Report No. KS-99-4
Final Report

EVALUATION OF COLD IN-PLACE RECYCLED MIXTURES ON US-283

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August 2000

1. Report No. KS-99-4	2. Government Accession No.	3. Recipient Catalog No.
4 Title and Subtitle EVALUATION OF COLD IN-PLACE RECYCLED MIXTURES ON US-283		5 Report Date November 1999 6 Performing Organization Code
7. Author(s) Stephen A. Cross, P.E.		8 Performing Organization Report No. 282 KS-99-4
9 Performing Organization Name and Address University of Kansas School of Engineering Lawrence, Kansas 66045		10 Work Unit No. (TRAIS) 11 Contract or Grant No. C1036
12 Sponsoring Agency Name and Address Kansas Department of Transportation Docking State Office Bldg. Topeka, Kansas 66612		13 Type of Report and Period Covered Final Report August 1997 to August 2000 14 Sponsoring Agency Code
15 Supplementary Notes		

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Recent research indicates that the use of CIR with asphalt emulsion and hydrated lime, introduced as hot slurry, provides improved performance. KDOT constructed two test sections on US-283 using type C fly ash and CSS-1 with hot lime slurry and type C fly ash. Two additional asphalt emulsions were evaluated as well, CMS-1 and HFE-150. The cores and laboratory samples were tested for tensile strength, AASHTO T283, resilient modulus and for rutting resistance and moisture damage using the Asphalt Pavement Analyzer (Georgia Rut Tester).

Results indicate that the use of hot lime slurry improves the performance of CIR with AE, regardless of the emulsion used and that AE with hot lime slurry could be an alternative to the use of type C fly ash in CIR mixtures.

17 Key Words		18 Distribution Statement	
Asphalt Emulsions, Cold In-Place Recycling, Fly Ash, Hot Lime Slurry		No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161	
19 Security Classification (of this report) Unclassified	20 Security Classification (of this page) Unclassified	21 No. of pages 83	22 Price

Form DOT F 1700.7 (8-72)

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Final Report

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by

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University of Kansas

A Report on Research Sponsored by

THE KANSAS DEPARTMENT OF TRANSPORTATION

CHEMICAL LIME COMPANY

BROWN & BROWN CONTRACTORS, INC.

UNIVERSITY OF KANSAS CENTER FOR RESEARCH, INC.

LAWRENCE, KANSAS

August 2000

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The Kansas Department of Transportation (KDOT) cold in-place recycles (CIR) approximately 120 to 160 km of pavement a year as a part of their 1-R maintenance program. Originally KDOT utilized asphalt emulsions (AE) as the additive in CIR mixtures, but based on performance concerns, KDOT currently utilizes type C fly ash.

Recent research indicates that the use of CIR with asphalt emulsion and hydrated lime, introduced as hot slurry, provides improved performance. KDOT constructed two test sections on US-283 using type C fly ash and CSS-1 with hot lime slurry. Cores from the test sections and samples of the paving materials were obtained and a laboratory evaluation was undertaken to evaluate the performance of CIR mixtures using AE with hot lime slurry, and type C fly ash. Two additional asphalt emulsions were evaluated as well, CMS-1 and HFE-150. The cores and laboratory samples were tested for tensile strength, AASHTO T 283, resilient modulus and for rutting resistance and moisture damage using the Asphalt Pavement Analyzer (Georgia Rut Tester).

Results indicate that the use of hot lime slurry improves the performance of CIR with AE, regardless of the emulsion used and that AE with hot lime slurry could be an alternative to the use of type C fly ash in CIR mixtures.

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CHAPTER 1
INTRODUCTION

The state of Kansas has been utilizing partial depth cold in-place recycling (CIR) for the rehabilitation of many of their roads. On lower volume roads, a thin (40 mm) hot mix asphalt (HMA) overlay is used as the wearing surface. On high traffic roads a thicker overlay is used. The primary distresses associated with the lower volume pavements with a thin HMA overlay has been transverse cracking and associated moisture damage due to the moisture sensitivity of the available sand and gravel aggregates (1). Additives used in CIR have included asphalt emulsions and class C fly ash. The use of asphalt emulsion resulted in shorter than desired pavement life or distress occurring, such as excessive rutting, before the existing transverse cracks reflected back to the surface (1). The use of class C fly ash has extended the life of CIR pavements by improving the stability and reducing the permeability of the mix, thus reducing the potential for moisture damage (2). However, test sections with high fly ash contents have shown variable performance and increased cracking associated with higher fly ash contents (2). Recent research (3) has shown that CIR with class C fly ash could be susceptible to fatigue cracking. To continue to improve the performance of CIR mixtures, other additives need to be investigated. A recent study (4) using quicklime introduced as hot slurry (HLS) has shown promise in improving CIR performance.

In 1997, the Kansas Department of Transportation (KDOT) used HLS in a CIR project on US-283 in Ford County. One half of the project was constructed using an average of 8 to 10% class C fly ash as the additive and the other half constructed using an average of 1.5% CSS-1 asphalt emulsion with HLS. Reclaimed asphalt pavement (RAP), asphalt emulsion, quicklime and fly ash were obtained from the project and provided for laboratory testing and evaluation. Test sections (300 m) were placed in each portion of the project and the performance monitored by KDOT. After a sufficient cure time, cores were obtained from each test section and returned to the Bituminous Laboratory at the University of Kansas for testing and evaluation.

OBJECTIVES

The project was undertaken in three phases. The objectives of the first phase were to evaluate the effects of HLS on laboratory compacted CIR mixtures with different asphalt emulsions; and to compare the HLS with asphalt emulsion results to laboratory compacted type C fly ash samples. The objective of the second phase was to compare the physical properties of the cores from the two test sections. The objective of the third phase was to evaluate the performance of laboratory compacted samples and pavement cores using the Asphalt Pavement Analyzer (APA).

In the first phase RAP was mixed with type C fly ash and with three different types of mixing grade asphalt emulsion with and without HLS. The mixtures were tested for indirect tensile strength (ASTM D 4123), moisture sensitivity (AASHTO T 283), resilient modulus (AASHTO TP 31-94), and index of retained resilient modulus (IRRM). In the second phase the surface mix and CIR layer from the cores from the two test sections were tested for bulk specific gravity (AASHTO T 166), indirect tensile strength (ASTM D 4123), moisture sensitivity (AASHTO T 283), resilient modulus (AASHTO TP 31-94), and IRRM. The third phase consisted of evaluating the resistance to permanent deformation and moisture induced damage of samples prepared in the first two phases using the APA in general accordance with Georgia DOT Test Method GDT-115.

CHAPTER 2
PHASE I
LABORATORY COMPACTED SAMPLES

INTRODUCTION

Phase I testing consisted of evaluating the effects of hot lime slurry (HLS) on laboratory compacted cold in-place recycled (CIR) mixtures with different asphalt emulsions. The mixtures were evaluated for indirect tensile strength, moisture sensitivity, resilient modulus and conditioned resilient modulus. The results were compared to laboratory compacted CIR mixtures with class C fly ash.

MATERIALS

Asphalt Emulsion

The three mixing grade asphalt emulsions utilized included a cationic medium set (CMS-1), a cationic slow set (CSS-1), and a high float (HFE-150). The CSS-1 was obtained from the US-283 project. Koch Materials provided the CMS-1 and HFE-150.

Lime

Powered quicklime was obtained from the US-283 project. The lime was utilized as hydrated lime slurry. To prepare one liter of hydrated lime slurry from quicklime, 277.4 g of CaO is mixed with 924.6 g of water. The solids content of the slurry will be between 30-35% depending on the amount of water lost to evaporation during the slaking process. The slurry was prepared in accordance with written instructions from Brown & Brown, and is included in the appendix.

RAP

The RAP was obtained from US-283. The gradation of the RAP, as received, was determined in accordance with AASHTO T 27. The RAP was processed by removing the oversized material (plus 25.4-mm) and the gradation recalculated. The gradation without the plus 25.4-mm RAP is referred to as the processed gradation. The asphalt content of the processed RAP was determined using an extraction furnace in general accordance with KDOT Test Method KT-57. The gradation of the recovered aggregate was determined in accordance with AASHTO T 11 and T 27. The results are shown in Table 1 and presented graphically in Figure 1.

The RAP contained 5.7% asphalt cement by weight of total mix. The RAP contained 58% coarse aggregate, retained on the 4.75-mm sieve, and 95% was retained on the 0.600-mm sieve. The extracted aggregate from the RAP was a mixture of limestone and siliceous sand and gravel. The coarse aggregate was 90% crushed. The fine aggregate angularity (KT-50) cannot be accurately determined from aggregates recovered from the ignition furnace.

MIXING, COMPACTION, AND CURING OF LABORATORY SAMPLES

Mixing

Asphalt Emulsion Samples

All samples were mixed for 2.5 minutes using a mechanical mixer. The asphalt emulsion only samples contained 1.5% emulsion and 3% mixing water, all based on the dry weight of the RAP. For mixing, half of the mix water (1.5%) was added to the RAP and mixed for 1 minute. The remainder of the mix water (1.5%) and asphalt emulsion (1.5%) was

Table 1. Gradation of RAP and Recovered Aggregate From US-283.

Sieve Size	RAP "As Received"	RAP "Processed"	Recovered Aggregate
	Percent Retained		
38.1 mm	0		
25.4 mm	1.4	0	
19.0 mm	4.3	2.9	0
12.5 mm	18.3	17.2	3.4
9.5 mm	31.0	30.0	8.7
4.75 mm	58.5	57.9	24.4
2.36 mm	77.1	76.8	40.1
1.18 mm	88.9	88.7	53.7
0.600 mm	95.0	94.9	66.3
0.300 mm	98.4	98.3	79.5
0.150 mm	99.6	99.6	88.6
0.075 mm	99.9	99.9	92.4

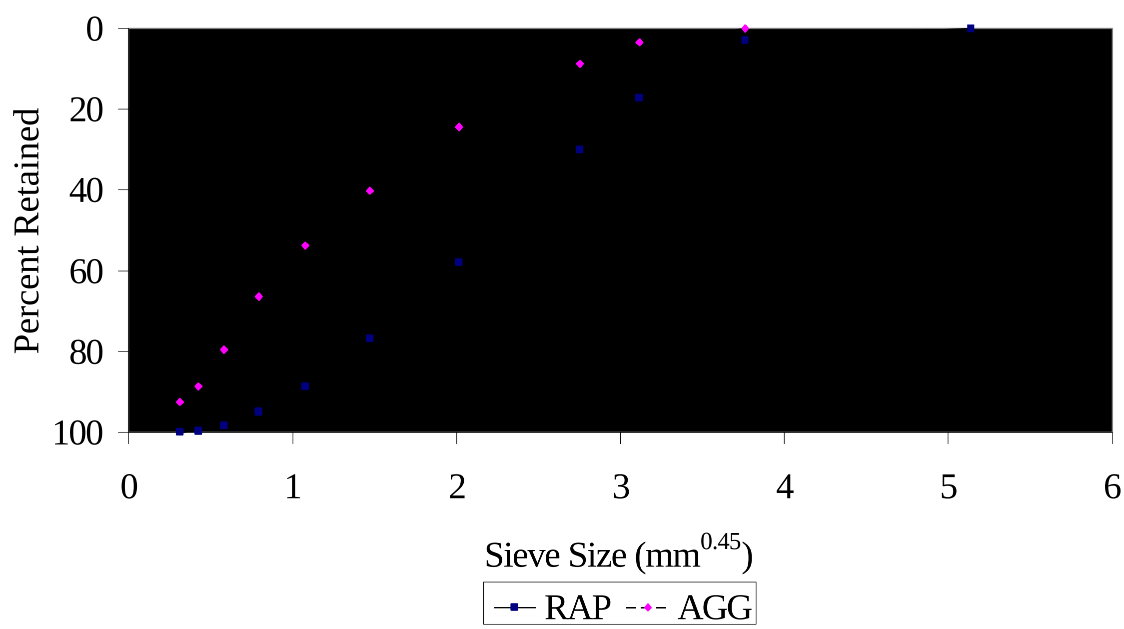

Figure 1. Gradation of RAP and Recovered Aggregate.

then added and the sample mixed for an additional 1.5 minutes. Lime samples were mixed in the same manner except the lime slurry was substituted for the mix water.

Fly Ash Samples

The fly ash samples contained 3% mix water and 8 or 10% fly ash, all based on the dry weight of the RAP. Fly ash samples were mixed with one half the mixing water (1.5%) for 1 minute and then the fly ash, retarder (2% by weight of mix water) and the remainder of the mixing water was added and the sample mixed for 1.5 minutes. The samples were covered and allowed to react for 30 minutes prior to compaction.

Compaction

One of the requirements of this study was to compact the laboratory samples to the same density they reached in the US-283 project. The average density of the lime section on the US-283 project was reported as 2123 kg/m^3 and 2141 kg/m^3 for the fly ash section. This was a wet density obtained 24-48 hours after compaction, with a nuclear density meter. Samples of both the CSS-1 with HLS and fly ash samples were compacted in the lab using a Marshall hammer with a rotating base and slanted compaction foot. The samples were compacted to 50 blows per side at 37.7^{o}C and at 51.7^{o}C, and to 75 blows per side at 43.3^{o}C. The samples were allowed to air cure and their weights monitored for 14 days. The results are shown in Figures 2 and 3 for the lime and fly ash samples, respectively. As shown in Figure 2, a compactive effort of 75 blows per side with the RAP heated to 43.3^{o}C gave similar densities after 24-48 hours for the lime samples. The same compactive effort was used for the fly ash samples, as it was desired to compact the laboratory samples to the same compactive effort. Figure 3 shows that 75 blows per side with the Marshall hammer with the RAP at 43.3^{o}C gave reasonable densities.

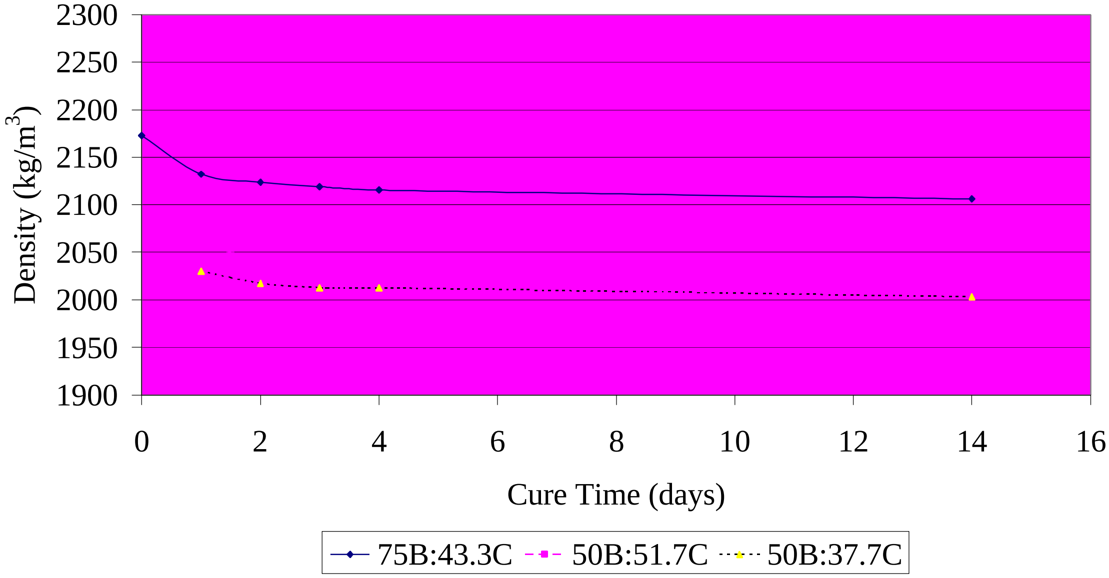

Figure 2. Compactive Effort vs. Cure Time for CSS-1 + HLS.

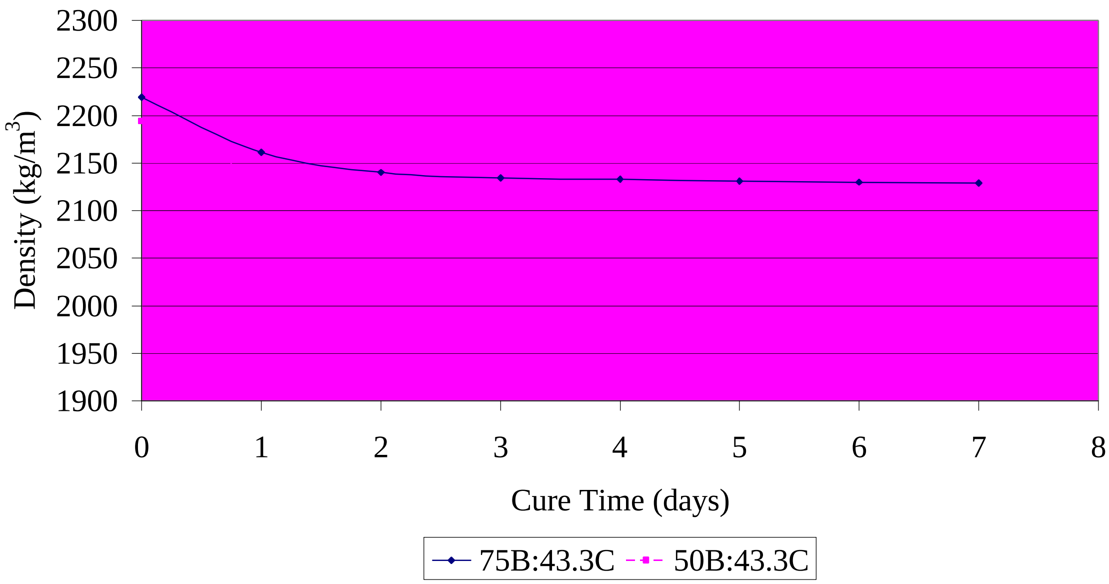

Figure 3. Compactive Effort vs. Cure Time for 10% Fly Ash.

This compactive effort was used for all subsequent sample fabrication. Samples for the phase 3 testing in the APA (76mm x 150mm) were compacted in the Strategic Highway Research Program's (SHRP) gyratory compactor to the average density obtained using Marshall compaction.

Final Curing

Asphalt Emulsion Samples

The test samples were left in their molds for 24 hours immediately following Marshall compaction. After 24 hours, the samples were extruded and allowed to air-cure for an additional six days. After the seven-day cure, the bulk specific gravity was determined (AASHTO T 166) and the samples were available for additional testing. Samples for testing in the APA were extruded from the compaction mold immediately after compaction and allowed to air-cure for seven days.

Fly Ash Samples

Immediately after compaction, the fly ash samples were sealed in plastic bags in the molds and allowed to cure for 24 hours. After 24 hours, the samples were extruded from the molds, resealed in a plastic bag, and allowed to moist cure for an additional six days. After the seven-day cure the bulk specific gravity was determined (AAHTO T 166) and the samples were available for additional testing. Samples for testing in the APA were extruded from the compaction mold immediately after compaction and allowed to air-cure for seven days.

Initial AASHTO T 283 test results indicated low strength for the fly ash samples. The tensile strengths were low when compared to typical CIR-type C fly ash samples. Therefore, the compaction and curing procedures were changed and all samples not made in this manner were retested. The retarder was deleted along with the 30-minute compaction delay. The samples were removed from the molds and plastic bags after 24 hours and placed in a moisture room at 25^{o}C at 100% relative humidity. The samples were protected from dripping water. After six days in the moisture room the samples were tested for bulk specific gravity (AASHTO T 166) and were available for additional testing.

TEST RESULTS

Indirect Tensile Strength and AASHTO T 283

The test results from the indirect tensile strength testing (ASTM D 4123) and moisture sensitivity testing (AASHTO T 283) are shown in Tables 2-5. The indirect tensile strengths (ASTM D 4123) were used as the control strengths in AASHTO T 283. The seven-day density of the samples was used to evaluate the effects of HLS on density.

Density

Density has a significant effect on the performance properties of CIR mixtures (1, 2, 3). The seven-day air-cured bulk specific gravity (AASHTO T 166) was determined for all samples used for indirect tensile strength and AASHTO T 283 testing. The bulk specific gravity was converted to density and the results shown in Tables 2-5. The average density for each additive is shown in Figure 4. A two-way analysis of variance was performed on the densities. The results show that 10% fly ash had a significantly higher density than asphalt emulsion samples. For the asphalt emulsion samples, the use of HLS results in a significant increase in density with all HLS samples being significantly higher than the samples without HLS, at a 95% confidence limit. The CMS-1 samples gave

Table 2. Results of Indirect Tensile Strength and AASHTO T 283 Testing for CMS-1.

Additive	Sample	Bulk Specific Gravity	7-Day Density (kg/m^3)	VTM (%)	Tensile Strength: Control Strength (kPa)	Tensile Strength: Conditioned Strength (kPa)	Tensile Strength Ratio (TSR)
CMS-1	1	2.123	2123	11.5	.	102.3	
CMS-1	2	2.100	2100	12.5	227.5	.	
CMS-1	3	2.105	2105	12.3	.	102.9	
CMS-1	4	2.083	2083	13.2	.	116.3	
CMS-1	5	2.104	2104	12.3	200.5	.	
CMS-1	6	2.122	2122	11.6	241.2	.	
CMS-1	Average	2.106	2106	12.2	223.1	107.2	48.0
CMS-1 L	1	2.164	2164	9.8	.	217.4	
CMS-1 L	2	2.173	2173	9.4	278.2	.	
CMS-1 L	3	2.170	2170	9.6	273.3	.	
CMS-1 L	4	2.173	2173	9.4	.	216.9	
CMS-1 L	5	2.152	2152	10.3	267.8	.	
CMS-1 L	6	2.161	2161	9.9	.	196.5	
CMS-1 L	Average	2.166	2166	9.7	273.1	210.3	77.0

CMS-1 L = CMS-1 + Hot Lime Slurry.

Table 3. Results of Indirect Tensile Strength and AASHTO T 283 Testing for CSS-1.

Additive	Sample	Bulk Specific Gravity	7-Day Density (kg/m^3)	VTM (%)	Tensile Strength: Control Strength (kPa)	Tensile Strength: Conditioned Strength (kPa)	Tensile Strength Ratio (TSR)
CSS-1	1	2.087	2087	13.0	224.9	.	
CSS-1	2	2.082	2082	13.2	.	95.9	
CSS-1	3	2.101	2101	12.4	.	105.3	
CSS-1	4	2.097	2097	12.6	222.5	.	
CSS-1	5	2.073	2073	13.6	236.8	.	
CSS-1	6	2.074	2074	13.6	.	104.3	
CSS-1	Average	2.086	2086	13.1	228.1	101.8	44.7
CSS-1 L	1	2.130	2130	11.2	364.9	.	
CSS-1 L	2	2.124	2124	11.5	323.3	.	
CSS-1 L	3	2.133	2133	11.1	346.8	.	
CSS-1 L	4	2.143	2143	10.7	.	290.4	
CSS-1 L	5*	2.070	2070	13.7	.	228.5	
CSS-1 L	6	2.124	2124	11.5	.	263.5	
CSS-1 L	Average	2.131	2131	11.2	345.0	277.0	80.3

* Sample not used in average, VTM too high.

CSS-1 L = CSS-1 + Hot Lime Slurry.

Table 4. Results of Indirect Tensile Strength and AASHTO T 283 Testing for HFE-150.

Additive	Sample	Bulk Specific Gravity	7-Day Density (kg/m^3)	VTM (%)	Tensile Strength: Control Strength (kPa)	Tensile Strength: Conditioned Strength (kPa)	Tensile Strength Ratio (TSR)
HFE-150	1	2.100	2100	12.5	.	90.6	
HFE-150	2	2.085	2085	13.1	.	90.7	
HFE-150	3	2.106	2106	12.2	.	101.6	
HFE-150	4	2.091	2091	12.8	204.2	.	
HFE-150	5	2.091	2091	12.8	221.0	.	
HFE-150	6	2.102	2102	12.4	242.2	.	
HFE-150	Average	2.096	2096	12.6	222.5	94.3	42.4
HFE-150 L	1	2.146	2146	10.6	.	291.2	
HFE-150 L	2	2.148	2148	10.5	332.6	.	
HFE-150 L	3	2.136	2136	11.0	302.3	.	
HFE-150 L	4	2.125	2125	11.4	.	260.7	
HFE-150 L	5	2.136	2136	11.0	328.5	.	
HFE-150 L	6	2.121	2121	11.6	.	236.7	
HFE-150 L	Average	2.135	2135	11.0	321.1	262.9	81.9

HFE-150 L = HFE 150 + Hot Lime Slurry.

Table 5. Results of Indirect Tensile Strength and AASHTO T 283 Testing for 10% Fly Ash.

Additive	Sample	Bulk Specific Gravity	7-Day Density (kg/m^3)	VTM (%)	Tensile Strength: Control Strength (kPa)	Tensile Strength: Conditioned Strength (kPa)	Tensile Strength Ratio (TSR)
2% Retarder	1	2.123	2233	6.9	.	439.2	
2% Retarder	2	2.100	2233	6.9	.	514.0	
2% Retarder	3	2.105	2226	7.2	232.8	.	
2% Retarder	4	2.083	2236	6.8	.	387.8	
2% Retarder	5	2.104	2230	7.0	255.3	.	
2% Retarder	6	2.122	2248	6.3	231.0	.	
2% Retarder	Average	2.106	2234	6.9	239.7	447.0	186.5
0% Retarder	1	2.232	2232	7.0	382.4	.	
0% Retarder	2	2.281	2281	4.9	440.1	.	
0% Retarder	3	2.286	2286	4.7	433.4	.	
0% Retarder	4	2.173	2173	9.4	.	422.0	
0% Retarder	5	2.152	2152	10.3	.	322.0	
0% Retarder	6	2.161	2161	9.9	.	353.2	
0% Retarder	Average	2.214	2214	7.7	418.6	365.7	87.4

2% Retarder, 6-day bag cure, 30 minute compaction delay.
0% Retarder, 6-day moist cure, no compaction delay.

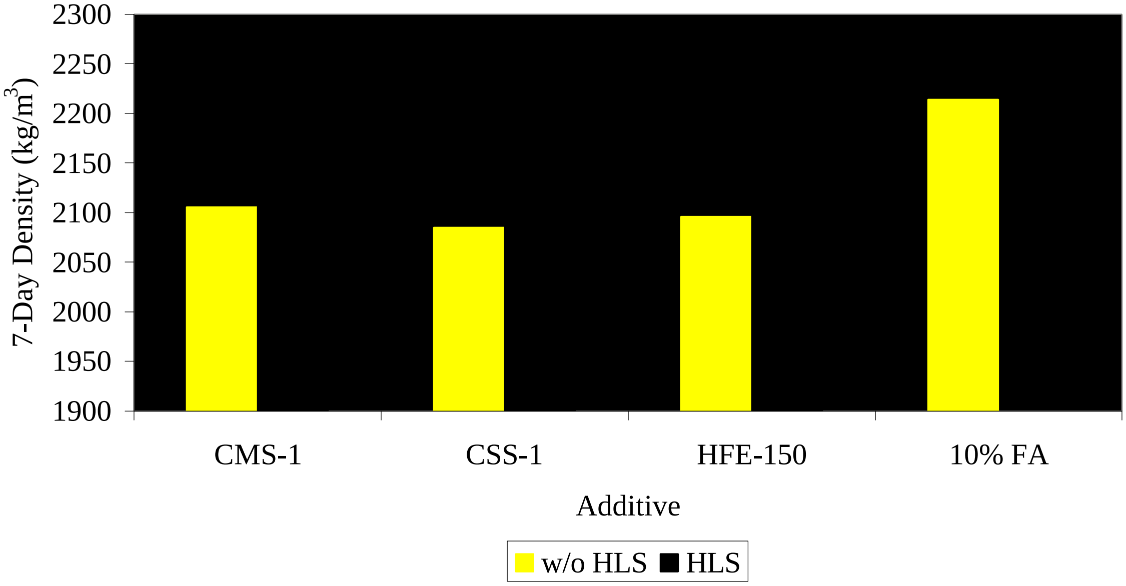

Figure 4. Average Compacted Density.

higher densities than HFE-150 or CSS-1. The use of HLS did not change this ranking of the densities, but the significance of the rankings changed slightly.

Indirect Tensile Strength

The indirect tensile strengths were performed on three samples from each asphalt emulsion with and without HLS and on the 10% fly ash samples with and without retarder. The results are shown in Tables 2-5. The 10% fly ash samples had very low tensile strengths and it appeared that the samples were not fully cured out. This was evident by the higher conditioned tensile strength values for the samples with retarder. As previously discussed, samples were remade without the retarder and without the delayed compaction. The analysis was performed on the samples without retarder.

The average indirect tensile strengths are shown graphically in Figure 5. A two-way analysis of variance was performed on the tensile strengths and the results indicate

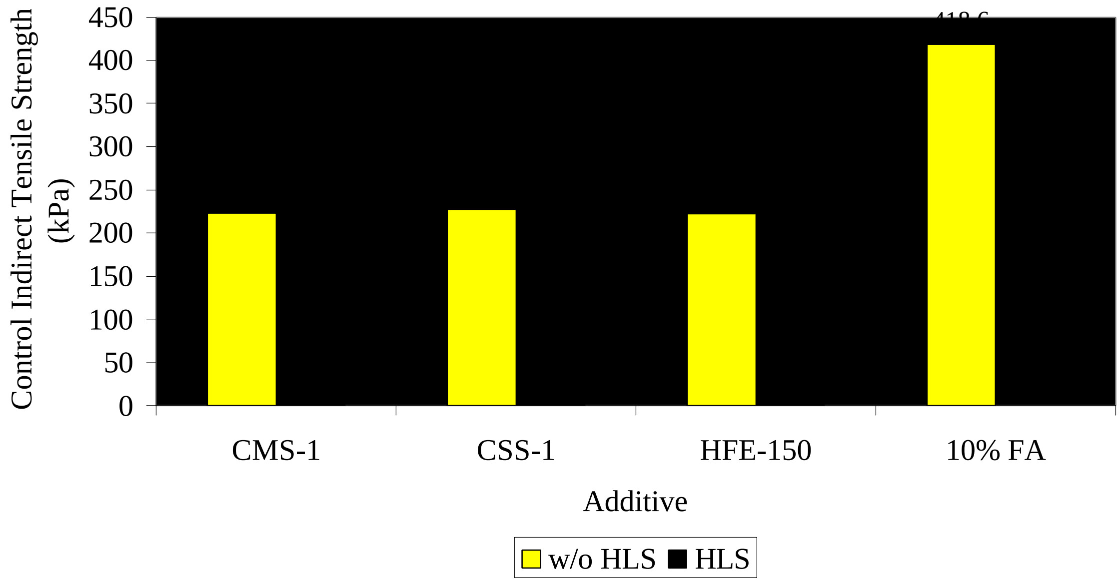

Figure 5. Indirect Tensile Strength of Control Specimens.

that 10% class C fly ash results in significantly higher indirect tensile strengths than asphalt emulsion samples. For the asphalt emulsion samples the use of HLS results in a statistically significant increase in tensile strength, regardless of asphalt emulsion, at a confidence limit of 95%. For the samples without HLS there was no significant difference in the tensile strengths. For the HLS samples, the CSS-1 asphalt emulsion was significantly stronger than CMS-1. The HFE-150 with HLS was not significantly different from the other two asphalt emulsions.

AASHTO T 283

The resistance to moisture induced damage was evaluated using AASHTO T 283. The conditioned (with optional freeze cycle) indirect tensile strength was determined on three samples from each asphalt emulsion with and without HLS and on 10% fly ash samples with and without 2% retarder. The results are shown in Tables 2-5. The tensile strength ratio (TSR) was determined by dividing the average conditioned tensile strength by the average control tensile strength. The high conditioned tensile strengths and TSRs over 100% for the 10% fly ash samples with 2% retarder indicate that the control samples did not reach their fully cured strength. The analysis was conducted on the samples without retarder.

The results of the average conditioned indirect tensile strengths are shown in Figure 6. A two-way analysis of variance was performed on the conditioned tensile strengths and the results indicate that the use of HLS results in a statistically significant increase in conditioned tensile strength, regardless of asphalt emulsion, at a confidence limit of 95%. The asphalt emulsion samples without HLS were not significantly different from each other. For the HLS samples, the CMS-1 with HLS had significantly lower strength than either CSS-1 or HFE-150.

The results of the TSRs are shown in Figure 7. The use of HLS results in significantly higher TSRs. For the samples without HLS, there is little significant difference in the TSRs. None of the asphalt emulsions without HLS had TSRs above 50%. Using HLS resulted in significantly higher TSRs with all being above 75% and the CSS-1 and HFE-150 with HLS being above 80%. A TSR of 80% or above has typically been utilized as a minimum acceptable value for hot mix asphalt. Minimum acceptable TSR values for CIR mixtures have not been determined.

Resilient Modulus

The total resilient modulus was determined in general accordance with AASHTO TP 31-94, using an assumed Poisson's ratio of 0.35 and 0.20 for asphalt emulsion and fly ash samples, respectively. The samples were tested at 25°C using a haversine load pulse at 1

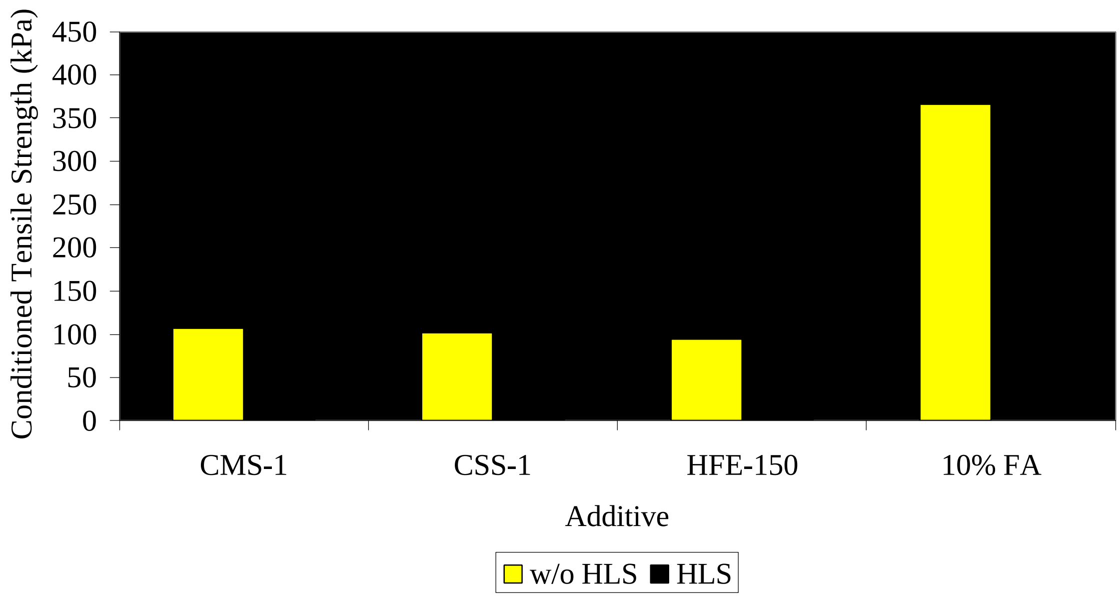

Figure 6. Conditioned Indirect Tensile Strengths.

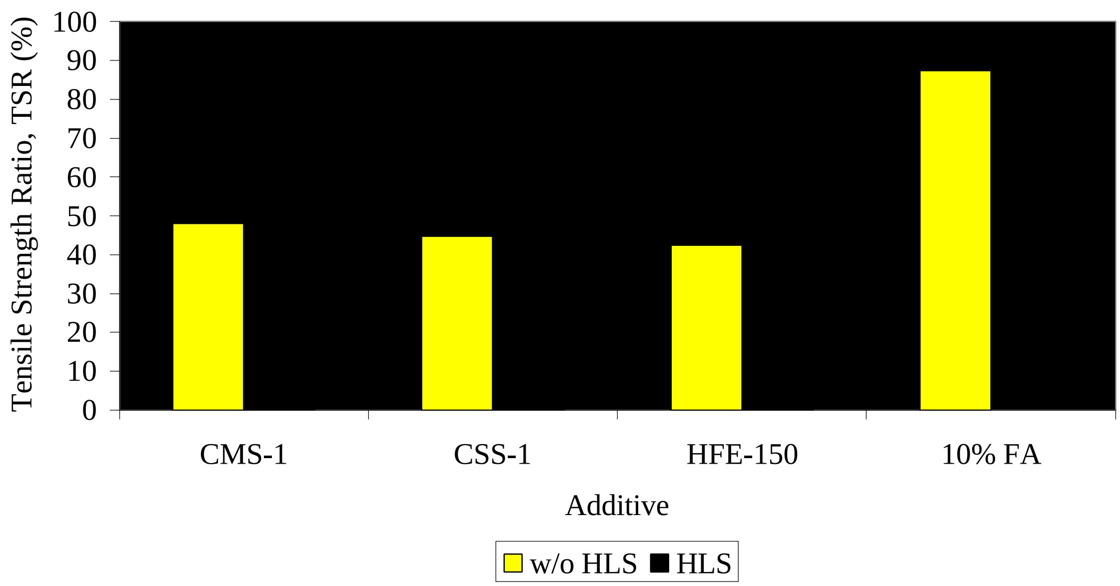

Figure 7. AASHTO T 283 Tensile Strength Ratios.

hertz with a 0.9-second rest period. The samples were loaded to 15% of their indirect tensile strength. The results are shown in Tables 6-9. The average resilient modulus values are shown in Figure 8. A two-way analysis of variance was performed on the resilient modulus values and the results indicate that the use of HLS results in a statistically significant increase in resilient modulus, regardless of asphalt emulsion, at a confidence limit of 95%. The asphalt emulsion samples with HLS were not significantly different from each other. For the asphalt emulsion samples without HLS, the CSS-1 had a significantly higher resilient modulus than either CMS-1 or HFE-150.

Index of Retained Resilient Modulus

The index of retained resilient modulus (IRRM) was determined by dividing the resilient modulus of samples conditioned using the AASHTO T 283 optional freeze cycle by the resilient modulus of air-cured (control) samples. The results are presented in Tables 6-9. The IRRM is the average conditioned resilient modulus divided by the average control resilient modulus.

The results of the average conditioned resilient modulus values are shown in Figure 9. A two-way analysis of variance was performed on the conditioned resilient modulus values and the results indicate that the use of HLS results in a statistically significant increase in resilient modulus, regardless of asphalt emulsion, at a confidence limit of 95%. The asphalt emulsion samples with HLS were not significantly different from each other. For the asphalt emulsion samples without HLS, the CSS-1 was significantly stiffer than HFE-150 which was significantly stiffer than CMS-1.

Table 6. Summary of Resilient Modulus Testing for CMS-1.

Sample	Bulk Specific Gravity	7-Day Density (kg/m^3)	VTM (%)	Resilient Modulus Control (MPa)	Resilient Modulus Conditioned (MPa)	Index Retained Resilient Modulus (%)
1	2.104	2104	12.3	113.7	.	
2	2.105	2105	12.3	94.7	.	
3	2.095	2095	12.7	83.6	.	
Average	2.101	2101.3	12.4	97.3	.	
4	2.046	2046	14.7	.	60.3	
5	2.057	2057	14.3	.	92.6	
6				.	S/F	
Average	2.052	2051.5	14.5	.	76.5	78.5
1	2.152	2152	10.3	241.3	.	
2	2.162	2162	9.9	303.6	.	
3	2.143	2143	10.7	211.0	.	
Average	2.152	2152.3	10.3	252.0	.	
4	2.126	2126	11.4	.	312.6*	
5	2.119	2119	11.7	.	211.9	
6	2.139	2139	10.8	.	209.2	
Average	2.128	2128.0	11.3	.	210.6	83.6

*Value not used in average

Table 7. Summary of Resilient Modulus Testing for CSS-1.

Sample	Bulk Specific Gravity	7-Day Density (kg/m^3)	VTM (%)	Resilient Modulus Control (MPa)	Resilient Modulus Conditioned (MPa)	Index Retained Resilient Modulus (%)
1	2.063	2063	14.0	176.9	.	
2	2.035	2035	15.2	179.8	.	
3	2.088	2088	13.0	199.1	.	
Average	2.062	2062.0	14.1	185.3	.	
4	2.072	2072	13.7	.	159.5	
5	2.071	2071	13.7	.	164.8	
6	2.050	2050	14.5	.	155.4	
Average	2.064	2064.3	14.0	.	159.9	86.3
1	2.123	2123	11.5	S/F	.	
2	2.120	2120	11.7	276.6	.	
3	2.126	2126	11.4	339.6	.	
Average	2.123	2123.0	11.5	308.1	.	
4	2.124	2124	11.5	.	240.9	
5	2.134	2134	11.1	.	325.6	
6	2.118	2118	11.7	.	238.5	
Average	2.125	2125.3	11.4	.	268.3	87.1

Table 8. Summary of Resilient Modulus Testing for HFE-150.

Sample	Bulk Specific Gravity	7-Day Density (kg/m^3)	VTM (%)	Resilient Modulus Control (MPa)	Resilient Modulus Conditioned (MPa)	Index Retained Resilient Modulus (%)
1	2.063	2063	14.0	255.4	.	
2	2.107	2107	12.2	S/F	.	
3	2.075	2075	13.5	283.5	.	
Average	2.069	2069.0	13.8	269.5	.	
4	2.090	2090	12.9	.	132.6	
5	2.098	2098	12.6	.	113.1	
6	2.077	2077	13.4	.	111.6	
Average	2.088	2088.3	13.0	.	119.1	44.2
1	2.122	2122	11.6	305.2	.	
2	2.134	2134	11.1	357.3	.	
3	2.111	2111	12.0	295.7	.	
Average	2.122	2122.3	11.6	319.4	.	
4	2.116	2116	11.8	.	206.5	
5	2.106	2106	12.2	.	224.0	
6	2.110	2110	12.1	.	287.3	
Average	2.111	2110.7	12.0	.	239.3	74.9

Table 9. Summary of Resilient Modulus Testing for 10% Fly Ash.

Sample	Bulk Specific Gravity	7-Day Density (kg/m^3)	VTM (%)	Resilient Modulus Control (MPa)	Resilient Modulus Conditioned (MPa)	Index Retained Resilient Modulus (%)
1	2.234	2234	6.9	136.5	59.7	43.7
2	2.236	2236	6.8	165.7	66.3	40.0
3	2.205	2205	8.1	102.2	54.5	53.3
Average	2.225	2224.9	7.3	134.8	60.2	45.7

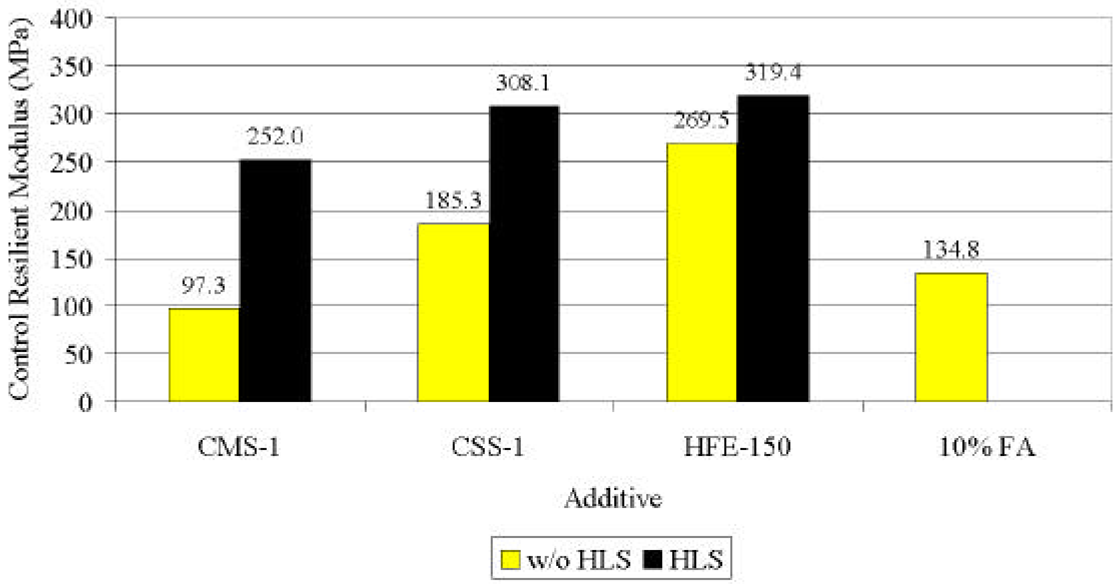

Figure 8. Resilient Modulus of Control Specimens.

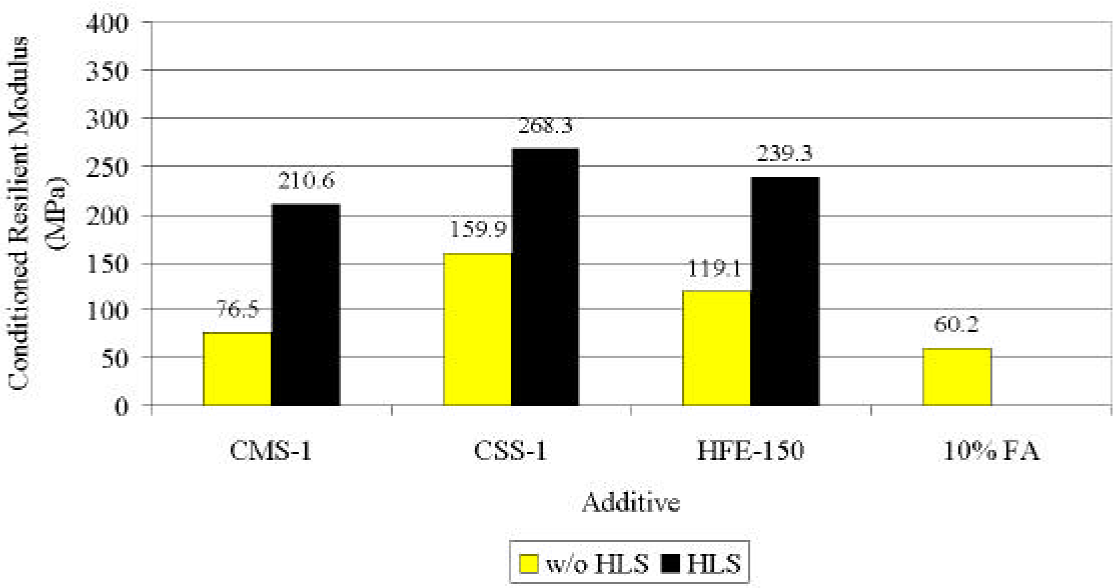

Figure 9. Conditioned Resilient Modulus Results.

The results of the IRRM testing are shown in Figure 10. The IRRM values did not follow the same trend as the TSRs from AASHTO T 283. The fly ash samples showed a significant drop in IRRM, to less than 50% whereas the TSR was over 80%. For the asphalt emulsion only samples, only the HFE-150 had an IRRM in the same range as its TSR. The CMS-1 and CSS-1 asphalt emulsion only samples had an IRRM at or above 80%. The use of HLS significantly increased the IRRM of HFE-150 and slightly increased the IRRM of the other emulsions.

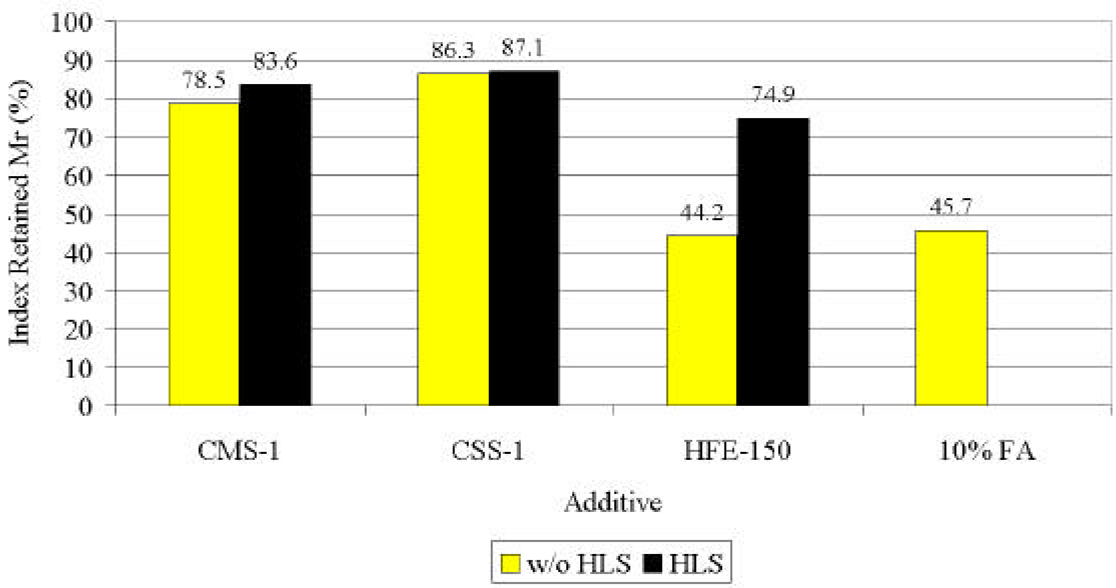

Figure 10. Index of Retained Resilient Modulus Results.

CHAPTER 3
PHASE II
EVALUATION OF CORES

TEST SECTIONS

Two 300-m test sections were laid out by KDOT in 1997. The south test section (sta. 10+240 to sta. 10+540) was constructed using an average of 8% to 10% class C fly ash as the additive. The north test section (sta. 14+691 to sta. 14+991) was constructed using an average of 1.5% CSS-1 asphalt emulsion with HLS (AE with HLS). Cores were obtained from three areas in each test section. The three areas within each test section were referred to as the south, middle and north areas. The areas were 100-m apart and began 50-m north of the south end of each test section. Six 100-mm diameter cores and four 150-mm diameter cores were obtained from each area of each test section. One half of the cores were obtained from between the wheel paths and one half from the outer wheel path. The cores were obtained within a 5-m section.

TEST PLAN

The cores were returned to the Bituminous Laboratory at the University of Kansas for testing and evaluation. First the cores were measured for the thickness of the surface mix and the CIR layer. The cores were then sawed into their respective layers using a water-cooled diamond saw blade. Next the cores were air-dried and the bulk specific gravity of the layers determined in accordance with AASHTO T 166 (KT-15 Procedure III). The CIR layers were then sawed to the necessary height for testing and the bulk specific gravity determined on the top and bottom halves of the samples. The top half of the CIR layer was used for testing. The 100-mm cores were used for further testing in this phase and the 150-mm cores were tested as a part of Phase III of this project.

Air permeability testing (ASTM D 3637) was performed on six 100-mm cores from the AE with HLS and fly ash test sections. Two cores, one from each wheel path, were obtained from the north, middle and south section of each test section. The air permeability testing was performed by KDOT. The test is not a destructive test; therefore, the cores were returned for further testing.

Six 100-mm cores were obtained from each area of each test section. From these cores two were tested for indirect tensile strength (ASTM D 4123), two for moisture sensitivity (AASHTO T 283), and two for resilient modulus (AASHTO TP 31-94). The two cores used for resilient modulus testing were retested, after conditioning, for index of retained resilient modulus (IRRM). One core from each wheel path was used to make up the set of two cores for the above testing.

The gradation of the CIR with fly ash could not be readily determined. Therefore, only the gradation and asphalt content of the surface mix was determined. One core from each area of each test section was selected after completion of the above testing and tested for asphalt content in accordance with KDOT Test method KT-57. The gradation of the recovered aggregate was determined in accordance with AASHTO T 11 and T 27.

TEST RESULTS

Gradation of Surface Mix

The asphalt content (KT-57) and recovered aggregate gradation (AASHTO T 11 and T 27) of the surface mix was determined from one core from each area of each test section. The results are shown in Table 10 and graphically in Figure 11. The gradations

Table 10. Gradation and Asphalt Content of Surface Mix.

Sieve Size (mm)	HLS Section North	HLS Section Middle	HLS Section South	Fly Ash Section North	Fly Ash Section Middle	Fly Ash Section South
	Percent Retained (%)					
19.0	0.0	0.0	0.0	0.0	0.0	0.0
12.5	6.6	3.8	7.2	5.7	5.5	7.1
9.5	13.8	9.4	11.9	11.4	11.8	12.5
4.75	34.7	29.0	33.4	33.4	33.0	32.6
2.38	51.3	46.1	49.7	50.9	50.4	50.2
1.18	62.5	58.8	61.2	62.6	61.8	61.8
0.600	72.2	70.1	71.4	72.7	71.7	71.8
0.300	81.7	80.8	81.4	82.3	81.6	81.8
0.150	87.8	87.4	87.7	88.6	88.2	88.5
0.075	91.0	90.8	90.9	91.8	91.6	91.8
% AC	5.2	5.4	5.2	4.9	5.1	5.0

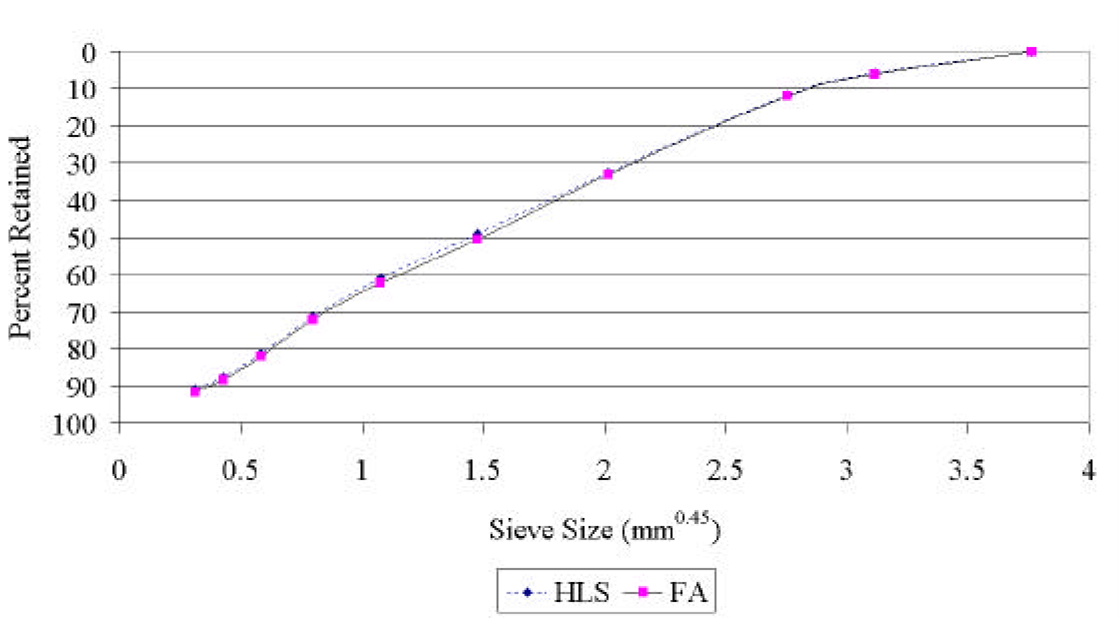

Figure 11. Gradation of Surface Mix.

of the two test sections are similar and within KDOT’s specification tolerances. However, the asphalt contents are slightly different. The AE with HLS section had an average asphalt content of 5.3% and the 10% class C fly ash section 5.0%. The reduced asphalt content of the surface mix in the fly ash section could account for some of the differences observed in the properties of the surface mix.

Layer Thickness

The results of the thickness measurements of the surface mix and CIR layer are shown in Tables 11 and 12 for the AE with HLS and fly ash sections, respectively. The results indicate that the CIR layer is thicker in the fly ash section than in the AE with HLS section. The fly ash section contains more material, 8-10% filler, resulting in a thicker CIR layer. The thickness of the surface mixture was not significantly different between the fly ash and AE with HLS test sections.

Bulk Specific Gravity

The results of the bulk specific gravity testing of the 100-mm cores for the surface mix, CIR layer, and top and bottom halves of the CIR layer are shown in the appendix. The results of the bulk specific gravity tests on the 100-mm cores of the surface mix and CIR layer are shown in Tables 13 and 14 for the AE with HLS and fly ash cores, respectively. The results for the 150-mm cores are shown in Tables 15 and 16. The bulk specific gravity was determined in accordance with AASHTO T 166, with the exception of two cores from the middle area of the fly ash test section. The bulk specific gravity of these cores was determined by KDOT in accordance with KT-15, Procedure IV. Procedure IV results in a lower bulk specific gravity than AASHTO T 166 does. Therefore, these two cores were excluded from further analysis.

Table 11. Layer Thickness Measurements for AE With HLS Section.

Additive	Area	Diameter	Location	Core	Thickness (mm) HMA	CIR	Total
HLS	N	150	BWP	1	37	103	140
HLS	N	150	OWP	2	37	98	135
HLS	N	150	BWP	3	37	103	140
HLS	N	150	OWP	4	38	98	137
HLS	N	100	OWP	1	38	97	135
HLS	N	100	BWP	2	38	98	137
HLS	N	100	BWP	3	38	102	140
HLS	N	100	OWP	4	37	106	143
HLS	N	100	BWP	5	38	102	140
HLS	N	100	OWP	6	35	102	137
HLS	M	150	BWP	1	43	106	149
HLS	M	150	OWP	2	40	105	144
HLS	M	150	BWP	3	57	89	146
HLS	M	150	OWP	4	43	103	146
HLS	M	100	BWP	1	41	105	146
HLS	M	100	OWP	2	N/T	N/T	N/T
HLS	M	100	BWP	3	N/T	N/T	N/T
HLS	M	100	OWP	4	43	102	144
HLS	M	100	BWP	5	43	103	146
HLS	M	100	OWP	6	43	103	146
HLS	S	150	OWP	1	48	105	152
HLS	S	150	BWP	2	44	108	152
HLS	S	150	BWP	3	48	105	152
HLS	S	150	OWP	4	48	105	152
HLS	S	100	BWP	1	48	105	152
HLS	S	100	OWP	2	48	105	152
HLS	S	100	BWP	3	49	110	159
HLS	S	100	OWP	4	48	106	154
HLS	S	100	OWP	5	48	108	156
HLS	S	100	BWP	6	51	107	158

N/T = Not tested.
BWP = Between wheel paths.
OWP = Outer wheel path.

Table 12. Layer Thickness Measurements for Fly Ash Section.

					Thickness (mm)		
Additive	Area	Diameter	Location	Core	HMA	CIR	Total
FA	N	150	OWP	1	41	121	162
FA	N	150	BWP	2	43	122	165
FA	N	150	BWP	3	43	119	162
FA	N	150	OWP	4	41	111	152
FA	N	100	BWP	1	41	130	171
FA	N	100	OWP	2	38	121	159
FA	N	100	OWP	3	38	108	146
FA	N	100	BWP	4	44	121	165
FA	N	100	BWP	5	41	124	165
FA	N	100	OWP	6	38	121	159
FA	M	150	BWP	1	37	144	181
FA	M	150	OWP	2	38	133	171
FA	M	150	BWP	3	38	137	175
FA	M	150	OWP	4	38	137	175
FA	M	100	BWP	1	N/T	N/T	N/T
FA	M	100	OWP	2	N/T	N/T	N/T
FA	M	100	BWP	3	44	133	178
FA	M	100	OWP	4	41	130	171
FA	M	100	BWP	5	N/T	N/T	N/T
FA	M	100	OWP	6	N/T	N/T	N/T
FA	S	150	OWP	1	40	119	159
FA	S	150	BWP	2	41	127	168
FA	S	150	BWP	3	41	130	171
FA	S	150	OWP	4	41	121	162
FA	S	100	BWP	1	44	124	168
FA	S	100	OWP	2	46	116	162
FA	S	100	BWP	3	44	121	165
FA	S	100	OWP	4	48	108	156
FA	S	100	BWP	5	44	121	165
FA	S	100	OWP	6	46	119	165

N/T = Not tested.
BWP = Between wheel paths.
OWP = Outer wheel path.

Table 13. Bulk Specific Gravity and Density of 100-mm Cores, HLS Section.

Additive	Area	Core	Layer	Location	Gmb	Density (kg/m^3)
HLS	N	1	1	OWP	2.273	2273
HLS	N	1	2	OWP	2.133	2133
HLS	N	2	1	BWP	2.206	2206
HLS	N	2	2	BWP	2.136	2136
HLS	N	3	1	BWP	2.209	2209
HLS	N	3	2	BWP	2.121	2121
HLS	N	4	1	OWP	2.263	2263
HLS	N	4	2	OWP	2.136	2136
HLS	N	5	1	BWP	2.213	2213
HLS	N	5	2	BWP	2.120	2120
HLS	N	6	1	OWP	2.267	2267
HLS	N	6	2	OWP	2.150	2150
HLS	M	1	1	BWP	2.275	2275
HLS	M	1	2	BWP	2.122	2122
HLS	M	2	1	OWP	2.274	2274
HLS	M	2	2	OWP	2.177	2177
HLS	M	3	1	BWP	2.281	2281
HLS	M	3	2	BWP	2.149	2149
HLS	M	4	1	OWP	2.291	2291
HLS	M	4	2	OWP	2.134	2134
HLS	M	5	1	BWP	2.270	2270
HLS	M	5	2	BWP	2.144	2144
HLS	M	6	1	OWP	2.287	2287
HLS	M	6	2	OWP	2.166	2166
HLS	S	1	1	BWP	2.232	2232
HLS	S	1	2	BWP	2.182	2182
HLS	S	2	1	OWP	2.267	2267
HLS	S	2	2	OWP	2.186	2186
HLS	S	3	1	BWP	2.211	2211
HLS	S	3	2	BWP	2.142	2142
HLS	S	4	1	OWP	2.271	2271
HLS	S	4	2	OWP	2.178	2178
HLS	S	5	1	OWP	2.277	2277
HLS	S	5	2	OWP	2.206	2206
HLS	S	6	1	BWP	2.220	2220
HLS	S	6	2	BWP	2.163	2163

OWP = Outer wheel path. BWP = Between wheel paths.

Table 14. Bulk Specific Gravity and Density of 100-mm Cores, Fly Ash Section.

Additive	Area	Core	Layer	Location	Gmb	Density (kg/m^3)
FA	N	1	1	BWP	2.227	2227
FA	N	1	2	BWP	2.172	2172
FA	N	2	1	OWP	2.272	2272
FA	N	2	2	OWP	2.182	2182
FA	N	3	1	OWP	2.230	2230
FA	N	3	2	OWP	2.151	2151
FA	N	4	1	BWP	2.271	2271
FA	N	4	2	BWP	2.143	2143
FA	N	5	1	BWP	2.245	2245
FA	N	5	2	BWP	2.172	2172
FA	N	6	1	OWP	2.287	2287
FA	N	6	2	OWP	2.182	2182
FA	M	1	1	BWP	2.287	2287
FA	M	1	2	BWP	2.131	2131
FA	M	2	1	OWP	2.272	2272
FA	M	2	2	OWP	2.146	2146
FA	M	3	1	BWP	2.233	2233
FA	M	3	2	BWP	2.156	2156
FA	M	4	1	OWP	2.284	2284
FA	M	4	2	OWP	2.143	2143
FA	M	5	1	BWP	2.234*	2234*
FA	M	5	2	BWP	2.105*	2105*
FA	M	6	1	OWP	2.232*	2232*
FA	M	6	2	OWP	2.109*	2109*
FA	S	1	1	BWP	2.260	2260
FA	S	1	2	BWP	2.218	2218
FA	S	2	1	OWP	2.282	2282
FA	S	2	2	OWP	2.215	2215
FA	S	3	1	BWP	2.263	2263
FA	S	3	2	BWP	2.206	2206
FA	S	4	1	OWP	2.303	2303
FA	S	4	2	OWP	2.222	2222
FA	S	5	1	BWP	2.255	2255
FA	S	5	2	BWP	2.208	2208
FA	S	6	1	OWP	2.297	2297
FA	S	6	2	OWP	2.216	2216

* KT-15 Procedure IV. OWP = Outer wheel path. BWP = Between wheel paths.

Table 15. Bulk Specific Gravity and Density of 150-mm Cores, HLS Section.

Additive	Area	Core	Layer	Location	Gmb	Density (kg/m^3)
HLS	N	1	1	BWP	2.188	2188
HLS	N	1	2	BWP	2.072	2072
HLS	N	2	1	OWP	2.236	2236
HLS	N	2	2	OWP	2.145	2145
HLS	N	3	1	BWP	2.193	2193
HLS	N	3	2	BWP	2.110	2110
HLS	N	4	1	OWP	2.267	2267
HLS	N	4	2	OWP	2.137	2137
HLS	M	1	1	BWP	2.269	2269
HLS	M	1	2	BWP	2.165	2165
HLS	M	2	1	OWP	2.273	2273
HLS	M	2	2	OWP	2.147	2147
HLS	M	3	1	BWP	2.261	2261
HLS	M	3	2	BWP	2.158	2158
HLS	M	4	1	OWP	2.279	2279
HLS	M	4	2	OWP	2.123	2123
HLS	S	1	1	OWP	2.249	2249
HLS	S	1	2	OWP	2.157	2157
HLS	S	2	1	BWP	2.202	2202
HLS	S	2	2	BWP	2.157	2157
HLS	S	3	1	BWP	2.201	2201
HLS	S	3	2	BWP	2.140	2140
HLS	S	4	1	OWP	2.255	2255
HLS	S	4	2	OWP	2.149	2149

BWP = Between wheel paths. OWP = Outer wheel path.

Table 16. Bulk Specific Gravity and Density of 150-mm Cores, Fly Ash Section.

Additive	Area	Core	Layer	Location	Gmb	Density (kg/m^3)
FA	N	1	1	OWP	2.282	2282
FA	N	1	2	OWP	2.156	2156
FA	N	2	1	BWP	2.212	2212
FA	N	2	2	BWP	2.149	2149
FA	N	3	1	BWP	2.210	2210
FA	N	3	2	BWP	2.140	2140
FA	N	4	1	OWP	2.276	2276
FA	N	4	2	OWP	2.169	2169
FA	M	1	1	BWP	2.254	2254
FA	M	1	2	BWP	2.124	2124
FA	M	2	1	OWP	2.257	2257
FA	M	2	2	OWP	2.155	2155
FA	M	3	1	BWP	2.264	2264
FA	M	3	2	BWP	2.136	2136
FA	M	4	1	OWP	2.267	2267
FA	M	4	2	OWP	2.177	2177
FA	S	1	1	OWP	2.278	2278
FA	S	1	2	OWP	2.226	2226
FA	S	2	1	BWP	2.246	2246
FA	S	2	2	BWP	2.200	2200
FA	S	3	1	BWP	2.256	2256
FA	S	3	2	BWP	2.194	2194
FA	S	4	1	OWP	2.278	2278
FA	S	4	2	OWP	2.225	2225

BWP = Between wheel paths. OWP = Outer wheel path.

Air Permeability

The results of the air permeability testing (ASTM D 3736) are shown in Table 17. The test was performed by KDOT. The air permeability test is not a destructive test so the cores were used for further testing.

Indirect Tensile Strength and AASHTO T283

The test results from the indirect tensile strength testing (ASTM D 4123) and moisture sensitivity testing (AASHTO T 283) are shown in Tables 18 and 19. The indirect tensile strengths (ASTM D 4123) were used as the control strengths in AASHTO T 283. The conditioned indirect tensile strength was determined using the optional freeze cycle.

Resilient Modulus

The total resilient modulus was determined in general accordance with AASHTO TP 31-94, using an assumed Poisson’s ratio of 0.35 for AE with HLS samples and 0.20 for fly ash samples. The samples were tested at 25^{o}C using a haversine load pulse at 1 hertz with a 0.9-second rest period. The samples were loaded to 15% of their indirect tensile strength. The results are shown in Table 20.

Index of Retained Resilient Modulus

The index of retained resilient modulus (IRRM) was determined by dividing the resilient modulus of samples conditioned using the AASHTO T 283 optional freeze cycle by the resilient modulus of air-cured (control) samples. The results are presented in Table 20. The IRRM is the average conditioned resilient modulus divided by the average control resilient modulus.

Table 17. Results of Air Permeability Testing on Cores.

Additive	Area	Core	Layer	Location	Air Permeability (10^{-10cm^2})
HLS	N	3	1	BWP	319
HLS	N	4	1	OWP	46
HLS	M	1	1	BWP	28
HLS	M	2	1	OWP	18
HLS	S	3	1	BWP	281
HLS	S	4	1	OWP	58
HLS	N	3	2	BWP	249
HLS	N	4	2	OWP	178
HLS	M	1	2	OWP	37
HLS	M	2	2	BWP	53
HLS	S	3	2	BWP	77
HLS	S	4	2	OWP	55
FA	N	3	1	OWP	45
FA	N	4	1	BWP	71
FA	M	1	1	BWP	24
FA	M	2	1	OWP	9
FA	S	3	1	BWP	86
FA	S	4	1	OWP	38
FA	N	3	2	OWP	151
FA	N	4	2	BWP	85
FA	M	1	2	BWP	133
FA	M	2	2	OWP	71
FA	S	3	2	BWP	67
FA	S	4	2	OWP	48

BWP = Between wheel paths. OWP = Outer wheel path.

Table 18. Results of Indirect Tensile and AASHTO T 283 Testing on HLS Cores.

Additive	Area	Core	Layer	Location	Tensile Strength Control (kPa)	Tensile Strength Conditioned (kPa)	TSR (%)
HLS	N	1	1	OWP	827.1	.	.
HLS	N	2	1	BWP	632.3	.	.
HLS	N	4	1	OWP	.	701.3	84.8
HLS	N	3	1	BWP	.	511.2	80.8
HLS	M	1	1	BWP	946.0	.	.
HLS	M	2	1	OWP	840.9	.	.
HLS	M	3	1	BWP	.	797.1	84.3
HLS	M	4	1	OWP	.	721.0	85.7
HLS	S	1	1	BWP	675.5	.	.
HLS	S	2	1	OWP	924.3	.	.
HLS	S	3	1	BWP	.	545.6	80.8
HLS	S	4	1	OWP	.	716.0	77.5
HLS	N	1	2	OWP	527.9	.	.
HLS	N	2	2	BWP	454.6	.	.
HLS	N	4	2	OWP	.	545.7	103.4
HLS	N	3	2	BWP	.	464.7	102.2
HLS	M	1	2	BWP	726.2	.	.
HLS	M	2	2	OWP	671.9	.	.
HLS	M	3	2	BWP	.	507.4	69.9
HLS	M	4	2	OWP	.	628.5	93.5
HLS	S	1	2	BWP	547.9	.	.
HLS	S	2	2	OWP	695.5	.	.
HLS	S	3	2	BWP	.	527.9	96.3
HLS	S	4	2	OWP	.	638.7	91.8

BWP = Between wheel paths. OWP = Outer wheel path.

Table 19. Results of Indirect Tensile and AASHTO T 283 Testing on Fly Ash Cores.

Additive	Area	Core	Layer	Location	Tensile Strength Control (kPa)	Tensile Strength Conditioned (kPa)	TSR (%)
FA	N	1	1	BWP	868.3	.	.
FA	N	2	1	OWP	978.2	.	.
FA	N	4	1	BWP	.	624.8	72.0
FA	N	3	1	OWP	.	799.6	81.7
FA	M	1	1	BWP	1035.8	.	.
FA	M	2	1	OWP	1089.4	.	.
FA	M	3	1	BWP	.	756.3	73.0
FA	M	4	1	OWP	.	751.3	69.0
FA	S	1	1	BWP	1080.6	.	.
FA	S	2	1	OWP	1208.7	.	.
FA	S	3	1	BWP	.	834.2	77.2
FA	S	4	1	OWP	.	980.4	81.1
FA	N	1	2	BWP	956.8	.	.
FA	N	2	2	OWP	818.1	.	.
FA	N	4	2	BWP	.	796.5	83.2
FA	N	3	2	OWP	.	731.4	89.4
FA	M	1	2	BWP	815.2	.	.
FA	M	2	2	OWP	989.7	.	.
FA	M	3	2	BWP	S/M	S/M	S/M
FA	M	4	2	OWP	S/M	S/M	S/M
FA	S	1	2	BWP	1009.3	.	.
FA	S	2	2	OWP	1043.9	.	.
FA	S	3	2	BWP	.	779.9	77.3
FA	S	4	2	OWP	.	850.7	81.5

S/M = Sample Missing.
BWP = Between wheel paths. OWP = Outer wheel path.

Table 20. Results of Resilient Modulus Testing.

Additive	Area	Core	Layer	Location	Resilient Modulus Control (MPa)	Resilient Modulus Conditioned (MPa)	IRRM (%)
HLS	N	5	1	BWP	1231.5	642.3	52.2
HLS	N	6	1	OWP	1666.9	987.8	59.3
HLS	M	5	1	BWP	753.1	590.0	78.3
HLS	M	6	1	OWP	603.3	428.9	71.1
HLS	S	5	1	OWP	488.4	321.7	65.9
HLS	S	6	1	BWP	795.7	455.9	57.3
HLS	N	5	2 Top	BWP	304.8	172.7	56.7
HLS	N	6	2 Top	OWP	508.8	277.0	54.4
HLS	M	5	2 Top	BWP	568.4	366.8	64.5
HLS	M	6	2 Top	OWP	537.8	286.9	53.3
HLS	S	5	2 Top	OWP	425.0	301.2	70.9
HLS	S	6	2 Top	BWP	321.1	268.3	83.6
FA	N	5	1	BWP	965.0	687.8	71.3
FA	N	6	1	OWP	570.2	376.7	66.1
FA	M	5	1		S/M		
FA	M	6	1		S/M		
FA	S	5	1	BWP	593.6	519.0	87.4
FA	S	6	1	OWP	593.6	497.9	83.9
FA	N	5	2 Top	BWP	253.1	144.5	57.1
FA	N	6	2 Top	OWP	365.0	217.6	59.6
FA	M	5	2 Top		S/M		
FA	M	6	2 Top		S/M		
FA	S	5	2 Top	BWP	291.8	132.7	45.5
FA	S	6	2 Top	OWP	264.0	131.2	49.7

S/M = Sample Missing.
BWP = Between wheel paths.   OWP = Outer wheel path.

ANALYSIS OF RESULTS

One of the objectives of this phase of the study was to compare the material properties of the AE with HLS and fly ash CIR sections. An ANOVA was performed on the test results to determine if the material properties of the fly ash and AE with HLS sections were significantly different at a confidence limit of 95% ($\alpha = 0.05$). The material properties within each test section were also evaluated by area to evaluate material variability and by wheel path to evaluate the effects of traffic densification. However, due to the expense of obtaining and testing samples, the confidence level, ($1-\beta$) of the later two analyses is not as high as typically desired.

Bulk Specific Gravity

The summary of the means for the bulk specific gravity testing for the 100-mm and 150-mm cores, by layer, are shown in Table 21. The results for the surface mix and CIR layer are shown graphically in Figures 12 and 13, respectively. For the surface mix, the analysis shows a significant difference in the bulk specific gravity for the 150-mm at a 95% confidence limit and at a 90% confidence limit for the 100-mm cores, with the fly ash section having a higher bulk specific gravity. The asphalt content, by ignition, of the surface mix indicated more asphalt cement in the AE with HLS test section (5.3%) than the fly ash section (5.0%). This could account for some of the difference in bulk specific gravity. The surface mix in the AE with HLS section showed a significant difference in bulk specific gravity by wheel path and area. The fly ash section showed inconsistent results for the 100-mm and 150-mm cores.

Figure 13 shows the results of the bulk specific gravity testing for the CIR layer. The analysis of the bulk specific gravity testing for the CIR layer showed that the fly ash

Table 21. Summary of Means and ANOVA for Bulk Specific Gravity and Air Permeability.

Physical Property	AE with HLS						Fly Ash					
	Average	OWP	BWP	N	M	S	Average	OWP	BWP	N	M	S
Layer 1 (HMA)												
Gmb 100-mm	2.255	2.274	2.235	2.239	2.280	2.246	2.267	2.278	2.255	2.255	2.269	2.277
Sig, Difference	No*	Yes	Yes	B	A	B	No*	No	No	No	No	No
Gmb 150-mm	2.240	2.260	2.219	2.221	2.271	2.227	2.257	2.273	2.24	2.245	2.261	2.265
Sig, Difference	Yes	Yes	Yes	B	A	B	Yes	Yes	Yes	B	A	A
Permeability $(10^{-10\ cm^{2}})$	125	41	209	183	23	170	46	31	60	58	17	62
Sig, Difference	No	No	No	A	B	A	No	No	No	No	No	No
Layer 2 (CIR)												
Gmb 100-mm	2.153	2.163	2.142	2.133	2.149	2.176	2.177	2.182	2.176	2.167	2.144	2.214
Sig, Difference	Yes	Yes	Yes	B	B	A	Yes	No	No	B	C	A
Gmb 150-mm	2.138	2.143	2.134	2.116	2.148	2.151	2.171	2.185	2.157	2.154	2.148	2.211
Sig, Difference	Yes	No	No	No	No	No	Yes	Yes	Yes	B	B	A
Permeability (10^-10 cm^2)	108	90	126	213	45	66	93	90	95	118	102	58
Sig, Difference	No	No	No	A	B	B	No	No	No	No	No	No

Sig. Difference = Significant difference in means at alpha = 0.05.

* Significant difference in means at alpha = 0.10.

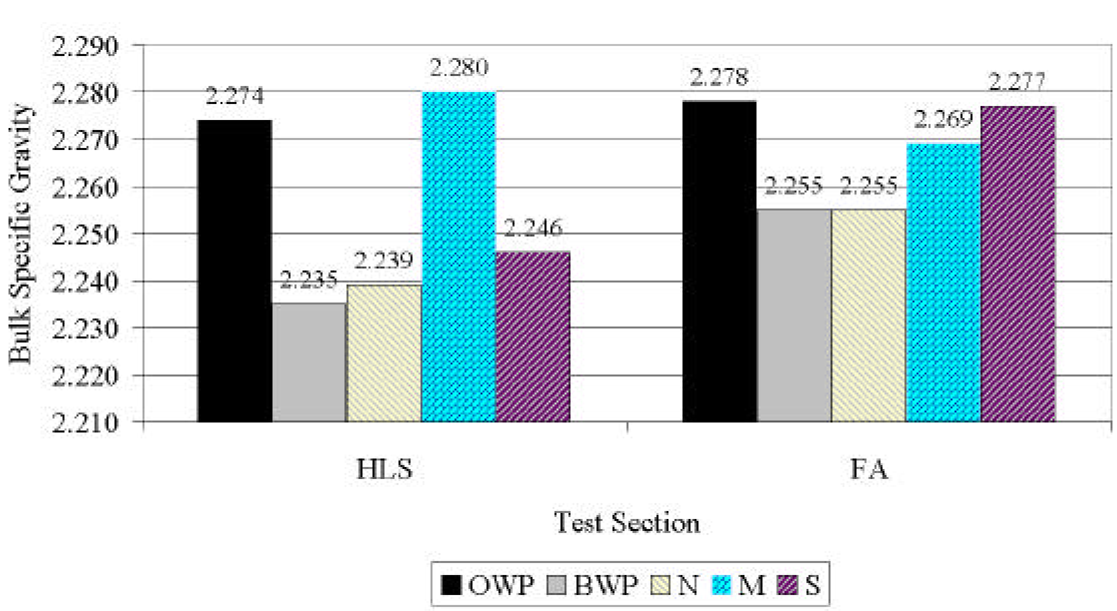

Figure 12. Bulk Specific Gravity of 100-mm Cores, Surface Mix.

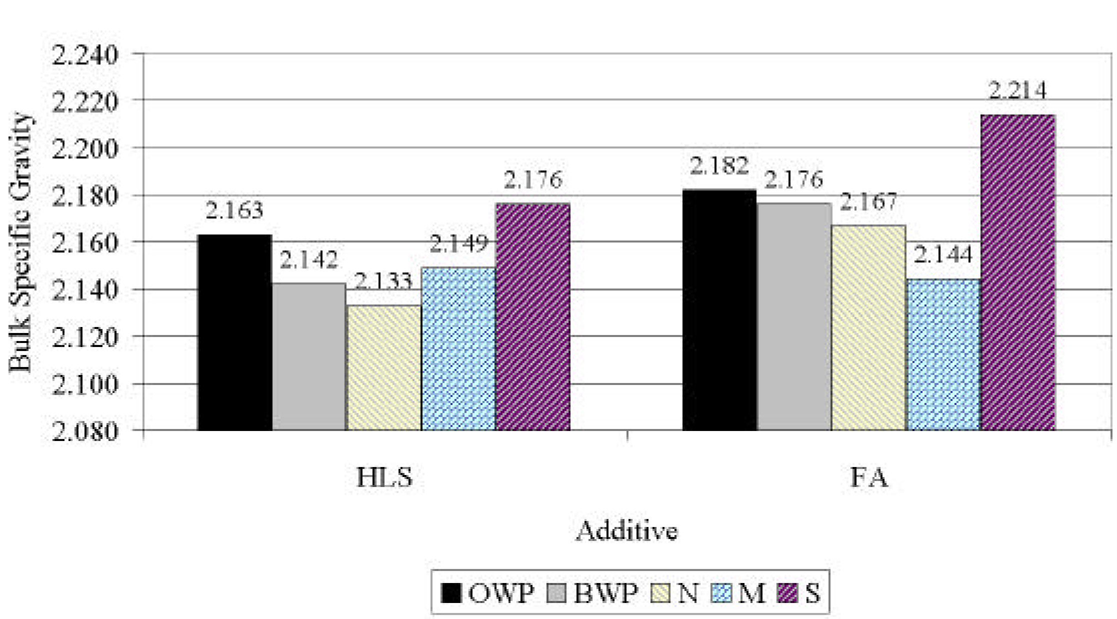

Figure 13. Bulk Specific Gravity of 100-mm Cores, CIR Layer.

mix had a higher bulk specific gravity than the AE with HLS mix. The fly ash accounts for an additional 8-10% mineral filler in the mix, which would result in a higher bulk specific gravity. There was no consistent trend for either the fly ash or AE with HLS mix by wheel path or area. The pavement had only been open to traffic for about six months when sampled, possibly too soon to allow for consistent densification of the CIR layer by traffic. The low number of samples also effects the significance of the results.

Air Permeability

The means and ANOVA results from the air permeability testing are also shown in Table 21. The results for the CIR layer are shown graphically in Figure 14. The analysis indicates no difference in air permeability by test section for the surface or CIR mixes. The wheel path did not have a significant effect; however, the area did have a significant effect on air permeability of the CIR AE with HLS mix. The air permeability did not correlate well with air voids. ASTM has withdrawn ASTM D 3736 as a test standard.

Tensile Strength & AASHTO T 283

The results from indirect tensile strength testing and AASHTO T 283 are shown graphically in Figures 15-17 for the CIR layer. The summary of the means and results of the ANOVA are shown in Table 22. For the surface mix, the fly ash section had a significantly higher tensile strength and TSR than the AE with HLS section. The difference could be attributed to the increased density and/or lower asphalt content of the surface mix in the fly ash section. The wheel path and area did not have a significant effect on either tensile strength or TSR.

The fly ash CIR mix had a significantly higher tensile strength and conditioned tensile strength than the AE with HLS section. However, the AE with HLS mix had a

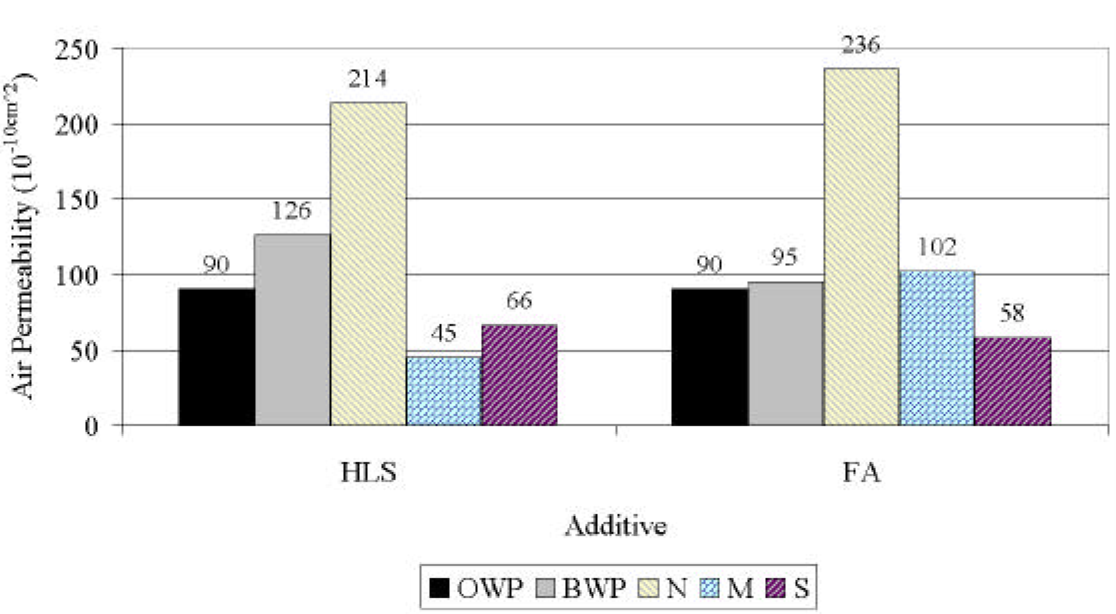

Figure 14. Air Permeability for CIR Layer.

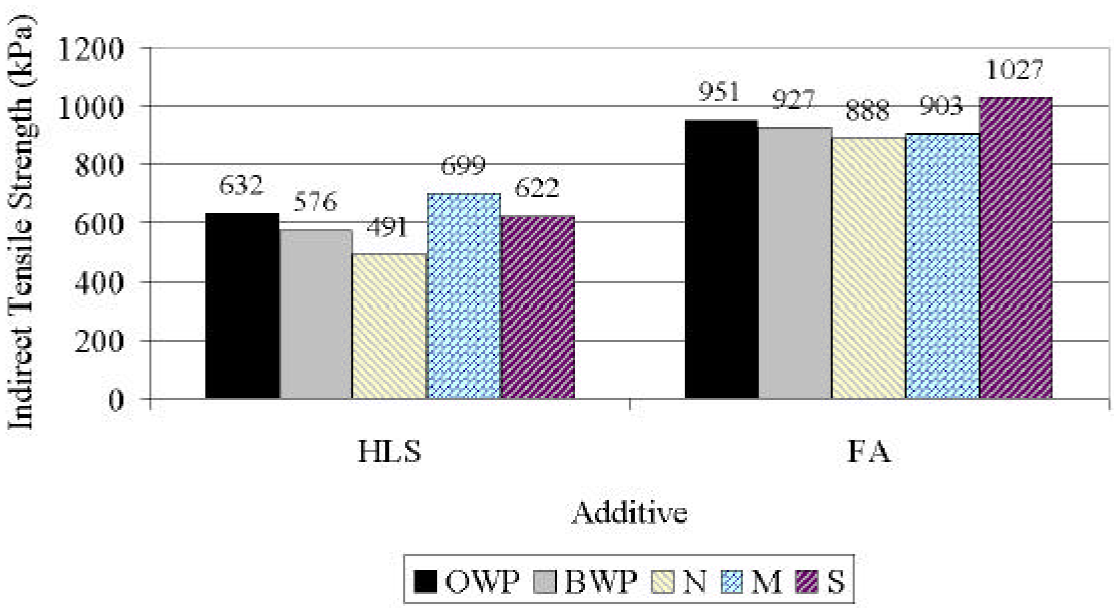

Figure 15. Indirect Tensile Strength for CIR Layer.

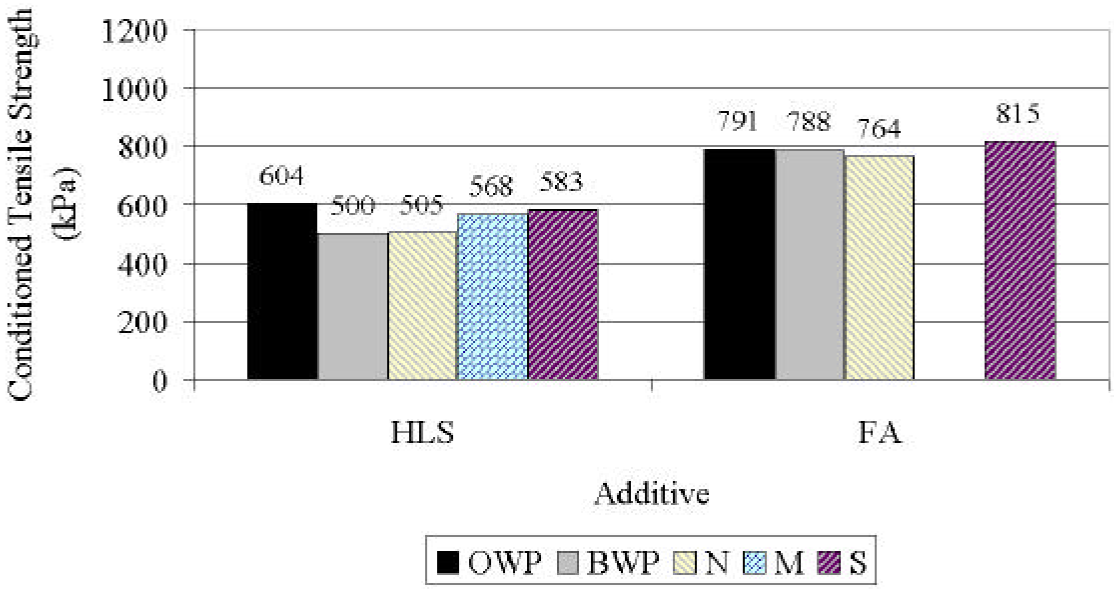

Figure 16. Conditioned Indirect Tensile Strength for CIR Layer.

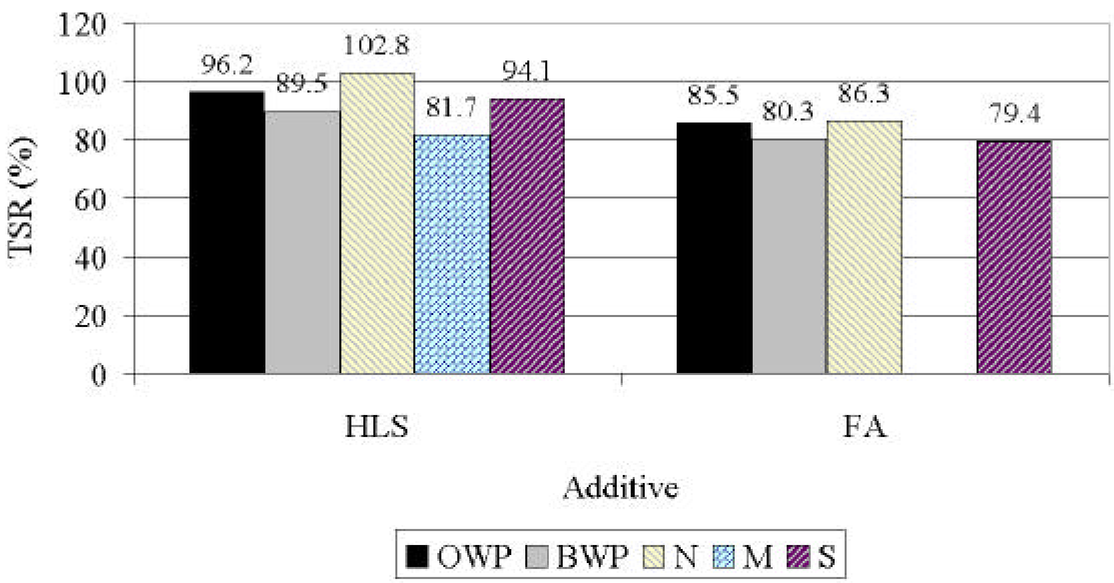

Figure 17. TSR for CIR Layer.

Table 22. Summary of Means and ANOVA for Tensile Strength and AASHTO T 283 Testing.

Physical	Hot Lime Slurry						Fly Ash					
Property	Average	OWP	BWP	N	M	S	Average	OWP	BWP	N	M	S
Layer 1 (HMA)												
Tensile Str. (kPa)	807.7	864.1	751.3	729.7	893.5	799.9	1043.5	1092.1	994.9	923.3	1062.6	1144.7
Sig, Difference	Yes	No	No	No	No	No	Yes	No	No	No	No	No
Conditioned Tensile Str. (kPa)	665.4	712.8	618.0	606.3	759.1	630.8	791.1	843.8	738.4	712.2	753.8	907.3
Sig, Difference	No*	No	No	No	No	No	No*	No	No	No	No	No
TSR (%)	82.3	82.7	82.0	82.8	85.0	79.2	75.7	77.3	74.1	76.9	71.0	79.2
Sig, Difference	Yes	No	No	No	No	No	Yes	No	No	No	No	No
Layer 2 (CIR)												
Tensile Str (kPa)	604.0	631.8	576.2	491.3	699.1	621.7	938.9	950.6	927.1	887.5	902.5	1026.6
Sig, Difference	Yes	No	No	No	No	No	Yes	No	No	No	No	No
Conditioned Tensile Str (kPa)	552.2	604.3	500.0	505.2	568.0	583.3	789.7	791.1	788.2	764.0	S/M	815.3
Sig, Difference	Yes	No	No	No	No	No	Yes	No	No	No		No
TSR (%)	92.9	96.2	89.5	102.8	81.7	94.1	82.9	85.5	80.3	86.3	S/M	79.4
Sig, Difference	No*	No	No	No	No	No	No*	No	No	No		No

Sig. Difference = Significant difference in means at alpha = 0.05.

* Significant difference in means at alpha = 0.10.

higher TSR. The relationship was significant at a 90% confidence limit. All samples had TSRs above 80%, the typical pass-fail threshold for HMA. The required TSR for CIR materials has not been determined. There was no significant difference between any of the parameters evaluated by area or wheel path.

Resilient Modulus and IRRM

The summary of the means and ANOVA for the resilient modulus and IRRM testing is shown in Table 23. The average resilient modulus values for the CIR layer are shown in Figure 18. Figures 19 and 20 show the results of the conditioned resilient modulus testing and IRRM for the CIR layer.

The resilient modulus results for the surface mix indicate that the AE with HLS test section was stiffer than the fly ash test section for both the air-cured and conditioned samples. This is contrary to what would be expected based on the lower asphalt content and higher density of the surface mix in the fly ash section. The results are highly influenced by the very high modulus values from the north area of the AE with HLS section. The IRRM results show better resistance to moisture damage for the surface mix from the fly ash section, which could be attributed to the higher density.

The AE with HLS CIR mix had a significantly higher resilient modulus, conditioned resilient modulus and IRRM than the fly ash CIR mix. There was no significant effect due to wheel path or area except for area on the IRRM of the fly ash CIR mix. The results show the stiffening ability of the lime slurry and its resistance to moisture induced damage.

Table 23. Summary of Means and ANOVA for Resilient Modulus and IRRM Testing.

Physical Property	Hot Lime Slurry						Fly Ash					
	Average	OWP	BWP	N	M	S	Average	OWP	BWP	N	M	S
Layer 1 (HMA)												
Mr (MPa)	923.2	919.5	926.8	1449.2	678.2	642.1	680.6	581.9	779.3	767.6	S/M	593.6
Sig, Difference	No	No	No	No	No	No	No	No	No	No		No
Conditioned Mr (MPa)	571.1	579.5	562.7	815	509.5	388.8	520.4	437.3	603.4	532.3	S/M	508.4
Sig, Difference	No	No	No	No	No	No	No	No	No	No		No
IRRM (%)	64.0	65.4	62.6	55.8	74.7	61.6	77.2	75.0	79.4	68.7	S/M	85.7
Sig, Difference	Yes	No	No	No*	No*	No*	Yes	No	No	No*		No*
Layer 2 (CIR)												
Mr (MPa)	444.3	490.5	398.1	406.8	553.1	373.1	293.5	314.5	272.5	309.1	S/M	277.9
Sig, Difference	No*	No	No	No	No	No	No*	No	No	No		No
Conditioned Mr (MPa)	278.9	288.4	269.3	224.9	326.9	284.8	156.3	174.4	138.6	181.1	S/M	131.2
Sig, Difference	Yes	No	No	No	No	No	Yes	No	No	No		No
IRRM (%)	63.6	58.8	67.6	55.6	58.9	77.3	53.1	55.5	50.9	58.4	S/M	47.6
Sig, Difference	Yes	No	No	No	No	No	Yes	No	No	A		B

Sig. Difference = Significant difference in means at alpha = 0.05.
* Significant difference in means at alpha = 0.10.
S/M = Sample missing.

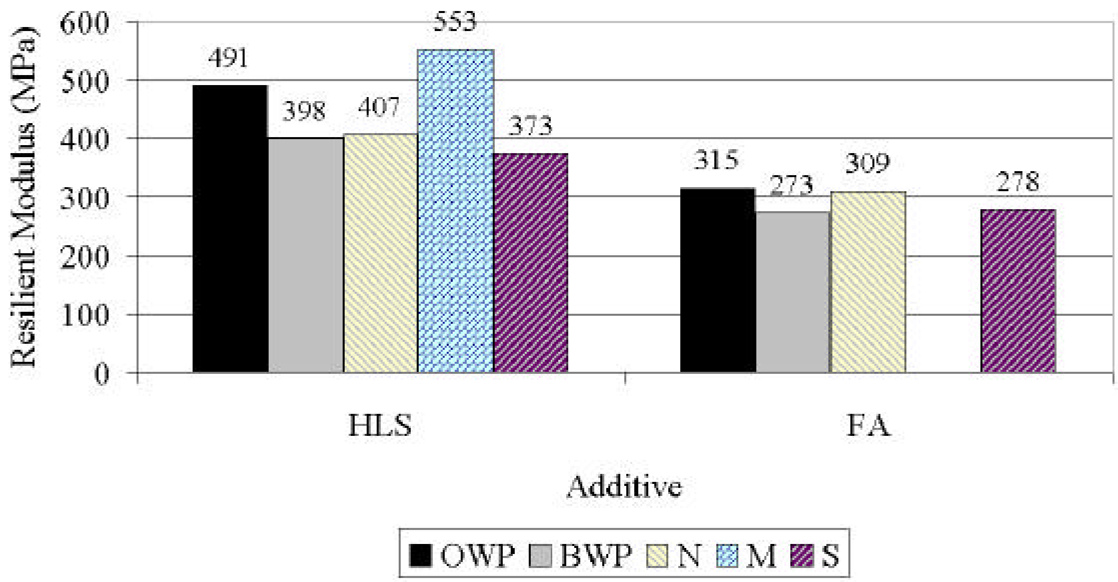

Figure 18. Resilient Modulus for CIR Layer.

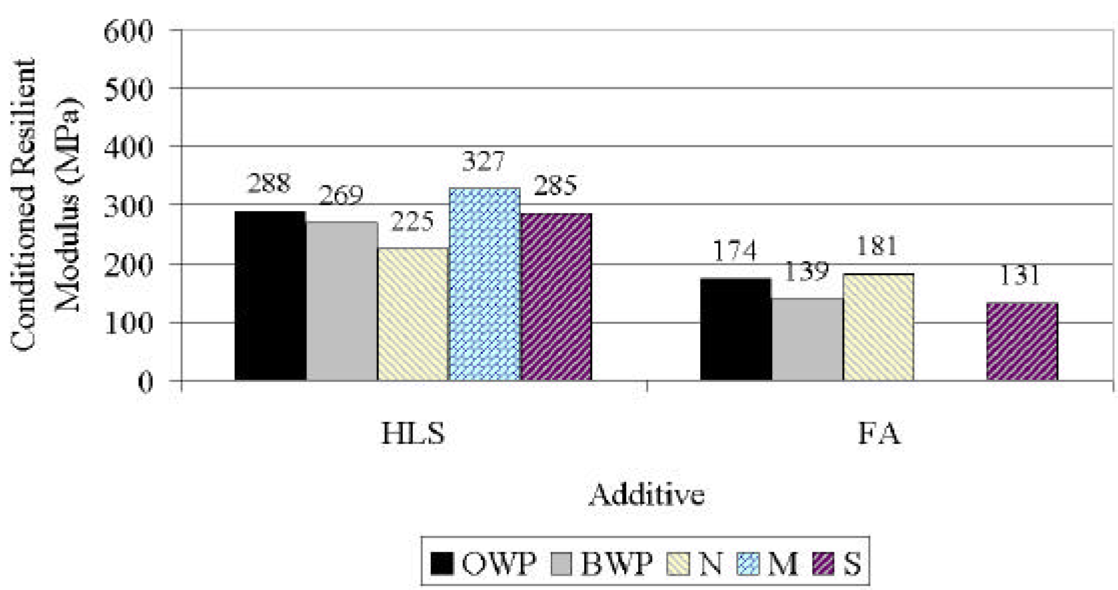

Figure 19. Conditioned Resilient Modulus for CIR Layer.

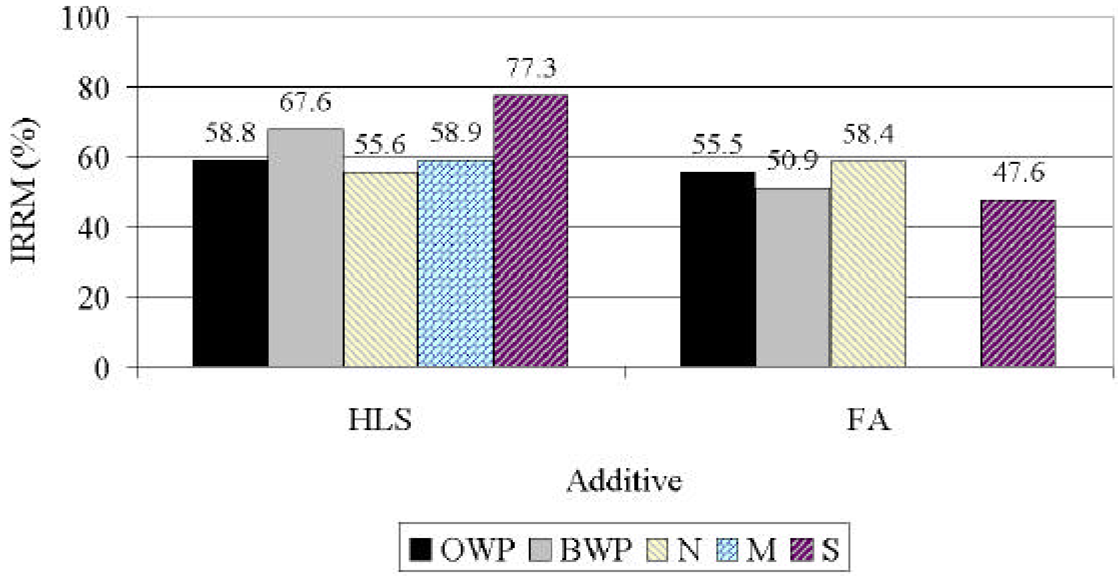

Figure 20. IRRM for CIR Layer.

CHAPTER 4
PHASE III
APA TESTING

LABORATORY COMPACTED SAMPLES

Permanent Deformation

The resistance to permanent deformation was determined using the APA in accordance with GDT-115, Method A (test at dry-conditions). The test was performed using a 0.44 kN load on a 690 kPa pressurized hose at a test temperature of 40^{o}C. The results are shown in Table 24.

A plot of the dry rut depths versus load cycles is shown in Figure 21 and the maximum rut depths in Figure 22. The fly ash samples had less rutting than the AE samples. For the AE samples, the use of HLS resulted in decreased dry rut depths. The rutting test is an empirical test and only a few state highway agencies have developed minimum rut depth requirements. These requirements range from 5 to 7-mm maximum rut depths and are for hot mix asphalt on heavily trafficked pavements (6). Recommendations for low volume pavements and CIR mixtures have not been established. However, the AE with HLS and fly ash samples had rut depths at or below the typical 6-mm recommendation, with the HFE-150 with HLS having the least amount of rutting for the AE samples. The use of HLS resulted in a reduction in rut depths of 23%, 13% and 21% for CMS-1, CSS-1 and HFE-150, respectively.

Moisture Sensitivity

The resistance to moisture induced damage is evaluated in the APA using GDT-115, Method B (test under water). The samples are tested in the same manner as in the permanent deformation test, except that the samples are submerged in 40^{o}C water during

Table 24. Results of GDT-115 Method A (Dry Test).

Number of Cycles	CMS -1 w/o HLS	CMS -1 HLS	CSS -1 w/o HLS	CSS -1 HLS	HFE -150 w/o HLS	HFE -150 HLS	10% Fly Ash
	Rut Depth (mm)						
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1000	4.1	2.9	4.0	2.9	3.2	2.2	0.8
2000	5.2	3.8	4.9	4.1	4.3	3.1	0.9
4000	6.3	5.0	5.9	5.2	5.7	4.6	1.0
8000	8.0	6.2	7.0	6.1	7.0	5.5	1.2

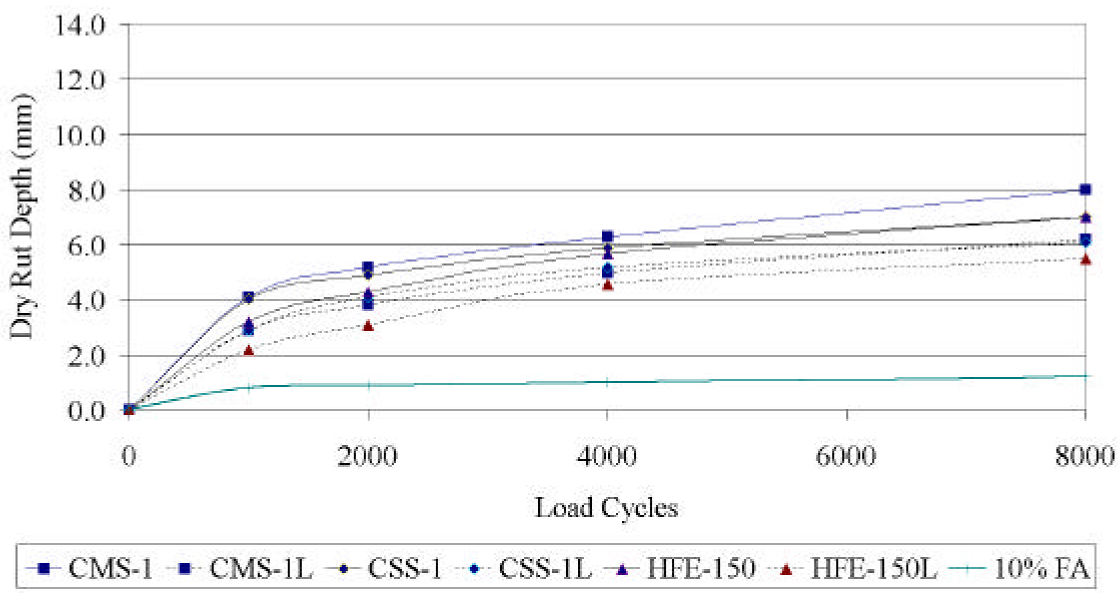

Figure 21. Dry Rut Depths vs. Load Cycles for Laboratory Compacted Samples.

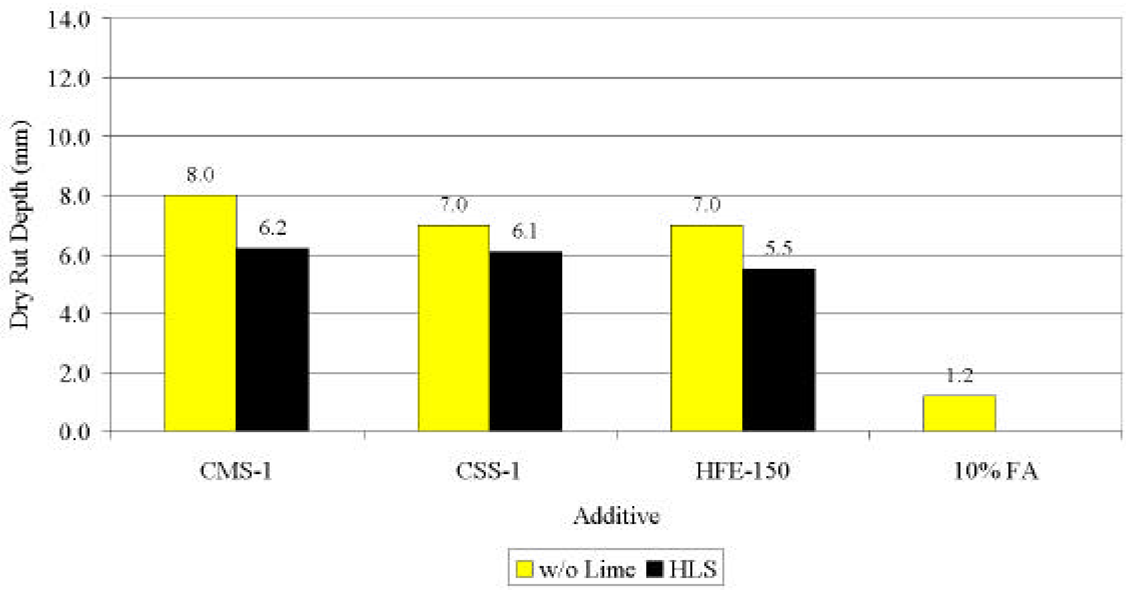

Figure 22. Maximum Dry Rut Depths for Laboratory Compacted Samples.

the test. The results are shown in Table 25 and graphically in Figure 23. The maximum rut depths are shown in Figure 24. The fly ash samples had the least amount of rutting. For the AE samples without HLS, the CMS-1 had the most rutting followed by HFE-150 and CSS-1. The addition of HLS had an effect on wet rut depths. The type of AE also influenced the amount of rutting. The CSS-1 with HLS had the least rutting followed by the CSS-1. The use of HLS did not improve the wet rutting resistance of HFE-150 significantly. The fly ash samples had wet rut depths slightly less than the AE with HLS samples. The use of HLS resulted in a reduction in wet rut depths of 45%, 28% and 21% for CMS-1, CSS-1 and HFE-150, respectively.

Figure 25 shows the average percent increase in wet rut depths compared to the dry rut depths for each of the additives evaluated. The fly ash samples showed the largest

Table 25. Results of GDT-115 Method B (Wet Test).

Number of Cycles	CMS -1 w/o HLS	CMS -1 HLS	CSS -1 w/o HLS	CSS -1 HLS	HFE -150 w/o HLS	HFE -150 HLS	10% Fly Ash
	Rut Depth (mm)						
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1000	6.1	3.5	5.6	4.1	5.8	3.7	2.0
2000	7.5	4.8	6.5	5.1	7.2	5.0	2.8
4000	9.9	5.7	7.5	6.0	8.4	6.1	3.3
8000	12.0	6.6	8.8	6.3	9.6	7.6	5.0

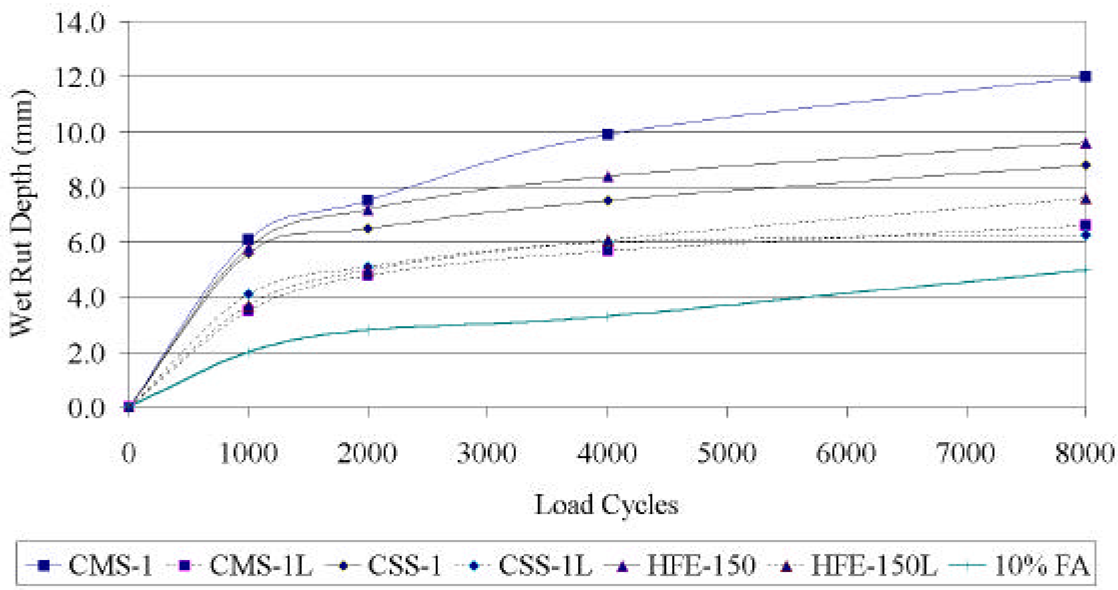

Figure 23. Wet Rut Depths vs. Load Cycles for Laboratory Compacted Samples.

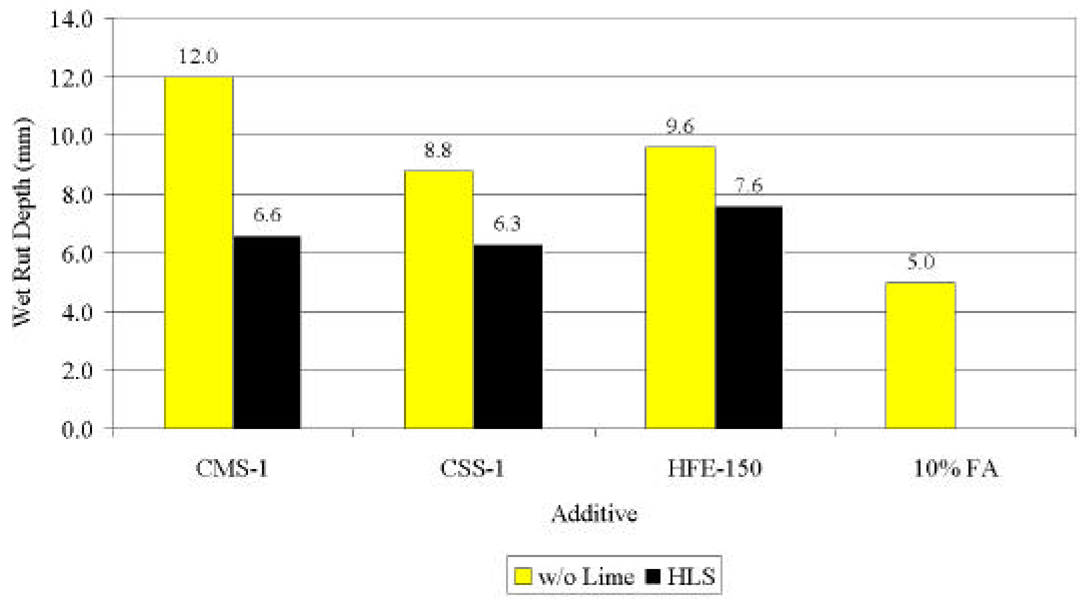

Figure 24. Maximum Wet Rut Depths for Laboratory Compacted Samples.

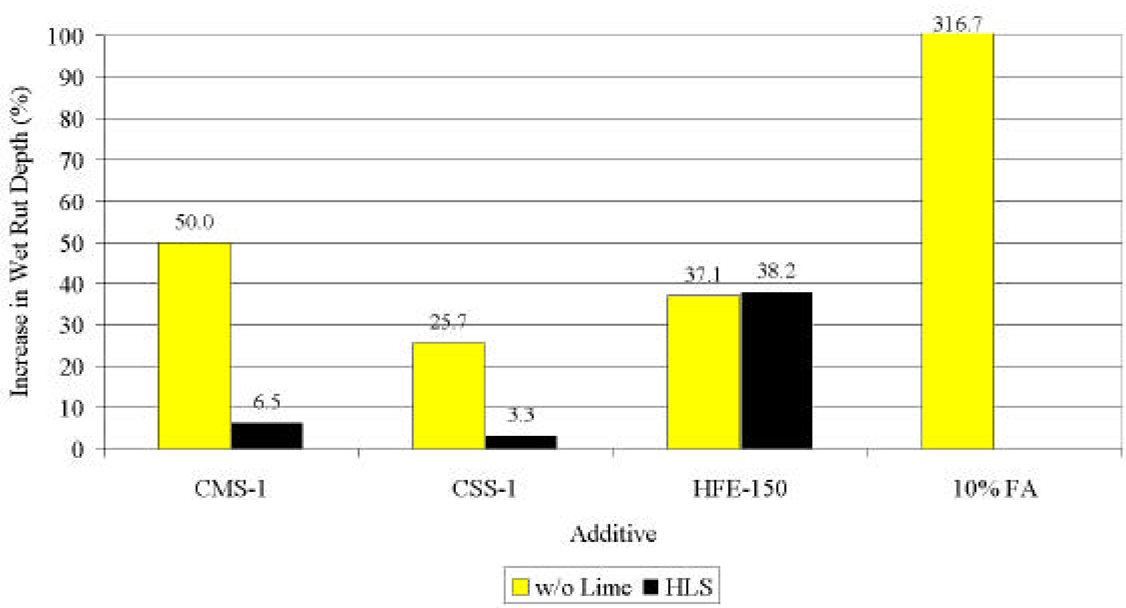

Figure 25. Increase in Wet Rut Depth for Laboratory Compacted Samples.

percent increase in rut depth, over 300%. The maximum dry rut depth for the fly ash sample was 1.2 mm and the maximum wet rut depth was 5 mm, less than the typical 6 mm maximum, and less than the AE samples. Although the fly ash samples had the least amount of rutting in the wet and dry APA testing, they had the largest percent increase. There is no method currently available to interpret wet and dry APA rut depths as they relate to moisture induced damage. However, it is obvious that the fly ash samples would not be susceptible to moisture induced damage as measured by the APA.

The AE samples without HLS showed average increases in rut depths from the dry condition of 26-50 %, indicating their susceptibility to moisture induced damage. The use of HLS resulted in a 6% and 3% increase in wet rut depths over the dry condition for CMS-1 and CSS-1, respectively. HLS was not as effective with HFE-150. The HFE-150 showed an increase in rut depths of 38% and 37% with and without HLS.

PAVEMENT CORES

Permanent Deformation

Surface Mix

The resistance to permanent deformation of the surface mix from the cores was determined using the APA in the same manner as for the laboratory compacted samples. Four cores from between the wheel path of each test section were tested, two at 40^{o}C and two at 50^{o}C. The results are shown in Table 26.

The maximum rut depths after 8,000 load cycles are shown in Figure 26. The surface mix from the fly ash section had less rutting than the surface mix from the AE with HLS section. This could be attributed to the higher density and reduced asphalt

Table 26. Results of GDT-115 Method A (Dry Test) for Layer 1 Cores.

Number of Cycles	HLS Section				FA Section			
	Middle 40 C	South 40 C	North 50 C	North 50 C	North 40 C	Middle 40 C	South 50 C	South 50 C
	Rut Depth (mm)							
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1000	0.9	0.8	1.3	1.4	0.8	0.7	0.8	0.6
2000	1.4	1.2	1.9	1.8	1.2	1.0	0.9	0.9
4000	2.1	1.7	2.5	2.4	1.5	1.4	1.3	1.2
8000	3.3	2.5	3.5	3.1	1.7	1.6	1.8	1.5

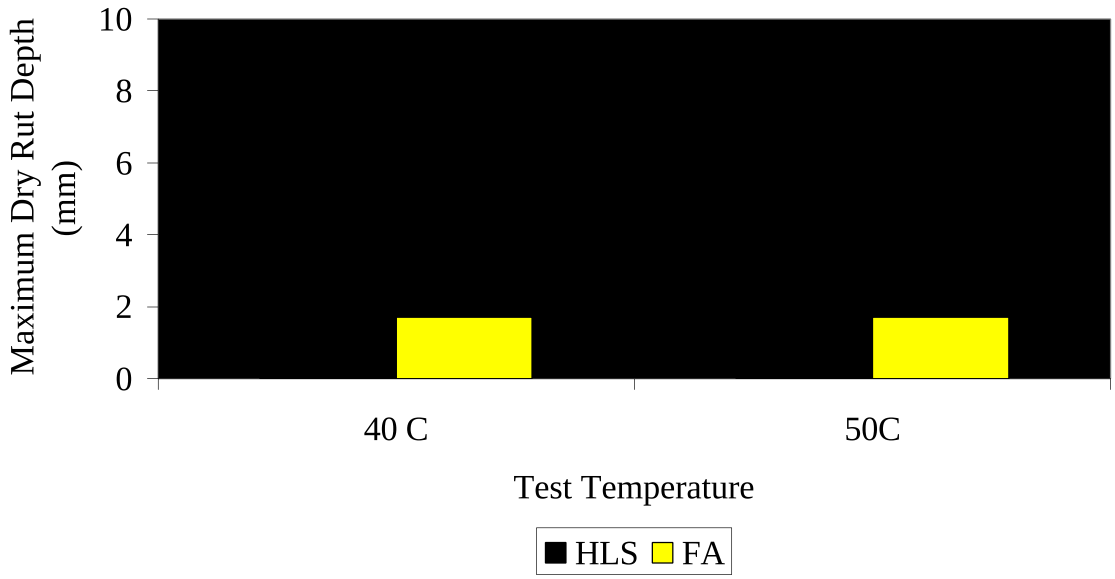

Figure 26. Maximum Dry Rut Depths from Layer 1 Cores.

content of the surface mix in the fly ash section. All rut depths were well below the typical maximum of 6-mm. However, the maximum rut depth is based on laboratory compacted samples, not aged cores.

CIR Mix

The results of the dry rut depths for the CIR cores are shown in Table 27. There was little to no rutting in the samples at 40°C, 1.4-mm for the AE with HLS cores and 0.6-mm for the fly ash cores. Therefore, the cores were turned over and retested at 50°C. Rut depths increased slightly for the AE with HLS cores (3.6 mm) and decreased slightly for the fly ash cores (0.2 mm). The effect of retesting samples has not been established, but it is not recommended. A plot of the maximum dry rut depths at 40°C is shown in Figure 27. The rut depths were all well below the recommended maximums of 6-mm for HMA (6).

Moisture Sensitivity

The resistance to moisture damage of the CIR layer was evaluated in the APA using GDT-115, Method B (test under water). The samples were tested in the same manner as in the permanent deformation test, except that the samples are submerged in 40°C water as well. The results are shown in Table 28. The maximum rut depths are shown in Figure 28. All wet rut depths were less than 2 mm. The average wet rut depth for the CIR with fly ash was 0.9 mm, slightly more than for the dry test. This difference is insignificant and is an indication that the fly ash samples did not rut during the testing. The average wet rut depth for the AE with HLS cores was 1.5 mm, compared to 1.4 mm for the dry test. Moisture did not adversely affect the CIR cores and, based on core samples, neither additive was prone to premature rutting.

Table 27. Results of GDT-115 Method A (Dry Test) for Layer 2 (CIR) Cores.

Number	North				Middle				South			
of	BWP		OWP		BWP		OWP		OWP		BWP	
Cycles	40 C	50 C	40 C	50 C	40 C	50 C	40 C	50 C	40 C	50 C	40 C	50 C
	Rut Depth (mm)											
	10% Fly Ash											
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1000	0.2	0.2	0.3	0.0	0.3	0.1	0.3	0.1	0.0	0.1	0.1	0.0
2000	0.2	0.3	0.5	0.0	0.3	0.2	0.4	0.1	0.1	0.2	0.1	0.0
4000	0.2	0.3	0.5	0.2	1.8	0.2	0.5	0.1	0.1	0.2	0.1	0.0
8000	0.2	0.3	0.5	0.2	1.8	0.2	0.5	0.1	0.2	0.3	0.1	0.1
	HLS											
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1000	0.9	1.4	0.4	0.5	0.4	0.8	0.5	0.7	0.5	1.2	0.8	1.1
2000	1.3	2.6	0.5	1.2	0.5	2.1	0.6	1.7	0.8	3.0	1.8	2.4
4000	2.1	3.4	0.6	1.8	0.7	3.0	0.8	2.6	0.8	3.9	1.8	3.1
8000	2.8	4.1	0.7	2.3	1.0	3.8	1.1	3.3	0.8	4.5	1.9	3.7

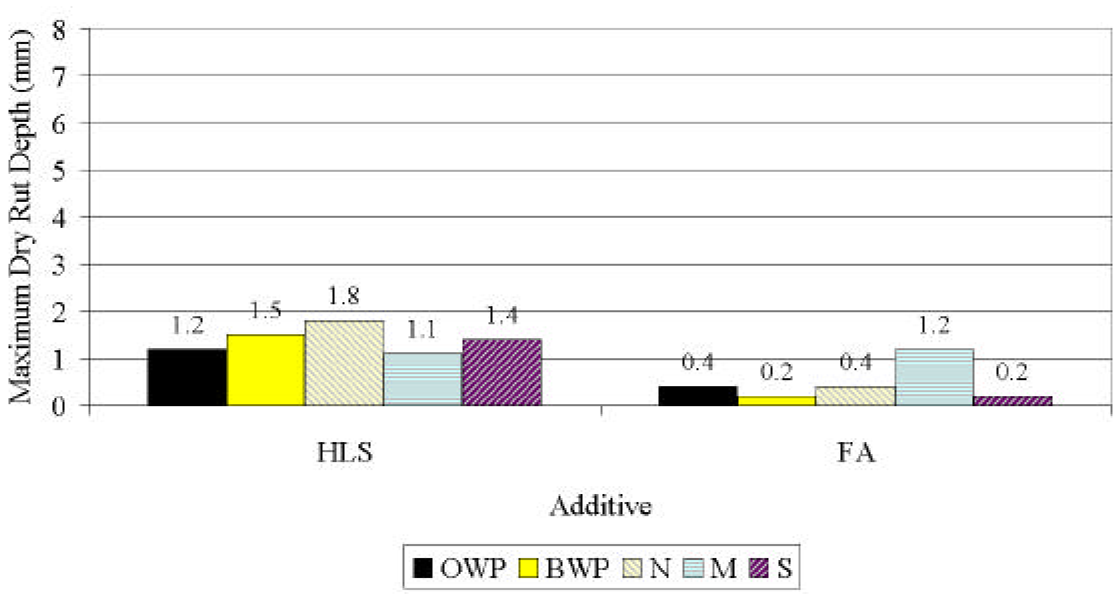

Figure 27. Maximum Dry Rut Depths from CIR Layer.

Table 28. Results of GDT-115 Method B (Wet Test) for CIR Cores.

Number of Cycles	North		Middle		South	
	BWP	OWP	BWP	OWP	BWP	OWP
	Wet Rut Depth (mm)					
	10% Fly Ash					
0	0.0	0.0	0.0	0.0	0.0	0.0
1000	0.2	0.2	0.1	0.2	0.2	0.4
2000	0.3	0.3	0.3	0.3	0.4	0.6
4000	0.4	0.4	0.6	0.4	0.6	0.9
8000	0.5	0.5	0.8	0.5	1.7	1.3
	HLS					
0	0.0	0.0	0.0	0.0	0.0	0.0
1000	0.6	0.4	0.7	0.3	0.5	0.4
2000	0.8	0.5	0.7	0.3	0.5	0.4
4000	1.3	0.9	1.1	0.6	1.0	0.8
8000	2.2	1.4	1.7	1.3	1.3	1.3

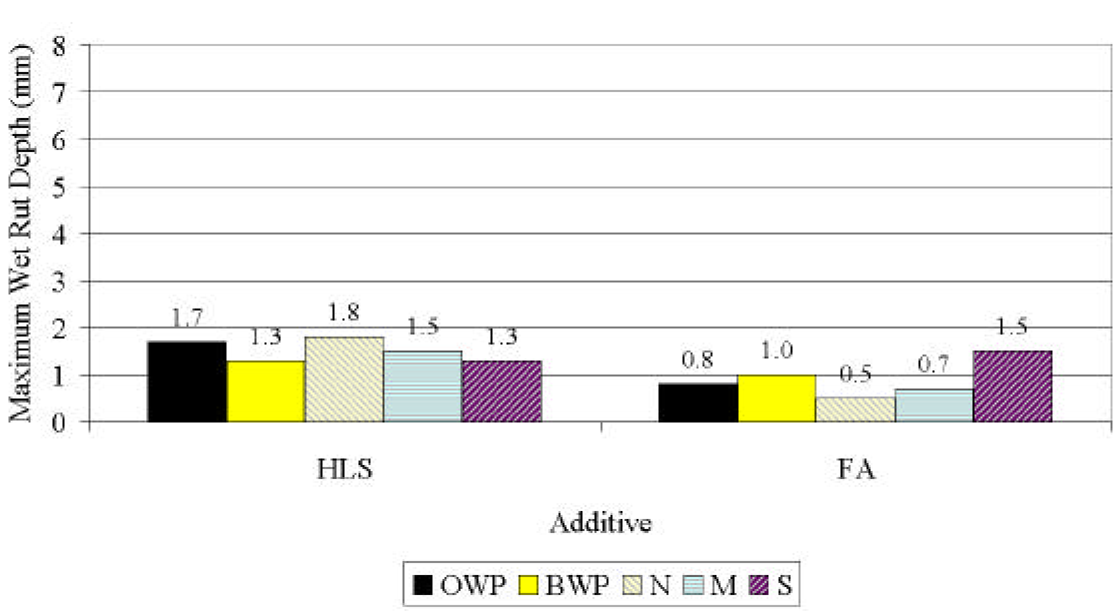

Figure 28. Maximum Wet Rut Depths for CIR Layer.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Laboratory Compacted Samples

The use of hot lime slurry (HLS) resulted in an improvement in material properties that affect the performance of cold in-place recycled pavements. The use of HLS resulted in increased density, increased tensile strength, increased conditioned tensile strength, and increased resilient and conditioned resilient modulus, regardless of the asphalt emulsion. The APA testing showed that the use of HLS resulted in decreased wet and dry rut depths. The effectiveness of HLS in reducing the wet rut depths was much better with CMS-1 and CSS-1 than HFE-150 mixtures.

The 10% fly ash laboratory compacted samples had higher densities than the AE samples. The additional 10% filler has an effect on the increased density. The fly ash samples had higher indirect tensile strengths and conditioned tensile strengths. However, the TSR's of asphalt emulsion with HLS samples were comparable to 10% fly ash. The asphalt emulsions with HLS samples were stiffer than the fly ash samples both before and after conditioning. The conditioning resulted in a greater decrease in modulus for the 10% fly ash samples than the asphalt emulsion samples.

The 10% fly ash samples had less rutting in both the dry and wet tests. The asphalt emulsion with HLS samples and fly ash samples had maximum rut depths below the recommended maximum of 6 mm for hot mix asphalt. The use of HLS was effective in reducing the wet rut depths compared to asphalt emulsion only samples.

Pavement Cores

Surface Mix

The asphalt content of the surface mix was 0.3% higher in the CSS-1 with hot lime slurry (AE with HLS) test section than in the fly ash section. The surface mix in the fly ash section had a higher density as well. Density and asphalt content are known to effect the tensile strength, air permeability, moisture sensitivity, resilient modulus and rutting potential of mixtures. Because of this, it is impossible to discern what portion of the improvement in material properties of the surface mix are attributable to the support supplied by the different CIR layers and by the different density and asphalt content of the surface mix in each section.

The results from the material property tests of the surface mix fell in line with the expected trends based on asphalt content and density. The samples with higher density and lower asphalt content had higher tensile strength, lower air permeability, reduced moisture sensitivity, higher resilient modulus and reduced rutting potential.

CIR Layer

The bulk specific gravity of the fly ash mix was higher than the AE with HLS mix. Based on the bulk specific gravity from the three areas within each test section, the variability of the fly ash mix was not significantly different from the AE with HLS mix. There was some variability in bulk specific gravity by area within each test section, but this variability did not carry over to the other material properties evaluated.

The fly ash section had significantly higher indirect tensile strengths and conditioned tensile strengths than the AE with HLS, as expected. The AE with HLS had significantly higher TSRs than the fly ash section. However, all CIR mixtures exceeded the 80% retained strength, which is a typical specification limit for hot mixed asphalt.

The use of HLS with CSS-1 resulted in significantly higher resilient modulus values at the 90% confidence limit, but not the 95% confidence limit. The AE with HLS section had significantly higher conditioned resilient modulus values and a higher IRRM. The IRRM values were much lower than the TSR values, regardless of additive. This was true for the surface mix as well.

The results from the APA testing indicated that neither CIR mix was prone to premature rutting or moisture induced damage. The CIR with fly ash had less rutting than the AE with HLS mix. However, both mixtures were well below the recommended maximum of 6 mm for hot mixed asphalt.

RECOMMENDATIONS AND IMPLEMENTATION

The results from the field cores and laboratory compacted samples indicate that CIR mixtures containing asphalt emulsion with HLS results in improvements in material properties that relate to performance. The asphalt emulsion samples with HLS compared favorably with the fly ash CIR mixture. The field performance of the two test sections on US-283 should be monitored for long-term performance.

The material properties of the aggregates in the RAP exceeded the quality of aggregates encountered in previous CIR work by the author (1) in Kansas). The use of CIR mixtures containing asphalt emulsion with HLS should be considered as an equivalent substitution for CIR with fly ash when the RAP contains better quality aggregates. For mixtures where the aggregates in the RAP do not meet the minimum recommended requirements (1,7), asphalt emulsion with HLS should be reviewed on a case by case basis pending final performance results of the test sections.

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APPENDIX

Preparation of Lime Slurry Using Quicklime

The following method is used to prepare one liter of hydrated lime slurry from quicklime in the laboratory. The solids content of the slurry will be between 30% and 35% depending on the amount of water lost to evaporation during the slaking process. Slaking is the chemical reaction of quicklime (CaO) with water to produce hydrated lime [$Ca(OH)_2$]. This chemical reaction is exothermic or with considerable heat produced and the slurry temperatures approaching or possibly exceeding the boiling point. Therefore, precautions must be taken to avoid eye or skin contact with the lime slurry. A greater or lesser amount of slurry can be prepared by proportionally increasing or decreasing the ingredient amounts.

Procedures: One Liter Total Volume of Slurry

1. Put on safety glasses and waterproof gloves.
2. Select a beaker or other mixing vessel with at least a 1200-ml capacity. This vessel should be able to withstand a temperature of at least 100^oC (212^oF). Do <u>not</u> use an aluminum vessel.
3. Add 924.6 g of water to the beaker or other mixing vessel and stir with a low shear mixer. Always keep the mixer running fast enough to move the slurry, but not too fast so as to avoid “whipping” the slurry.
4. Add 277.4 g of quicklime to the water. The quicklime should be added uniformly and should take about 15 to 30 seconds to add.
5. Continue the mixing as the lime slakes. The temperature of the slurry will increase as the chemical reaction converts the quicklime to hydrated lime. The final temperature could approach or exceed boiling and some splattering of the slurry could occur.
6. After the temperature ceases to rise (usually within 15 minutes), the slaking reaction is completed. The slurry can now be used for laboratory testing.
7. Store the slurry in a tightly capped polyethylene bottle if not to be used immediately.

Safety Note: If the lime slurry comes in contact with bare skin, wash immediately with cold water. Refer to the Material Safety Data Sheet (MSDS) for quicklime for the specific treatment.

Materials Needed to Make One Liter of Slurry

1. 1200 ml beaker or other similar size mixing vessel
2. 277.4 g of quicklime (CaO)
3. 924.6 g of water (H_2O)
4. Low shear mixer – Steadfast, Coframo, Hobart or similar type mixer
5. One liter polyethylene storage bottle
6. Laboratory thermometer, liquid immersion, maximum temperature of at least 110^oC
7. Safety glasses and protective (waterproof) gloves

Table A-1. Bulk Specific Gravity and Density of 100-mm Cores, HLS Section.

Additive	Area	Core	Layer	Location	Gmb	Density (kg/m^3)
HLS	N	1	1	OWP	2.273	2273
HLS	N	1	2	OWP	2.133	2133
HLS	N	1	2T	OWP	2.150	2150
HLS	N	1	2B	OWP	2.092	2092
HLS	N	2	1	BWP	2.206	2206
HLS	N	2	2	BWP	2.136	2136
HLS	N	2	2T	BWP	2.143	2143
HLS	N	2	2B	BWP	2.084	2084
HLS	N	3	1	BWP	2.209	2209
HLS	N	3	2	BWP	2.121	2121
HLS	N	3	2T	BWP	2.127	2127
HLS	N	4	1	OWP	2.263	2263
HLS	N	4	2	OWP	2.136	2136
HLS	N	4	2T	OWP	2.139	2139
HLS	N	5	1	BWP	2.213	2213
HLS	N	5	2	BWP	2.120	2120
HLS	N	5	2T	BWP	2.132	2132
HLS	N	5	2B	BWP	2.068	2068
HLS	N	6	1	OWP	2.267	2267
HLS	N	6	2	OWP	2.150	2150
HLS	N	6	2T	OWP	2.159	2159
HLS	N	6	2B	OWP	2.117	2117
HLS	M	1	1	BWP	2.275	2275
HLS	M	1	2	BWP	2.122	2122
HLS	M	1	2T	BWP	2.168	2168
HLS	M	1	2B	BWP	2.058	2058
HLS	M	2	1	OWP	2.274	2274
HLS	M	2	2	OWP	2.177	2177
HLS	M	2	2T	OWP	2.203	2203
HLS	M	2	2B	OWP	2.131	2131
HLS	M	3	1	BWP	2.281	2281
HLS	M	3	2	BWP	2.149	2149
HLS	M	3	2T	BWP	2.179	2179
HLS	M	3	2B	BWP	2.109	2109
HLS	M	4	1	OWP	2.291	2291
HLS	M	4	2	OWP	2.134	2134
HLS	M	4	2T	OWP	2.168	2168
HLS	M	4	2B	OWP	2.084	2084
HLS	M	5	1	BWP	2.270	2270
HLS	M	5	2	BWP	2.144	2144
HLS	M	5	2T	BWP	2.171	2171
HLS	M	5	2B	BWP	2.103	2103
HLS	M	6	1	OWP	2.287	2287
HLS	M	6	2	OWP	2.166	2166
HLS	M	6	2T	OWP	2.193	2193
HLS	M	6	2B	OWP	2.118	2118

Table A-1 (Con't.). Bulk Specific Gravity and Density of 100-mm Cores, HLS Section

Additive	Area	Core	Layer	Location	Gmb	Density (kg/m^3)
HLS	S	1	1	BWP	2.232	2232
HLS	S	1	2	BWP	2.182	2182
HLS	S	1	2T	BWP	2.215	2215
HLS	S	1	2B	BWP	2.151	2151
HLS	S	2	1	OWP	2.267	2267
HLS	S	2	2	OWP	2.186	2186
HLS	S	2	2T	OWP	2.225	2225
HLS	S	2	2B	OWP	2.141	2141
HLS	S	3	1	BWP	2.211	2211
HLS	S	3	2	BWP	2.142	2142
HLS	S	3	2T	BWP	2.168	2168
HLS	S	3	2B	BWP	2.084	2084
HLS	S	4	1	OWP	2.271	2271
HLS	S	4	2	OWP	2.178	2178
HLS	S	4	2T	OWP	2.233	2233
HLS	S	4	2B	OWP	2.127	2127
HLS	S	5	1	OWP	2.277	2277
HLS	S	5	2	OWP	2.206	2206
HLS	S	5	2T	OWP	2.225	2225
HLS	S	5	2B	OWP	2.171	2171
HLS	S	6	1	BWP	2.220	2220
HLS	S	6	2	BWP	2.163	2163
HLS	S	6	2T	BWP	2.189	2189
HLS	S	6	2B	BWP	2.118	2118

Table A-2. Bulk Specific Gravity and Density of 100-mm Cores, Fly Ash Section.

Additive	Section	Core	Layer	Location	Gmb	Density (kg/m^3)
FA	N	1	1	BWP	2.227	2227
FA	N	1	2	BWP	2.172	2172
FA	N	1	2T	BWP	2.179	2179
FA	N	1	2B	BWP	2.158	2158
FA	N	2	1	OWP	2.272	2272
FA	N	2	2	OWP	2.182	2182
FA	N	2	2T	OWP	2.184	2184
FA	N	2	2B	OWP	2.163	2163
FA	N	3	1	OWP	2.230	2230
FA	N	3	2	OWP	2.151	2151
FA	N	3	2T	OWP	2.143	2143
FA	N	4	1	BWP	2.271	2271
FA	N	4	2	BWP	2.143	2143
FA	N	4	2T	BWP	2.171	2171
FA	N	4	2B	BWP	2.119	2119
FA	N	5	1	BWP	2.245	2245
FA	N	5	2	BWP	2.172	2172
FA	N	5	2T	BWP	2.185	2185
FA	N	5	2B	BWP	2.145	2145
FA	N	6	1	OWP	2.287	2287
FA	N	6	2	OWP	2.182	2182
FA	N	6	2T	OWP	2.194	2194
FA	N	6	2B	OWP	2.153	2153
FA	M	1	1	BWP	2.287	2287
FA	M	1	2	BWP	2.131	2131
FA	M	1	2T	BWP	2.134	2134
FA	M	1	2B	BWP	2.125	2125
FA	M	2	1	OWP	2.272	2272
FA	M	2	2	OWP	2.146	2146
FA	M	2	2T	OWP	2.179	2179
FA	M	2	2B	OWP	2.109	2109
FA	M	3	1	BWP	2.233	2233
FA	M	3	2	BWP	2.156	2156
FA	M	3	2T	BWP	2.169	2169
FA	M	3	2B	BWP	2.124	2124
FA	M	4	1	OWP	2.284	2284
FA	M	4	2	OWP	2.143	2143
FA	M	4	2T	OWP	2.165	2165
FA	M	5	1	BWP	2.234*	2234*
FA	M	5	2	BWP	2.105*	2105*
FA	M	6	1	OWP	2.232*	2232*
FA	M	6	2	OWP	2.109*	2109*

* KT-15 Procedure IV.

Table A-2 (Con't.). Bulk Specific Gravity and Density of 100-mm Cores, Fly Ash Section.

Additive	Section	Core	Layer	Location	Gmb	Density (kg/m^3)
FA	S	1	1	BWP	2.260	2260
FA	S	1	2	BWP	2.218	2218
FA	S	1	2T	BWP	2.225	2225
FA	S	1	2B	BWP	2.198	2198
FA	S	2	1	OWP	2.282	2282
FA	S	2	2	OWP	2.215	2215
FA	S	2	2T	OWP	2.225	2225
FA	S	2	2B	OWP	2.186	2186
FA	S	3	1	BWP	2.263	2263
FA	S	3	2	BWP	2.206	2206
FA	S	3	2T	BWP	2.212	2212
FA	S	3	2B	BWP	2.189	2189
FA	S	4	1	OWP	2.303	2303
FA	S	4	2	OWP	2.222	2222
FA	S	4	2T	OWP	2.220	2220
FA	S	4	2B	OWP	2.216	2216
FA	S	5	1	BWP	2.255	2255
FA	S	5	2	BWP	2.208	2208
FA	S	5	2T	BWP	2.220	2220
FA	S	5	2B	BWP	2.183	2183
FA	S	6	1	OWP	2.297	2297
FA	S	6	2	OWP	2.216	2216
FA	S	6	2T	OWP	2.231	2231
FA	S	6	2B	OWP	2.190	2190