made to each selected field project where five locations were identified as having potential for moisture damage (such as the bottom of a vertical curve or over a random crack. At each of five locations on each project a core was sampled and returned to the laboratory for further evaluation. In the lab, specific gravities were determined for air void calculations and then each core was evaluated for external and internal stripping. A subjective scale of 0 to 5 was used with 0 having no signs of moisture damage and 5 being completely stripped. The field experience was analyzed with respect to the laboratory tests evaluated in the study.

RESULTS

LOUISIANA TEN-MINUTE BOIL TEST

Tables A1 - A5 in the Appendix present boil test results for each asphalt cement by aggregate and antistrip. These results are mean values of the percent retained asphalt cement coating of four raters with the exception of several combinations where only three raters were used (all aggregates/all asphalts for Unichem 8140 and Klingbeta 2550 antistrip additives and all aggregates with Unistrip 85 and Texaco asphalt). The data set was tested for statistical differences using analysis of variance methods at a 0.05 significance level. The effects of the aggregate, asphalt cement and antistrip sources were evaluated with a means test controlling the experimentwise error.

Table 1 examines the effect of aggregate source. Sources with different letter groupings demonstrate significant differences. The "A" grouping represents limestone aggregates which are clearly superior to all other aggregates in this test. The A033 source, a syenite granite, is the worst performer in the boil test indicating that this aggregate source has strong potential for moisture damage in the field even with antistrip materials at a 0.5 percent dosage. All of the aggregate sources between these groupings are gravel sources distributed throughout the state. This table demonstrates that some gravel sources perform significantly better or worse than other sources indicating the need for specific source testing (ie. group "B" A133 and A823 perform much better than group "D" A903, A817, A602 and A502). These results duplicate the findings of reference 6.

The effect of antistrip source is presented in Table 2. The Permatac Plus, Pavebond Special, Klingbeta 2550 and Unichem 8140 were identified as the high efficiency antistrip additives and the BA2000 was identified as the "super" antistrip. Similar to previous findings (6), the antistrip materials perform differently. Permatac Plus outperforms all other antistrip

TABLE 1. BOIL TEST - EFFECT OF AGGREGATE		
Source	**Mean, % Retained**	**Grouping**
AA01	98.8	A
A040	98.1	A
A133	90.0	B
A823	86.4	B C
A903	83.0	C D
A817	82.1	D
A602	80.1	D E
A502	78.9	D E F
A901	77.0	E F G
A703	76.9	E F G
A022	75.0	F G
A020	73.4	G
A033	61.6	H

materials with Pavebond LP and Unistrip 85 performing significantly worse than all other antistrip additives. Generally the high efficiency additives outperform the low efficiency additives although the low efficiency products from Klingbeta and Permatac were not significantly different from the high efficiency products. While all of the additives meet the minimum 70 percent retained criteria of the old boil test procedure over the range of aggregates and asphalt cements tested, only the Permatac Plus met the new minimum of 90 percent retained using 0.05 percent additive.

TABLE 2. BOIL TEST - EFFECT OF ANTISTRIP ADDITIVE		
Source	**Mean, % Retained**	**Grouping**
Permatac Plus	90.3	A
Pavebond Special	86.8	B
Klingbeta 2550	86.3	B
BA 2000	86.0	B
Unichem 8140	85.0	B
Permatac	84.6	B
Klingbeta LV	83.0	B
Pavebond LP	78.0	C
Unistrip 85	74.3	D
None	62.7	E

Again, similar to reference 6, the asphalt cement sources performed differently according to Table 3. In this case, Exxon and Sunshine performed better than the other asphalt cements while Calumet clearly was the most difficult source to adhere.

TABLE 3. BOIL TEST - EFFECT OF ASPHALT CEMENT		
Source	**Mean, % Retained**	**Grouping**
Exxon	89.0	A
Sunshine	87.1	A
Texaco	83.2	B
Ergon	81.3	B
Calumet	67.6	C

The effect of rater was evaluated as presented in Table 4. No difference in ratings was found after the evaluation of 650 samples (13 aggregates x 10 additives x 5 asphalt cements). This finding was not anticipated because of the subjectivity involved in rating the sample.

TABLE 4.
BOIL TEST - EFFECT OF RATERS

Rater	Mean, % Retained	Grouping
Lay	82.6	A
Fugler	82.4	A
Gueho	81.1	A
Kemp	80.3	A

One set of replicate samples was tested for three of the aggregate sources, using eight antistrip additives and five asphalt cements. The replicate samples were fabricated well after the original set of samples. Table 5 indicates that mean percent retained coating can be repeated as each pairing of original and replicate samples show no significant difference.
In addition, each rater scored the replicate samples similar to their original sample scores.

TABLE 5.
BOIL TEST - REPLICATE SAMPLES

Source	Mean, % Retained	Grouping
A823	88.7	A
A823 Replicate	87.7	A
A602	84.5	B
A602 Replicate	82.9	B
A502 Replicate	81.3	B C

A502	81.2	C

Three aggregate sources (two gravel sources and the syenitic granite) which demonstrated moisture susceptibility were identified to determine the effect of hydrated lime as an antistrip additive. Hydrated lime in both a slurry and dry form was added to the aggregates. The effect of lime is demonstrated in Table 6. The hydrated lime in the slurry form performed similar to the high efficiency antistrip materials, while the lime added dry performed similar to the two worst low efficiency antistrip additives from the original data set. It is noted that the antistrip materials performed in almost the exact order of the original data set.

TABLE 6.
BOIL TEST - EFFECT OF HYDRATED LIME

Source	Mean, % Retained	Grouping
Lime Slurry	83.9	A
Permatac Plus	83.6	A B
BA 2000	79.4	A B C
Pavebond Special	77.8	A B C
Klingbeta 2550	76.8	A B C
Unichem 8140	75.6	B C
Permatac	74.6	B C
Klingbeta LV	72.3	C
Pavebond LP	64.4	D
Unistrip 85	59.7	D
Lime Dry	59.6	D
None	43.5	E

The same aggregate sources evaluated with hydrated lime were also examined with an increased dosage of antistrip additive (1.25 percent). It had been reported that increased additive dosages could be beneficial but that sometimes increased dosages could cause more damage because of the emulsifying agent in the additives. The 1.25 percent rate was selected on this basis. Table 7 indicates that significant improvements were obtained for two of the aggregate sources. A means test that controls the comparisonwise error rate was used to determine the effect of the increased dosage versus the standard 0.5 percent dosage. Although not presented here, two of the high efficiency antistrip additives, Klingbeta 2550 and Unichem 8140 and two of the low efficiency additives, Klingbeta LV and Permatac performed significantly better at the higher dosage rate. The other additives did not provide significant improvements.

TABLE 7.
BOIL TEST - INCREASED ANTISTRIP DOSAGE

Source	Mean, % Retained	Grouping
A020 - 1.25%	79.8	A
A901 - 1.25 %	79.5	A
A901	77.0	A B
A020	73.4	B
A033 - 1.25 %	72.5	B
A033	61.6	C

INDIRECT TENSILE TEST

Indirect tensile test (ITT) or modified Lottman tensile strength ratio (TSR) results are presented in Tables B1 - B3 in the Appendix by asphalt for each aggregate and antistrip type. Similar to the boil test results this data was analyzed using analysis of variance with a means test controlling the experimentwise error at a significance level of 0.05. The effects of aggregate, asphalt cement and antistrip were evaluated.

Table 8 examines the effect of aggregate. The various groupings indicate that there were significant differences between the means for the aggregate sources. Assuming a TSR requirement of 70 percent retained strength after conditioning, half of the gravel aggregate sources should not be moisture susceptible using 0.5 percent antistrip additive. It is observed that different gravel sources perform to different levels with mix using source A133 providing outstanding results. The syenite granite, A033, did not perform well in this test similar to the boil test. However, the limestone aggregate mix, AA01, was one of the worst performing mixtures. Because this was the best performer in the boil test this result may indicate that the coarse and fine natural sands may be contributing to these poor results. Conversely, the A020 mix improved possibly with the aide of the sands. If the required TSR is increased to 75 percent only several aggregate mixes would be qualified using 0.5 percent antistrip additive.

TABLE 8.
ITT - EFFECT OF AGGREGATE

Source	Tensile Strength Ratio	Grouping
A133	89.3	A
A502	78.1	B
A703	73.6	B
A020	71.9	B
A823	71.0	B
A901	70.3	B
A903	66.1	B C
A022	56.7	C D
A817	56.3	C D
A033	55.6	D
AA01	50.9	D
A602	46.9	D

Table 9 provides the effect of antistrip additive on the TSR. While the high efficiency Unichem 8140 performed better the low efficiency Unichem 85, it performed similar to the Pavebond products. These results indicate that this test may not be able to distinguish between the performance of additives at least at the dosage of 0.5 percent. The Unichem 8140 antistrip was significantly better than no additive. That the boil test did distinguish between additives may provide reason for maintaining the boil test.

TABLE 9.
ITT - EFFECT OF ANTISTRIP ADDITIVE

Source	Tensile Strength Ratio	Grouping
Unichem 8140	71.0	A
Pavebond Special	68.5	A
Pavebond LP	66.6	A B
Unistrip 85	61.5	B C
None	60.5	C

In examining the effect of asphalt cement on the TSR, Table 10 demonstrates that the ITT distinguishes between asphalt cements similar to and in the same order as the boil test.

TABLE 10.
ITT - EFFECT OF ASPHALT CEMENT

Source	Tensile Strength Ratio	Grouping
Exxon	72.4	A
Ergon	66.8	B
Calumet	57.5	C

Samples were prepared for an additional combination of six aggregate mixes and three asphalt cements in which hydrated lime was added either in a slurry or dry format. These TSRs were compared to the results using antistrip additives. Table 11 reveals that the lime slurry mixture clearly outperformed all of the other antistrip additives. The use of lime dry as a mineral filler provided no difference in performance between the antistrip additives and no additive.

TABLE 11.
ITT - EFFECT OF HYDRATED LIME

Source	Tensile Strength Ratio	Grouping
Lime Slurry	88.3	A
Unichem 8140	71.0	B
Pavebond Special	68.5	B C
Pavebond LP	66.6	B C D
Lime Dry	65.6	B C D
Unistrip 85	61.5	C D
None	60.5	C D

It should be noted that 9.5 percent (121/1278) of the total specimens produced for the ITT were outside test method limits for air voids or percent saturation. Additional specimens were not fabricated because of quantities of remaining materials. All data was analyzed with both the full data set including the out-of-specification specimens and after deleting these specimens. The data presented herein includes all data. The removal of data slightly changed several means. The ordering or grouping of the asphalt cements and additives did not change with the removal of data; the ordering of the aggregates changed with minor modification of the groupings. The following pairs of aggregates changed order in the reduced data set: A703/A020, A022/A817 and AA01/A602.

A correlation analysis of the mean boil test and the ITT data revealed a very poor correlation coefficient, r^2=0.11. However, a plot of boil test versus ITT data as presented in Figure 1 provides some useful information. Assuming a minimum TSR of 75 for the ITT and a minimum percent retained coating in the boil test as 80, the plot is divided into four quadrants. Numbered counterclockwise from the top right, quadrant I should represent materials with both good performing aggregate and sands, quadrant II good aggregate/poor sands, quadrant III both poor performing aggregate and sands and quadrant IV poor aggregate/good sands. On this basis, mix with A133 aggregate is the only mix which should not be susceptible to moisture damage. Quadrant II mixes AA01, A602, A817, A823 and A903 may display moisture damage because of the sands as their aggregate had good boil test results but poor ITT TSR. Quadrant III mixes A020, A022, A033, A703 and A901 should show moisture damage because of poor performing boil test and ITT TSRs. Finally, Quadrant IV mix A502 may indicate damage because of poor aggregate response in the boil test while the sands may help provide good ITT results. This analysis formed the basis for the pedestal test evaluation and was related to the field evaluation.

FREEZE-THAW PEDESTAL TEST

Because the pedestal test can take up to twenty days to complete it was considered as a diagnostic tool rather than a quality control or acceptance test. For this reason and because of a limitation of materials after the extensive boil test and ITT factorials, only selective materials were evaluated in this test. Generally two asphalt cements and seven additive treatments were used. Either a full mix, coarse aggregate, coarse sand or fine sand was combined with the asphalt cements and additives depending on how the mix performed in Figure 1. The results are tabulated in Table C1 in the Appendix. The data were analyzed using analysis of variance with a means test controlling the experimentwise error rate at a 0.05 significance level.

The effect of coarse aggregate source was not evaluated because of the use of only a partial factorial. Similar to the boil test and ITT, the pedestal test did detect a difference in performance between the two asphalt cements used.

Table 12 examines the effect of additive for all pedestal tests. Surprisingly, no additive performs better than all additives except the Pavebond Special. Similar to the boil test, the pedestal test distinguishes between the performance of additives. The pedestal test ranks the high efficiency Unichem 8140 lower than both the boil test and ITT. Unlike the boil test and ITT, the pedestal test does not distinguish between the slurry and dry forms of hydrated lime.

TABLE 12.
PEDESTAL TEST - EFFECT OF ADDITIVES

Source	Cycles	Grouping
None	18.4	A
Pavebond Special	15.4	A B
Lime Slurry	13.2	B C
Lime Dry	10.4	C D
Pavebond LP	9.7	D
Unichem 8140	6.1	E
Unistrip 85	5.6	E

TABLE 13.
PEDESTAL TEST - EFFECT OF AGGREGATE TYPE

Source	Cycles	Grouping
Full Mix	18.3	A
Coarse Aggregate	15.9	B
Fine Sand	11.2	C
Coarse Sand	8.8	D

Testing the effect of aggregate type in the pedestal test revealed a difference in performance (Table 13). The full mix, coarse aggregate, fine sand and coarse sand provide a descending number of cycles. The coarse sand is the worst performing component with the full mix performing the best. Perhaps there is a better fit of aggregates in the full mix compared to each individual aggregate component which permits the full mix specimens to perform better.

FIELD EVALUATION

The field evaluation data is presented in Table D1 in the Appendix. Generally, core IDs labeled 1 through 5 were from one project with cores 6 through 10 from a second project for each aggregate source. In some cases several cores were extracted from the same location or nearby when moisture damage was found. Only one project was cored for two of the aggregate sources.

Signs of stripping were found at at least one location on 13 of the 24 projects evaluated. Table 14 relates the field data to the three moisture susceptibility tests examined in this study. In this table the potential for moisture susceptibility is indicated with an “X”. A “?” in the pedestal data indicates possible moisture problems.

The pedestal test, similar to the other tests, indicated that mix made with A133 aggregate, a quadrant I material which should provide good performance, should not have moisture problems (the Unichem and low efficiency Pavebond antistrips detracted from the performance of the A133 aggregate mix). With respect to quadrant II mixes which should exhibit good coarse aggregate response and poor sand response, the pedestal test correctly indicated questionable or poor sands for mixes made with A903, AA01 and A817 materials. Mixes using materials from A602 and A823 which should have demonstrated poor field performance did not appear stripped in the field. The pedestal test correctly identified materials from quadrant III including both coarse aggregates and sands having potential to strip, for three sources, A022, A020 and A033 while incorrectly identifying the sands in mix A 901 as potential strippers based on the field results evaluated. For quadrant IV mixes the A703 coarse aggregate was correctly identified as having moisture problems and the A502 questionable coarse aggregate was not yet found to be a problem in the field. Overall, the pedestal correctly confirmed 8 of 12 mixtures or components to be potential strippers in the field. Two mixtures identified as having stripping potential have not yet experienced damage in the field. Similar results were achieved with the ITT. The ability of the boil test to identify potential field problems is dependant on the failure criteria. Using the 80 percent retained coating criteria from Figure 1, the boil test did not identify stripping found in the field. With the criteria raised to 90 percent, all field stripping would have been identified, but four materials would have indicated potential problems where the field experience has not yet demonstrated stripping.

TABLE 14. MOISTURE SUSCEPTIBILITY POTENTIAL

Agg Source	Pedestal Test				Boil Test	ITT	Field Result
	Mix	Agg	C.S.	F.S.			
A022			?	?	X	X	Agg oily, stripped; sands stripped
A033	X	?	?	?	X	X	Agg OK; sands stripped
A602			?	?		X	Agg oily
A903		?	X			X	Agg stripped; sands stripped
A901			X		X	X	Agg oily, stripped
A133	X						Agg oily, no stripping
A817		?	?			X	Agg oily, stripped; fines stripped
A823	?		?			X	Agg stripped
A703	?	X			X	X	Agg oily
A502		X			X		Agg OK
A020		X			X	X	Agg stripped
AA01			X	X		X	C.S. stripped

CONCLUSIONS

The following conclusions are drawn from the data generated in this study and, as such, are constrained by the number of materials examined.

1. Each test evaluated, the Louisiana ten-minute boil test, indirect tensile test (Lottman) and the freeze-thaw pedestal test (Texas), were effective in identifying moisture susceptible mixes or individual aggregate components.

2. These test methods indicate that most commonly used Louisiana materials and mixes are moisture susceptible and that the current addition rate of 0.5 percent antistrip may not be sufficient to prevent stripping. Addition of 1.25 percent antistrip additive improved boil test results.

3. The boil test was discriminating with respect to aggregate source, antistrip source and asphalt cement source. Even though this is a subjective test, no differences were found between raters. Replicate samples produced reproducible ratings.

4. The hydrated lime in a slurry form and high efficiency additives performed better than the low efficiency additives in the boil test. Lime dry performed similarly to several low efficiency antistrips. Boil tests with no additive performed worse than boil tests with additives.

5. An increased antistrip dosage improved the boil test results for two of three aggregates evaluated indicating the potential to use this test for determining antistrip dosage rate for job mix approval. The increase in dosage is necessary because only one aggregate source would meet the current 90 percent retained coating at a 0.5 percent dose. Improvement with increased dosage was also demonstrated to be affected by antistrip source; increased rates did not improve the performance of all antistrip additives.

6. The ITT was able to distinguish performance between different aggregate asphalt cement sources. It was not able to determine differences in performance between antistrip additives. Hydrated lime slurry provided ITT results significantly better than antistrip additives. Hydrated lime added dry performed similarly to the low efficiency antistrip additives and to the use of no additives.

7. As a diagnostic test, the freeze-thaw pedestal test correctly identified potential moisture problems for 8 of 12 mixtures or aggregate components as determined by field experience. The ITT, using a 75 percent retained strength criteria, also identified these same mixtures as being moisture susceptible but incorrectly identified two mixtures which have not demonstrated field stripping. The boil test has similar success identifying potential moisture problems depending on failure selection criteria.

8. The pedestal test was capable of discriminating between all antistrip additives including hydrated lime but did not demonstrate differences in performance between lime slurry and lime added dry as did the other test methods. Also, most of the full mixes tested in the pedestal test did not indicate poor performance which may not make this test useful for establishing job mix performance.

9. Both the ITT and pedestal test demonstrate that sands have the potential to strip; field results confirm problems with sands.

RECOMMENDATIONS

The conclusions of this study indicate that each of the test methods evaluated can be used to predict potential moisture susceptibility problems. However, certain shortcomings are associated with each test method as the boil test only examines the coarse aggregate and the pedestal test can take up to 20 days to complete. The boil test, therefore, would not determine problems associated with sands and the pedestal test would be too time consuming for job mix formula approval or quality control testing. While the ITT examines the entire mixture, it is not discriminating with respect to antistrip type or possibly quantity. On this basis the following implementation program is recommended.

1. The boil test, because it is a quick, easily conducted test, should be used to establish the quantity of antistrip to be used to prevent moisture damage of the coarse aggregate. The current 90 percent retained coating requirement should be continued. The total quantity of antistrip should be limited to no more than the 1.25 percent used in this study. Quantities of antistrip additive above this amount may induce stripping because of the emulsifying agents in the additive. The boil test will discriminate between antistrip additives.

2. The ITT should be used to confirm mix performance as part of the job mix approval. The required tensile strength ratio should be 75 percent, minimum.

3. The pedestal test should be used as a diagnostic tool to individual mix components which may contribute to moisture susceptibility. Additional work should be continued to determine the effect of increased antistrip dosages in this test method and why the use of no antistrip in the full mixture performed so well. Pending successful results, the pedestal test could be used to supplant the boil test for QPL approval of antistrip

additives. While it would take longer to approve the additives, the results would be more objective.

4. Strong consideration should be given to the required use of hydrated lime as an antistrip additive based on its strong performance in this study.

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APPENDIX

TABLE D1
FIELD EVALUATION

Aggregate Type	Core ID	Mix Type	Air Voids	External Rating	Internal Rating	Comments
A022	A1	WC	7.4	0	2	Some Uncoated Agg
A022	A2	WC	4.8	0	.5	SL Oily on Some Agg
A022	A3	WC	3.0	0	.5	SL Oily on Some Agg
A022	A4	WC	2.8	0	2	Oily Agg
A022	A5	WC	2.8	0	2	Oily Agg
A022	A6	WC	Broke	0	2	Over Crk- Dry AC and Some Uncoated Agg
A022	A7	WC	4.3	0	2	Oily Coating Agg
A022	A7	BC	6.7	0	3	Dry AC Crumbly- Uncoated Sand LT Oil Agg
A022	A8	WC	6.4	0	2.5	Uncoated Sand- LT Oil Agg
A022	A8	BC	6.8	0	2.5	Uncoated Sand- LT Oil Agg
A022	A9	WC	3.8	0	2.5	Same
A022	A9	BC	5.9	0	2.5	Same- Dry AC
A022	A10	WC	3.0	0	3	Uncoated Agg and Sand

A022	A10	BC	5.2	0	3	Uncoated Agg and Sand
A033	B1	WC	2.6	0	0	
A033	B1	BC	6.6	0	0	
A033	B2	WC	2.3	0	0	
A033	B2	BC	3.5	0	0	
A033	B3	WC	2.5	0	0	
A033	B3	BC	4.6	0	0	
A033	B4	WC	2.4	0	0	
A033	B4	BC	3.3	0	0	
A033	B5	WC	4.1	0	0	
A033	B5	BC	4.9	0	1	Dryer AC than Others and Some SL Uncoated
A033	B6	WC	8.3	0	0	
A033	B6	BC	8.9	0	0	
A033	B7	WC	6.2	0	1	C.S. SL Stripped
A033	B7	BC	8.9	0	1	Uncoated Gravel
A033	B8	WC	9.4	0	1	Uncoated F.S.
A033	B9	WC	5.9	0	1	Dry Looking- Uncoated F.S.
A033	B10	WC	8.8	0	0	Dry AC- Dull Coating on Agg
A602	C2	BC	4.1	1	1	Several Uncoated Agg
A602	C5	BC	5.0	0	1	Oily Coating on Agg

A602	C7	WC	4.7	0	.5	SL Oily Coated Agg
A602	C8	WC	6.9	0	.5	SL Oily Coated Agg
A602	C9	WC	6.5	0	.5	SL Oily Coated Agg
A602	C9	BC	4.3	0	.5	SL Oily Coated Agg
A602	C10	WC	5.5	0	.5	SL Oily Coated Agg
A602	C10	BC	3.8	0	.5	SL Oily Coated Agg
A903	D1	WC	NA	4	4	Dry AC- Lots of Stripped Agg (Fines and C.A.)
A903	D1A	WC	5.5	0	0	
A903	D1A	BC	NA	3	0	
A903	D1B	WC	5.9	0	0	
A903	D2	WC	Broke	4	4	Over Crk- Stripped Agg at Lift Interface and Dry AC with Stripped Agg
A903	D3	WC	4.3	5	5	Stripped Dry AC Loose Gravel
A903	D3A	WC	NA	0	1	SL Oily Agg
A903	D3B	WC	NA	5	5	Loose Gravel- Dry AC Stripped

A903	D3C	WC	NA	5	5	Loose Gravel- Dry AC Stripped
A903	D4	WC	Broke	4	4	Brittle- Stripped C.A. and C.S.
A903	D5	WC	Broke	3	3	Cracked
A903	D6	WC	Broke	0	2-3	Over Crk- AC Dry with some Interface Stripping
A903	D7	WC	Broke	4	3	WC < 1 in and AC is Brittle with some Fines Stripped- Agg Oily- Coated Kept Dry
A903	D8	WC	Broke	3	2	Fines Stripped
A903	D9	WC	Broke	1	2	Fines Stripped
A903	D10	WC	9.1	1-2	2	Fines Stripped
A901	E1	WC	Broke	2	3	Over Crk- AC Dry and Agg Stripped
A901	E2	WC	5.0	0	1	Agg Oily
A901	E3	WC	2.8	0	1	Agg Oily
A901	E3	BC	5.2	0	2	AC Dry- Agg Oily
A901	E4	WC	4.4	0	2	AC Dry- Agg Oily
A901	E5	WC	2.7	0	2	AC Dry- Agg Oily
A901	E6	WC	Broke	0	.5	Agg Oily- AC Alive
A901	E6	BC	Broke	0	1	Agg Oily- AC Alive

A901	E6	WC	-------	0	.5	Over Crk
A901	E7	WC	3.9	0	2	Agg Oily
A901	E8	WC	5.9	0	.5	Agg Oily
A901	E9	WC	Broke	4	3-4	AC Dry- Agg Uncoated
A133	F1	WC	Broke	1	3	Over Transverse Crk- AC Dry and some Agg is Stripped
A133	F2	WC	2.9	0	1	Agg Oily
A133	F2	BC	3.9	0	1	Agg Oily
A133	F3	WC	3.3	0	0	---------
A133	F3	BC	4.2	0	1	Agg Oily- AC Dry
A133	F4	WC	2.1	0	2	Agg Oily
A133	F4	BC	6.8	0	2	Agg Oily- AC Dry
A133	F5	WC	3.4	0	2	Agg Oily
A133	F5	BC	5.8	0	0	AC Ok
A817	G1	WC	4.5	0	1	C.A. Oily
A817	G1	BC	7.0	2	1	C.A. Oily
A817	G2	WC	3.4	0	0	AC Fresh
A817	G2	BC	4.5	0	2	C.A. Oily
A817	G3	WC	Broke	0	1	C.A. Oily
A817	G3A	WC	10.0	0	3	Some Uncoated- AC Very Dry
A817	G4	WC	6.5	0	2	C.A. Oily

A817	G5	WC	4.5	2	4	Over Crk- Agg Totally Stripped in Crk Agg Stripped- AC Dead
A817	G5A	WC	Broke	4	4	Over Crk 20ft Away- AC Dead
A817	G5B	WC	7.0	4	4	Some Stripped Fines 40ft Away- AC Dead
A817	G6	WC	4.5	0	2	Agg Stripped in Crack- Agg Oily
A817	G7	WC	4.3	5	5	Core Fell Apart on Extraction C.A. and Fines
A817	G8	WC	6.5	0	1	Oily Agg
A823/A810	H1	WC	Broke	0	1	Oily C.A. - Fine Coated
A823/A810	H2	WC	4.0	1	3	Some Uncoated Agg
A823/A810	H3	WC	5.7	0	2	C.A. Oily
A823/A810	H3	BC	5.6	0	2.5	C.A. Oily- Several Uncoated
A823/A810	H4	WC	5.7	0	2	C.A. Oily
A823/A810	H5	WC	6.9	1	3	Several Uncoated

A823/A810	H5	BC	5.3	0	1	C.A. Oily
A823/A810	H5B	WC	6.9	3	4	Definite Stripping
A703	I1	WC	6.8	0	1	Large Agg Still Oily LT Coating- Fines Coated
A703	I1	BC	7.9	0	2	More C.A. Oily
A703	I2	WC	10.0	0	2	C.A. Oily
A703	I2	BC	10.3	0	0	
A703	I3	WC	8.7	0	2	C.A. Oily- Fines Ok
A703	I3	BC	8.7	0	1	C.A. Oily- Fines Ok
A703	I4	WC	7.3	0	2.5	Clay Balls- C.A. Oily
A703	I4	BC	9.0	0	1	C.A. Oily- Large Agg for Lift Thickness
A703	I5	WC	8.4	0	1	C.A. Oily
A703	I5	BC	7.9	0	1	C.A. Oily
A703	I6	WC	5.4	0	2	All C.A. Oily
A703	I6	BC	6.9	0	2	All C.A. Oily
A703	I7	WC	6.3	0	2	All C.A. Oily
A703	I7	BC	6.4	0	1	All C.A. Oily
A703	I8	WC	3.6	0	2	All C.A. Oily
A703	I8	BC	6.3	0	1	All C.A. Oily
A703	I9	WC	3.9	0	2	All C.A. Oily

A703	I9	BC	6.7	0	2	All C.A. Oily
A703	I10	WC	8.3	0	2	All C.A. Oily
A703	I10	BC	6.6	0	2	All C.A. Oily
A502	J1	WC	Broke	.5	2	Stripped in Crack
A502	J2	WC	8.5	1	0	
A502	J2	BC	5.2	0	.5	
A502	J3	WC	Broke	1.5	3	Stripped in Crack-Loose Gravel/Sand
A502	J3A	WC	5.4	1.5	.5	
A502	J3A	BC	3.7	1.5	1.5	
A502	J4	WC	5.9	1.5	.5	
A502	J4	BC	5.5	0	1	
A502	J5	WC	NA	1.5	1.5	Cracked Core
A502	J5	BC	NA	1	2.5	Cracked Core
A502	J5A	WC	6.6	1	1.5	
A502	J5B	WC	5.2	1	1	
A502	J5B	BC	4.4	.5	0	
A502	J5C	WC	5.9	0	.5	
A502	J6	WC	Broke	1	3	Cracked Core
A502	J6A	WC	7.2	0	0	
A502	J6B	WC	9.9	.5	0	
A502	J7	WC	NA	1	1	
A502	J8	WC	7.0	2.5	0	
A502	J9	WC	5.1	.5	.5	
A502	J10	WC	5.1	.5	.5	
A020	K1	WC	8.5	2.5	0	Stripped Externally
A020	K2	WC	8.1	2.5	0	Stripped Externally
A020	K3	WC	Broke	2	0	Stripped Externally

A020	K4	WC	8.7	2.5	0	Stripped Externally
A020	K5	WC	9.8	2.5	2	Stripped Externally- Larger Agg Shows Stripping
A020	K6	WC	6.2	1.5	0	Surface Wearing (Stripping)
A020	K7	WC	Broke	2.5	4	Core Taken on Crack (not Complete) Loose Gravel (Completely Stripped)
A020	K7A	WC	6.8	1.5	0	20ft E K7
A020	K7B	WC	5.3	2	0	Wearing Surface Shows Stripping
A020	K8	WC	8.0	1.5	0	Wearing Surface Shows Stripping
A020	K9	WC	5.9	1.5	0	Wearing Surface Shows Stripping
A020	K10	WC	Broke	1	0	Core Taken on Crack (Dirt Film in Crack)
AA01	L1	WC	6.7	0	1	C.S. , Pea Gravel, and SL Stripped
AA01	L2	WC	6.2	0	0	
AA01	L3	WC	6.5	0	0	

AA01	L3	BC	4.7	0	0	
AA01	L4	WC	7.3	0	.5	SL Gravel Stripped
AA01	L5	WC	6.2	0	0	
AA01	L5	BC	4.0	0	.5	SL- Pea Gravel
AA01	L6	WC	10.2	0	0	
AA01	L6	BC	Broke	0	1	Crack in BC
AA01	L7	WC	9.2	0	0	
AA01	L7	BC	8.9	0	.5	Slight Stripping
AA01	L8	WC	8.1	0	0	
AA01	L8	BC	9.7	0	0	
AA01	L9	WC	7.7	0	1	Slightly Dry (Shows Stripping)
AA01	L9	BC	11.7	0	.5	Pea Gravel Slightly Stripped
AA01	L10	WC	6.0	0	0	
AA01	L10	BC	11.0	0	0	
A040/A124	M1	WC	6.4	0	0	No Signs of stripping- SL Stripping C.S.
A040/A124	M1	BC	9.5	0	.5	No Signs of stripping- SL Stripping C.S.
A040/A124	M2	WC	Broke	0	.5	Taken Over Crack- Pumped Material in Crack- C.S. SL Stripped and Uncoated Sand Between Lifts

A040/A124	M2	BC	Broke	0	0	Taken Over Crack- Pumped Material in Crack- C.S. SL Stripped and Uncoated Sand Between Lifts
A040/A124	M3	WC	6.7	0	0	No Signs of Stripping
A040/A124	M3	BC	11.4	0	0	No Signs of Stripping
A040/A124	M4	WC	6.3	0	0	No Signs of Stripping
A040/A124	M4	BC	8.2	0	0	No Signs of Stripping
A040/A124	M5	WC	5.0	0	0	None
A040/A124	M5	BC	7.4	0	0	None
A040/A124	M6	WC	5.6	0	0	None
A040/A124	M6	BC	6.6	0	0	None
A040/A124	M7	WC	5.5	0	0	None
A040/A124	M7	BC	6.5	0	1	Pea Gravel from C.S.- SL Stripped
A040/A124	M8	WC	4.8	0	0	None

A040/A124	M8	BC	7.3	0	0	
A040/A124	M9	WC	5.9	0	0	
A040/A124	M9	BC	6.8	0	0	
A040/A124	M10	WC	5.7	0	0	
A040/A124	M10	BC	NA	0	0	