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research report

Installation of Warm Mix Asphalt Projects in Virginia

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16. Abstract:

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Trial sections were initiated through cooperative efforts by the Virginia Transportation Research Council; VDOT districts, residencies, and area headquarters; and participating contractors. Construction used typical mixture designs and practices so that performance under typical construction conditions could be evaluated. General experiences and processes used during construction were documented, and samples were taken for laboratory characterization. Density measurements and cores were taken at each site to determine the initial pavement properties. At the Evotherm installation, asphalt fume sampling was conducted by VDOT's Employee Safety & Health Division to evaluate differences in worker exposure between HMA and WMA pavement laydown operations.

The study showed that WMA can be successfully placed using conventional HMA paving practices and procedures with only minor modifications to account for the reduction in temperature. The evaluated technologies affected mixture properties in slightly different ways such as changes in tensile strength ratios and variability in air voids. Additional monitoring of constructed sections was recommended to evaluate long-term performance.

Inclusion of WMA technology as an option for paving operations provides potential benefits to VDOT and the contracting community. Theoretically, these technologies could extend the asphalt paving season into cooler weather, allowing for better optimization of paving resources. The technologies also allow the construction of asphalt pavements at lower temperatures, resulting in reduced cooling time before the pavement is opened to traffic. Lower production temperatures may also increase mixture durability by reducing production aging of the mix. Benefits to contractors may include the ability to increase hauling distances between the plant and project, reduced plant emissions resulting in improved air quality, and cost savings because of reduced energy costs. Because of the experimental nature of this study, no cost savings data are yet available to justify or refute the use of WMA technologies.

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FINAL REPORT

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(A partnership of the Virginia Department of Transportation
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ABSTRACT

Several processes have been developed to reduce the mixing and compaction temperatures of hot mix asphalt (HMA) without sacrificing the quality of the resulting pavement. The purpose of this study was to evaluate the installation of warm mix asphalt (WMA) to compile experiences and offer recommendations for future use. Three trial sections were installed using warm mix technologies between August and November of 2006. Two used the Sasobit technology, and the third employed the Evotherm technology. This report discusses the material makeup of these technologies and documents the production and placement of the three trial sections. The results of this study and further studies can serve as a basis for decision making by the Virginia Department of Transportation (VDOT) regarding the use of WMA technology.

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INTRODUCTION

Rising energy costs and increased environmental awareness have brought attention to the potential benefits of warm mix asphalt (WMA) in the United States. Warm asphalt is produced by incorporating additives into asphalt mixtures to allow production and placement of the mix when heated to temperatures well below the 300ºF+ temperatures of conventional hot mix asphalt (HMA). Benefits such as reduced plant emissions, improved compaction in the field, extension of the paving season into colder weather, and reduced energy consumption at the plant may be realized with different applications. Research and experience with WMA in the United States are limited at this time (Hurley and Prowell, 2005a,b; 2006a,b; Michael and Layman, 2006; Kanitpong et al., 2007; Prowell et al., 2007; Wasiuddin et al., 2007). European experience with these mixtures has been more extensive (Barthell et al., 2004; Larsen et al., 2004; Sasol Wax, 2004a). European Union targets for reduction of carbon dioxide emissions and the increased cost of energy have provided incentives for the development of innovative technologies for reducing the production and working temperatures of asphalt.

Currently, four technologies are available in the United States:

1. *Sasobit,* developed by Sasol International (Sasol Wax)
2. *Aspha-min zeolite,* developed by Eurovia Services GmbH
3. *WAM foam,* developed by Shell International and Kolo Veidekke
4. *Evotherm,* developed by MeadWestvaco Asphalt Innovations.

However, only Sasobit and Evotherm were used during this study because of the availability of trial sections.

Sasobit is a synthetic long-chain Fischer-Tropsch wax produced from coal gasification. It is introduced to HMA by blending with the binder at the terminal or contractor’s tank, adding it with the aggregate, or pneumatically blowing it into the plant through a modified fiber feed line. The recommended addition rate is 0.8% to 3% by mass of the binder. Sasobit lowers the viscosity of the binder such that working temperatures decrease by 32ºF to 97ºF. Sasobit has a congealing temperature of about 216ºF and is completely soluble in binders at temperatures higher than 248ºF (Sasol Wax, 2004b). At temperatures below the melting point, it forms a crystalline network structure in the binder that is reported to provide added stability (Butz et al., 2001).

Evotherm is a non-proprietary technology that is based on chemistry that includes additives to improve coating and workability, adhesion promoters, and emulsification agents. The additives are delivered in an emulsion with a relatively high asphalt residue (approximately 70%) that is stored at 176ºF (Hurley and Prowell, 2006). Water in the emulsion is liberated as steam when mixed with the hot aggregate.

PURPOSE AND SCOPE

The purpose of this study was to evaluate the installation of WMA to compile experiences with the various technologies and evaluate their effects on construction methods and performance.

Three trial sections were installed using warm mix technologies between August and November of 2006. Two used the Sasobit technology, and the third employed the Evotherm technology.

This report discusses the material makeup of these technologies and documents the production and placement of the three trial sections. The results of this study and further studies can serve as a basis for VDOT decision making regarding the use of WMA technology.

METHODOLOGY

General

Trial sections were initiated through cooperative efforts among the Virginia Transportation Research Council (VTRC); VDOT districts, residencies, and area headquarters; and participating contractors. Sections consisted of a control section of HMA and a trial section of WMA. Construction of the trial section was performed using typical mixture designs and practices (with the exception of temperatures) so as to evaluate performance under typical construction conditions.

During production and construction of the trial sections, VTRC personnel were present at the plant and paving location to document the experience. Loose mixture samples were collected at the plant for all mixtures and characterized in the laboratory. Processes used during construction were observed and documented. Density measurements and cores were taken at each site to determine the initial properties of the pavement. At the Evotherm installation, asphalt fume sampling was conducted by VDOT's Employee Safety & Health Division to evaluate differences in worker exposure between HMA and WMA pavement laydown operations.

Test Methods

Sample Collection

During production, loose samples of HMA and WMA were collected at the hot mix plant for future testing. Samples of the base asphalt binder used for each mix were collected, and, depending on the technology evaluated, samples of either the warm mix additive or warm mix emulsion were collected. In addition, cores were taken from the control and trial sections in the field. Core locations were determined in a random manner from the list of sites used for nuclear density measurements.

Superpave Gyratory Volumetrics

Volumetric analyses were performed to determine fundamental mixture properties. Properties included maximum theoretical specific gravity (G_{mm}), bulk specific gravity (G_{sb}), voids in total mix (VTM), voids filled with asphalt (VFA), and voids in mineral aggregate (VMA).

Sets of WMA gyratory specimens were produced on site at the contractor's plant using the contractor's facilities to eliminate differences in volumetrics or other properties that might be affected because of reheating. Most HMA gyratory specimens were produced post-construction from loose mix collected at the plant during HMA production, as reheating has not been shown to affect the properties of HMA when performed in a consistent manner to minimize overheating or excessive periods of heating.

Asphalt Content and Gradation

Asphalt content was determined using the ignition furnace in accordance with AASHTO T308, Determining the Asphalt Binder Content of Hot-Mix Asphalt by the Ignition Method. Sieve analysis was performed on the aggregate in accordance with AASHTO T30, Mechanical Analysis of Extracted Aggregate.

Moisture Susceptibility

Moisture susceptibility was assessed for each mixture in accordance with AASHTO T283, Resistance of Compacted Asphalt Mixtures to Moisture-Induced Damage.

Rut Testing

Testing was performed on gyratory pills using the Asphalt Pavement Analyzer (APA) to evaluate the rut resistance of each mixture in accordance with Virginia Test Method 110, Method of Test for Determining Rutting Susceptibility Using the Asphalt Pavement Analyzer. Testing was performed at a temperature of 120ºF, a hose pressure of 120 psi, and a vertical load of 120 lb.

Field Density

Density was measured in the field using a nuclear gage in the backscatter mode of measurement and through cores in accordance with AASHTO T-166, Bulk Specific Gravity Using Saturated Surface Dry Tests. Measurement locations were determined using random sampling methods.

Estimated air voids were determined from the uncorrected density results by using the following equation:

$$\text{Estimated air voids, \%} = \left(1 - \frac{\text{Uncorrected nuclear density}}{G_{mm} \cdot 62.4}\right) \cdot 100 \qquad \text{[Eq. 1]}$$

where G_{mm} is the maximum theoretical specific gravity of the mixture measured in the laboratory.

Permeability

Permeability testing was performed on cores taken from each site in accordance with Virginia Test Method 120, Method of Test for Measurement of Permeability of Bituminous Paving Mixtures Using a Flexible Wall Permeameter.

Worker Exposure Testing

Asphalt fume sampling was conducted during the construction of the Evotherm section. Air samples were collected to determine the degree to which paving crew members were exposed to asphalt fumes during paving operations for both the control section (HMA) and the test section (WMA). Samples were collected by VDOT's Employee Safety & Health Division in accordance with the National Institute for Occupational Safety and Health Method 0500/5042 using SKC Aircheck 52 air pumps. Air pumps were calibrated to 2.0 liters per minute with a pre-weighted Teflon filter cassette in-line.

During the 3-hour paving of the test section on October 26, 2006, air sampling pumps were placed within the breathing zone of the asphalt crew. Two sampling units were used. One unit was placed on the employee working at the rear of the paving vehicle, and the other was placed on the operator of the paving vehicle. During a 3-hour paving operation of the control section on October 30, the same air sampling methods were applied.

Asphalt fumes were analyzed for airborne particulates and benzene soluble aerosol. The results of air sample analyses conducted during the paving of the test section were compared with those obtained during the paving of the control section.

Statistical Analyses

Statistical analyses were performed to determine if control data and data from the applied WMA technology were statistically different. The *F*-test was used to identify any significant differences in data variance. The *t*-test was used to evaluate sample means for significant differences. For all tests, a *p*-value of 0.10 was used to determine significant differences.

RESULTS AND DISCUSSION

Trial A: Sasobit

Test Section Description

Trial A was constructed on August 11, 2006, as a 1.5-in overlay on Route 211 in Rappahannock County, Virginia. Superior Paving Corp. produced and paved approximately 300 tons of HMA before beginning WMA production. Approximately 775 tons of WMA was paved; the 0.5-mi Sasobit section evaluated in this study was located within this tonnage in such a manner as to minimize any influences from the beginning and ending of the WMA paving. Once the WMA section was complete, paving continued with conventional HMA and consisted of the placement of approximately 607 tons of material. This conventional HMA served as the control mixture for this evaluation. Testing was conducted on an 0.5-mi segment of the HMA section chosen to minimize transitional effects attributable to the change from paving WMA to paving HMA. Figure 1 indicates the location of the Sasobit and control sections.

Materials

The mixture used in this trial was an SM-9.5A mixture (9.5 mm nominal maximum surface mixture with PG 64-22 binder) containing 20% recycled asphalt pavement (RAP) with a design asphalt content of 5.5%. Morelife 3300 antistrip additive was used at a dosage of 0.5% by weight of the binder. To produce the WMA, Sasobit was added at a rate of 1.5% by weight of binder; no other changes to the mix design were made. Sasobit was supplied by Hi-Tech Asphalt Solutions, Inc., in the form of prills, approximately 3 to 4 mm in diameter, as shown in Figure 2. The prills were packaged in 20-kg bags for ease of handling.

Production and Construction

Weather conditions on the day of construction were good, with slightly overcast skies in the early morning and clearing in the afternoon. At the plant in Stevensburg, Virginia, ambient temperatures were in the upper 60s (ºF) at 6:30 A.M. and increased to a high of approximately 82ºF by mid-afternoon. The paving site was located approximately 30 mi from the plant at the foot of the Blue Ridge Mountains, so ambient temperatures were several degrees cooler. Approximately 0.8 in of rain fell the day prior to paving, so the aggregate stockpiles were damp.

The plant was an Astec parallel flow drum plant with a coater box. Production began with HMA at a temperature of approximately 300°F to ensure stable conditions prior to starting

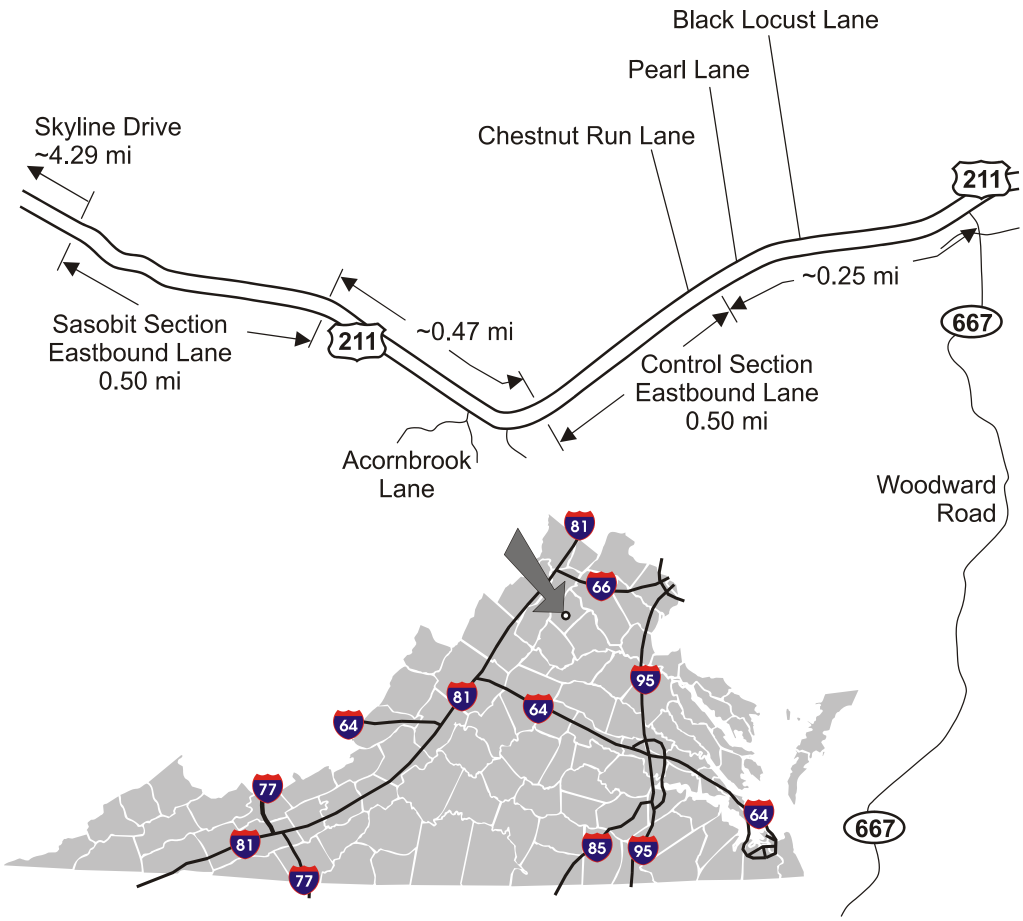

Figure 1. Location of Trial A in Rappahannock County

Figure 2. Sasobit Prills

production of the WMA. After production and placement of approximately 300 tons of HMA, Sasobit was added to the mix and the plant temperature was dropped approximately 50ºF. Sasobit was blown into the mixture using a modified fiber feed machine supplied by Hi-Tech Asphalt Solutions, Inc., through an inlet pipe located near the asphalt binder nozzle in the plant, as shown in Figure 3. Approximately 775 tons of Sasobit WMA was produced for the trial section, and then the plant temperature was raised and production of HMA resumed. Approximately 607 tons of HMA was produced following the WMA production and was considered to be the control mixture for this study.

Lay-down conditions were similar to those at the plant, albeit slightly cooler. Ambient temperatures at placement ranged from 60ºF to 75ºF. Mat temperatures immediately behind the screed ranged from approximately 265ºF to 275°F during placement of the conventional material to 215ºF to 225°F during placement of the WMA. The paving train included a Roadtec SB-2500 materials transfer vehicle and a Roadtec RP-190 paver. The roller pattern consisted of four vibratory passes followed by three static passes. Three rollers were used: an Ingersoll Rand DD90 for breakdown rolling, an Ingersoll Rand DD70 for intermediate rolling, and an Ingersoll Rand D8A for finish rolling. Placement and compaction procedures (i.e., roller weights and patterns) remained constant throughout the installation process, although the WMA was deemed "slightly stiffer" by several on the placement crew, including the contractor's quality control technician and VDOT's inspector. Although lay-down temperatures and a minor difference in mat stiffness were evident, the most noticeable difference between the HMA and WMA placement activities was the complete lack of smoke and visible fumes during WMA placement, seen in Figure 4.

Figure 3. Sasobit Being Blown Into the Plant

Figure 4. Reduction in Visible Emissions When Paving HMA *(left)* and WMA *(right)*

Test Results

Density measurements were taken on segments of the WMA and HMA using a nuclear gage. In addition, sets of six cores were taken to determine the layer thickness and in-situ properties of the mixtures. Figures 5 and 6 illustrate the layout of the control and trial sections, respectively. They also include the locations where nuclear density readings and cores were taken. Table 1 reports the average and standard deviation values for air void levels as measured from the cores and approximated from the uncorrected nuclear gage readings. Statistical analysis of the raw data using the *F*-test identified a higher variance in the Sasobit section, but analysis using the *t*-test with an appropriate variance assumption indicated no overall difference in average compaction level. Thus, the average densities were not statistically different, but there was greater variability in achieved density for the WMA section. Additional analysis using the *t*-test indicated that there were no significant differences between the voids measured for the cores and the voids estimated from the nuclear gage readings.

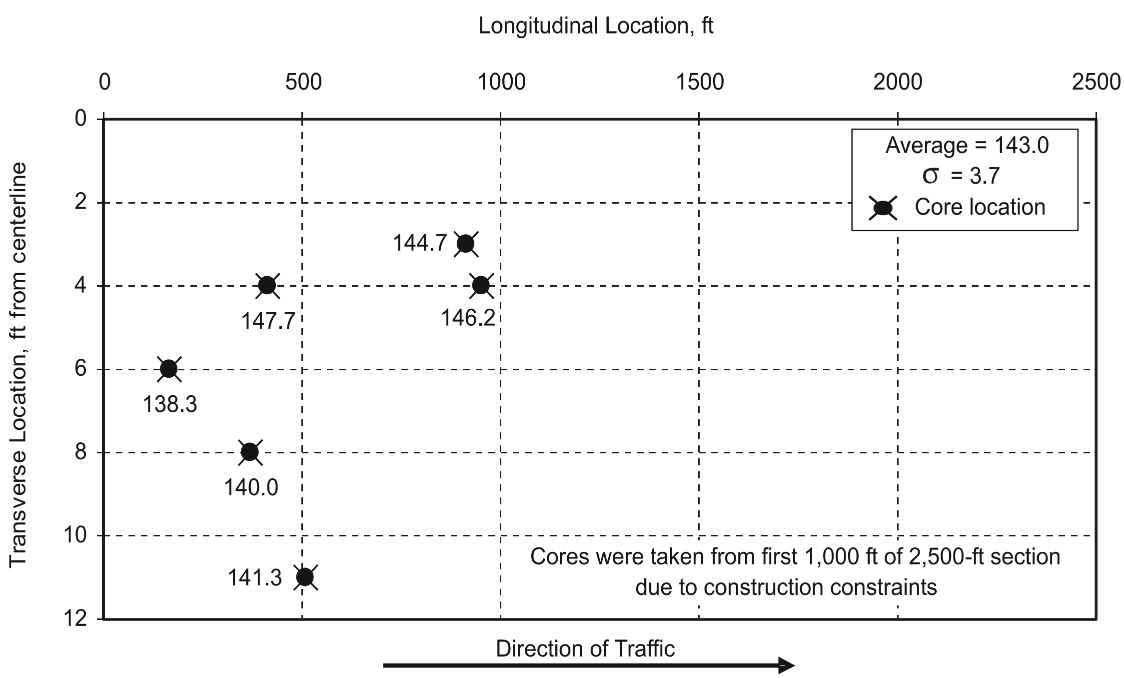

Figure 5. Uncorrected Nuclear Density Results for Control Section in Trial A

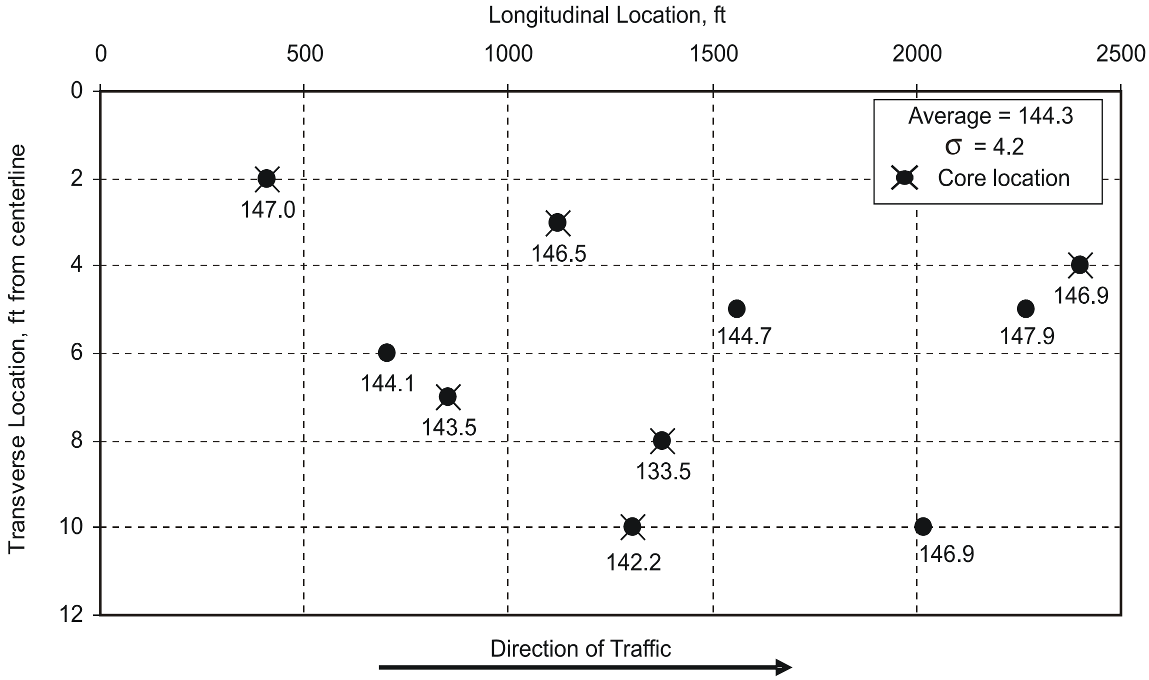

Figure 6. Uncorrected Nuclear Density Results for Sasobit Section in Trial A

Table 1. Field Properties from Trial A

Control Section				
Cores				**Nuclear Estimated Air Voids**
Specimen	**Bulk SG**	**Air Voids**	**Permeability, x 10^{-5} cm/sec**	
C2-2	2.303	7.9	57.0	-
C2-2	2.309	7.7	27.6	
C2-8	2.334	6.7	95.7	
C2-9	2.259	9.7	147.4	
C2-17	2.317	7.3	44.8	
C2-18	2.334	6.7	14.6	
Average	2.309	7.7	-	8.3
Standard Deviation	-	1.11	-	2.38
Sasobit Section				
Cores				**Nuclear Estimated Air Voids**
Specimen	**Bulk SG**	**Air Voids**	**Permeability, x 10^{-5} cm/sec**	
T-3	2.379	4.9	1.5	-
T-6	2.277	9.0	99.5	
T-7	2.393	4.4	0.0	
T-9	2.299	8.1	30.1	
T-10	2.309	7.7	37.1	
T-19	2.342	6.4	18.8	
Average	2.333	6.7	-	7.6
Standard Deviation	-	1.84	-	2.70

Figure 7 plots the results of laboratory permeability testing on field cores against air void level. As expected, the permeability of a specimen is proportional to the void level of the specimen. For Trial A, there does not appear to be a difference in overall permeability between the control and Sasobit sections. The graph indicates that both mixtures comply with the specification limit for permeability at air void contents less than approximately 9.5%.

During and following construction, laboratory specimens were fabricated to evaluate the effects of the warm mix additive on volumetric properties. Two subsets of specimens were made for the control and Sasobit mixtures: plant specimens were compacted on site at the contractor's laboratory immediately after the loose mixture was sampled; laboratory specimens were compacted several days later using loose mixture collected during production. The methodology followed for the laboratory specimens was intended to be indicative of results typical of VDOT quality assurance sampling, wherein the loose mixture is sampled at the contractor's plant, then returned to a district laboratory where it is reheated, compacted, and evaluated for compliance with specifications. The plant specimens were used to investigate the potential for differences in properties that could occur because of reheating.

Table 2 summarizes the volumetric properties from Trial A. This table indicates that some differences are apparent between the plant and laboratory specimens for the control and Sasobit mixes. It appears that the plant specimens compacted to a lower void level compared to the laboratory samples; greater differences between the plant and laboratory specimens were seen with the Sasobit mix.

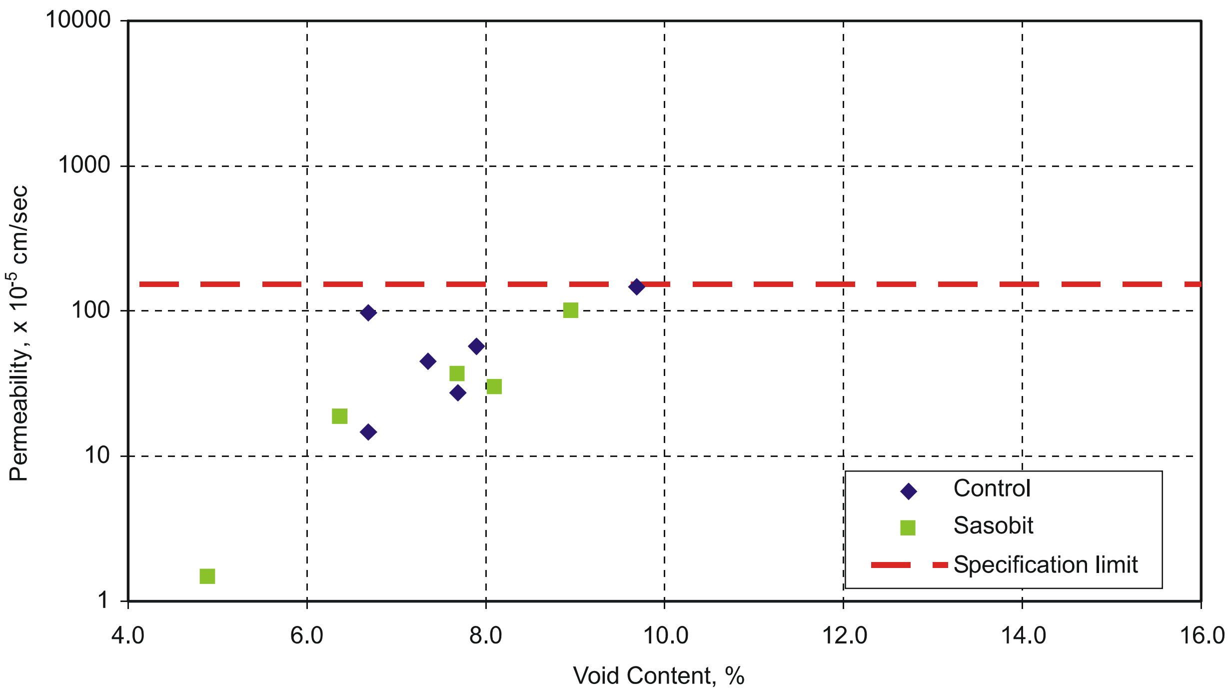

Figure 7. Permeability Results for Trial A

Table 2. Volumetric Properties of SM-9.5A Mixture Containing 20% RAP Used in Trial A

Property	Control Mix		Sasobit Mix	
	Plant[a]	Lab[b]	Plant	Lab
% AC	5.53	5.86	5.85	5.80
Rice SG (G_{mm})	2.504	2.501	2.498	2.502
% Air Voids (V_a)	2.8	3.1	2.7	4.5
% VMA	14.7	15.7	15.3	16.8
% VFA	80.7	80.4	82.2	73.3
Dust/AC Ratio	1.22	1.17	1.03	1.14
Bulk SG (G_{mb})	2.433	2.424	2.430	2.390
Aggregate Effective SG (G_{se})	2.733	2.744	2.741	2.743
Aggregate Bulk SG (G_{sb})	2.694	2.705	2.702	2.704
% Absorbed Binder (P_{ba})	0.55	0.54	0.54	0.54
% Effective Binder (P_{be})	5.01	5.35	5.34	5.29
Effective Film Thickness (F_{be})	7.9	8.3	8.9	8.2
% Density @ N_{ini}	89.5	89.5	89.6	88.1
Sieve	**Percent Passing**			
¾ in (19.0 mm)	100.0	100.0	100.0	100.0
½ in (12.5 mm)	99.6	100.0	100.0	99.8
3/8 in (9.5 mm)	94.3	93.5	94.6	93.5
No. 4 (4.75 mm)	62.0	62.9	61.1	62.0
No. 8 (2.36 mm)	43.9	44.0	42.9	44.0
No. 16 (1.18 mm)	33.9	34.0	32.9	34.1
No. 30 (600 µm)	25.2	25.5	24.8	26.2
No. 50 (300 µm)	16.2	16.5	16.2	17.5
No. 100 (150 µm)	9.9	10.2	9.5	10.3
No. 200 (75 µm)	6.10	6.26	5.50	6.05

[a]*Plant* indicates specimens that were compacted at the plant during production.
[b]*Lab* indicates specimens that were compacted after construction from loose mixture samples.

The tensile strength ratio (TSR) was determined for the control and Sasobit plant specimen sets (Table 3). The Sasobit plant specimens did not achieve the minimum TSR specification value of 0.80, and strength values were considerably lower than for the control mixture; this was thought to be due to residual moisture in the aggregate from rain the day prior to production that did not dry out in the drum at the reduced production temperatures. To investigate this further, a set of laboratory specimens was produced to measure the TSR of the Sasobit mixture after reheating and compaction. As expected, the TSR improved, although it still did not achieve the minimum specification requirement. *T*-tests were performed to compare the dry and conditioned strength values of the control and Sasobit plant specimens; these indicated that the strengths of the Sasobit plant specimen were significantly lower than the control strengths. However, when the strengths were compared to the control strengths, they were found to be significantly greater. The difference illustrates the influence that reheating may have on mixture tensile strength.

Table 3. Tensile Strength Ratios of Mixtures Produced During Trial A

Control Plant Specimens		Sasobit Plant Specimens[a]		Sasobit Lab Specimens[b]	
Dry Strength, psi	**Conditioned Strength, psi**	**Dry Strength, psi**	**Conditioned Strength, psi**	**Dry Strength, psi**	**Conditioned Strength, psi**
153	124	135	92	235	180
150	122	132	92	250	182
156	129	128	89	239	193
147	119	136	95	241	172
Avg. = 151	Avg. = 124	Avg. = 133	Avg. = 92	Avg. = 241	Avg. = 182
TSR = 0.82		TSR = 0.69		TSR = 0.75	

[a]Sample set was compacted on-site during production.
[b]Sample set was compacted post-construction from loose mixture.

Rut testing was performed on laboratory specimen sets to evaluate any differences in rutting resistance between the control and Sasobit mixtures (Table 4). Hand average values were calculated from measurements of rutting taken prior to testing and after the completion of 8,000 cycles of loading; automatic average values were automatically detected and collected by the APA. Previous research (Maupin and Mokarem, 2006) indicated that hand and automatic measurements are highly correlated, thus either is acceptable. Both specimen sets were found acceptable in rutting resistance, as the specification limit is 7.0 mm for the SM-9.5A mixture used in the trial. The Sasobit mixture was shown to have an average of more than 0.5 mm less rutting than the control mixture; however, this was not found statistically significant using the *t*-test. This is likely due to the stiffening influence of Sasobit at temperatures below the additive's melting point, which has been promoted as a benefit to the technology as discussed in the Introduction.

Table 4. APA Rut Results for Trial A

Sample Pair	Control Lab Specimens			Sasobit Lab Specimens		
	Hand Average, mm	**Automated Average, mm**	**Average Voids**	**Hand Average, mm**	**Automated Average, mm**	**Average Voids**
A	5.49	4.42	7.1	3.99	3.39	7.0
B	5.66	4.80	6.8	4.69	4.33	7.0
C	4.56	3.95	7.0	4.29	3.71	7.1
Average	5.23	4.39	6.97	4.32	3.81	7.03
Standard Deviation	0.59	0.43	0.15	0.35	0.48	0.06

Trial B: Sasobit

Test Section Description

Trial B was constructed as a 1.5-in overlay on Route 220 in Highland County, Virginia, on August 14 and 15, 2006, by B&S Construction Inc. Control section paving was performed on August 14 using approximately 634 tons of HMA, and the WMA was placed on August 15 using approximately 320 tons of WMA. Testing was performed on 1,000-ft segments of the control and Sasobit sections, as shown in Figure 8. This project considered the application of WMA to long-haul conditions, as the plant was located approximately 45 mi from the paving site.

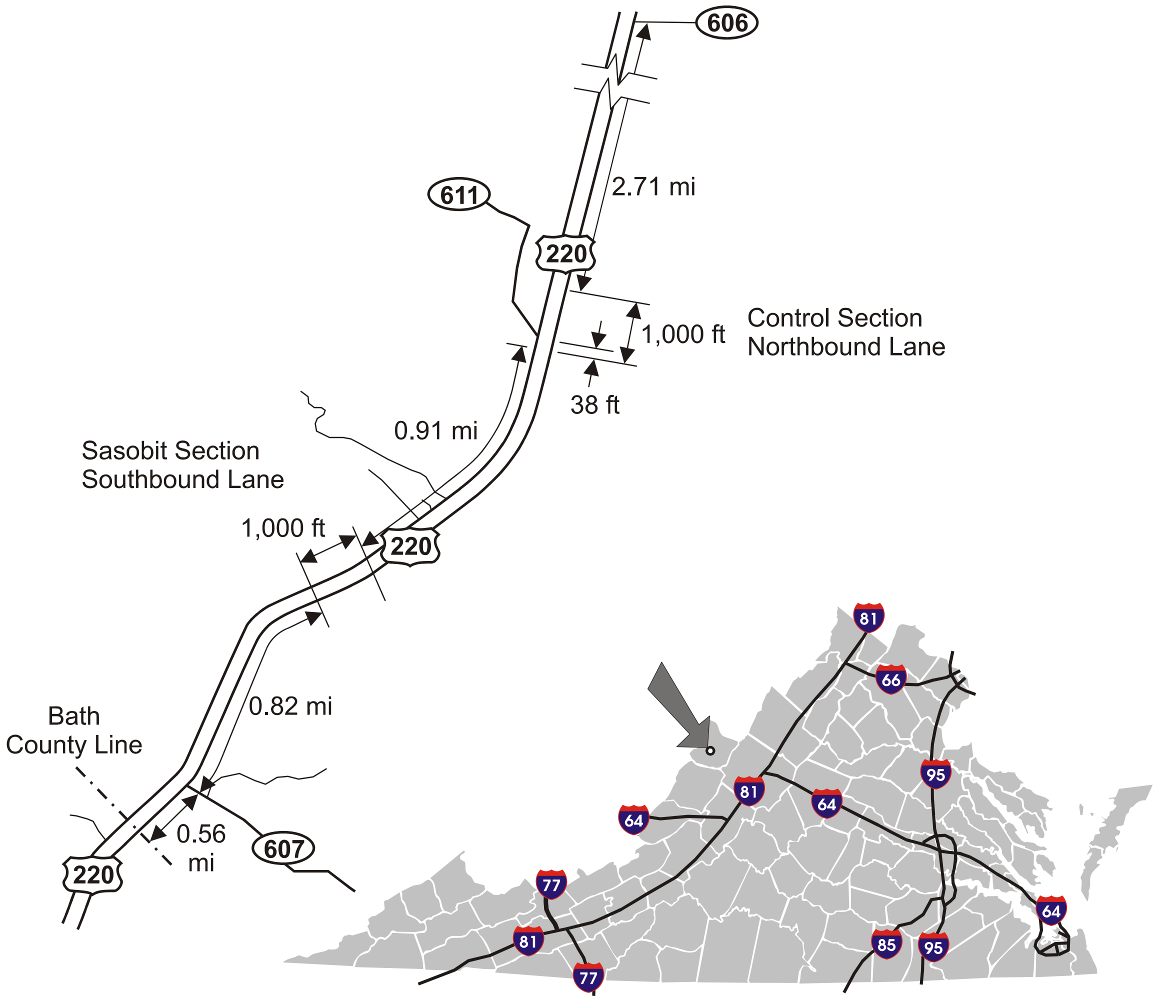

Figure 8. Location of Trial B in Highland County

Because of the mountainous terrain between the plant location in Staunton, Virginia, and the project location in Highland County, this translated to a haul of approximately 1 hr and 45 min across several mountains.

Materials

The mixture used in this trial was an SM-12.5A mixture (12.5 mm nominal maximum surface mixture with PG 64-22 binder) containing 10% RAP with a design asphalt content of 5.3%. Hydrated lime was used in the mixture to prevent stripping. Sasobit was added at a rate of 1.5% by weight of binder and was again provided by Hi-Tech Asphalt Solutions in the form of prills. No other changes were made to the mix design during the production of WMA.

Production and Construction

Weather conditions on August 14 during paving of the control section were excellent at both the plant and paving locations. The daily high/low ambient temperatures in Staunton and Monterey (the closest available weather station to the paving location) were 91°/60°F and

86º/68ºF, respectively, with sunny skies. On August 15, conditions were variable between the plant and paving location. At the plant, skies were overcast and temperatures ranged from a low of 68ºF to a high of 86ºF. In Monterey, temperatures ranged from a low of 68ºF to a high of 72ºF with overcast skies and occasional light drizzle. Drizzle and light rain fell most of the day across the mountains between Staunton and Monterey.

The plant was a Barber-Greene batch plant. During production of the control mixture, HMA was produced and stored in a silo; however, WMA was produced by the batch to minimize impacts to the production of other mixtures. Sasobit was blown into the mixing chamber using a modified fiber feed machine provided by Hi-Tech Asphalt Solutions. The distance from the plant to the paving site was approximately 45 mi; however, because of the mountainous terrain between the plant and paving site, the haul time was approximately 1 hr 45 min. Because of this hauling time, HMA was produced at temperatures of approximately 325ºF to 330ºF and WMA was produced at approximately 300ºF.

HMA material arrived at the paving site at an approximate temperature of 300ºF, with temperatures behind the screed ranging from 280ºF to 300ºF. WMA material arrived at the paving site at temperatures of 270ºF to 280ºF; temperatures behind the screed were approximately 250ºF to 275ºF. An Ingersoll Rand Blaw-Knox PF3200 paver was used; no material transfer vehicle was used. The contractor used two rollers: a Caterpillar CB-634 vibratory roller and Ingersoll Rand DD24 finish roller. The roller pattern consisted of four vibratory passes and finish rolling.

Test Results

Density measurements were taken on segments of the WMA and HMA using a nuclear gage. In addition, sets of six cores were taken to determine the layer thickness and in-situ properties of the mixtures. Figures 9 and 10 illustrate the testing layout of the control and Sasobit sections for Trial B. Uncorrected density averages for both sections were statistically equivalent, as measured by the *t*-test, although the values for the Sasobit section had a slightly greater standard deviation, indicating higher variability.

Table 5 summarizes the properties of the field cores and air voids estimated from the uncorrected nuclear density results. The difference in estimated void content between the two sections was found to be statistically significant using the *t*-test and assuming unequal variance; however, there was no significant difference between the core voids. The control section variability was significantly less than the Sasobit section variability for uncorrected density, estimated voids, and core voids, as evaluated by the *f*-test. A plot of the laboratory permeability results from the field cores versus void level is shown in Figure 11. Again, as with Trial A, there did not appear to be a large difference in permeability among specimens having similar void contents; however, the Sasobit cores showed a wider range of void contents, and thus permeability, than the control section cores. From the graph it can be seen that both mixtures failed the permeability specification at air void contents above approximately 8.0%.

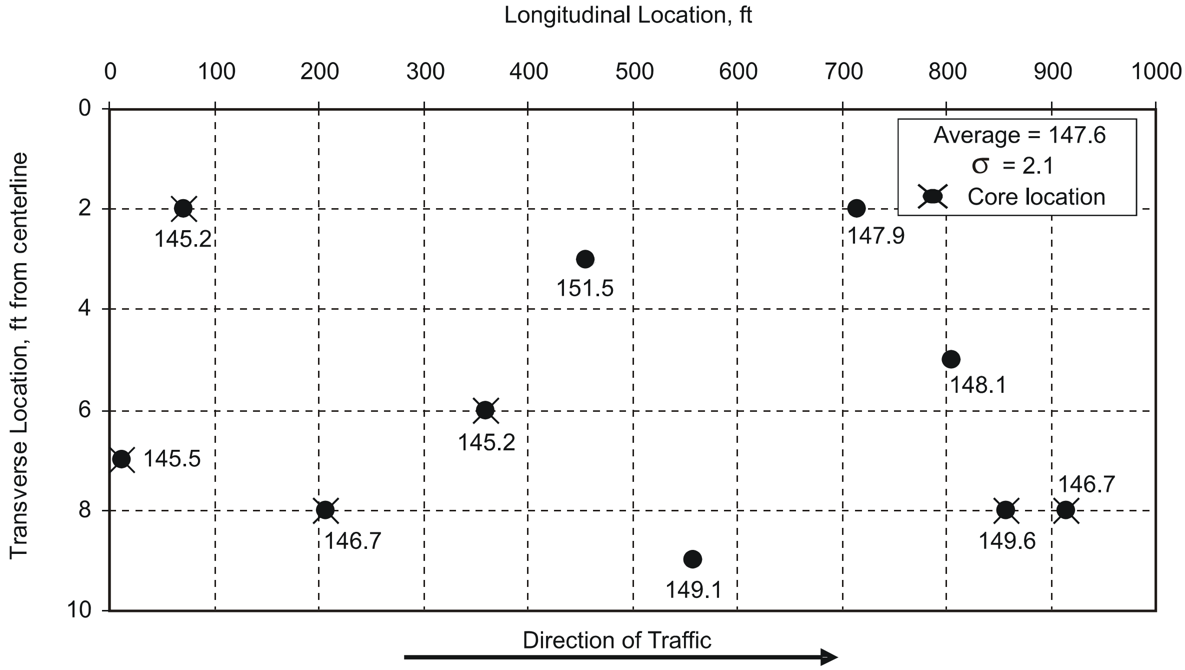

Figure 9. Uncorrected Nuclear Density Results for Control Section in Trial B

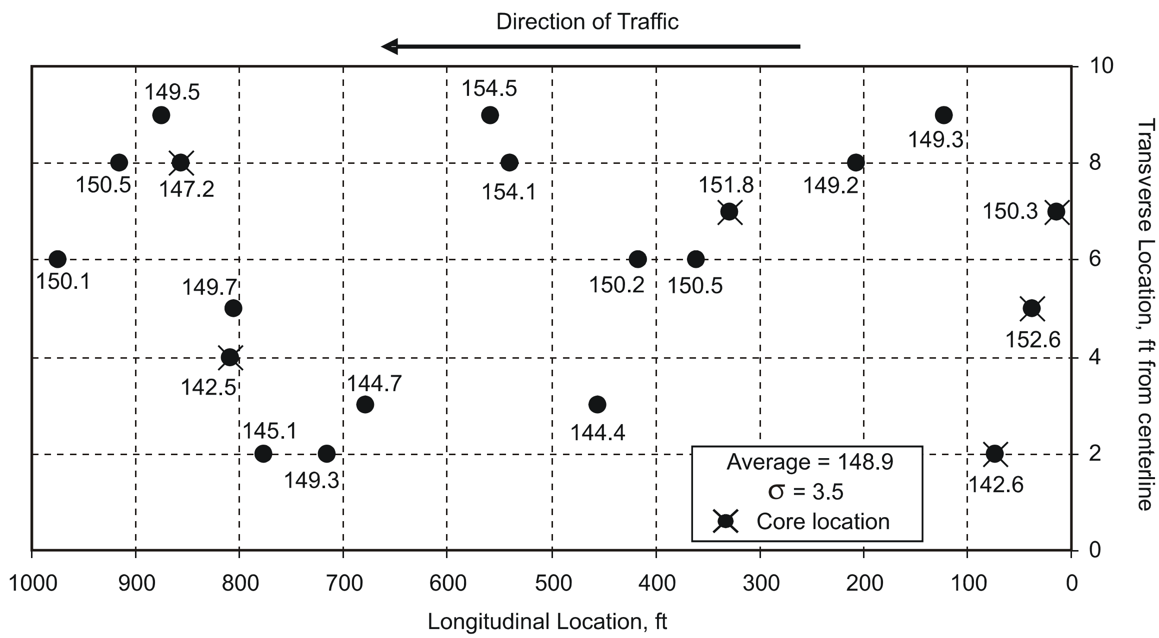

Figure 10. Uncorrected Nuclear Density Results for Sasobit Section in Trial B

Table 5. Field Properties from Trial B

Control Cores				Nuclear Estimated Air Voids
Specimen	**Bulk SG**	**Air Voids**	**Permeability, x 10-5 cm/sec**	
C-3	2.343	10.0	490.6	-
C-5	2.368	9.1	365.5	
C-7	2.311	11.3	1190.7	
C-9	2.406	7.6	113.2	
C-17	2.374	8.8	270.6	
C-19	2.379	8.6	989.6	
Average	2.363	9.2	-	9.2
Standard Deviation	-	1.26	-	1.29
Sasobit Cores				**Nuclear Estimated Air Voids**
Specimen	**Bulk SG**	**Air Voids**	**Permeability, x 10-5 cm/sec**	
S1-1	2.393	7.9	176.3	-
S1-2	2.440	6.0	71.8	
S1-3	2.279	12.2	3074.1	
S1-6	2.445	5.9	9.0	
S1-16	2.337	10.0	1714.1	
S1-17	2.420	6.8	77.1	
Average	2.386	8.1	-	8.1
Standard Deviation	-	2.51	-	2.14

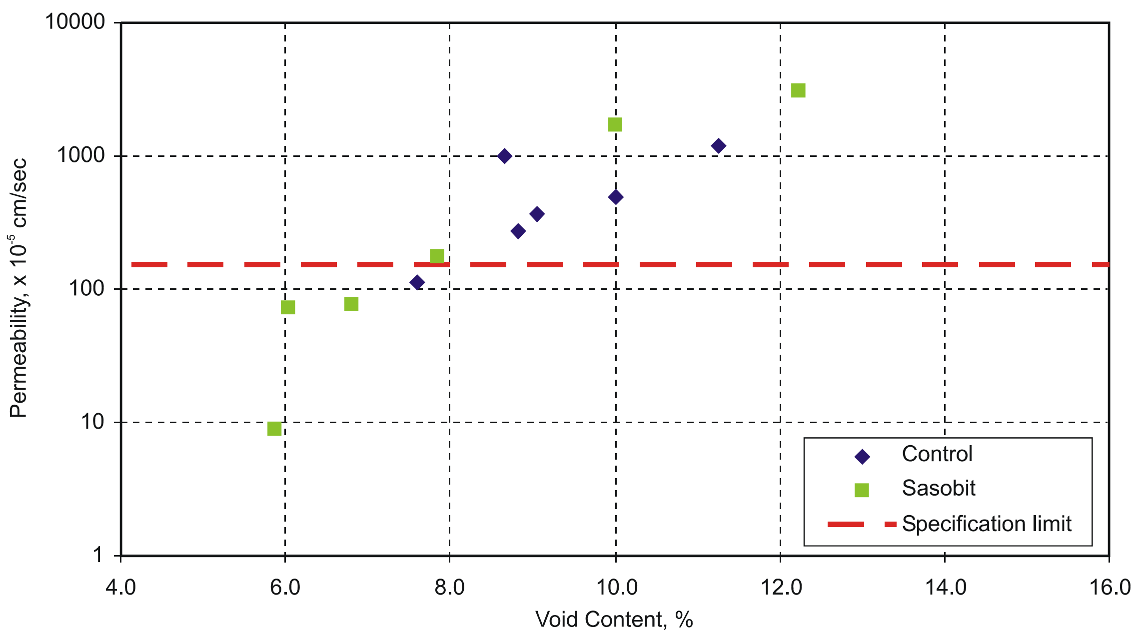

Figure 11. Permeability Results for Trial B

Table 6 summarizes the volumetric properties from Trial B. No plant specimen sets were produced for the control mixture. This table indicates that the control mix had a lower binder content than did the Sasobit mix. Aside from this, all other properties were similar.

Table 6. Volumetric Properties of SM-12.5A Mixture Containing 10% RAP Used in Trial A

Property	Control		Sasobit	
	Plant	Lab	Plant	Lab
% AC	No samples produced at plant	5.39	5.60	5.81
Rice SG (G_{mm})		2.604	2.571	2.597
% Air Voids (V_a)		3.3	2.3	2.9
% VMA		15.8	15.3	16.5
% VFA		79.1	85.2	82.5
Dust/AC Ratio		1.27	1.11	1.14
Bulk SG (G_{mb})		2.518	2.513	2.522
Aggregate Effective SG (G_{se})		2.852	2.821	2.865
Aggregate Bulk SG (G_{sb})		2.830	2.799	2.843
% Absorbed Binder (P_{ba})		0.28	0.29	0.28
% Effective Binder (P_{be})		5.12	5.33	5.55
Effective Film Thickness (F_{be})		9.1	10.8	10.0
% Density @ N_{ini}		86.7	87.8	87.0
Sieve	**Percent Passing**			
$^3/_4$ in (19.0 mm)	No samples produced at plant	100	100	100
$^1/_2$ in (12.5 mm)		100	100	100
$^3/_8$ in (9.5mm)		95.8	97.3	97.0
No. 4 (4.75 mm)		84.1	84.1	85.2
No. 8 (2.36 mm)		48.3	49.9	51.0
No. 16 (1.18 mm)		32.7	33.0	33.4
No. 30 (600 µm)		24.7	-	25.1
No. 50 (300 µm)		19.7	19.4	19.7
No. 100 (150 µm)		13.4	12.7	13.2
No. 200 (75 µm)		8.6	7.8	8.4
No.200 (75µm)		6.5	5.9	6.3

The TSR was determined for the control laboratory specimen set and Sasobit plant specimen set, as shown in Table 7. Both specimen sets achieved the TSR requirement of 0.80. Although the TSR value is higher for the Sasobit specimen set, the dry and conditioned strength values of the control section were higher, although not significantly different using the *t*-test.

Table 7. Tensile Strength Ratios of Mixtures Produced During Trial B

Control Lab Specimens		Sasobit Plant Specimens	
Dry Strength, psi	**Conditioned Strength, psi**	**Dry Strength, psi**	**Conditioned Strength, psi**
227	205	192	151
238	201	174	152
243	131	173	161
168	209	153	160
Avg. = 219	Avg. = 186	Avg. = 173	Avg. = 156
TSR = 0.85		TSR = 0.90	

Rut testing was performed on laboratory specimen sets to evaluate any differences in rutting resistance between the control and Sasobit mixtures. The results are presented in Table 8, where it can be seen that both specimen sets had similar results; the *t*-test confirmed that the rutting resistance values were not significantly different. Both specimen sets were found acceptable with regard to rutting resistance, as the specification limit is 7.0 mm for the SM-12.5A mixture used in the trial.

Table 8. APA Rut Results for Trial B

Sample Pair	Control Lab Specimens			Sasobit Lab Specimens		
	Hand Average	Automated Average	Average Voids	Hand Average	Automated Average	Average Voids
A	3.28	2.86	8.5	2.33	2.51	8.5
B	3.24	2.65	8.6	3.39	2.99	8.8
C	3.20	2.71	8.5	2.76	2.65	8.3
Average	3.24	2.74	8.53	2.83	2.72	8.53
Standard Deviation	0.04	0.11	0.06	0.53	0.25	0.25

Trial C: Evotherm

Test Section Description

Test C was constructed as a 1.5-in overlay on Route 143 in York County, Virginia, by Branscome, Inc., on October 26 and November 2, 2006. Approximately 530 tons of WMA was placed on October 26 in the southbound travel lane, and approximately 1,000 tons of HMA was placed on November 2 in the northbound travel lane. Testing was performed on 1,000-ft segments of this material; the segment locations are described in Figure 12.

Materials

The mixture used in this trial was an SM-9.5D mixture (9.5 mm nominal maximum surface mixture using PG 70-22 binder) containing 20% RAP and a design asphalt content of 5.7%. The control HMA contained Adhere HP Plus antistrip additive at a dosage rate of 0.3% by weight of the binder. Evotherm emulsion with a residual binder content of approximately 70% was used as the binder for the WMA. The Evotherm emulsion contained antistrip additives. The emulsion was engineered by MeadWestvaco Asphalt Innovations and produced on October 26 at the Asphalt Emulsions, Inc., emulsion plant in Richmond, Virginia, and delivered to the plant in two tankers on the morning of production. The base binder for the emulsion was a PG 70-22 supplied to Asphalt Emulsions, Inc., by Citgo Asphalt.

Production and Construction

Weather conditions for the WMA paving on October 26 were cool and breezy, with clear skies. Ambient temperatures started in the upper 30s (ºF), increasing to a high of approximately 60ºF. On November 2, the day of the control section paving, ambient temperatures began in the low 40s (ºF) and reached an afternoon high of approximately 64ºF; skies were overcast, and a moderate breeze was blowing.

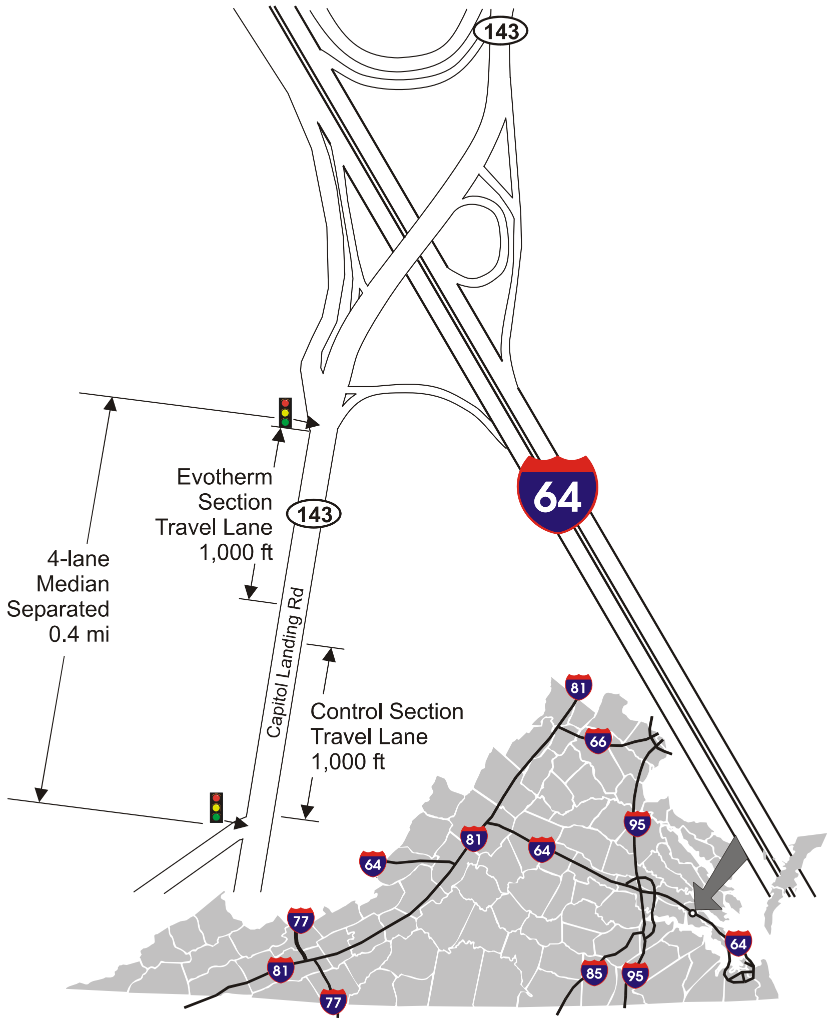

Figure 12. Location of Trial C in York County

The plant was a Gencor counterflow drum plant. On the day of WMA paving, production at the plant initially began with a conventional HMA for another paving operation. After a silo was filled with the conventional mix, WMA production began as the production temperature was reduced to approximately 220ºF to 230ºF. Approximately 530 tons of WMA was produced and stored in a silo, to be loaded out as necessary. The control HMA was produced several days later on November 2 at temperatures of approximately 300ºF to 310ºF.

The paving site was located approximately 10 mi from the plant. The paver used on the project was an Ingersoll Rand Blaw-Knox PF3200; no materials transfer vehicle was used. An Ingersoll Rand DD110 vibratory roller was used for breakdown rolling, and a Caterpillar CB434C roller was used for intermediate and finish rolling. The roller pattern consisted of four vibratory passes with the DD110 roller and three vibratory passes followed by static finish rolling using the CB434C roller. Two control sections were constructed to determine the roller pattern for the WMA section. Neither complied with the VDOT specification for density.

Test Results

Density measurements were taken on segments of the WMA and HMA using a nuclear gage. In addition, sets of six cores were taken to determine the layer thickness and in-situ properties of the mixtures. Figures 13 and 14 illustrate the layout of the control and trial sections for Trial C. Density averages for both sections were nearly equivalent, although the values for the Sasobit section had a slightly greater standard deviation, indicating higher variability.

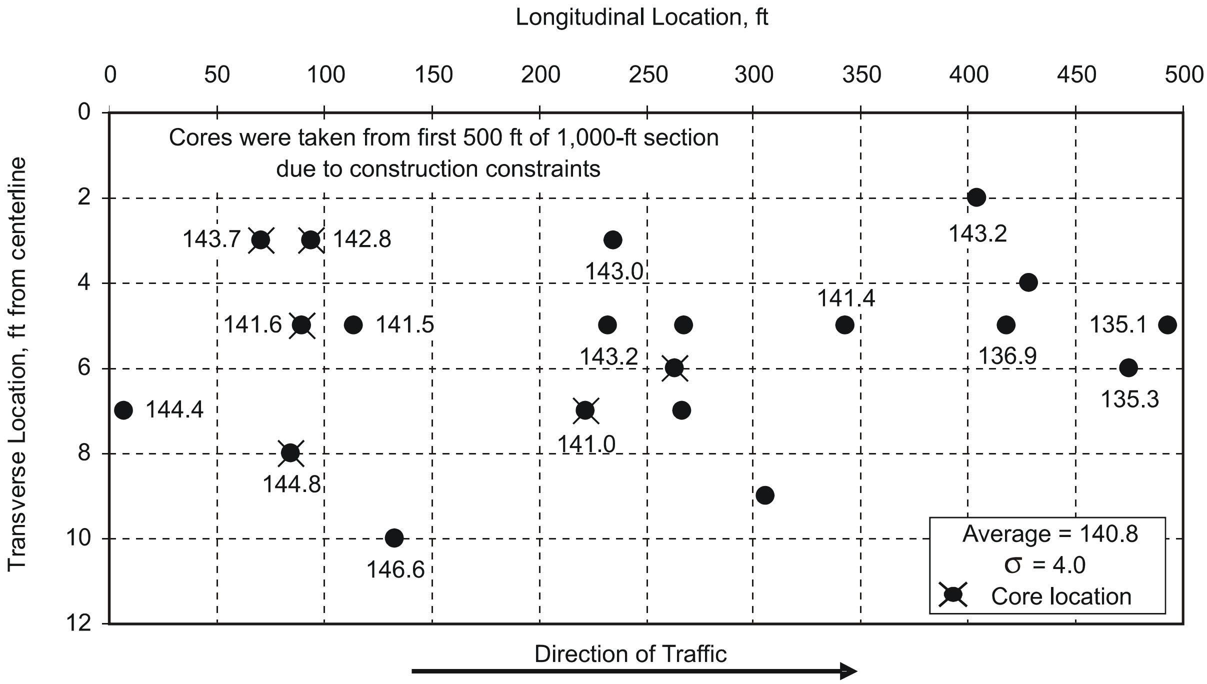

Figure 13. Uncorrected Nuclear Density Results for Control Section in Trial C

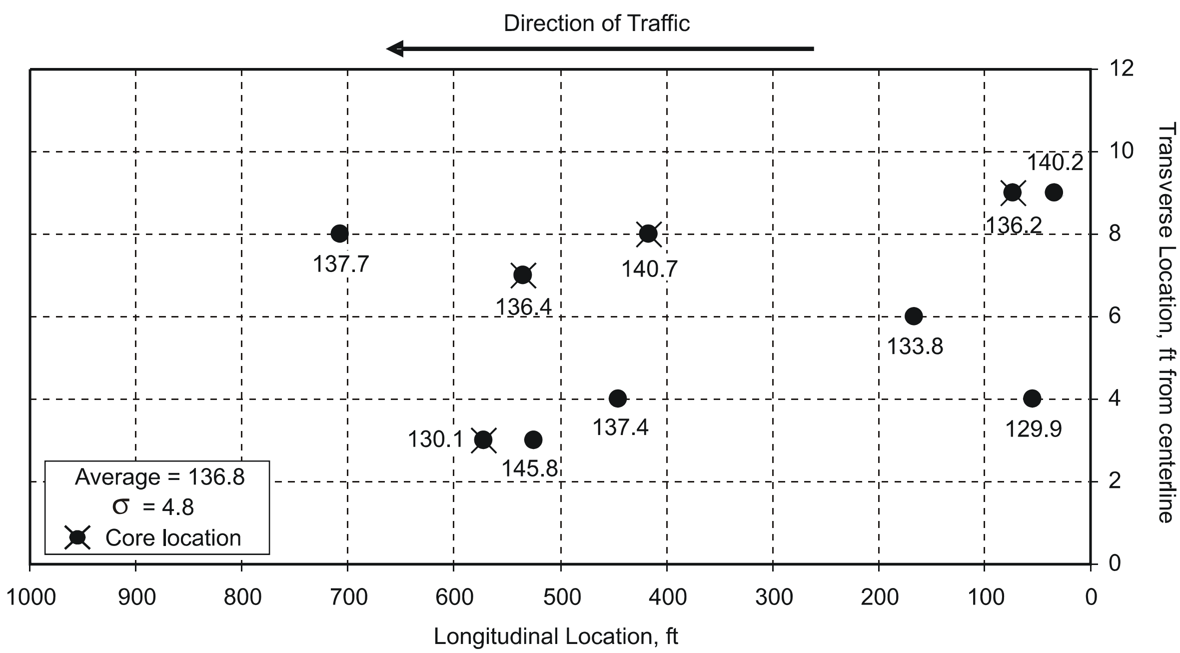

Figure 14. Uncorrected Nuclear Density Results for Evotherm Section in Trial C

Table 9 summarizes the properties of each set of cores and the voids estimated from the uncorrected nuclear density values. The *f*- and *t*-test analyses used in Trials A and B identified slightly higher variances in the Evotherm section as compared with the control. Although there continued to be no statistically significant difference in average void level as measured from the cores, the uncorrected nuclear density data did suggest a significant statistical difference in overall achieved compaction.

Figure 15 shows laboratory permeability results plotted versus air voids for the Evotherm cores. Permeability was not measured for the control section cores because the core diameters were incompatible with the permeameter. From the graph it can be seen that the Evotherm mixture did not comply with the permeability specification at air void contents above approximately 10%.

Table 10 summarizes the volumetric properties from Trial C. This table indicates that the primary differences between the control and Evotherm mixes were asphalt content and air void content. All other properties were similar.

Table 9. Field Properties from Trial C

Control Cores				**Nuclear Estimated Air Voids**
Specimen	**Bulk SG**	**Air Voids**	**Permeability, x 10^{-5} cm/sec**	
2	2.326	6.4	Data not available	-
3	2.354	5.3		
4	2.268	8.7		
5	2.314	6.9		
8	2.262	9.0		
11	2.254	9.3		
Average	2.296	7.6	-	8.5
Standard Deviation	-	1.63	-	2.60
Evotherm Cores				**Nuclear Estimated Air Voids**
Specimen	**Bulk SG**	**Air Voids**	**Permeability, x 10^{-5} cm/sec**	
T-5	2.084	15.4	781.9	-
T-9	2.345	4.8	0.0	
T-13	2.210	10.3	151.4	
T-15	2.252	8.6	85.6	
T-18	2.234	9.3	72.1	
C-20	2.266	8.0	27.6	
Average	2.232	9.4	-	11.1
Standard Deviation	-	3.48	-	3.45

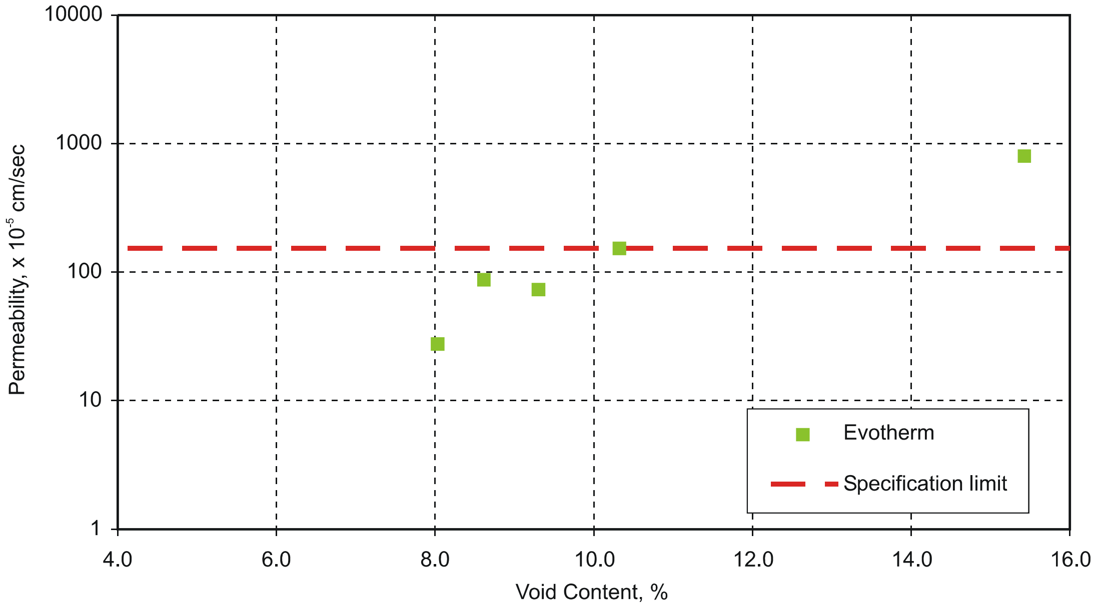

Figure 15. Permeability Results for Trial C

Table 10. Volumetric Properties of SM-9.5D Mixture Containing 20% RAP Used in Trial C

<table>
<tr><th rowspan="2">Property</th><th colspan="2">Control</th><th colspan="2">Evotherm</th></tr>
<tr><th>Plant</th><th>Lab</th><th>Plant</th><th>Lab</th></tr>
<tr><td>% AC</td><td rowspan="13">No samples produced at plant</td><td>5.83</td><td>6.06</td><td rowspan="13">Lab work incomplete.</td></tr>
<tr><td>Rice SG (G_{mm})</td><td>2.487</td><td>2.464</td></tr>
<tr><td>% Air Voids (V_a)</td><td>3.1</td><td>1.7</td></tr>
<tr><td>% VMA</td><td>16.4</td><td>15.5</td></tr>
<tr><td>% VFA</td><td>80.9</td><td>89.3</td></tr>
<tr><td>Dust/AC Ratio</td><td>0.94</td><td>0.90</td></tr>
<tr><td>Bulk SG (G_{mb})</td><td>2.409</td><td>2.423</td></tr>
<tr><td>Aggregate Effective SG (G_{se})</td><td>2.726</td><td>2.707</td></tr>
<tr><td>Aggregate Bulk SG (G_{sb})</td><td>2.713</td><td>2.694</td></tr>
<tr><td>% Absorbed Binder (P_{ba})</td><td>0.18</td><td>0.18</td></tr>
<tr><td>% Effective Binder (P_{be})</td><td>5.65</td><td>5.89</td></tr>
<tr><td>Effective Film Thickness (F_{be})</td><td>9.7</td><td>10.2</td></tr>
<tr><td>% Density @ N_{ini}</td><td>90.8</td><td>-</td></tr>
<tr><th>Sieve</th><th colspan="4">% Passing</th></tr>
<tr><td>¾ in (19.0mm)</td><td rowspan="10">No samples produced at plant.</td><td>100</td><td>100</td><td rowspan="10">Lab work incomplete.</td></tr>
<tr><td>½ in (12.5mm)</td><td>99.2</td><td>98.6</td></tr>
<tr><td>$^3/_8$ in (9.5mm)</td><td>90.9</td><td>88.2</td></tr>
<tr><td>No. 4 (4.75 mm)</td><td>60.2</td><td>60.0</td></tr>
<tr><td>No. 8 (2.36 mm)</td><td>46.5</td><td>47.0</td></tr>
<tr><td>No. 16 (1.18 mm)</td><td>37.1</td><td>38.0</td></tr>
<tr><td>No. 30 (600 µm)</td><td>27.5</td><td>27.7</td></tr>
<tr><td>No. 50 (300 µm)</td><td>15.6</td><td>14.8</td></tr>
<tr><td>No. 100 (150 µm)</td><td>7.8</td><td>7.5</td></tr>
<tr><td>No. 200 (75 µm)</td><td>5.3</td><td>5.3</td></tr>
</table>

The TSR was determined for the control and Evotherm plant specimen set, as shown in Table 11. In addition, a second set of plant specimens was prepared and stored at ambient laboratory temperatures for a period of 1 week prior to being conditioned and tested; this was to determine if the Evotherm mixture would continue to gain strength over time. In general, the control specimens decreased in strength after storage whereas the Evotherm specimens gained strength, although neither the dry nor conditioned strength after storage of the control or Evotherm specimens changed significantly as measured by the *t*-test. The dry and conditioned control specimen strengths and Evotherm specimen strengths were significantly different. Neither set of Evotherm specimens achieved the TSR requirement of 0.80.

Rut testing was performed on laboratory specimen sets to evaluate any differences in rutting resistance between the control and Evotherm mixtures. Results are presented in Table 12, where it can be seen that the Evotherm specimens had greater measured rutting than did the control specimens. Significant differences were found between the rutting values for the control and Evotherm specimens using the *t*-test. The control specimens were found acceptable in rutting resistance, as the specification limit is 5.5 mm for the SM-9.5D mixture used in the trial; however, the Evotherm specimens did not comply with the requirement.

Worker Exposure Testing

More visible asphalt fumes were seen during the HMA pavement operation than during the WMA operation. However, the air sample analysis report indicated that crew members tested during both WMA and HMA paving operations were exposed to non-detectable levels or levels below recommended exposure levels of airborne asphalt fumes (Tables 13 and 14).

Test Section (WMA)

The samplings results indicate that exposure levels were non-detectable or well below the maximum recommended exposure level of 5 mg/m^3 of the National Institute for Occupational Safety and Health for total dust/particulates and the threshold limit value of 0.5 mg/m^3 of benzene soluble aerosol recommended by the American Conference of Governmental Industrial Hygienists (Table 13).

Control Section (HMA)

The samplings results indicate that exposure levels were non-detectible or well below the maximum recommended exposure level of 5 mg/m^3 of the National Institute for Occupational Safety and Health for total dust/particulates and the threshold limit value of 0.5 mg/m^3 of benzene soluble aerosol recommended by the American Conference of Governmental Industrial Hygienists (Table 14).

Table 11. Tensile Strength Ratios (TSR) of Mixtures Produced During Trial C

Control Plant Specimens		Control Plant Specimens After 1 week Storage		Evotherm Plant Specimens		Evotherm Plant Specimens After 1 Week Storage	
Dry Strength, psi	**Conditioned Strength, psi**	**Dry Strength, psi**	**Conditioned Strength, psi**	**Dry Strength, psi**	**Conditioned Strength, psi**	**Dry Strength, psi**	**Conditioned Strength, psi**
199	168	190	156	121	88	130	92
191	150	195	145	124	96	121	101
198	166	162	159	128	88	130	95
200	163	187	163	119	81	127	99
Avg. = 197	Avg. = 162	Avg. = 184	Avg. = 156	Avg. = 123	Avg. = 88	Avg. = 127	Avg. = 97
TSR = 0.82		TSR = 0.85		TSR = 0.72		TSR = 0.76	

Table 12. Asphalt Pavement Analyzer Rut Results for Trial C

Sample Pair	Control Lab Specimens			Evotherm Lab Specimens		
	Hand Average	Automated Average	Average Voids	Hand Average	Automated Average	Average Voids
A	5.61	4.71	8.7	10.69	7.62	7.6
B	5.76	4.90	8.5	10.49	8.40	7.6
C	5.11	4.21	8.5	10.83	7.07	7.6
Average	5.49	4.61	8.57	10.67	7.69	7.60
Standard Deviation	0.34	0.36	0.12	0.17	0.67	0.00

Table 13. Results of Warm Mix Asphalt Fume Analyses for Airborne Particulates and Benzene Soluble Aerosols[a]

Employee	Job Task	Analyte	Laboratory Result	ACGIH (TLV)	NIOSH (REL)
Crew Member 1	Standing and walking in rear of paving vehicle	Total dust (particulate) Benzene soluble	0.35 mg/m^3 <83.4 μg/m^3	______ 0.5 mg/m^3	5 mg/m^3 ______
Crew Member 2	Operating paving vehicle	Total dust (particulate) Benzene soluble	<0.28 mg/m^3 <83.4 μg/m^3	________ 0.5 mg/m^3	5 mg/m^3 _____

[a]ACGIH = American Conference of Governmental Industrial Hygienists; TLV = threshold limit value; NIOSH = National Institute for Occupational Safety and Health; REL = recommended exposure level.

Table 14. Results of Hot Mix Asphalt Fume Analyses for Airborne Particulates and Benzene Soluble Aerosols[a]

Employee	Job Task	Analyte	Laboratory Result	ACGIH (TLV)	NIOSH (REL)
Crew Member 1	Standing and walking in rear of paving vehicle	Total dust (particulate) Benzene soluble	<0.28 mg/m^3 <83.4 μg/m3	________ 0.5 mg/m^3	5 mg/m^3 ______
Crew Member 2	Operating paving vehicle	Total dust (particulate) Benzene soluble	<0.28 mg/m^3 <83.4 μg/m^3	________ 0.5 mg/m^3	5 mg/m^3 ______

[a]ACGIH = American Conference of Governmental Industrial Hygienists; TLV = threshold limit value; NIOSH = National Institute for Occupational Safety and Health; REL = recommended exposure level.

SUMMARY OF FINDINGS

- The use of the Sasobit additive did not cause substantial changes in volumetric properties.

- Average air void contents of the Sasobit WMA cores were slightly less than those of the control cores, although the difference was not statistically significant. The variability in the voids was slightly greater for the Sasobit cores. Estimated void contents from the uncorrected nuclear density measurements generally supported this finding, although differences were significant for one of the two trial sections.

- Permeability was similar for the control and Sasobit sections in both trials.

- The TSR test provided inconsistent results for Sasobit mixtures when compared to the control mixture. Plant-produced Sasobit specimens had lower indirect tensile strengths, although the TSR was less than for the control in Trial A and greater than for the control in Trial B. Reheating the Sasobit mixture from Trial 1 to produce TSR specimens significantly increased the indirect tensile strength of the mixture, although TSR values still failed the specification requirement.

- The rutting resistance of the Sasobit WMA mixtures and the HMA control mixtures was not statistically different when the APA was used.

- The asphalt content of the control mixture was lower than that of the Evotherm mixture; no other differences in volumetric properties were seen.

- Air void contents of Evotherm cores were slightly higher than those of the control cores, although the difference was not statistically significant. The air void contents of the Evotherm cores did have greater variability. Estimated voids from the uncorrected nuclear density measurements also indicated slightly higher void contents and variability for the Evotherm section as compared to the control section; in addition, the difference in compaction was statistically significant as measured by the uncorrected density.

- TSR values for the Evotherm specimens were lower than those for the control mixture. Storage of both specimen sets at ambient temperature resulted in a slight increase in the dry and conditioned strengths of the Evotherm mixture and a slight reduction in the dry and conditioned strengths of the control mixture; however, these changes were not significant. Storage resulted in a small increase in the TSR values for both specimen sets, although the TSR of the Evotherm specimens still did not comply with the specification.

- Evotherm specimens exceeded the maximum allowable rutting depth when tested using the APA. Control specimens had acceptable rutting resistance.

- Asphalt fume sampling conducted during the Evotherm WMA paving and control HMA paving for Trial C indicated that crew members were exposed to non-detectable levels or levels below the maximum recommended exposure levels of airborne asphalt fumes.

CONCLUSION

- Warm mix asphalt can be successfully placed using conventional hot mix asphalt paving practices and procedures, with the primary difference being the reduction in temperature.

RECOMMENDATIONS

1. *VTRC and VDOT's Materials Division and districts should cooperate to place additional WMA sections using Sasobit and Evotherm to validate the experience gained in this study.* These sections should include cold weather installations to evaluate the potential for increasing the length of the paving season.

2. *VTRC and VDOT's Materials Division and districts should cooperate to place additional WMA sections to provide experience and evaluation opportunities for the additional available WMA technologies not included in this study.*

3. *VTRC and VDOT's Materials Division and districts should continue to cooperate to maintain the documentation of experiences with and performance of WMA.*

4. *VTRC should perform further laboratory investigations to determine if the TSR test is an appropriate test for use with WMA to determine stripping resistance. In addition, a further study of the influence of reheating on WMA should be performed to identify appropriate procedures for acceptance testing. Relationships between design properties and performance should also be considered.*

5. *VTRC should continue to monitor the performance of the three trial installations described in this report to evaluate the long-term performance of the WMA and HMA sections.*

COSTS AND BENEFITS ASSESSMENT

Inclusion of WMA technology as an option for paving operations provides potential benefits to VDOT and the contracting community. Theoretically, these technologies could extend the asphalt paving season into cooler weather, allowing for better optimization of paving resources. The technologies also allow the construction of asphalt pavements at lower temperatures, resulting in reduced cooling time before the pavement is opened to traffic. Lower production temperatures may also increase mixture durability by reducing production aging of the mix. Benefits to contractors may include the ability to increase hauling distances between the plant and project, reduced plant emissions resulting in improved air quality, and cost savings because of reduced energy costs. Because of the experimental nature of this study, no cost savings data are yet available to justify or refute the use of WMA technologies.

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