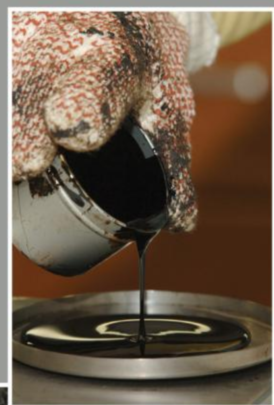
NCAT REPORT 10-01



PRELIMINARY EVALUATION OF WARM MIX ASPHALT FIELD DEMONSTRATION: FRANKLIN, TENNESSEE

FINAL REPORT

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ABSTRACT

The Tennessee Department of Transportation hosted a warm mix asphalt (WMA) demonstration. The production and constructability of four WMA technologies was demonstrated. Two control hot mix asphalt (HMA) mixes were also produced. The National Center for Asphalt Technology documented the demonstration and evaluated the mixes produced. The production, construction, and performance of the WMA to HMA were compared. The results of the comparison are detailed in this report.

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INTRODUCTION

The Tennessee Department of Transportation (TDOT) hosted a warm mix asphalt (WMA) field demonstration in October 2007. Four WMA technologies were included in the WMA demonstration. The four technologies were Advera® WMA, Astec Double Barrel Green® (DBG), Evotherm™ Dispersed Asphalt Technology (DAT), and Sasobit®. Two hot mix asphalt (HMA) mixes were produced to compare to the constructability and performance of the WMA technologies. This report summarizes the construction, laboratory performance testing, and one year field evaluations of the mixes produced as part of the WMA field demonstration.

BACKGROUND

WMA is an new technology that allows for the production of asphalt mixes at lower temperatures than traditionally employed for HMA. The production of an asphalt mix at temperatures less than 275°F can result in lower emissions, decreased fuel usage, and reduced oxidation of the asphalt compared to mixes produced at 300°F and above (*1*). The reduced emissions and fuel usage can be environmentally beneficial and reduced fuel usage can be economically beneficial. The question that arises is: Is the performance of the asphalt mix affected by using a WMA technology? If it is adversely affected, then the environmental and economic benefits are negated. If the performance of WMA pavements is as good as or better than HMA then the change in production practices is worthwhile.

The asphalt mix properties that are typically of interest when evaluating a new WMA technology are moisture susceptibility, rutting susceptibility, strength, and stiffness. Moisture susceptibility is of concern since the reduced temperatures may result in incomplete drying of aggregate. Any moisture remaining in or on the aggregate could affect the bond between the asphalt and aggregate, thus leading to premature pavement failure. The reduced mixing temperature of the WMA may also result in a softer asphalt than the same mix produced at HMA temperatures since there is less oxidation of the asphalt. The softer asphalt has raised some concern that WMA may be more prone to rutting and poor tensile strength. However, there may also be benefits to a softer asphalt. One of the benefits of a softer binder is a less stiff mix, which may improve the resistance to fatigue and thermal cracking.

Previous laboratory research (*1-4*) has shown that WMA is often more susceptible to moisture damage and rutting than HMA. The tensile strengths of WMA also tend to be lower than HMA. However, recent field evaluations conducted by NCAT indicate that the tensile strength of WMA increases with time to a similar tensile strength as that of HMA after two years of trafficking. It should also be noted that at these recent field evaluations, there has been no substantial difference in the WMA rutting compared to rutting in control HMA sections and no evidence of moisture damage has been observed (*7* and *8*).

PURPOSE AND SCOPE

The purpose of this study was to evaluate the constructability and performance of WMA. Four WMA technologies were evaluated and compared to two HMAs. Construction information, laboratory performance data, and field performance after one year have been documented in this report.

PROJECT DESCRIPTION

The field project was conducted in Franklin, Tennessee on State Road 46 (SR-46). SR-46 is a two-lane road with mostly automobile traffic. The average daily traffic volume is 10,492. TDOT surveyed the condition of the existing pavement before the overlay was constructed. TABLE 1 summarizes the pavement condition measurements obtained by TDOT. The existing asphalt pavement surface was cracked and crack sealant had been applied in several locations.

TABLE 1 Existing Pavement Condition (courtesy of TDOT)

Beginning Mile	End Mile	Roughness Index (PSI)	IRI	Rut Depth	Distress Index (PDI)	Pavement Quality Index (PQI)
0	1	2.31	146.33	0.15	5	3.97
1	2	2.47	129.9	0.16	5	4.04
2	3	2.91	99.98	0.14	4.88	4.18
3	4	3.11	87.82	0.15	4.97	4.32
4	5	3.03	91.81	0.15	4.97	4.28
5	5.64	2.71	118.87	0.17	4.84	4.07

The construction consisted of a 1.25 inch overlay. Six Marshall mixes were produced for the overlay. There was a mix design for each of plants. Two of the mix designs were the same with the exception that one was approved for the Danley Plant and the other was approved for the Murfeesboro plant. The two HMA mixes were placed first followed by Astec Double Barrel Green (DBG), Advera WMA, Evotherm DAT, and Sasobit mixes. HMA 1 is the same base mix as the Advera WMA and Sasobit mixes and all three were produced at the LoJac Inc. Franklin plant. HMA 2 is the same base mix as the Evotherm DAT and Astec DBG. HMA 2 and Evotherm DAT were produced at the Danley plant and the Astec DBG mix was produced at the Murfeesboro plant.

Construction

Material for all sections was delivered to the site in dump trucks. The mix was then emptied into a materials transfer device (Roadtec® SB-2500D), which transferred material to the hopper of the paver. The breakdown roller was a steelwheel Ingersoll Rand DD130 roller compactor. The intermediate and finishing rollers were also an Ingersoll Rand DD130.

FIGURE 1 Paving Train

The two HMAs were placed prior to the WMA pavement sections on October 1, 2007. The placement of the HMA pavement sections was not observed by NCAT personnel. Notes from the contractor indicated that the HMA mixes were produced at 320°F (based on control tower reading) and there were no problems during construction.

NCAT personnel were on site when the WMA pavement sections were placed. The first WMA section that was placed was the Astec DBG on October 2, 2007. The plant where the Astec DBG was produced in was an Astec Double Barrel plant that used natural gas. The plant was rated for 400 tons per hour; however, the WMA was produced at a rate of 250 tons per hour. Approximately 775 tons of the Astec DBG mix were produced. The target mixing temperature for the Astec DBG mix was 260°F (based on control tower readings). The haul time from the Murfeesboro plant to the site was approximately 45 minutes. The mat temperature at the start of compaction was 230°F. The mix was compacted with three steel-wheel rollers. There were no issues observed during the placement of the mix. The mat temperature was fairly consistent (see FIGURE 2).

FIGURE 2 Thermal Image of Astec DBG Mat (Picture courtesy of Becky Smith)

The second mix placed was Advera WMA and it was produced at the Franklin plant on October 3, 2007. The Franklin plant was an Astec Double Barrel plant that used natural gas. The plant was rated for 350 tons per hour; however, the WMA was produced at 250 tons per hour. Approximately 1150 tons of the Advera WMA mix were produced. The target mixing temperature for the Advera WMA was 250°F (based on control tower reading). The haul time from the Franklin plant to the paving site was approximately 10 minutes. The compaction temperature was 230°F. There were only two rollers compacting the Advera WMA pavement section for the majority of the day due to one roller being removed due to mechanical issues. Other than the reduced number of rollers, there were no issues observed with the placement of the Advera WMA pavement. FIGURE 3 illustrates the consistent temperature of the mat.

FIGURE 3 Thermal Image of Advera WMA Mat (Picture courtesy of Becky Smith)

On October 4, 2007, the Evotherm DAT was produced from the Danley plant. The Danley plant was an Astec Double Barrel plant that used natural gas. It was rated for 350 tons per hour; however, the WMA was produced at 250 tons per hour. Approximately 750 tons of Evotherm DAT mix were produced. The target mixing temperature for the Evotherm DAT mix was 240°F (based on control tower reading). The haul time from the Danley plant to the site was about 25 minutes. The compaction temperature was 230°F. The Evotherm DAT was placed on top of a section of pavement that exhibited alligator cracking in numerous locations see (FIGURE 4). The Evotherm DAT overlay was compacted with three rollers. There were no observed issues with placing the mix. The mat temperature for the Evotherm DAT mix was consistent (see FIGURE 5).

FIGURE 4 Pavement Distress Under Evotherm DAT Lift

On October 5, 2007 the Sasobit mix was produced at the Franklin plant. Approximately 705 tons of the Sasobit mix were produced. The target mixing temperature of the Sasobit was 250°F (based on control tower reading). The compaction temperature was 230°F. There were two steel wheel rollers compacting the Sasobit mix. There were no observed issues with the placement of the Sasobit mix. The temperature was consistent (see FIGURE 6).

Construction Summary

Six mixes were evaluated in the WMA demonstration conducted in Franklin, Tennessee. Four of the mixes were produced as WMA with production temperatures that ranged between 240 to 260°F. Two mixes were produced as HMA at a production temperature of 320°F.

TABLE 2 lists each mix, production temperature, production facility, aggregate source, and whether or not the material was reheated for laboratory testing.

FIGURE 5 Thermal Image of Evotherm DAT Mat (Picture courtesy of Becky Smith)

FIGURE 6 Thermal Image of Sasobit Mat (Picture courtesy of Becky Smith)

TABLE 2 Materials Summary

	Production Temperature	**Production Facility**	**Aggregate Source**	**Reheated**
		Mix Design 1		
HMA 1	320°F	Franklin	BonAqua, TN limestone	yes
Advera	250°F	Franklin	BonAqua, TN limestone	no
Sasobit	250°F	Franklin	BonAqua, TN limestone	no
		Mix Design 2		
HMA 2	320°F	Danley	Springfield, TN limestone	yes
Evotherm DAT	240°F	Danley	Springfield, TN limestone	no
		Mix Design 3		
Astec DBG	260°F	Murfeesboro	Springfield, TN limestone	no

In-Place Densities

Cores were obtained for each section and densities of the cores were determined by the contractor in accordance with AASHTO T 166. The cores on this project were not randomly selected throughout the length of the pavement, but all obtained within the first 100 ft of each section. Initially, the cores were obtained from the beginning of the pavement sections. However, the initial core densities were poor for all of the WMA sections and a second set of cores were obtained further into each WMA section. FIGURE 7 illustrates the field densities for each set of cores extracted from the pavement. The whiskers represent plus and minus one standard deviation. The first core set for each pavement section consisted of 10 cores. The contractor selected the number of cores obtained for the second set of cores. The number of cores obtained for the second core set ranged between two to ten. Ten cores were obtained for Astec DBG. Five cores were obtained from the Advera WMA. Four cores were obtained for the Evotherm DAT. Two cores were obtained for the Sasobit. The densities increased with the second set of cores. In most cases, with the exception of the Evotherm DAT, the variability also decreased with the second set of cores. The change in densities may be attributed to the paving crew working out the rolling pattern for the day at the beginning of each section or the removal of one roller on the Advera section.

The first set of cores for the WMA sections exhibited densities that were lower than those determined for both HMA sections. In general, the densities of the second set of cores from the WMA sections were similar to the densities of the HMA sections.

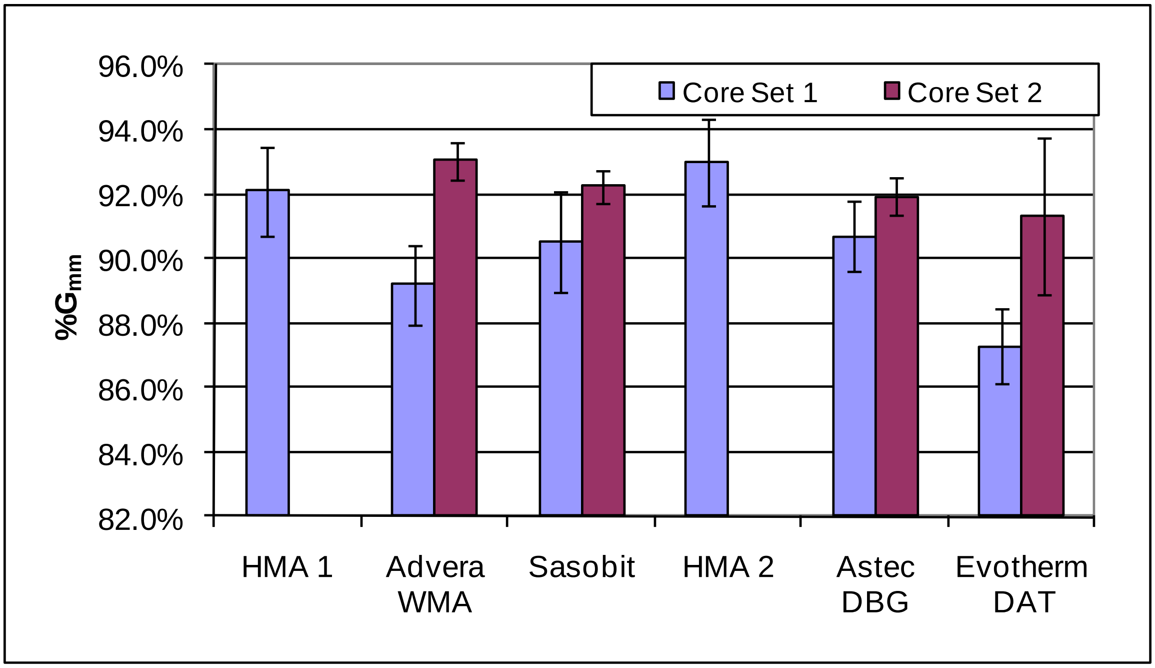

FIGURE 7 Field Densities After Construction

Asphalt Aging

Asphalt binders were extracted and recovered from plant produced mix to evaluate the aging that occurred at the different mix production temperatures. Binders were extracted and recovered in accordance with AASHTO T 319-03 and ASTM D 5404-03, respectively. The recovered binders were graded in accordance with AASHTO R 29-02. TABLE 3 summarizes average binder properties based on two performance grade (PG) classifications per mix. The HMA that corresponds to the Advera WMA and Sasobit is HMA 1. The continuous grade of both the Sasobit and Advera WMA exhibited a high temperature grade softer than HMA 1; however, both had low temperature grades slightly higher than HMA 1. Based on the continuous grade classification, HMA 1 may be less prone to thermal cracking than the Sasobit and Advera WMA mixes. The HMA that corresponds to the Astec DBG and Evotherm DAT is HMA 2. However, it should be noted that the Astec DBG mix was produced in a different plant than HMA 2, which may also have an effect on the asphalt aging. Binders from the Astec DBG and the Evotherm DAT sections exhibited slightly lower high PG temperatures than the binder from HMA 2. The Astec DBG had a slightly lower low temperature grade than HMA 2, which may be an indication that it is more resistant to thermal cracking. The Evotherm DAT had a slightly higher low temperature grade, indicating that it may be less resistant to thermal cracking. Overall, the asphalt binder data indicates that WMA reduces the aging of the binder compared to HMA, however the magnitude of the change depends on the WMA technology, mixing temperature, and possibly plant in which the mix was produced.

TABLE 3 Asphalt Performance Grade After Construction

	HMA 1	Advera	Sasobit	HMA 2	Astec DBG	Evotherm DAT
Continuous Grade	76.2-22.5	70.4-20.9	74.1-22.1	74.2-23.1	73.0-24.0	72.8-22.0
PG Grade	76-22	70-16	70-22	70-22	70-22	70-22

MATERIALS

Three Marshall mix designs were used. All three of the designs were 12.5 mm nominal maximum aggregate size 75 blow Marshall mixes. The SBS modified PG 70-22 asphalt used in all of the mixes was supplied by Ergon Asphalt & Emulsions, Inc.

Murfeesboro Plant

One mix was produced at the LoJac, Inc. Murfeesboro plant. The mix was the Astec Double Barrel Green. Water was injected into the asphalt binder to create a foamed binder. The amount of water injected was 0.1% of the total weight of the mix. The asphalt contained the anti-strip agent Pavegrip 650. The dosage rate of the anti-strip agent was 0.3% by weight of asphalt. The design asphalt content of the mix was 5.3% by weight of the mix. The predominant aggregate of the mix was a limestone from Rinker Materials in Springfield, Tennessee. TABLE 4 summarizes aggregate gradations and asphalt contents of the job mix formula (JMF) and solvent extractions of the plant mix. The mix design can be found in Appendix A. The solvent extraction and recoveries were conducted in accordance with AASHTO T 319-03 and ASTM D 5404-03, respectively. The aggregate gradations of the JMF and Astec DBG mix were similar. The asphalt content of the plant produced mix was 0.5% less than the target asphalt content. The reduced asphalt content may have affected the in-place densities.

TABLE 4 Sieve Analysis of Murfeesboro Plant Mix

Sieve Size		Percent Passing	
English	**Metric**	**JMF**	**Astec DBG**
2"	50	100	100
1 1/2"	37.5	100	100
1"	25	100	100
3/4"	19	100	100
1/2"	12.5	99	98
3/8"	9.5	85	86
#4	4.75	59	57
#8	2.36	46	43
#16	1.18	--	33
#30	0.6	26	24
#50	0.3	10	10
#100	0.15	6	6
#200	0.075	4.0	5.1
Extracted AC Content		5.3	4.8

Franklin Plant

Three mixes were produced at the LoJac, Inc. Franklin Plant. One mix was a HMA and two mixes were WMAs: Advera WMA and Sasobit. The Advera WMA zeolite was added in at 0.3% by weight of the mix by a pneumatic system, which introduced the additive in the outer mixing drum of the plant. The Sasobit prills were added at 1.5% by weight of the asphalt. The same base asphalt was used for all three of the mixes. The asphalt content was 5.3% by weight of the mix. The asphalt contained AD-Here 77-00 as an antistripping agent using a dosage rate of 0.3% by weight of asphalt. The predominant aggregate was a limestone from Bon Aqua, Tennessee. The mix design for the three mixes can be found in Appendix A. The solvent extraction and recoveries were conducted in accordance with AASHTO T 319-03 and ASTM D 5404-03, respectively. TABLE 5 summarizes the aggregate gradations and asphalt contents of the JMF and three plant produced mixes.

TABLE 5 Sieve Analysis for Franklin Plant Mixes

Sieve Size		Percent Passing			
English	Metric	JMF	HMA 1	Advera WMA	Sasobit
2"	50	100	100	100	100
1 1/2"	37.5	100	100	100	100
1"	25	100	100	100	100
3/4"	19	100	100	100	100
1/2"	12.5	98	97	97	98
3/8"	9.5	86	84	85	84
#4	4.75	56	57	58	52
#8	2.36	41	46	42	40
#16	1.18	--	37	32	30
#30	0.6	24	28	24	22
#50	0.3	10	10	10	8
#100	0.15	6	6	6	4
#200	0.075	4.1	4.5	5.2	4.1
Extracted AC Content		5.3	5.2	5.1	4.9

Danley Plant

The Evotherm DAT and the second control mix were produced at the LoJac, Inc. Danley Plant. The same mix design was used for these two mixes as was used at the Murfreesboro plant. TABLE 6 summarizes the aggregate gradations and asphalt contents of the JMF and two plant produced mixes. The gradations for the Evotherm DAT and HMA mixes were similar with the exception of the 9.5, 4.75, and 0.075 mm sieves. The asphalt content of the HMA mix was similar to the JMF asphalt content. The Evotherm DAT mix asphalt content was lower than the JMF and control by 0.4%. The lower asphalt content for the Evotherm DAT was unintentional and may have contributed to the poor field densities.

Mix Testing

Mix testing was conducted for the material sampled. The WMA specimens were compacted in the field without reheating while the HMA specimens were compacted from reheated mix. The mix tests selected evaluated compactability, moisture susceptibility, rutting susceptibility, and low temperature cracking resistance. The following sections describe the testing and results from the mix evaluations.

TABLE 6 Sieve Analysis of Danley Plant Mixes

Sieve Size		Percent Passing		
English	Metric	JMF	HMA 2	Evotherm DAT
2"	50	100	100	100
1 1/2"	37.5	100	100	100
1"	25	100	100	100
3/4"	19	100	100	100.0
1/2"	12.5	99	98	98
3/8"	9.5	85	88	83
#4	4.75	59	60	55
#8	2.36	46	44	43
#16	1.18	--	33	34
#30	0.6	26	24	25
#50	0.3	10	10	10
#100	0.15	6	5	6
#200	0.075	4.0	4.4	5.1
Extracted AC Content		5.3	5.3	4.9

Compactability

The air voids at a constant compaction effort were evaluated. Since Tennessee does not use the gyratory, the design level of gyrations could not be used. A set number of gyrations of 60 was selected for evaluating the difference in compaction. The WMA specimens were compacted hot and the HMA specimens were compacted from reheated mix. FIGURE 8 illustrates the compaction differences of gyratory compacted specimens. The whiskers represent plus and minus one standard deviation. HMA 1 had lower average air voids than both the Advera WMA and Sasobit, which may be partially a result of the difference in asphalt contents.

HMA 2 and the Astec DBG had similar air voids. The Astec DBG had less asphalt than HMA 2; however, it has more fines, which can fill in voids. The Evotherm DAT mix yielded higher air voids than HMA 2, however, the difference was within 0.5%. The lower asphalt content in the Evotherm may have been the primary cause of the higher air void content.

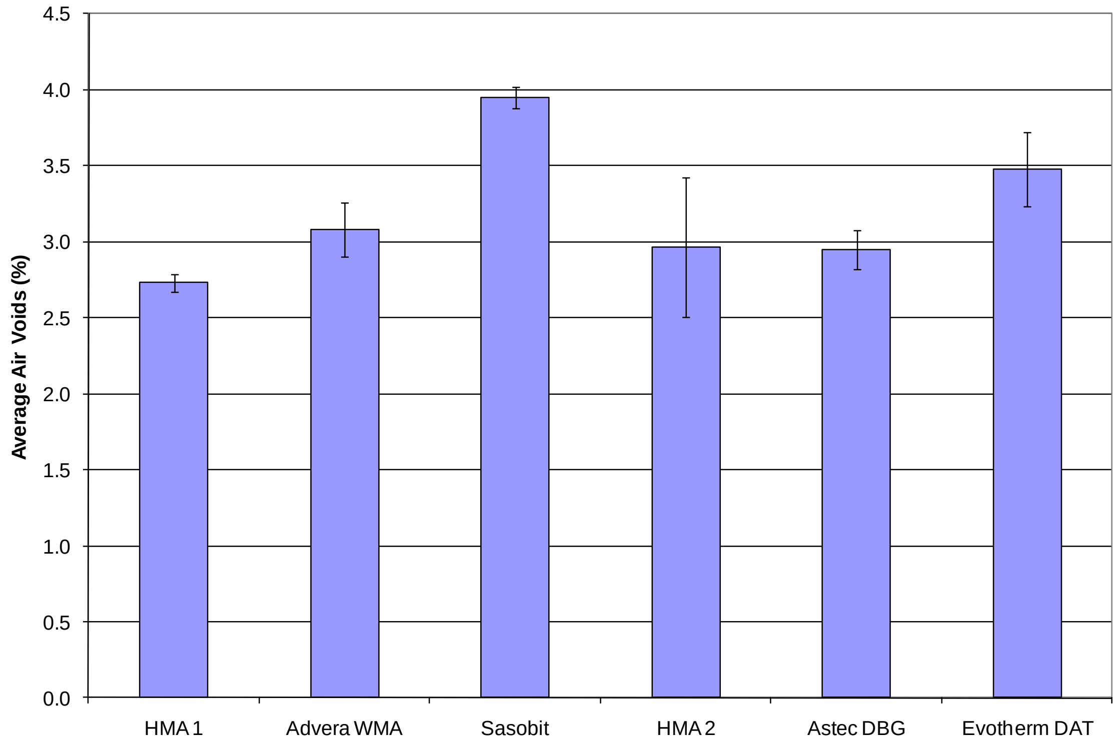

FIGURE 8 Air Voids at a Set Compaction Effort

The air void content trend for laboratory compacted specimens partially coincided with the in-place densities. The HMA in the laboratory and in the field exhibited lower air voids than the WMA sections. The mixes with lower asphalt contents than the HMAs yielded high air void contents in both the field and laboratory.

Moisture Susceptibility

Moisture susceptibility testing was conducted in accordance with ASTM D 4867 without a freeze-thaw cycle. Conditioned specimens were moisture saturated with no freeze-thaw cycle. Specimens were six inches in diameter. The HMA mixes were compacted from reheated mix and the WMA specimens were compacted on site without any reheating. FIGURE 9 illustrates the indirect tensile strength results of the two WMA mixes and the corresponding HMA mix produced at the Franklin plant. The columns represent the average of three indirect tensile strength results. The whiskers represent plus and minus one standard deviation. The red triangles represent the average air voids. The Sasobit and HMA 1 had average dry indirect tensile strengths that were similar. The wet indirect tensile strengths for both of the WMAs were less than 100 psi while the HMA 1 wet indirect tensile strengths was greater than 100 psi. The tensile strength ratio (TSR) for Advera WMA, Sasobit, and HMA 1 were 59%, 45%, and 88%, respectively. The TSR results indicate that the two WMAs produced at the Franklin plant may be prone to moisture damage based on an acceptable TSR of 80%. However, previous research has shown that indirect tensile strength results and TSRs from reheated mix tend to be better than those from mix not reheated prior to compaction; therefore, reheating the WMA for the moisture susceptibility testing could result in improved indirect tensile strength and TSR results.

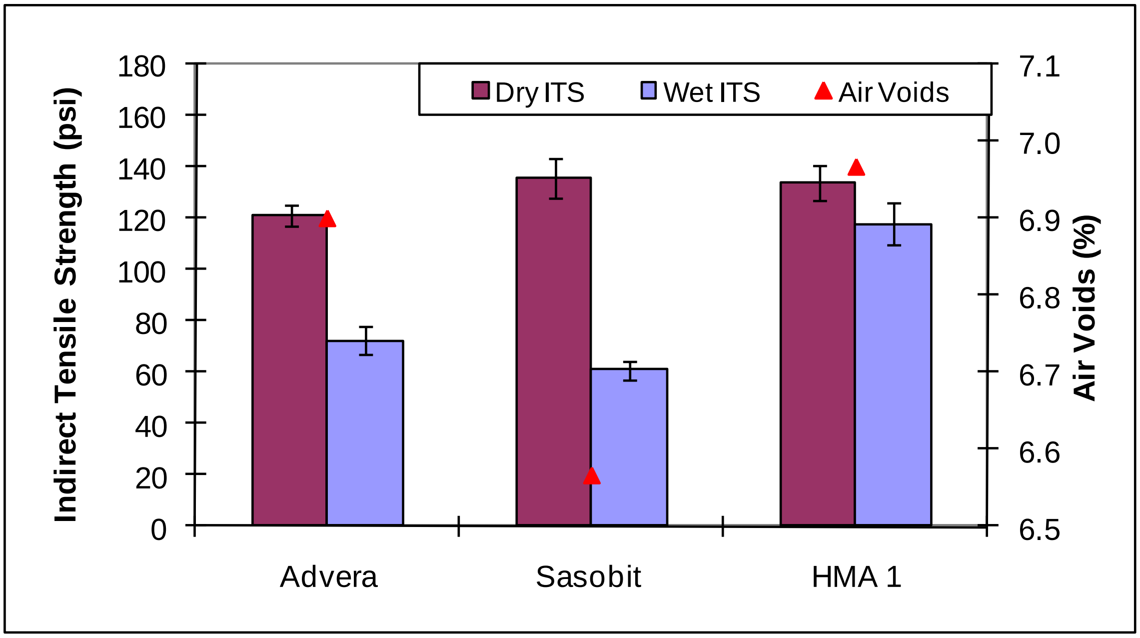

FIGURE 9 Indirect Tensile Strength of Franklin Plant Mixes

FIGURE 10 illustrates the results of the indirect tensile testing of mixes produced at the Danley and Murfeesboro plants. The Astec DBG and Evotherm DAT mixes had similar dry indirect tensile strengths, which were lower than the dry strengths of HMA 2. The wet indirect tensile strengths of HMA 2 were similar to the wet indirect tensile strength of the Astec DBG mix. The TSR values for the Astec DBG, Evotherm DAT, and HMA 2 mixes were 83%, 53%, and 73%, respectively.

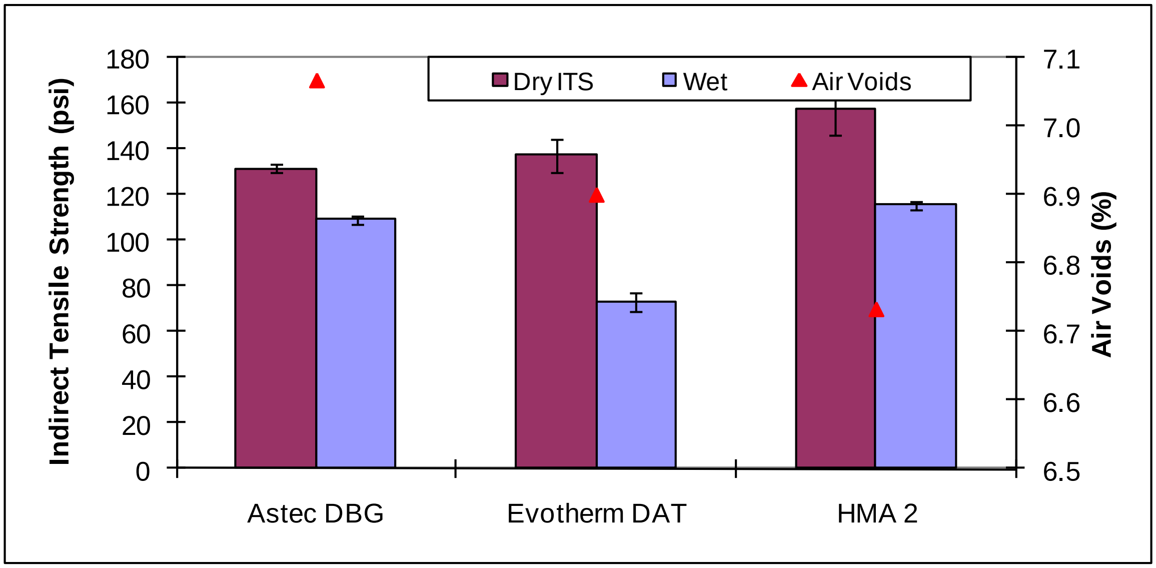

FIGURE 10 Indirect Tensile Strength of Danley and Murfeesboro Plant Mixes

Tukey's studentized range test was used to compare the mean indirect tensile strengths (α=0.05). The data was grouped by unsaturated and saturated. The mean indirect tensile strength comparisons for the unsaturated specimens indicated that there was no significant difference between the corresponding Franklin plant mixes. The dry indirect tensile strengths of HMA 2 were significantly higher than the mean dry indirect tensile strengths of the Astec DBG and Evotherm DAT mixes. The mean comparisons conducted on the mean saturated indirect tensile strengths suggested that HMA 2, and Astec DBG were not statistically different. However, the mean saturated strengths of all other corresponding WMA and HMA mixes indicated that there was a statistical difference between the WMA and HMA saturated strengths.

The moisture susceptibility testing indicated that the mixes with all of the WMA technologies except Astec DBG do not meet the TSR criterion of 0.80. The Astec DBG most likely exhibited better results than the other WMAs because of the higher mixing temperature, which may have allowed for more complete drying of the aggregate. The differences in plants may have affected the moisture susceptibility of the mixes. If the flighting in the Murfeesboro plant resulted in a longer dwell time than the other plants, it could have resulted in drier aggregates.

Hamburg Wheel Track Test

The Hamburg testing was conducted in accordance with AASHTO T 321 “Standard Method of Test for Hamburg Wheel-Track Testing of Compacted Hot-Mix Asphalt (HMA)”. Six inch cylindrical gyratory specimens were compacted to 7±0.5% air voids. Two sets of Hamburg specimens were tested and each set consisted of two specimens. The WMA specimens were compacted on site without reheating. The HMA mixes were reheated and compacted. All sets of specimens were conditioned and tested in a 50°C water bath. The test was run for 10,000 cycles (20,000 passes) or until the specimens failed. The stripping inflection point and total rut depth at 10,000 cycles (20,000 passes) were determined for each set of specimens. Preliminary criteria for the Hamburg stripping inflection point is equal to or greater than 5,000 cycles (10,000 passes), and a total rut depth at 10,000 cycles (20,000 passes) of less than 10 mm. The criteria was established based on a current practice of WMA researchers and DOT agencies.

FIGURE 11 illustrates the average stripping inflection points of the mixes produced at the Franklin plant. Both the Sasobit and HMA 1 exceeded the minimum criterion of 5000 cycles; thus indicating that the Sasobit did not negatively affect the mix. Advera WMA had an average stripping inflection point of 4325 cycles, which did not meet the preliminary criterion. The lower stripping inflection point may be an indication that the Advera negatively affected the mix.

FIGURE 12 depicts the average stripping inflection points for the mixes produced at the Danley and Murfeesboro plants. Both Astec DBG and HMA 2 exhibited stripping inflection points greater than the minimum requirement. The Astec DBG stripping inflection point was lower than the HMA 2 stripping inflection point indicating that either the additional moisture or lower production temperature may have slightly affected the mix. However, the difference may also be an effect of using a different plant. The Evotherm DAT had an average stripping inflection point of 3513 cycles, which did not meet the preliminary criterion. The Evotherm DAT may be more prone to moisture damage than the HMA 2 mix

The Hamburg stripping inflection point results ranked the moisture susceptibility of the mixes differently than the TSR results. The mix containing Sasobit was ranked as the least moisture resistant based on TSR but exhibited a better stripping inflection point than all of the other WMAs and the two HMA mixes. This indicates that the addition of Sasobit should improve the moisture resistance of the mix.

The rutting susceptibility of each mix was also determined from the Hamburg data. FIGURE 13 illustrates the average rut depths for the mixes produced at the Franklin plant. The Advera and HMA 1 both had average rut depths that exceeded the preliminary maximum rut depth criterion of 10 mm. The Sasobit mix had a rut depth that was well below 10 mm. FIGURE 14 depicts the average rut depths at 10,000 cycles for the mixes produced at the Danley and Murfeesboro plants. All three of the mixes exceeded the maximum allowable rut depth of 10 mm. HMA 2 exhibited the greatest rut depth of the three mixes.

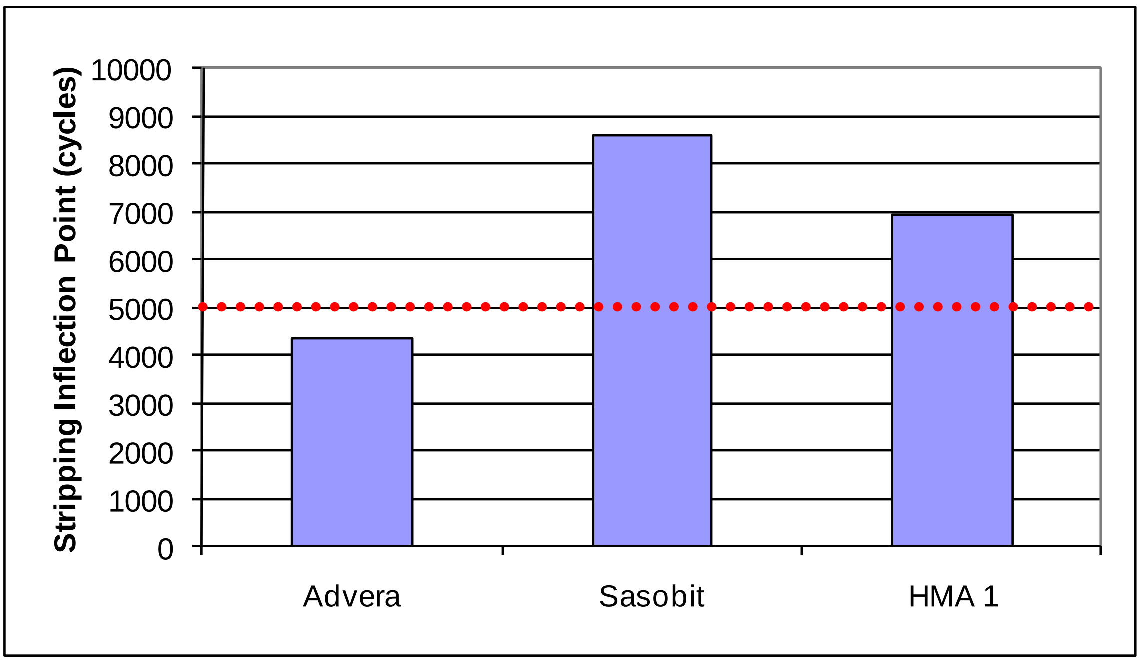

FIGURE 11 Stripping Inflection Points for Franklin Plant Mixes

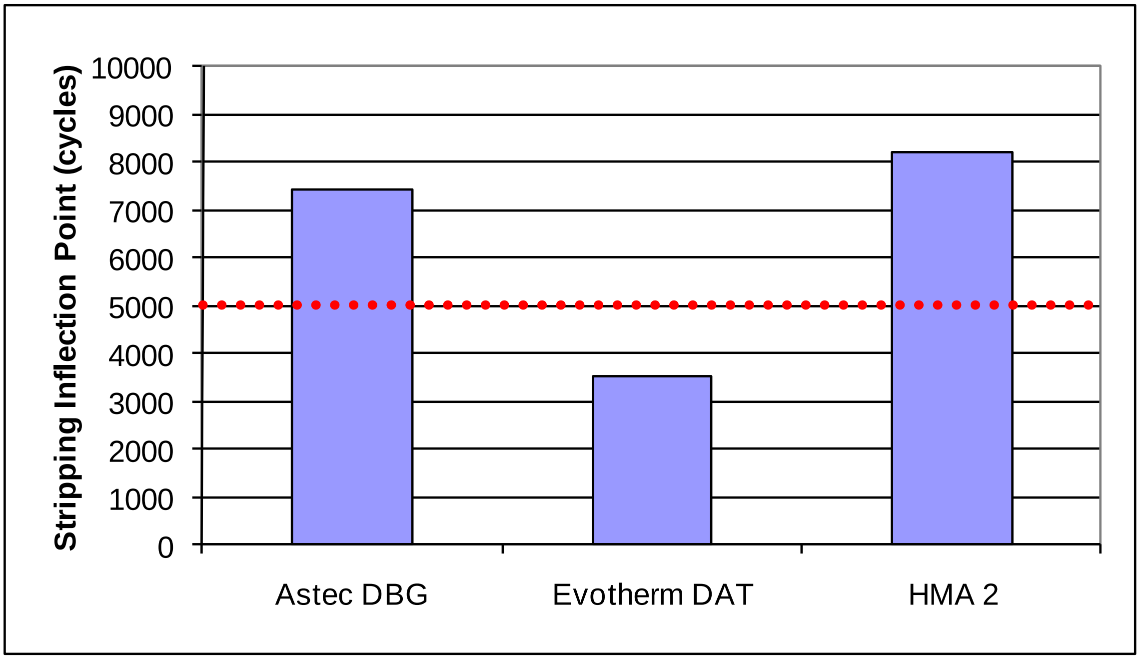

FIGURE 12 Stripping Inflection Points for Danley and Murfeesboro Plant Mixes

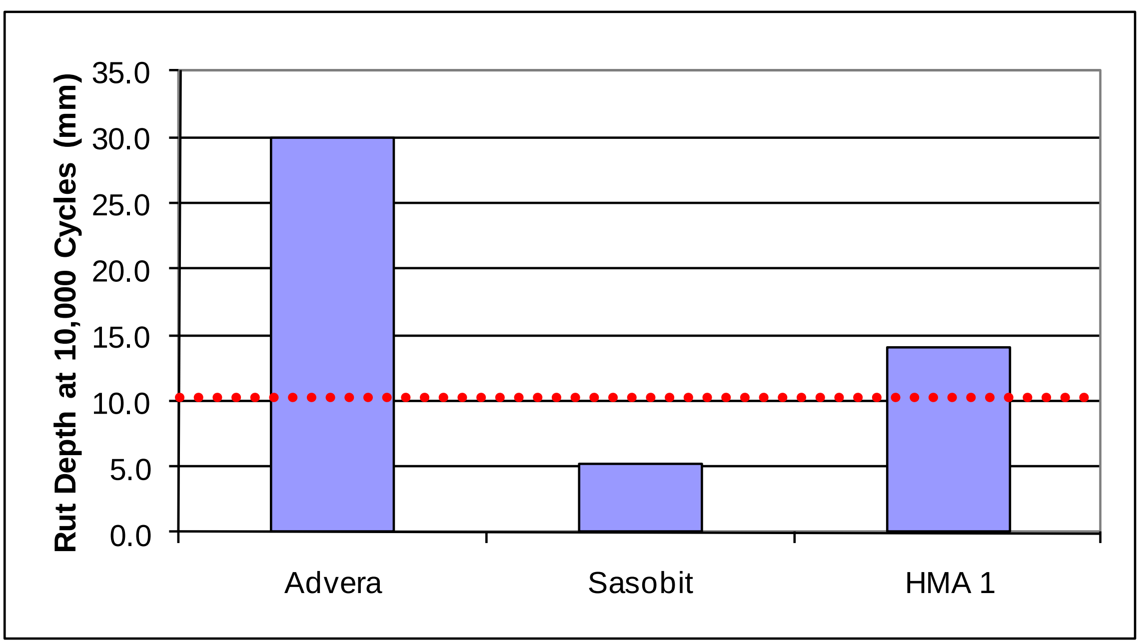

FIGURE 13 Hamburg Rut Depths for Franklin Plan Mixes

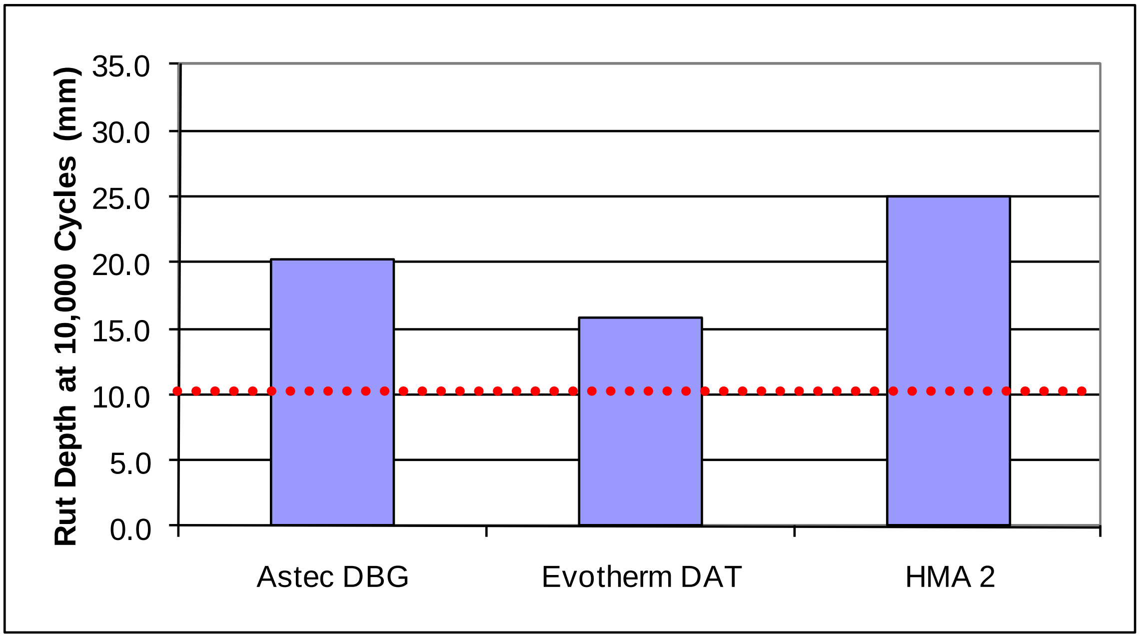

FIGURE 14 Hamburg Rut Depths for Danley and Murfeesboro Plant Mixes

The Hamburg is a severe rutting test. Based on the preliminary criteria of 10 mm, the only one of the six mixes that would have been deemed acceptable was the WMA mix that contained Sasobit. Since both HMA mixes failed to meet the rut depth criterion, it is not considered detrimental that most of the WMA mixes also failed to meet the preliminary criterion. The Advera WMA mix was the only WMA technology that did not perform as well as its corresponding control mix in the rutting test.

Asphalt Pavement Analyzer

The Asphalt Pavement Analyzer (APA) is another loaded wheel-rutting test. APA testing was conducted in accordance with AASHTO TP 63. Six cylindrical specimens per mix were tested in a heated air chamber. The test temperature was 64°C. The WMA APA specimens made on site did not have air voids within the AASHTO TP 63 range of 7±0.5%; therefore, field sampled mixes were reheated and a second set of specimens were compacted to the appropriate air void content. The HMA specimens were also made from reheated mix. Manual rut depth measurements were used in this report.

FIGURE 15 depicts the average rut depth measurements for the mixes produced at the Franklin plant. The dashed red line indicates a maximum allowable rut depth criterion of 8 mm. The HMA 1 mix exhibited an unaccepted average rut depth. The

Advera WMA mix exhibited an average rut depth that passed; however, there were samples that did not meet the criterion. The Sasobit mix had an average rut depth that was acceptable, which is similar to the results from the Hamburg testing. FIGURE 16 depicts the average APA rut depth results for the mixes produced at the Danley and Murfeesboro plants. Both the Evotherm DAT and HMA 2 barely met the maximum allowable rut depth of 8 mm. The Astec DBG exhibited an average rut depth of less than 8 mm.

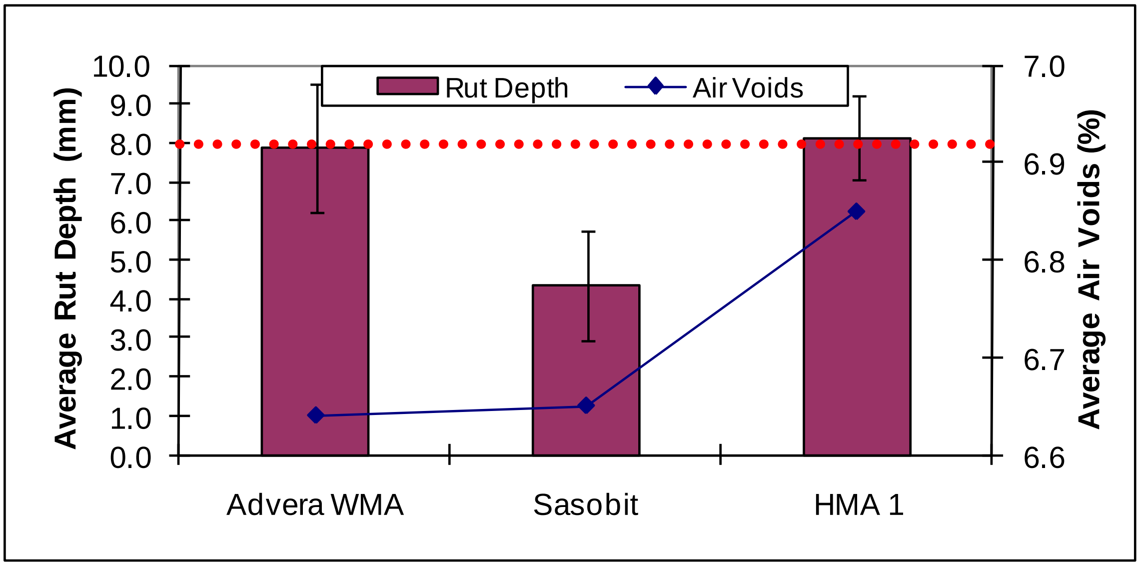

FIGURE 15 APA Rut Depths for Franklin Plant Mixes

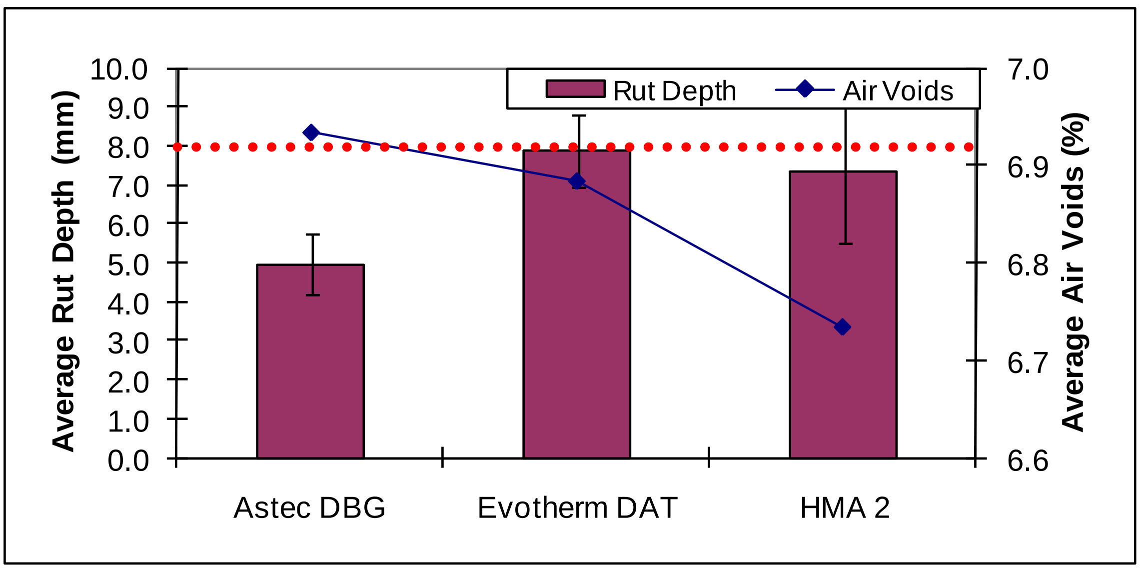

FIGURE 16 APA Rut Depths for Danley and Murfeesboro Plant Mixes

Tukey's studentized range was used to statistically compare the mean rut depths. TABLE 7 summarizes the results of the mean comparisons. If there was no significant difference between two mixes, then NS was entered into the corresponding cell. If there was a significant difference, then SD was entered. The mean rut depth of the Advera WMA was not significantly different than the mean rut depth of HMA 1. The mean Sasobit rut depth was significantly lower than the mean HMA 1 rut depth, indicating that the Sasobit mix may be less prone to rutting. The mean rut depth of the Astec DBG mix was significantly lower than the mean rut depth of HMA 2, indicating that using the WMA technology may result in improved rutting resistance. The mean rut depth of the Evotherm DAT mix was not found to be significantly different than the mean rut depth of HMA 2. It should be noted that in all cases, the WMA technology either resulted in improved or equal rutting resistance based on the APA results.

TABLE 7 APA Mean Comaprison Results

Mix	HMA 1	HMA 2
Advera WMA	NS	
Sasobit	SD	
Astec DBG		SD
Evotherm DAT		NS

Dynamic Modulus Testing

Dynamic modulus testing was conducted in accordance with AASHTO TP 62 to evaluate the stiffness of the WMA mixes compared to HMA. The test is run at multiple temperatures and frequencies, shown in TABLE 8, within the elastic response range of a mix. Tall cylindrical specimens were tested and were confined for this evaluation. The confining pressure was 138 kPa (20 psi). Three specimens per mix were tested. All specimens were compacted from reheated mix.

TABLE 8 Frequencies and Temperatures for Dynamic Modulus Testing

Frequency, Hz	Temperatures, °C
25	4.4
10	21.1
5	37.8
1	54.4
0.5	
0.1	

The data from the dynamic modulus test was used to construct a master curve for each mix, which relates a material's stiffness over a range of frequencies. Master curves were developed to compare the response of the HMA to that of the WMAs. Master curves are developed by shifting dynamic modulus test results from different testing temperatures and frequencies to form one continuous curve. A reference temperature of 21.1°C was employed to build the master curves. The data towards the -4.0 Hz log frequency region of the master curves was obtained from the high test temperatures; therefore, the first set of data points on each curve originate from the test results obtained at the 54.4°C test temperature. The lowest test temperature results, 4.4°C, are located along the x-axis around 2.0 Hz log frequency. Master curves and the shift factors used to create the master curves yield information about the loading and temperature dependency, respectively, of the material (*6*).

FIGURE 17 illustrates the dynamic modulus master curves for the Franklin plant mixes using on a reference temperature of 21.1°C. The stiffest mix was HMA 1 and the least stiff mix was the Sasobit mix. FIGURE 18 illustrates the master curves for the mixes produced at the Danley and Murfeesboro plants. For this set of mixes, HMA 2 was the stiffest and Astec DBG was the least stiff. However, the difference in stiffness between these three mixes was much less than that observed with the Franklin plant mixes. Overall, both HMAs were stiffer than their respective WMAs, thus indicating that WMAs tend to result in less stiff mixes regardless of technology type.

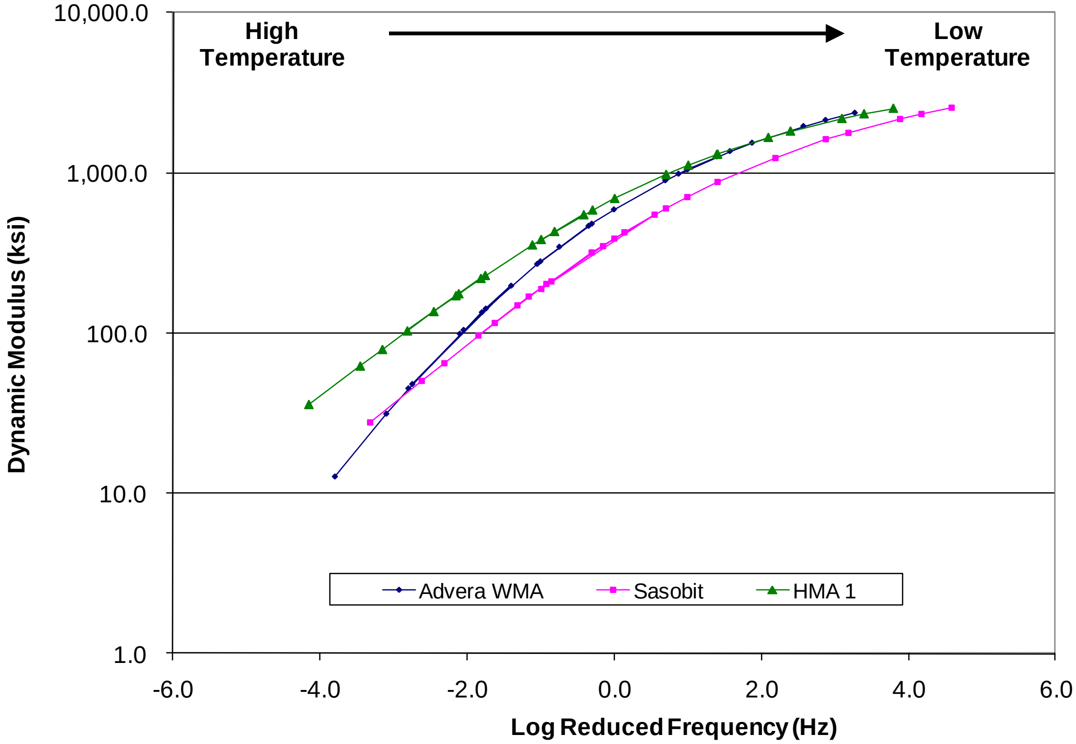

FIGURE 17 Dynamic Modulus for Franklin Plant Mixes

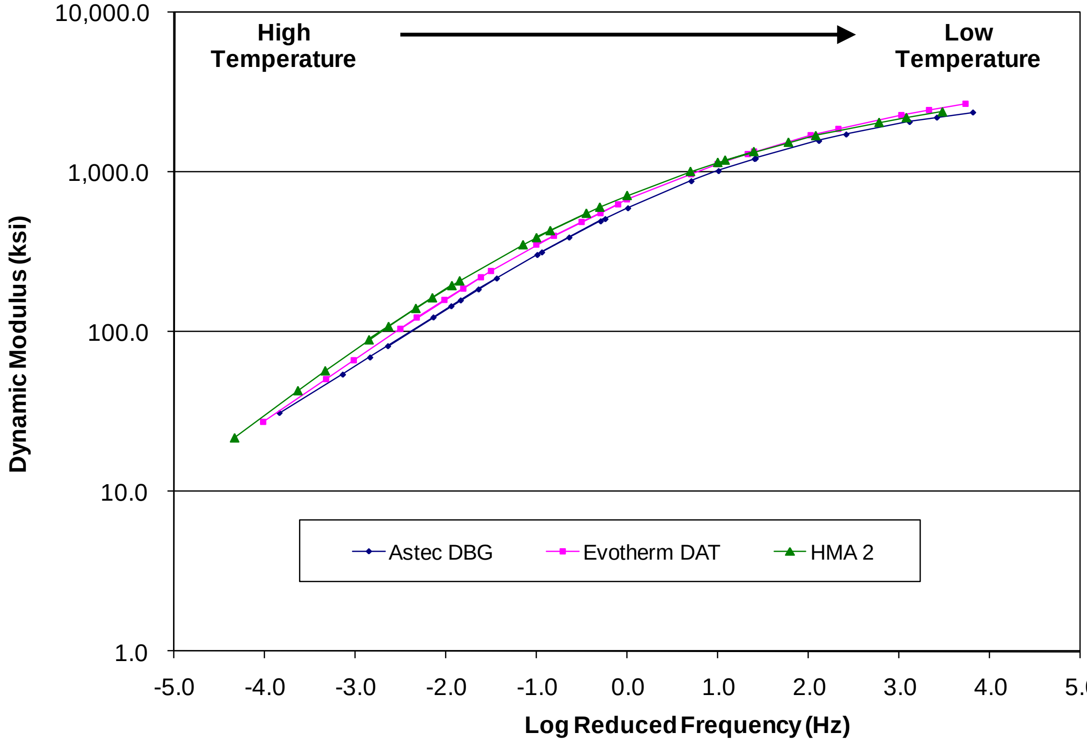

FIGURE 18 Dynamic Modulus for Danley and Murfeesboro Plant Mixes

The shift factors used to develop the master curves are affected by the response of a mix to changes in test temperatures. A large shift factor number indicates that a mix is sensitive to changes in temperature, while a small shift factor indicates that a mix less sensitive to changes in temperatures. FIGURE 19 illustrates the shift factors for the mixes produced at the Franklin plant. The two WMAs have similar shift factors and those shift factors tend to be smaller than the ones for HMA 1. The shift factor analysis indicates that HMA 1 is more temperature dependent than the two Franklin plant WMAs. FIGURE 20 illustrates the shift factors for the Danley and Murfeesboro plants. HMA 2 tends to be less temperature dependent at the low temperatures than the WMAs but more temperature dependent at the high test temperatures. Overall, the two HMAs tend to be slightly more temperature dependent at the high temperatures than the WMAs.

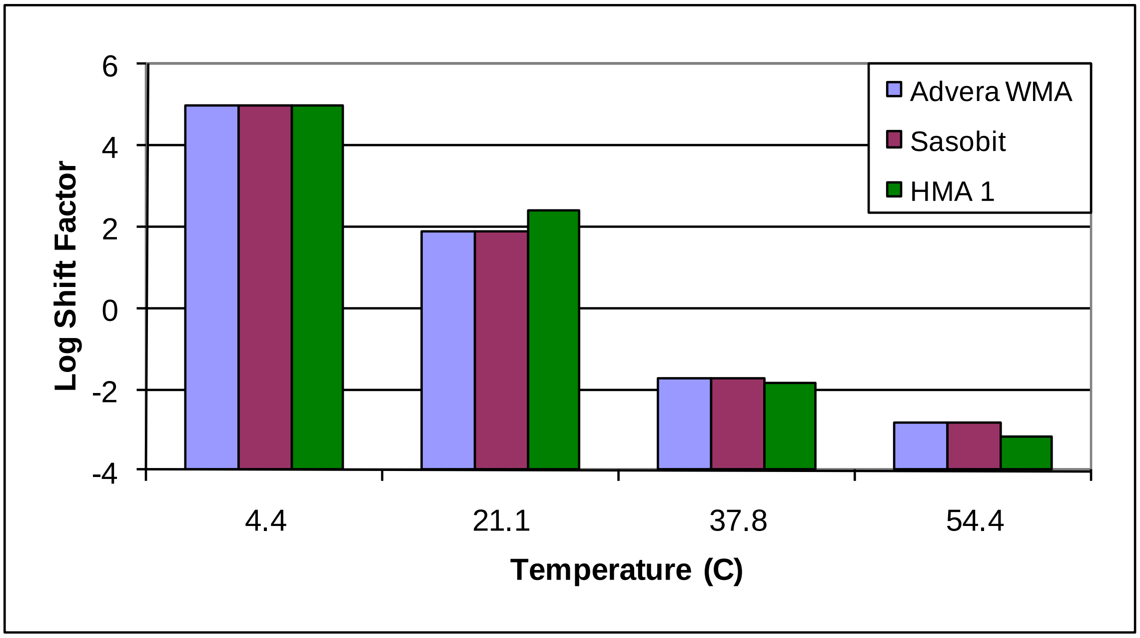

FIGURE 19 Log Shift Factors for Franklin Plant Mixes

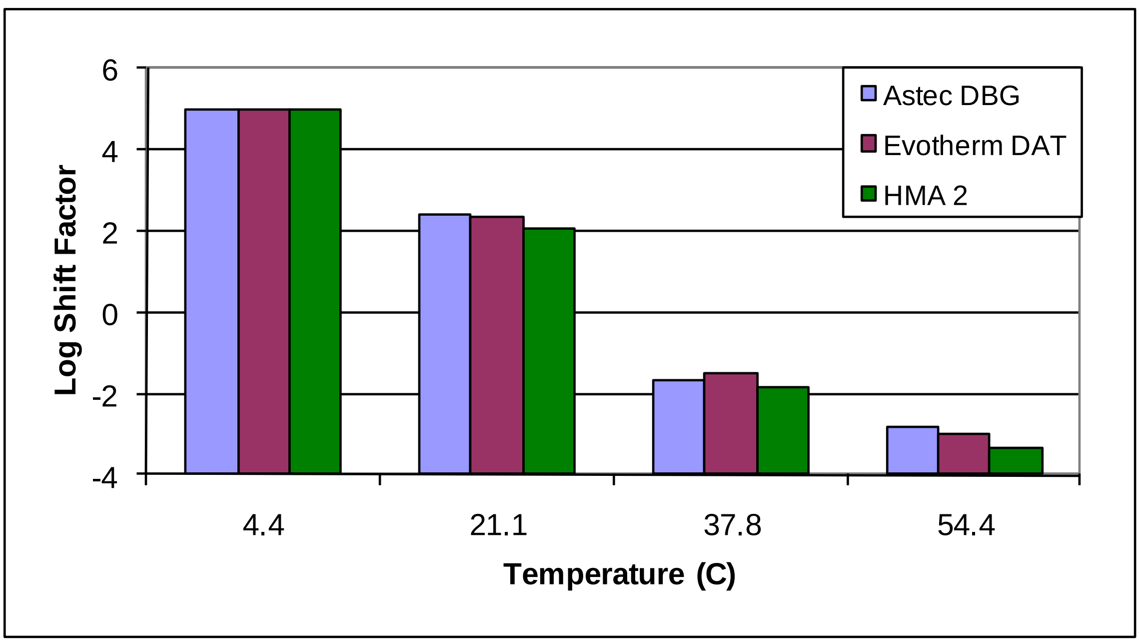

FIGURE 20 Log Shift Factors for Danley and Murfeesboro Plant Mixes

Indirect Tensile Creep Compliance

Indirect tensile creep compliance testing was conducted in accordance with AASHTO T 322. Comparisons of indirect tensile creep compliance testing can indicate if using a

WMA technology may improve resistance to thermal cracking. It has been hypothesized that the lower mixing temperatures used for WMA will reduce low temperature cracking during the early stages of a pavements life since the asphalt will be less oxidized compared to HMA. FIGURE 21 illustrates the creep compliance results for the mixes produced at the Franklin plant. HMA 1 has the greatest compliance value at -20 and 0°C indicating that it is more compliant than the two WMAs. The Sasobit WMA mix had the lowest compliance of the three Franklin mixes at -10 and 0°C, indicating that it may be more prone to thermal cracking than HMA 1. The creep compliance results indicate that the Advera WMA and Sasobit may affect the dissipation of thermal stresses since the two mixes yielded creep compliance results that are lower than HMA 1 results. At -10 and 0°C the Advera WMA and Sasobit were less compliant indicating that both may be more prone to low temperature distresses.

FIGURE 22 depicts the creep compliance results for the mixes produced at the Danley and Murfeesboro plants. The Astec DBG and Evotherm DAT mixes were more compliant than HMA 2 at -10 and 0°C. HMA 2 is the most compliant at -20°C. However, the differences at -20°C are relatively small. The creep compliance results indicate that the Astec foaming process and Evotherm DAT positively affect the dissipation of thermal stresses. The lower mixing temperatures of the Astec DBG and Evotherm DAT may have improved thermal cracking performance of the mixes. The benefits of the lower mixing temperatures may not have been realized for Sasobit and Advera WMA because of the nature of the additives, which tend to stiffen the lower grade of an asphalt.

The method of processing the data by combining the results of three samples to calculate the creep compliance prevents the usage of a statistical analysis to compare differences between the mixes.

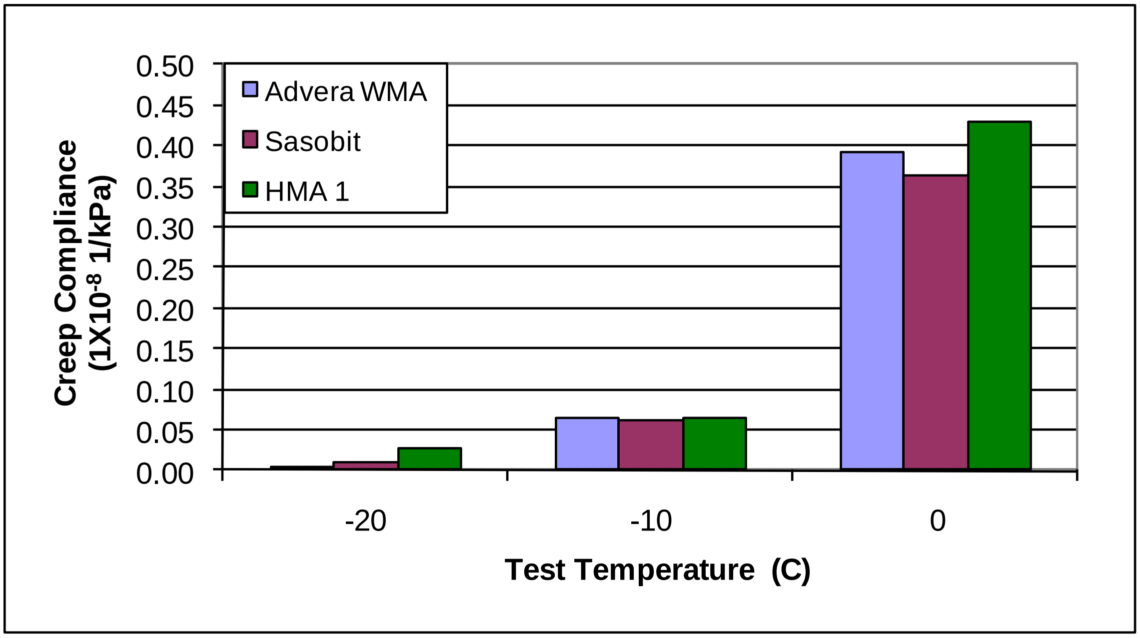

FIGURE 21 Creep Compliance of Franklin Plant Mixes

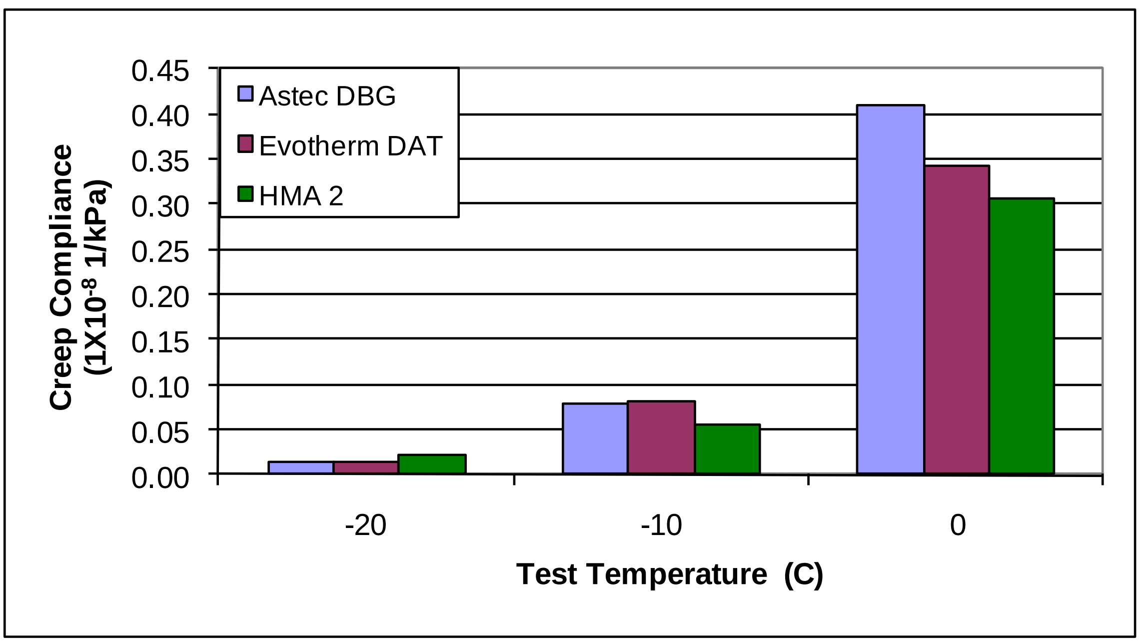

FIGURE 22 Creep Compliance of Danley and Murfeesboro Plant Mixes

One Year Evaluation

In November 2008, visual inspections of the pavement sections were conducted. Asphalt pooling on the surface in the shape of small circular spots (most approximately the size of a half dollar) was observed in both HMA sections (see FIGURE 23 and FIGURE 24) and in the Advera WMA section (FIGURE 25). HMA 1 and HMA 2 sections exhibited raveling along with asphalt and fines surfacing. Raveling was observed around the centerline of both the Astec DBG and Evotherm DAT mixes. Sasobit exhibited less raveling than the Astec DBG and Evotherm DAT section. The Advera WMA section exhibited the most severe raveling, which appeared to be worse under the tree coverage.

FIGURE 23 HMA 2 Pavement Condition

FIGURE 24 HMA 1 Pavement Condition

FIGURE 25 Advera Pavement Condition

For each section, three cores were obtained in the wheelpath and one core was obtained from between the wheelpaths. Two additional cores were obtained for the Advera WMA section because two of the original cores broke apart leaving a core that was too thin to test. The removal of the cores from the Advera WMA section indicated that there may be issues with the section since the underlying material tended to crumble in some sections. The material in the core hole was granular and broke apart easily. The densities of the cores were determined (see FIGURE 26). The error bars represent plus and minus one standard deviation. In four of the six cases, the between wheelpath densities were greater than the average within wheelpath densities. In the majority of these cases, the between wheelpaths density falls within the range of densities determined for the within wheelpath densities.

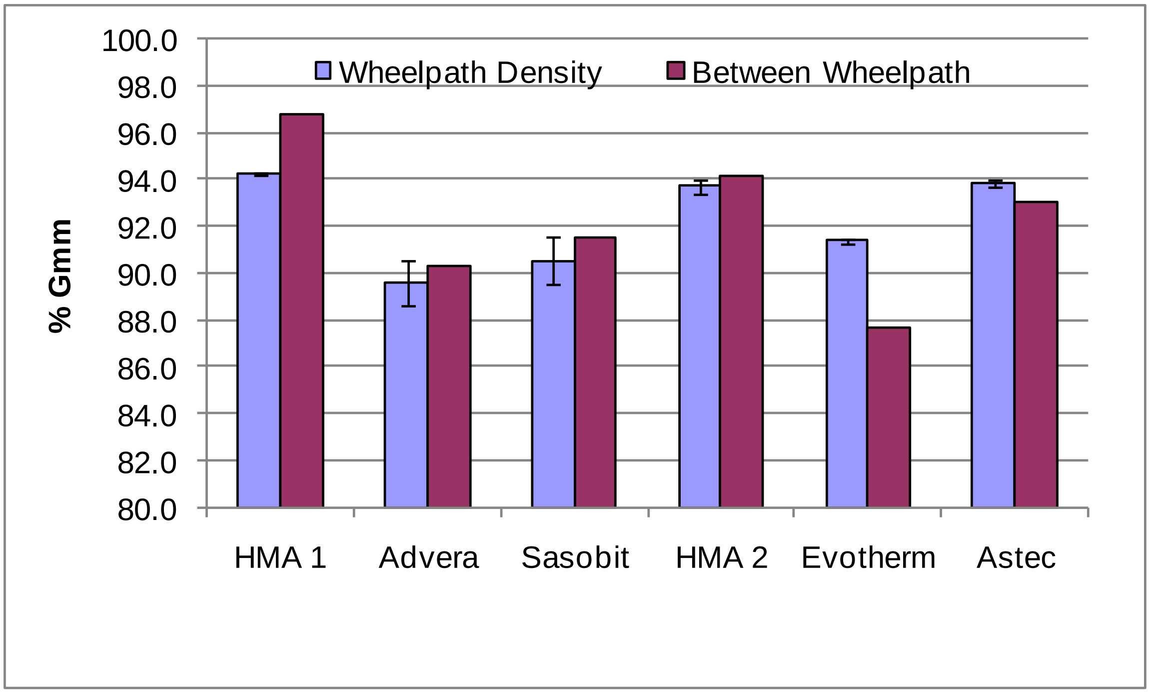

FIGURE 26 Densities After One Year of Trafficking

FIGURE 27 illustrates the average indirect tensile strengths and air void content for the mixes produced at the Franklin plant. The HMA 1 mix exhibited the lowest air void content and highest indirect tensile strength. FIGURE 28 illustrates the average indirect tensile strength and air void content of the cores from sections from the Danley and Murfeesboro plants. The HMA 2 mix exhibited the highest indirect tensile strength. The air void content of the Astec DBG and HMA 2 were similar. The Astec DBG mix exhibited high variability in the indirect tensile strengths. The cores from the Evotherm DAT section exhibited the least amount of variability in terms of indirect tensile strength. Overall, the two HMAs are exhibiting higher indirect tensile strengths than the WMAs after one year and appear to have compacted more than the WMAs. It should be noted that the cores with low indirect tensile strengths often had substantially higher air void contents than the HMA cores.

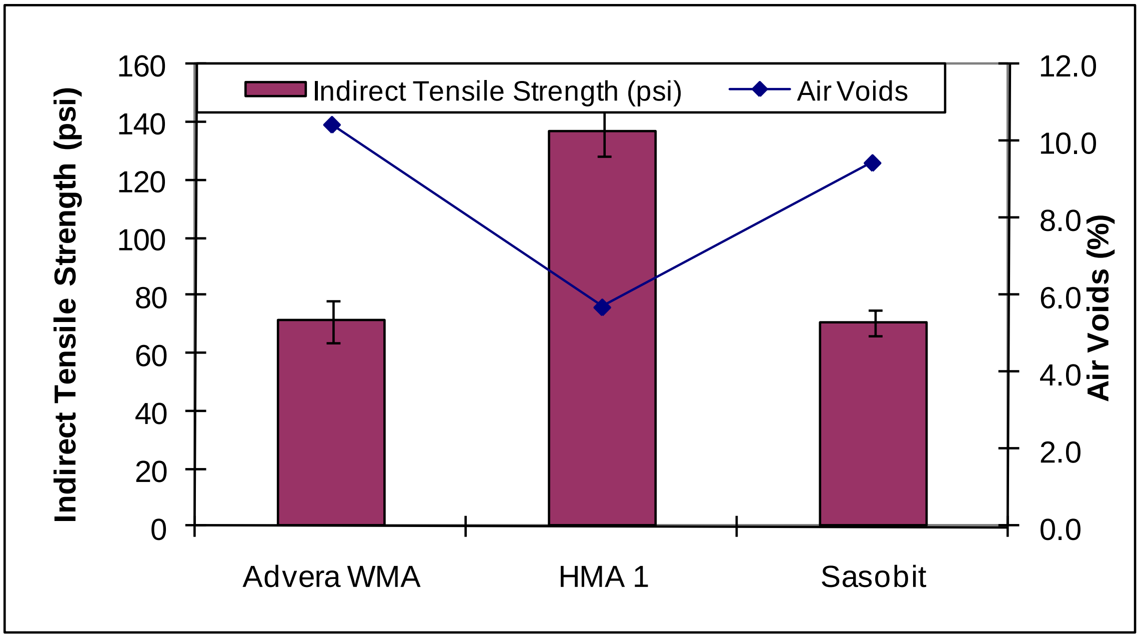

FIGURE 27 Indirect Tensile Strength of Wheelpath Cores for Franklin Plant Mixes

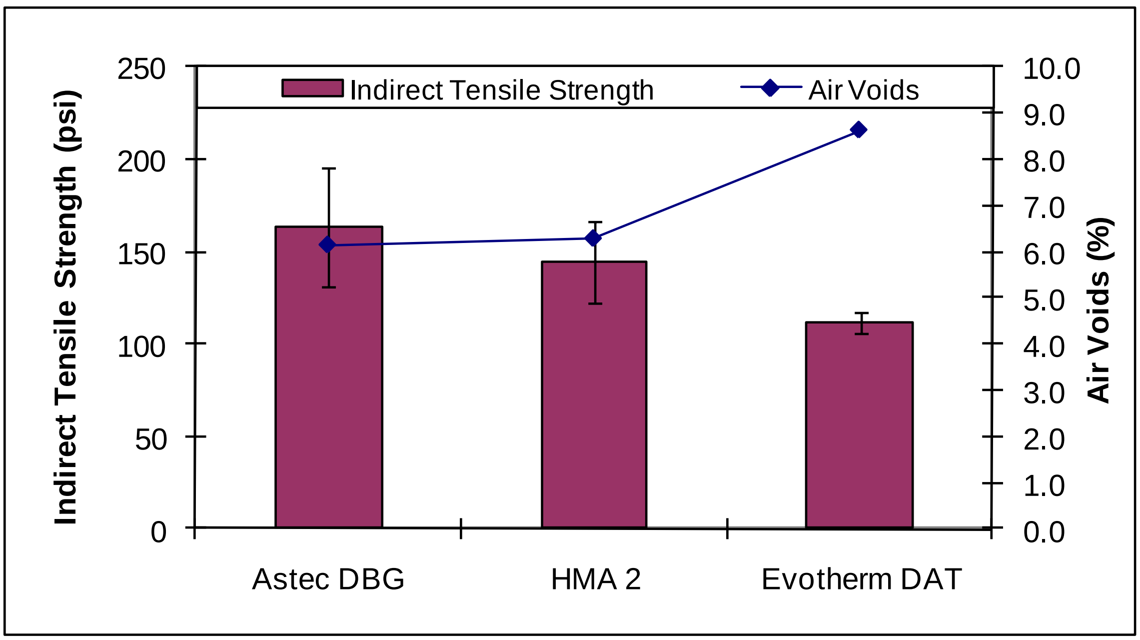

FIGURE 28 Indirect Tensile Strength of Wheelpath Cores for Danley and Murfeesboro Plant Mixes

Tukey's studentized range was used to statistically compare the mean indirect tensile strengths of the field cores. TABLE 9 summarizes the mean comparisons. The Advera WMA and Sasobit mixes were significantly different than the HMA 1 results.

Both mixes exhibited significantly lower tensile strengths. The differences in indirect strength between HMA 2 and Astec DBG and Evotherm DAT were not statistically significant.

TABLE 9 Mean Comparison Results of Field Core Indirect Tensile Strengths

Mix	HMA 1	HMA 2
Advera WMA	SD	
Sasobit	SD	
Astec DBG		NS
Evotherm DAT		NS

SD = Significant Difference; NS=Not Significantly Different

After the cores were tested, solvent extractions and recoveries were conducted. TABLE 10 lists the sieve analysis results for the Franklin plant produced mixes. There were slight differences between the three mixes, but overall the gradations were similar. TABLE 11 lists the sieve analysis results for the mixes produced at Danley and Murfeesboro plants. Overall the aggregate gradations are similar.

TABLE 10 Sieve Analysis of Cores from Franklin Plant Mixes

Sieve Size		After 1-Year			After Construction		
std.	**metric**	**HMA 1**	**Advera**	**Sasobit**	**HMA 1**	**Advera**	**Sasobit**
3/4"	**19.0**	100	100	100	100	100	100
1/2"	**12.5**	96	98	99	97	97	98
3/8"	**9.5**	84	83	86	84	85	84
#4	**4.75**	54	54	55	57	58	52
#8	**2.36**	40	40	42	46	42	40
#16	**1.18**	32	32	33	37	32	30
#30	**0.600**	23	25	25	28	24	22
#50	**0.300**	11	11	10	10	10	8
#100	**0.150**	10	7	6	6	6	4
#200	**0.075**	5.4	5.4	5	4.5	5.2	4.1
Asphalt Content		4.9	5.3	4.9	4.9	5.2	5.1

TABLE 11 Sieve Analysis of Cores from Danley and Murfeesboro Plant Mixes

Sieve Size		After 1-Year			After Construction		
std.	metric	HMA 2	Astec DBG	Evotherm DAT	HMA 2	Astec DBG	Evotherm DAT
3/4"	19	100	100	100	100	100	100
1/2"	12.5	98	99	98	98	98	98
3/8"	9.5	88	91	89	88	86	83
#4	4.75	59	63	62	60	57	55
#8	2.36	47	48	47	44	43	43
#16	1.18	38	36	36	33	33	34
#30	0.6	29	26	26	24	24	25
#50	0.3	11	12	11	10	10	10
#100	0.15	6	8	7	5	6	6
#200	0.075	4.8	6.3	5.2	4.4	5.1	5.1
Asphalt Content		5.4	5.1	4.7	5.3	4.8	4.9

The asphalt contents were also determined for the cores. The asphalt content of the Franklin plant mixes; Advera WMA, Sasobit, and HMA 1 were 4.92, 4.87, and 5.31, respectively. The higher asphalt content of the HMA 1 mix may account partially for its higher indirect tensile strengths. The asphalt contents for Astec DBG, Evotherm DAT, and HMA 2 were 5.07, 4.68, and 5.41, respectively. Once again the asphalt content of the HMA was higher than that of the WMAs. The difference in asphalt content between the Evotherm DAT and HMA 2 mixes was 0.73%, which is a significant difference and could partially explain the difference in indirect tensile strength results.

The recovered asphalt binders were classified. The extraction and recoveries from the cores did not yield enough asphalt to classify both the high and low performance grade; therefore, only the high performance grade was classified. TABLE 12 lists the continuous high grade and the high performance grade for the Franklin plant mixes. The binder from the Sasobit mix exhibited the highest temperature grade and HMA 1 mix had the lowest. TABLE 13 lists the results of the binder testing for the Danley and Murfeesboro plant mixes. Astec DBG exhibited the lowest high temperature grade and Evotherm DAT exhibited the highest. Differences between binder grades of HMA and WMA observed at the time of construction does not appear to be permanent. Field aging of the WMA mixes appears to erase the reduced aging of WMA during production.

Additional cores will be obtained at the two year revisit to evaluate if the aging trend continues or slows.

TABLE 12 Recovered Asphalt High PG after One Year for Franklin Plant Mixes

Mix	High True Grade	High PG
Advera WMA	77.4	76
HMA 1	75.6	70
Sasobit	82	82

TABLE 13 Recovered Asphalt High PG after One Year for Danley and Murfeesboro Plant Mixes

Mix	High True Grade	High PG
Astec DBG	70.1	70
HMA 2	76.6	76
Evotherm DAT	79.6	76

CONCLUSIONS

Six field test sections were produced as part of a TDOT demonstration project for WMA technologies. Four sections with different WMA technologies and two sections with HMA mixes were produced, tested, and evaluated. The production, constructability, and performance of the mixes were documented. The following observations were made concerning the mixes produced:

- No problems were encountered during production of any of the WMA mixes.
- There were no observed issues with placing the WMAs. Initial core density results indicated that the WMAs did not meet the target density. A second set of cores were obtained that marginally met the density requirement.
- Results of solvent extractions indicate that WMA mixes with Sasobit and Evotherm DAT had 0.4% less asphalt than required by the JMF. This reduction in asphalt may affect the performance of those two mixes. The other four mixes contained the appropriate amount of asphalt.

- Recovered asphalt grading indicates that the asphalt does not age to the same extent during WMA production as it does during HMA production. The WMAs overall were less stiff than the HMAs because of the reduced oxidation. The difference in continuous grades was dependent upon the mixing temperature and WMA technology.
- Moisture susceptibility testing using the modified Lottman test indicated that WMAs may be more prone to moisture damage than the HMAs. However, the reheating of the HMA may have improved the HMA results in comparison to the WMA which was not reheated.
- Hamburg testing indicated that all of the mixes except Advera and Evotherm WMA mixes are moisture resistant. The results of the Hamburg testing contradict the results of the modified Lottman testing. Therefore, the test section will be monitored to determine which test appropriately ranks the moisture damage resistance mixes. Reheating of the HMA may have resulted in better HMA results than if the mix had been compacted on site.
- Results of the Hamburg rut depths indicate that only the Sasobit mix was able to meet the preliminary rutting criterion, indicating that Sasobit improved the rutting resistance of the mix. The other WMA technologies did not result in increased rutting resistance compared to their respective HMAs.
- Results of the APA indicate that two mixes, Sasobit and Astec DBG, of the six mixes are the most rut resistant. HMA 1 failed the rut criterion, while the associated WMA technologies, Advera and Sasobit, passed the average rut depth criterion. The Advera did not significantly improve the rutting resistance of the mix. The addition of Sasobit, however, did improve the rutting resistance of the mix. HMA 2 passed the APA criterion. The Evotherm DAT appeared to negatively affect the rutting resistance while Astec DBG improved the rutting resistance. However, the differences in plants may partially explain the differences observed in the mixes.
- Dynamic modulus testing indicated that the two HMAs were stiffer than the four WMAs. The initial stiffness of the mixes was most likely affected by the oxidation of the asphalt during production.

- Creep compliance testing indicated that two of the WMAs were less compliant than the associated HMA and this may be due to the affect of the additive on the mix. The other two WMA were more compliant than the associated HMA indicating that in those two cases the reduced oxidation of the binder may improve the dissipation of thermal stresses.
- One year field evaluations revealed asphalt bleeding and raveling in the two HMA sections and the Advera WMA section. It should be noted that the WMA sections did not appear darker than the HMA.
- Cores obtained at the one-year evaluations indicated that the HMAs had higher indirect tensile strengths than the WMAs. The indirect tensile strengths of the WMAs were still low after one year. The in-place densities of many of the WMAs were also lower.
- Absorption was also evaluated and the WMAs did not appear negatively affect the absorption process.
- Tests on the recovered asphalt from the one year cores indicated that the WMA aged more rapidly than the HMA during the first year.

Overall, the production of the WMA was comparable to that of HMA. The construction of the WMA sections could have been improved with establishing a rolling pattern for each mix. The WMA process does reduce the oxidation of the asphalt; however, the difference in aging does not appear to be maintained. The WMA appears to age more rapidly than the HMA initially. The laboratory test results of the WMA mixes indicates that moisture susceptibility and rutting may be an issue for some of the WMA technologies.

ACKNOWLEDGEMENTS

The authors would like to thank FHWA for sponsoring this research. The cooperation of both LoJac, Inc. and the Tennessee Department of Transportation is also much appreciated by the authors.

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APPENDIX A: MIX DESIGNS

STATE OF TENNESSEE ASPHALT JOB MIX FORMULA

1/31/2007 V6.0

L-13, L-20

Project Ref. No.		**Date**	09/04/2007
Project No.	14019-4203-04	**Region**	3
Contract No.	CNF172	**County**	Williamson
Contractor	LoJac Ent	**Date of Letting**	06/01/07
State Route No.	SR 46	**Roadway Surface**	Yes
Hot-mix Producer	LOJAC, INC., MURFREESBORO PLANT		

Type ACS-HM **Mix** 411-D PG 70-22 **Item** 411-02.10

Serial No.:	Design No.:

Material	Size or Grade	Producer and Location	Percent Used
D Rock(Limestone)	Medium Coarse Aggregate	Rinker Springfield,TN	47.350
#10 (Soft)	Screenings	Vulcan Danley Antioch,TN	9.470
Natural Sand	Natural Sand	Ingram Mtls Nashville,TN	23.675
#10 (Soft)	Washed Screenings	Vulcan Danley Antioch,TN	14.205
Asphalt Cement	PG 70-22	ERGON ASPHALT CO., NASHVILLE TERMINAL	5.300

Percent AC in RAP:		**Optimum AC Content:**	5.3	**Total**	100.000
Anti-Strip Additive:		Pavegrip 650		**Dosage:**	0.3%
AC Contribution:	**Virgin AC** 5.30	**RAP AC**		**Percent Virgin AC:**	
Asphalt Sp. Gravity:	1.03			**Dust to Asphalt Ratio:**	0.75

% Fracture Face on CA:	100	**% Glassy Particles on CA:**	
Theo.Gravity of RAP:		**Eff. Gravity of Agg:**	2.628

Theo. Gravity of Mix:	2.428	**T.S.R.:**	85.4	**Lbs/Ft^3:**	151.5
L.O.I.:	20.5	**Ignition Oven Corr. Factor:**			
ADT	**Log Miles**	**Beginning:**		**Ending:**	

Lab Temperature		**Plant Temperature**	
Mixing Temperature (± 5 °F):	**320**	**Mixing Temp Range(°F):**	**320°F ≤ T ≤ 350°F**
Lab Compaction Temp (± 5 °F):	**305**	**Delivery Temperature(°F):**	**320°F ≤ T ≤ 350°F**

	Percents Used								
Sieve Size			D Rock(Limestone) 50.0	#10 (Soft) 10.0	Natural Sand 25.0	#10 (Soft) 15.0		**% Req. 100**	**Design Range**
2"									
1.5"									
1.25"									
1"									
3/4"									
5/8"			100	100	100	100		**100**	**100**
1/2"			97	100	100	100		**99**	**95-100**
3/8"			70	100	100	100		**85**	**80-93**
No.4			21	93	99	99		**59**	**54-76**
No.8			7	63	94	84		**46**	**35-57**
No.16									
No.30			5	29	63	29		**26**	**17-29**
No.50			4	22	13	19		**10**	**10-18**
No.100			3.5	19.0	2.0	9.0		**5.5**	**3-10**
No.200			2.5	16.0	1.5	5.0		**4.0**	**0-6.5**

Requested: LoJac Ent. Mike Ford LT020
Contractor Personnel and Lab Tech Cert No.

Approved: ______________________
Regional Materials and Tests Supervisor

Date last lab inspection 2/28/2007

Approved: ______________________
Headquarters Materials and Tests

Job #32517 6,305 Tons

STATE OF TENNESSEE ASPHALT JOB MIX FORMULA

1/31/2007 V8.0

L-13, L-20

Project Ref. No.		**Date**	09/14/2007
Project No.	94019-4203-04	**Region**	3
Contract No.	CNF172	**County**	Williamson
Contractor	LoJac Ent.	**Date of Letting**	06/01/07
State Route No.	SR 46	**Roadway Surface**	Yes
Hot-mix Producer	LOJAC, INC., FRANKLIN PLANT #1		

Type ACS-HM **Mix** 411-D PG 70-22 **Item** 411-02.10

Serial No.:	Design No.:

Material	Size or Grade	Producer and Location	Percent Used
D Rock(Limestone)	Medium Coarse Aggregate	RGI,BonAqua,TN.	47.350
#10 (Soft)	Screenings	Vulcan Mtls. Franklin,TN	9.470
Natural Sand	Natural Sand	Ingram Mtls Nashville,TN	23.675
#10 (Soft)	Washed Screenings	Vulcan Danley Antioch,TN	14.205
Asphalt Cement	PG 70-22	ERGON ASPHALT CO., NASHVILLE TERMINAL	5.300

Percent AC in RAP:		**Optimum AC Content:**	5.3	**Total**	100.000
Anti-Strip Additive:	AD-Here 77-00			**Dosage:**	0.3%
AC Contribution:	**Virgin AC** 5.30	**RAP AC**		**Percent Virgin AC:**	
Asphalt Sp. Gravity:	1.03			**Dust to Asphalt Ratio:**	0.77

% Fracture Face on CA:	100	**% Glassy Particles on CA:**	
Theo.Gravity of RAP:		**Eff. Gravity of Agg:**	2.612

Theo. Gravity of Mix:	2.415	**T.S.R.:**	89.6	**Lbs/Ft^3:**	150.7
L.O.I.:	22.5	**Ignition Oven Corr. Factor:**			
ADT	**Log Miles**	**Beginning:**		**Ending:**	

Lab Temperature		**Plant Temperature**	
Mixing Temperature (± 5 °F):	**320**	**Mixing Temp Range(°F):**	**320°F ≤ T ≤ 350°F**
Lab Compaction Temp (± 5 °F):	**295**	**Delivery Temperature(°F):**	**320°F ≤ T ≤ 350°F**

Sieve Size	Percents Used							% Req.	Design Range
		D Rock(Limestone)	#10 (Soft)	Natural Sand	#10 (Soft)				
		50.0	10.0	25.0	15.0			100	
2"									
1.5"									
1.25"									
1"									
3/4"									
5/8"		100	100	100	100			100	100
1/2"		95	100	100	100			98	95-100
3/8"		72	100	100	100			86	80-93
No.4		15	93	98	99			56	54-76
No.8		6	65	93	55			41	35-57
No.16									
No.30		5	30	63	17			24	17-29
No.50		4	26	13	12			10	10-18
No.100		3.5	21.0	2.0	8.0			5.6	3-10
No.200		2.5	17.0	1.0	6.0			4.1	0-6.5

Requested: LoJac Ent. Mike Ford LT020
Contractor Personnel and Lab Tech Cert No.

Approved: ____________________
Regional Materials and Tests Supervisor

Date last lab inspection 3/20/2007

Approved: ____________________
Headquarters Materials and Tests

Job#32517 6,305 Tons

STATE OF TENNESSEE ASPHALT JOB MIX FORMULA

1/31/2007 V6.0

L-13, L-20

Project Ref. No.		**Date**	09/04/2007
Project No.	14019-4203-04	**Region**	3
Contract No.	CNF172	**County**	Williamson
Contractor	LoJac Ent	**Date of Letting**	06/01/07
State Route No.	SR 46	**Roadway Surface**	Yes
Hot-mix Producer	LOJAC, INC., DANLEY PLANT		

Type ACS-HM **Mix** 411-D PG 70-22 **Item** 411-02.10

Serial No.:	Design No.:

Material	Size or Grade	Producer and Location	Percent Used
D Rock(Limestone)	Medium Coarse Aggregate	Rinker Springfield,TN	47.350
#10 (Soft)	Screenings	Vulcan Danley Antioch,TN	9.470
Natural Sand	Natural Sand	Ingram Mtls Nashville,TN	23.675
#10 (Soft)	Washed Screenings	Vulcan Danley Antioch,TN	14.205
Asphalt Cement	PG 70-22	ERGON ASPHALT CO., NASHVILLE TERMINAL	5.300

Percent AC in RAP:		**Optimum AC Content:**	5.3	**Total**	100.000
Anti-Strip Additive:	Pavegrip 650			**Dosage:**	0.3%
AC Contribution:	**Virgin AC** 5.30	**RAP AC**		**Percent Virgin AC:**	
Asphalt Sp. Gravity:	1.03			**Dust to Asphalt Ratio:**	0.75

% Fracture Face on CA:	100	**% Glassy Particles on CA:**	
Theo.Gravity of RAP:		**Eff. Gravity of Agg:**	2.628

Theo. Gravity of Mix:	2.428	**T.S.R.:**	85.4	**Lbs/Ft^3:**	151.5
L.O.I.:	20.5			**Ignition Oven Corr. Factor:**	
ADT	**Log Miles**	**Beginning:**		**Ending:**	

Lab Temperature		**Plant Temperature**	
Mixing Temperature (± 5 °F):	**320**	**Mixing Temp Range(°F):**	**320°F ≤ T ≤ 350°F**
Lab Compaction Temp (± 5 °F):	**305**	**Delivery Temperature(°F):**	**320°F ≤ T ≤ 350°F**

Sieve Size	**Percents Used**							**% Req. 100**	**Design Range**
			D Rock(Limestone)	#10 (Soft)	Natural Sand	#10 (Soft)			
			50.0	10.0	25.0	15.0			
2"									
1.5"									
1.25"									
1"									
3/4"									
5/8"			100	100	100	100		**100**	**100**
1/2"			97	100	100	100		**99**	**95-100**
3/8"			70	100	100	100		**85**	**80-93**
No.4			21	93	99	99		**59**	**54-76**
No.8			7	63	94	84		**46**	**35-57**
No.16									
No.30			5	29	63	29		**26**	**17-29**
No.50			4	22	13	19		**10**	**10-18**
No.100			3.5	19.0	2.0	9.0		**5.5**	**3-10**
No.200			2.5	16.0	1.5	5.0		**4.0**	**0-6.5**

Requested: LoJac Ent. Mike Ford LT020
Contractor Personnel and Lab Tech Cert No.

Approved: ____________________
Regional Materials and Tests Supervisor

Date last lab inspection 2/28/2007

Approved: ____________________
Headquarters Materials and Tests

Job #32517 6,305 Tons