Reuse of Moisture-Damaged Asphaltic Concrete Pavements

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Many of South Carolina's asphaltic concrete pavements have experienced stripping. It is not known whether these materials will experience stripping again if recycled. A laboratory and field study was initiated to evaluate the effects of reusing moisture-damaged asphaltic concrete, the recycled mix design procedures that use cored reclaimed asphalt pavement (RAP) instead of milled RAP, the effects of antistrip additives on recycled mixtures, and the ability of laboratory-prepared Marshall specimens (25 blows per side compaction effort) to predict certain characteristics of recycled asphaltic concrete pavement. A total of 144 Marshall specimens were made and tested. In addition, sixty-four 4-in.-diameter and thirty-two 8-in.-diameter field cores were obtained from a test pavement section before and after recycling. Both laboratory and field specimens (4 in. in diameter) were subjected to two moisture conditions (i.e., dry and wet) and tested for indirect tensile strength (ITS), resilient modulus (MR), visual strip rating, and air voids. Tunnicliff and Root testing procedures were used for moisture conditioning of specimens. Marshall specimens containing moisture-damaged asphaltic concrete mixtures obtained significantly higher ITS and MR values than those prepared with virgin materials. In addition, the results indicated that there were no statistical differences between ITS and MR of specimens prepared with cored RAP and milled RAP. Antistrip additives were found to be effective in improving the ITS and MR of specimens in the saturated condition.

Asphaltic concrete has been used to pave nearly 2 million mi of pavements in the United States, approximately 93 percent of the hard-surfaced roads in this country. Maintenance of these highways accounts for more than one-third of the total highway budget (*1*).

As soon as the flexible pavement is placed, weather (e.g., rain, sunshine, etc.) begins to affect it. Stripping has been a problem ever since highways have been paved with asphaltic concrete mixtures. Stripping occurs when there is a loss of adhesion between the aggregate and the asphalt cement due to the action of moisture.

Severe stripping was found in more than 8 percent of asphalt pavements sampled in South Carolina and in some areas has caused serious pavement damage resulting in increased maintenance (*2*). Stripping is a complex problem dependent on many variables, including the type of mix, asphalt cement characteristics, aggregate characteristics, environment, traffic, construction practice, and use of antistrip additives. The mechanisms of stripping are detachment, displacement, spontaneous emulsification, and pore pressure (*3*).

Antistrip additives have been used to increase the pavement's resistance to stripping, and many state highway agencies now require their use in asphaltic concrete pavements. Antistrip additives can be liquid chemicals, hydrated lime, or portland cement. Hydrated lime is considered to be one of the most effective antistrip additives available (*4*). These additives improve the "wetting" of the aggregate which, in essence, promotes the bonding of asphalt cement and aggregate, resulting in pavement that is stronger and more resistant to stripping.

Although many researchers have investigated stripping of conventional asphaltic concrete pavements, not many investigations were found in the use of stripped materials in recycled asphaltic concrete mixtures. The South Carolina Department of Highways and Public Transportation (SCDHPT) and the Federal Highway Administration (FHWA) funded a research effort to study the reuse of moisture-damaged asphaltic concrete pavements. The research was conducted by the Department of Civil Engineering at Clemson University. This paper represents a portion of this research project.

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BACKGROUND

Before the mid-1970s, highway agencies had little incentive to reduce the cost of maintaining asphalt pavements. Virgin aggregates were inexpensive and plentiful, liquid asphalt cost as little as $20/ton, and the cost of fuel and electricity to produce a ton of virgin mix amounted to only about 9 cents. The nation was then faced with an energy crisis. As a result, the cost of materials and services needed in the production of asphaltic concrete mixtures increased dramatically. The average price of hot-mix asphaltic concrete has increased by more than 300 percent since 1970, with aggregate and asphalt cement increasing 300 percent and 700 percent, respectively (*5*). When highway departments realized that their budgets could no longer fund highway programs, material supply, and energy, they investigated alternatives such as the recycling of asphalt pavements (*6*).

The process of recycling includes the removal of asphalt pavement from the highway using a milling machine that produces an aggregate-like material referred to as reclaimed asphalt pavement (RAP). The RAP material is mixed with hot aggregate and asphalt cement. Researchers were able to produce a recycled pavement that has proven to be the equal of and at times superior to conventional pavements (*7*). FHWA estimated that various highway agencies saved approximately $105.5 million in 1985 by using recycled asphaltic concrete mixtures (*8*).

RESEARCH OBJECTIVES

The primary objective of this research was to evaluate the reuse of moisture-damaged asphaltic concrete mixtures. The evaluation was performed by comparing laboratory-prepared Marshall specimens containing recycled materials with those containing only virgin materials. The secondary objectives were to evaluate (*a*) the use of the SCDHPT recycled mix design method that uses RAP taken from field cores (cored RAP) instead of using milled RAP that is used in the actual pavement construction, (*b*) the ability of laboratory-prepared Marshall specimens to predict some characteristics of field specimens [i.e., indirect tensile strength (ITS), resilient modulus (MR), tensile strength retained (TSR), resilient modulus retained (MRR), and visual strip rating (VSR)], and (*c*) the effects of antistrip additives on the recycled asphaltic concrete mixtures.

METHODOLOGY AND MATERIALS

A 2-mi test pavement section was selected by SCDHPT personnel for this research. The test section was divided into four ½-mi-long subsections. One coring site was randomly selected from each of the four subsections using a random number table.

Eight 8-in. cores were obtained using a water-cooled truck-mounted drill from each of the four coring locations before the highway was paved with the recycled asphaltic concrete mixture. These cores (cored RAP) were obtained to duplicate the procedure that the SCDHPT uses in its recycled mix design. Since the contractor milled the top 2.5 in. from the highway surface, 2.5 in. were cut from the top of four 8-in. core specimens using a masonry saw. These 2.5-in. layers were placed in an oven until the sides began to soften (15 to 20 min). Aggregate that had been scored or cut by the saw blade and coring bit were removed from the surfaces of the 2.5-in. layers.

The layers were then placed back into the oven until they were soft enough to be separated into their smallest fractions without fracturing the aggregate. The contractor used a cold milling machine to reclaim the asphaltic concrete pavement. As the milling machine milled each of the four coring sites, milled RAP was obtained from the conveyor belt.

After the test section was paved with the recycled asphaltic concrete mixture, core specimens were obtained from the four coring sites. Sixteen 4-in. cores and eight 8-in. cores were obtained from each coring site. Half of the 4-in. and 8-in. cores were obtained from the wheelpath (2 ft from pavement stripe) and the other half were obtained from the center path (between the wheelpaths). These cores were to be used as a comparison with the laboratory-prepared marshall specimens.

The materials used in the preparation of laboratory-prepared Marshall specimens were identical to those that were used to recycle the test section. One aggregate and one asphalt cement (AC-20) source were used. Two antistrip additives (liquid and lime) and two types of RAP (cored and milled) were used in the preparation of specimens.

The Marshall method of mix design (*9*) was performed to produce a mixture to be used for the preparation of virgin specimens (i.e., containing no recycled materials). The mix design that was prepared by the SCDHPT for the test pavement section was used in the preparation of the recycled laboratory-prepared Marshall specimens. The mixture was used to pave the binder course of the 2-mi test section.

Tunnicliff and Root procedures (*10*) were used for moisture conditioning of specimens. This procedure requires the specimens to contain between 6 and 8 percent air voids with a saturation level between 55 and 80 percent. To achieve these requirements, the compaction level for the laboratory-prepared Marshall specimens was determined by trial and error. However, the percent air voids for the virgin specimens could not reach the 6 percent level without breaking apart in the hot water bath. Twenty-five was the smallest number of blows that could be used to maintain a 55 to 80 percent saturation level while preventing the specimens from breaking apart in the water baths. To maintain uniformity in preparation of the specimens, this compaction level (i.e., 25 blows per side) was used for the specimens containing virgin, cored RAP, and milled RAP materials.

PREPARATION OF MARSHALL SPECIMENS

One-third of the recycled and virgin specimens were treated with lime while another third were treated with the liquid additive. The remaining third (control) contained no additive. The aggregate pans of the specimens that were to contain the lime were treated with 1 percent hydrated lime by weight of total aggregate (including RAP). For those specimens that were to be treated with the liquid antistrip additive, ½ percent of liquid antistrip additive by weight of asphalt cement (including RAP) was added by a syringe to the hot asphalt cement.

The virgin aggregate pans were placed in the oven (340°F ± 20°F) 24 hours before mixing. The RAP pans were placed in the oven 30 min before mixing. The RAP was placed in the oven for this short time period to reduce oxidation. Each specimen was prepared and mixed separately using a mechanical mixer. The order of the preparation was randomized to prohibit any bias.

TESTING PROCEDURES

Field and laboratory-prepared Marshall specimens were both subjected to the same testing procedures. The specimens were randomly selected and placed into two testing groups, wet and dry. Dry specimens were then placed in a temperature control cabinet (77°F ± 2°F) for 24 hr. Wet specimens were subjected to Tunnicliff and Root's (*10*) moisture susceptibility test. The test requires that each specimen be submerged under water with a vacuum of 20 psi for 5 min. Then, the specimens must be placed in a water bath (140°F ± 2°F) for 24 hr and then placed in another water bath (77°F ± 2°F) for 1 hr.

Wet and dry specimens were both tested for MR (ASTM D-4123). This test was performed at 77°F ± 2°F using a Retsina Mark VI resilient modulus testing machine. The specimen was placed on its circular side in the measuring yoke that measured horizontal deformation when the specimen was subjected to repeated vertical loads (10 repetitions in 30 sec) of approximately 70 lb. Each specimen was tested, turned 90 degrees on its circular side, and then tested again. The mean of the two tests was the value used for MR.

Wet and dry specimens were then tested for ITS. This was performed on a Marshall testing machine (deformation rate of 2 in./min) using a testing head that was modified by the addition of ½-in. curved metal strips.

The TSR and the MRR were calculated by dividing the wet value by the respective dry value. These values indicate the percentage of strength that is retained when the specimen is saturated. A VSR was then performed on each specimen (*2*). In addition, sieve analyses were performed on the recovered aggregates from field and laboratory specimens.

STATISTICAL DESIGN

A complete random design (CRD) was used for the statistical design because the laboratory specimens were essentially homogeneous. The effects of laboratory treatments (materials and antistrip additives) on some of the physical characteristics (ITS, MR, TSR, MRR, VSR, and air voids) of the asphaltic concrete specimens were measured using analysis of variance (ANOVA).

There were 18 combinations of variables as shown in Figure 1 (i.e., 3 material sources × 3 antistrip additives × 2 moisture conditions). A total of 144 specimens (18 combinations × 8 replicates) were made and tested. Thirty-six specimens were prepared and tested each day. The preparation order within each replicate was randomly selected to ensure that the preparation was not biased.

A complete random design, similar to that used in the laboratory phase, was also used for the field phase. The difference was that subsamples, observations made within the experimental unit, were used. The experimental unit was a 2-mi highway test section. Each site, the random effect, was randomly selected from each of the four ½-mi subsections. The location (center and wheelpath) was the fixed effect.

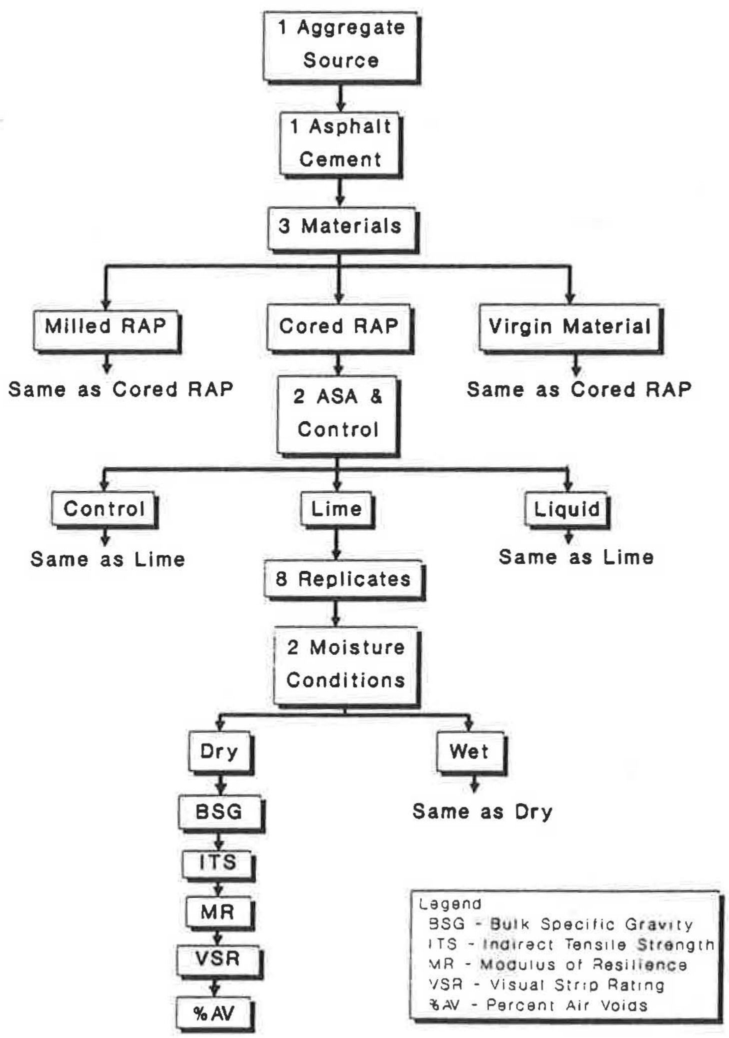


FIGURE 1 Statistical design for laboratory experiments.

STATISTICAL RESULTS

Effectiveness of Recycled Materials

Tables 1 and 2 give the statistical results obtained in laboratory testing of field and laboratory-prepared specimens. The least squares difference (LSD) test was used when the ANOVA indicated that there was a significant effect, at the 0.05 level, within groups (materials or additives). The LSD test was used to identify pairs of treatments that were different. This test, for instance, indicated that for the specimens containing no antistrip additive, there was a significant difference ($\alpha = 0.05$) between the recycled materials and the virgin material for the dry and wet ITS.

Figure 2A shows that for the specimens containing no antistrip additives, the recycled materials (milled and cored RAP) had dry and wet ITS strengths that were higher than the virgin material. These differences in strengths were statistically different at the 0.05 level. Figure 2B shows that the recycled materials containing no antistrip additive had higher dry and wet MR means than the virgin material that contained no additive. These differences in strengths were statistically different at the 0.05 level.

For the specimens containing no antistrip additive, there were differences between the recycled materials and the virgin material for the TSR and MRR (Figure 3A). The virgin material produced TSR and MRR means that were nearly half those produced by the recycled materials. The differences between the recycled materials and the virgin material for both the TSR and MRR were significant at the 0.05 level.

For the specimens containing no antistrip additive, the virgin material experienced a higher, although not significantly different ($\alpha = 0.05$), wet VSR than the recycled materials (Figure 3B). There were some laboratory-prepared Marshall specimens containing virgin material and no antistrip additive that experienced severe stripping and broke apart while being saturated in a hot water bath. None of the specimens containing recycled materials or antistrip additives experienced stripping this severe.

Effectiveness of the SCDHPT Recycling Mix Design Procedures

The current recycling mix design method used by SCDHPT uses RAP material taken from cylindrical (8-in. diameter)

TABLE 1 MEAN, STANDARD DEVIATION, AND COEFFICIENT OF VARIANCE FOR (A) ITS, (B) MR, AND (C) TSR AND MRR OF LABORATORY-PREPARED SPECIMENS ($N = 8$)

(A)

MATL	ASA	MEAN DRY	STD DEV	COEF VAR	MEAN WET	STD DEV	COEF VAR
M	Ctl	119.6	17.6	14.7	85.5	20.0	23.4
	Lqd	115.8	9.8	8.5	122.4*	10.8	8.8
	Lme	112.3	9.3	8.3	120.5	9.8	8.2
R	Ctl	113.2	14.6	12.9	93.5	16.3	17.4
	Lqd	112.8	9.5	8.4	114.7	12.7	11.1
	Lme	112.8	10.3	9.2	116.9	9.1	7.8
V	Ctl	85.5	4.4	5.1	29.4#	7.2	24.5
	Lqd	88.9	6.9	7.7	99.0	12.8	13.0
	Lme	88.6	7.8	8.8	90.4	9.9	10.9

(B)

M	Ctl	277	53	19.1	160	49	30.8
	Lqd	286	49	17.0	277	49	17.7
	Lme	319	61	19.0	343	62	18.0
R	Ctl	266	64	24.0	192	57	29.6
	Lqd	286	39	13.7	224	63	27.9
	Lme	303	67	22.0	342	107	31.1
V	Ctl	182	33	18.3	38*	6	15.8
	Lqd	190	42	21.9	173	41	23.4
	Lme	224	52	23.1	189	27	14.2

(C)

MATL	ASA	MEAN TSR	STD DEV	COEF VAR	MEAN MRR	STD DEV	COEF VAR
M	Ctl	71.7	13.7	19.1	60.4	23.7	19.1
	Lqd	106.6#	8.0	7.5	98.0	19.4	19.7
	Lme	107.7	9.1	8.5	109.5	23.1	21.1
R	Ctl	83.0	13.1	15.8	73.8	21.8	29.5
	Lqd	101.8	9.0	8.8	80.7	28.0	34.7
	Lme	104.0	8.8	8.5	112.5	23.8	21.2
V	Ctl	34.8*	8.2	23.5	17.6*	1.5	8.7
	Lqd	111.5	14.3	12.8	91.8	17.0	18.5
	Lme	103.1	16.4	15.9	87.8	21.6	24.6

Legend:
M = Milled RAP Material, R = Cored RAP Material, V = Virgin Material, Ctl = Control (no additive), Lqd = Liquid Antistrip Additive, Lme = Lime Antistrip Additive, * n = 9, # n = 4

TABLE 2 MEAN, STANDARD DEVIATION, AND COEFFICIENT OF VARIANCE FOR (A) ITS AND (B) MR OF THE RECYCLED PAVEMENT (N = 4)

(A)

CORE SITE	LOC	Mean DRY ITS (psi)	STD DEV (psi)	COEF VAR (%)	Mean WET ITS (psi)	STD. DEV (psi)	COEF VAR (%)
1	CP	136.7	6.3	4.6	187.3	6.7	3.6
	WP	142.2	3.3	2.3	189.0	8.7	4.6
2	CP	126.0	5.5	4.4	157.4	10.0	6.4
	WP	109.5	2.9	2.6	135.3	11.7	8.7
3	CP	150.1	5.7	3.8	206.5	15.0	7.2
	WP	154.4	6.7	4.4	193.5	6.0	3.1
4	CP	134.0	4.5	3.4	173.3	10.8	6.2
	WP	126.9	10.1	7.9	177.8	6.7	3.8

(B)

CORE SITE	LOC	Mean DRY MR (ksi)	STD DEV (ksi)	COEF VAR (%)	Mean WET MR (ksi)	STD DEV (ksi)	COEF VAR (%)
1	CP	655	147	22.4	819	293	35.8
	WP	561	28	4.9	713	147	20.6
2	CP	608	30	5.0	566	117	20.6
	WP	473	48	10.1	461	67	14.5
3	CP	587	56	9.5	765	165	21.6
	WP	700	50	7.1	730	36	5.0
4	CP	468	40	8.5	553	82	14.8
	WP	478	31	6.4	657	57	8.6

Legend:
LOC: Location
CP: Center Path
WP: Wheel Path

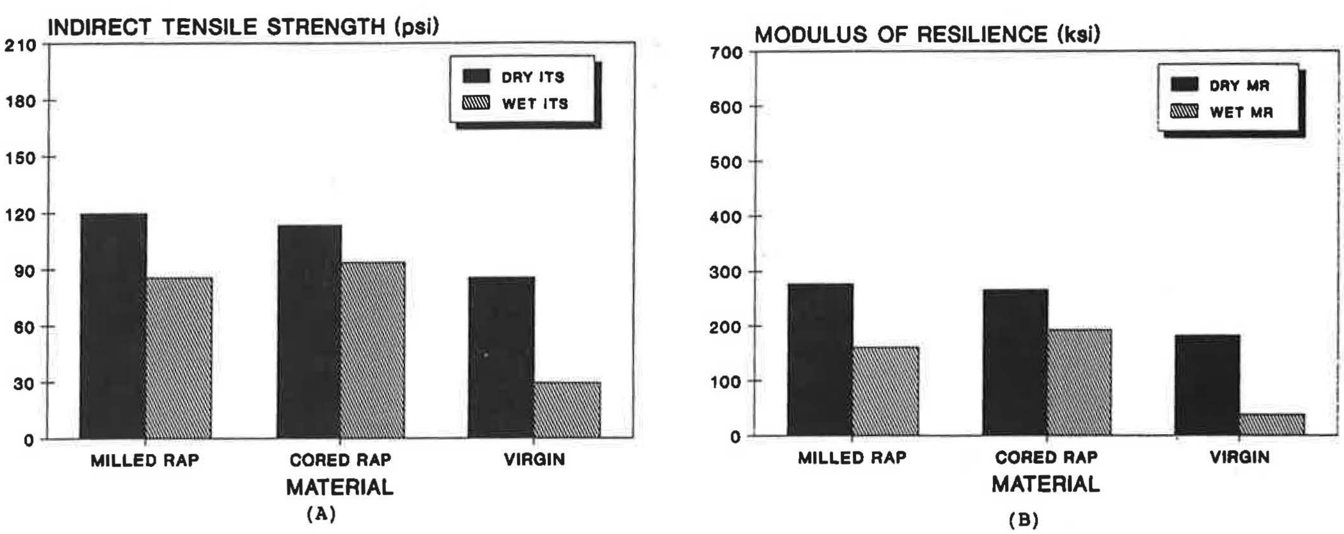


FIGURE 2 Mean ITS (A) and mean MR (B) of laboratory- prepared Marshall specimens containing no antistrip additive (N = 8).

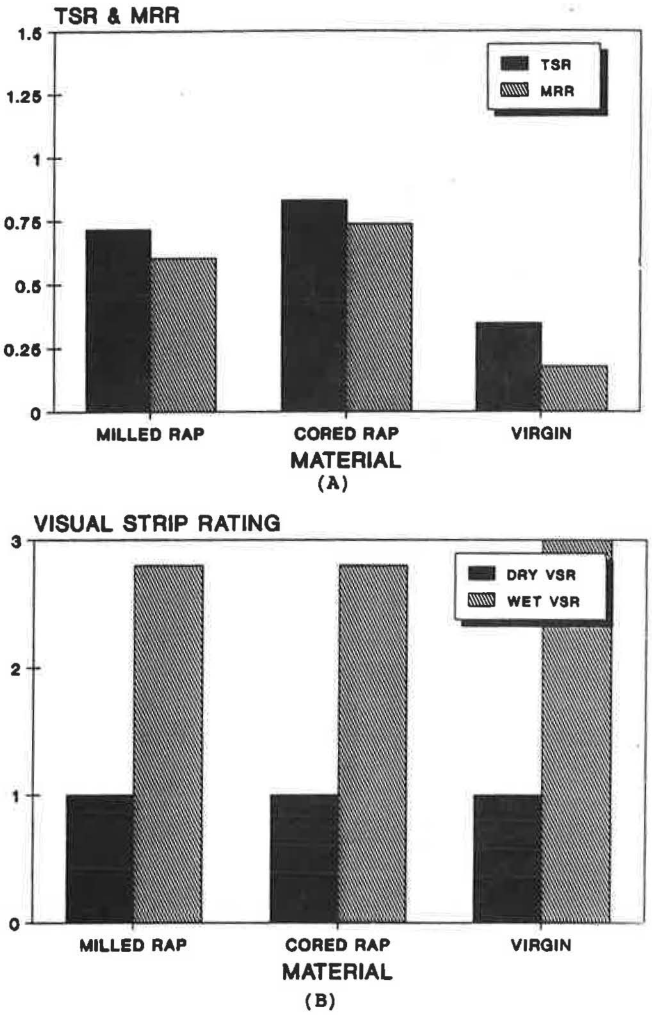


FIGURE 3 Mean tensile strength and MRR (A) and mean VSR (B) for laboratory-prepared Marshall specimens containing no antistrip additive (*N* = 4 except for dry VSR, for which *N* = 8).

cores obtained from the highway section to be paved. However, during the construction of the recycled asphaltic concrete pavement, the RAP material is obtained from a milling machine.

Sieve analyses were performed on the recovered aggregates from the milled and cored RAP materials. Both failed to meet the specification requirements. The milled RAP contained finer materials as a result of the milling machine's breaking the RAP as the machine removed the RAP from the road.

Generally, there were no significant differences (at the 0.05 level) between the laboratory-prepared Marshall specimens containing the milled RAP material and those containing the cored RAP material in ITS, MR, TSR, MRR, and VSR. Figure 2 shows that for the specimens containing no antistrip additive, the milled RAP had dry ITS and dry MR means that were slightly higher than those of the cored RAP. Figure 2 also shows that for the wet ITS and the wet MR, the cored RAP had means that were slightly higher than the milled RAP. However, these differences were not significant at the 0.05 level.

For the specimens containing no antistrip additives, the cored RAP produced TSR and MRR means that were higher than, but not significantly ($\alpha = 0.05$) different from, the milled RAP material. Both recycled materials obtained equal dry and wet VSR means (Figure 3B).

The specimens containing the milled RAP and no antistrip additive had a slightly higher percentage of air voids than those containing cored RAP and no additive. The difference between the RAP materials was not significant for air voids.

Effectiveness of Antistrip Additives

Milled RAP

There were statistically significant differences, at the 0.05 level, with respect to wet ITS, wet MR, TSR, MRR, and wet VSR between the specimens containing no antistrip additive and those containing liquid and lime antistrip additives for the milled RAP material. Generally, the specimens containing the antistrip additives produced higher wet ITS, wet MR, TSR, and MRR means.

For the specimens containing the milled RAP material, there were no major differences between specimens containing antistrip additives and those containing no antistrip additive for the dry ITS and the dry MR means (Figure 4). These differences between the specimens containing antistrip additives and those containing no additive for both the dry ITS and MR were not significant at the 0.05 level.

The specimens containing the antistrip additives had higher wet ITS means than those not containing an additive. For the wet ITS, the specimens containing the liquid and the lime additives were significantly different ($\alpha = 0.05$) from those containing no additive. The specimens containing the lime additive had the highest wet MR mean, followed by those containing the liquid additive and those containing no additives, respectively. For the wet MR, specimens prepared with the lime additives produced strengths significantly different ($\alpha = 0.05$) from those prepared with the liquid additive. In addition, the specimens containing no additive were significantly different from ($\alpha = 0.05$) and produced lower strength than those containing the additives for the wet MR.

The specimens containing additives had higher TSR and MRR values than those containing no additive (Figure 5A). For the TSR, the specimens made with additives had means that were nearly equal, whereas the lime had a mean that was higher than the liquid additive for the MRR. For the TSR and MRR, the specimens containing the antistrip additive were significantly different ($\alpha = 0.05$) from those containing no additives.

For the specimens containing the milled RAP material (Figure 5B), those containing the liquid and the lime additives had mean wet VSRs of 1.0 (i.e., no visual stripping), whereas those containing no additive had a mean wet VSR of 2.8 (i.e., severe stripping). The specimens containing the antistrip additives produced visual stripping values that were significantly different ($\alpha = 0.05$) from those containing no additives. In addition, there were no major statistical differences, at the 0.05 level, between the specimens containing the antistrip additives and those containing no additive with respect to percentage of air voids.

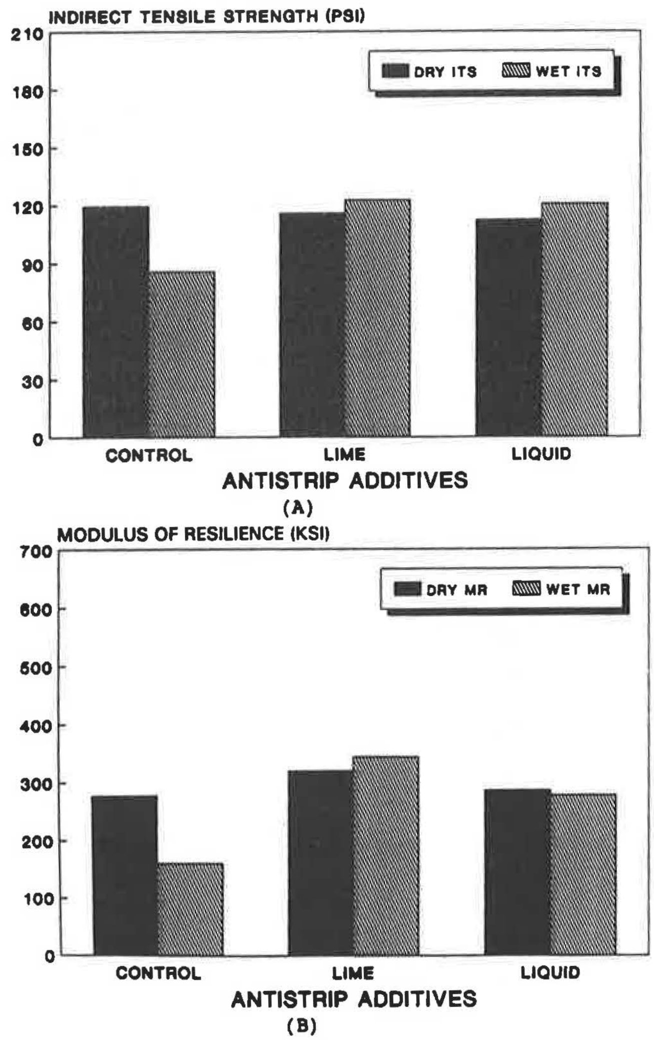


FIGURE 4 Mean ITS (A) and mean MR (B) for laboratory-prepared Marshall specimens containing milled RAP material (N = 8 except for lime for wet ITS, for which N = 9).

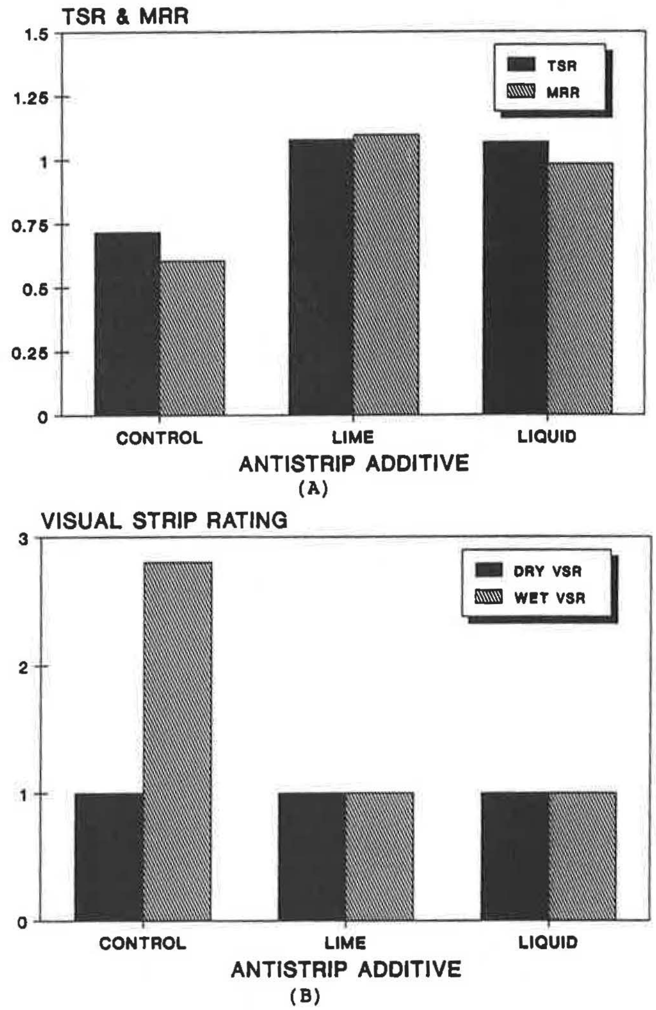


FIGURE 5 Mean tensile strength and MRR (A) and mean VSR (B) for laboratory-prepared Marshall specimens containing milled RAP material (N = 8 except for lime for TSR, for which N = 9).

Cored RAP

There were statistically significant differences, at the 0.05 level, with respect to wet ITS, wet MR, TSR, MRR, and wet VSR between the specimens containing antistrip additives and those containing no additives. Generally, the specimens containing the antistrip additives produced higher mean wet ITS, wet MR, TSR, and MRR values.

There were no major differences between the specimens containing antistrip additives and those containing no additive for the dry ITS and the dry MR means (Figure 6). The LSD comparisons indicated that the differences between the specimens containing additives and those containing no additive for the dry ITS and the dry MR means were not significant at the 0.05 level.

The specimens containing antistrip additives had higher wet ITS values (significant at the 0.05 level) than those containing no additive. The specimens containing the lime additive had the highest mean wet MR, whereas those with the liquid additive were slightly higher than those with no additive. For the wet MR, there was a significant difference (α = 0.05) between specimens containing the lime additive and those containing the liquid additive. The specimens containing the lime additive were also significantly different (α = 0.05) from those that contained no additives.

The specimens containing no additive had the lowest TSR mean, whereas the liquid and the lime TSRs were nearly equal (Figure 7A). The TSR values of the specimens containing the liquid and the lime additives were significantly different (α = 0.05) from those containing no additive. The specimens containing lime produced significantly higher MRR mean values at the 0.05 level compared with specimens containing the liquid and no additives.

Figure 7B shows that the specimens containing no additive had a mean wet VSR of 2.8 (i.e., severe stripping), whereas those containing additives had means of 1.0 (i.e., no stripping). The differences were significant at the 0.05 level. In addition, there were no major differences between the specimens containing the antistrip additives and those containing no additive with respect to air voids. The differences that existed were not significant at the 0.05 level.

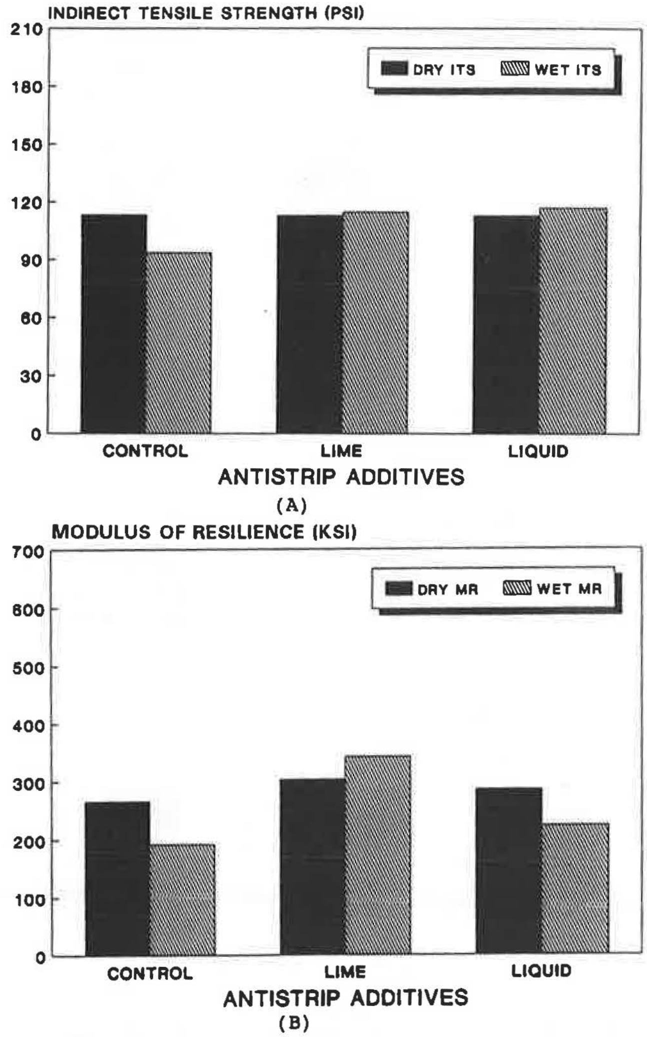


FIGURE 6 Means ITS (A) and mean MR (B) for laboratory-prepared Marshall specimens containing cored RAP material (N = 8).

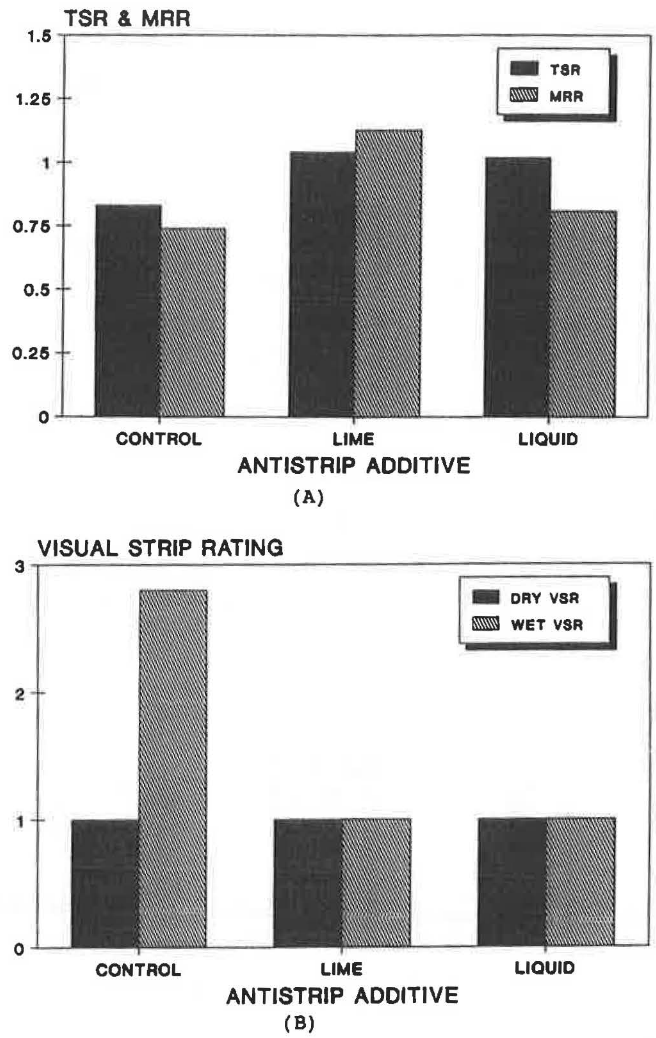


FIGURE 7 Mean tensile strength and MRR (A) and mean VSR (B) for laboratory-prepared Marshall specimens containing cored RAP material (N = 8).

Field Versus Laboratory Specimens

The field phase of the experiment consisted of 16 combinations of variables as shown in Figure 8 (i.e., 4 coring sites × 2 locations × 2 moisture conditions). There were a total of 64 specimens (16 combinations × 4 replicates) obtained and tested for this phase of the project. The pavement contained 15 percent RAP and 1 percent lime by total weight of aggregate.

Laboratory-prepared Marshall specimens containing milled RAP material and cored RAP material were compared with the recycled pavement. The comparisons were conducted to determine whether laboratory specimens could predict the field characteristics (e.g., ITS, MR, TSR, MRR, etc.). Milled RAP and field core specimens both contained the lime antistrip additive. In addition, the cored RAP containing the lime additive was used in this comparison because the SCDHPT used this material when designing the specifications for the recycled pavement.

The ANOVA tables for the recycled pavement section indicated that there was not a significant effect (α = 0.05) within either site or location for the dry ITS, dry or wet MR, TSR, or MRR. Therefore, comparisons were made using the overall mean (i.e., combined specimens from all sites and locations) for the dry ITS, dry and wet MR, TSR, and MRR. The ANOVA tables for the recycled pavement indicated significant effects within site for the wet ITS and within site and location for the air voids. Comparisons were made using means from site (i.e., combined wheel and center paths for each site) for the wet ITS and from site and location for the air voids. The t-test was used to compare the means from the recycled pavement with the laboratory specimens.

Generally, the field specimens had much higher mean values, with respect to dry and wet ITS (Figure 9), dry and wet MR (Figure 10A), and TSR (Figure 10B), than the laboratory specimens containing cored and milled RAP materials. The t-test results indicate that all of the comparisons with respect to ITS and MR between the field (recycled pavement) and

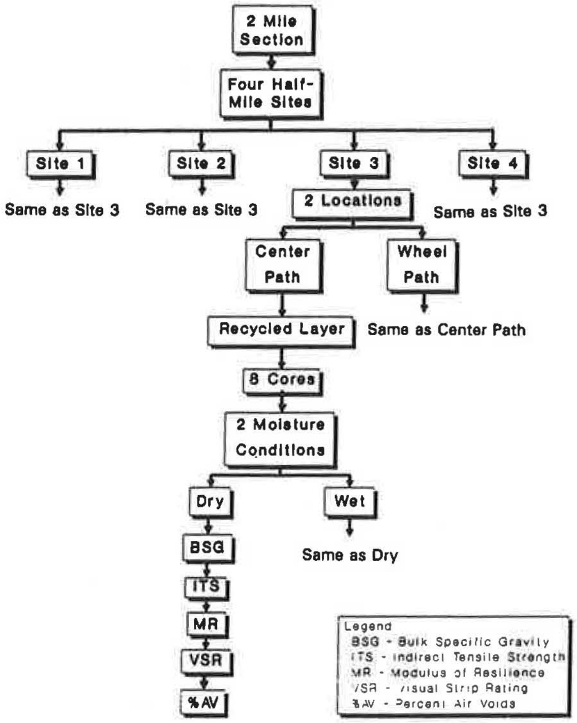


FIGURE 8 Field treatment design for recycled pavement.

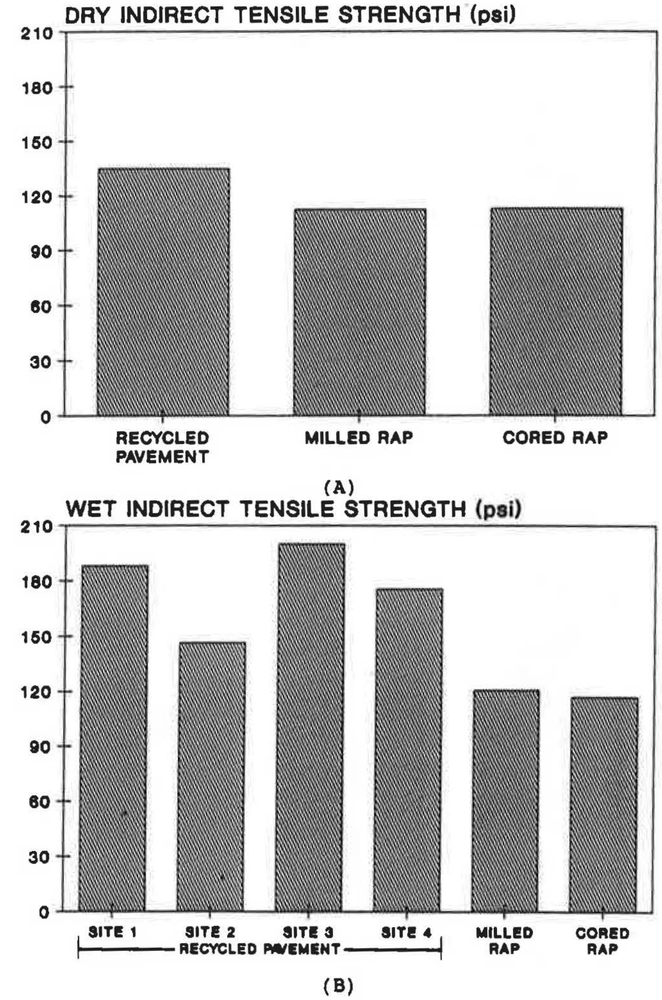


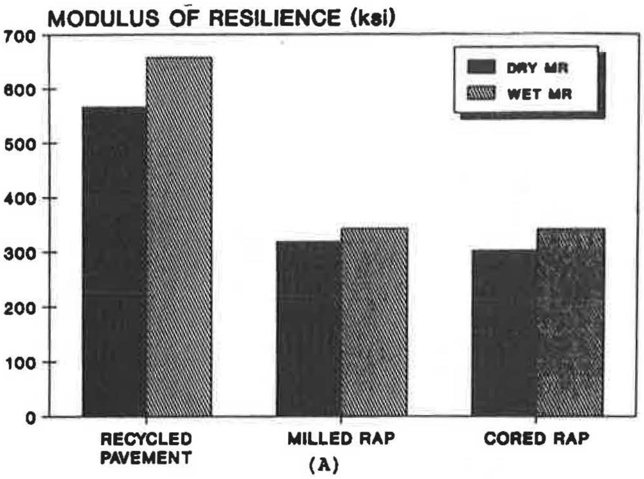
FIGURE 9 Mean dry ITS (N = 8 except for recycled pavement, for which N = 32) (A) and mean wet ITS (N = 8) for recycled pavement and laboratory-prepared Marshall specimens containing milled and cored RAP (B).

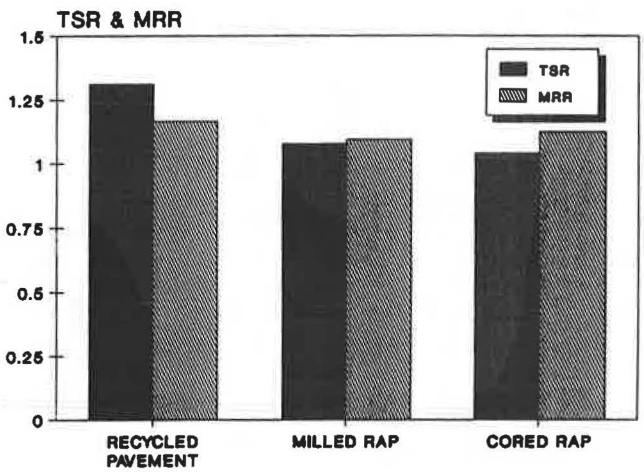
the laboratory (milled and cored RAP) specimens were significantly different (α = 0.05). The recycled pavement's mean MRR (Figure 10B) was slightly higher than, although not significantly different (α = 0.05) from, those obtained by the laboratory specimens.

FINDINGS AND CONCLUSIONS

The following findings and conclusions are based on the statistical analyses of the data obtained from the laboratory and field phases of this research project.

1. Laboratory-prepared Marshall specimens containing moisture-damaged asphaltic concrete mixtures produced dry and wet ITS and MR, TSR, and MRR mean values that were significantly (α = 0.05) higher than those obtained from specimens containing virgin materials. There was not a significant difference with respect to the VSR. The specimens containing recycled mixtures had a significantly lower percentage of air voids than those containing virgin materials.
2. There was not a significant difference (α = 0.05) in certain physical characteristics (i.e., ITS, MR, TSR, MRR, and VSR) between laboratory-prepared Marshall specimens containing the milled RAP (used in the actual highway construction) material and those containing cored RAP (used by SCDHPT for the mix design) material.
3. The laboratory-prepared Marshall specimens containing RAP (milled and cored materials) were not able to predict some of the physical characteristics of the recycled asphaltic concrete pavement. For instance, the field specimens had significantly higher means for TSR and dry and wet ITS and MR. The MRR for the recycled specimens was not significantly different from those of laboratory specimens. More than half of the mean air voids values from the recycled pavement were significantly higher than those obtained by the laboratory specimens.
4. Antistrip additives are effective when used with recycled asphaltic concrete mixtures. Laboratory-prepared Marshall specimens containing the lime and the liquid antistrip additives had significantly higher (α = 0.05) means (wet ITS, wet MR, TSR, and MRR) than those containing no antistrip additive (control). The specimens containing the antistrip additives experienced significantly less stripping damage during moisture conditioning than did the specimens containing no antistrip additive.
5. As a result of the reclaiming process, the milled RAP contained more fines than the cored RAP material. This difference did not produce a significant difference between the two materials in ITS, MR, TSR, MRR, or VSR.
6. The results, in general, indicate that the procedures established in a previous study (*2*) for determining the moisture





(B)

FIGURE 10 Mean MR (N = 8 except for recycled pavement, for which N = 32) (A) and mean tensile strength and MRR (N = 8) for recycled pavement and laboratory-prepared Marshall specimens containing milled and cored RAP.

susceptibility of asphaltic concrete mixtures could be used to determine the extent of moisture damage in flexible pavements.

7. The results of the laboratory and field testing indicate that recycled mixtures containing 15 to 20 percent RAP do not exhibit more moisture susceptibility than similar virgin mixes containing no RAP. This was found to be true even when the RAP was from a pavement that had been shown to have already suffered moisture damage.

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