Final Report VTRC 10-R17

Virginia Transportation Research Council

research report

Performance of Virginia's Warm-Mix Asphalt Trial Sections

http:/www.virginiadot.org/vtrc/main/online_reports/pdf/10-r17.pdf

STACEY D. DIEFENDERFER, Ph.D., P.E.
Research Scientist

AMY J. HEARON
Graduate Research Assistant

Virginia Transportation Research Council, 530 Edgemont Road,
Charlottesville, VA 22903-2454, www.vtrc.net, (434) 293-1900

Standard Title Page - Report on Federally Funded Project

1. Report No.: FHWA/VTRC 10-R17	2. Government Accession No.:	3. Recipient's Catalog No.:

4. Title and Subtitle: Performance of Virginia's Warm-Mix Asphalt Trial Sections	5. Report Date: February 2010 6. Performing Organization Code:
7. Author(s): Stacey D. Diefenderfer, Ph.D., P.E., and Amy J. Hearon	8. Performing Organization Report No.: VTRC 10-R17
9. Performing Organization and Address: Virginia Transportation Research Council 530 Edgemont Road Charlottesville, VA 22903	10. Work Unit No. (TRAIS): 11. Contract or Grant No.: 87460
12. Sponsoring Agencies' Name and Address: Virginia Department of Transportation 1401 E. Broad Street Richmond, VA 23219 Federal Highway Administration 400 North 8th Street, Room 750 Richmond, VA 23219-4825	13. Type of Report and Period Covered: Final 8/20/2007-1/31/2010 14. Sponsoring Agency Code:

15. Supplementary Notes:

16. Abstract:

Three trial sections using two warm-mix asphalt (WMA) technologies were constructed in various locations in Virginia in 2006, and experiences with these trial sections were used in the development of the Virginia Department of Transportation's special provision to allow the use of WMA.

WMA for two of the sections was produced using Sasobit, an organic additive (developed by Sasol Wax), and WMA for the third section was produced using Evotherm ET (developed by MeadWestvaco Asphalt Innovations) as the modification method. The sections were evaluated over a 2-year period to assess the initial performance of the WMA and compare it with that of hot-mix asphalt (HMA) control sections constructed at the same time. Coring and visual inspections were performed during the initial construction and at intervals of 3 months, 6 months, 1 year, and 2 years. The cores were tested to determine air-void contents and permeability prior to undergoing extraction and recovery of the asphalt binder for performance grading. In addition, for the two Sasobit trial sites, historic data, core data, and ground-penetrating radar scans were collected and compared to provide documentation of the pavement structure for future analysis.

Visual surveys indicated no significant distresses in either the WMA or HMA sections during the first 2 years in service. Evaluations of the core air-void contents indicated that generally the contents for the WMA and HMA were not significantly different in each trial. The air-void contents at different ages were significantly different in a few instances; however, no trends concerning air voids were observed. Permeability measurements did not indicate any trends concerning permeability over time. Performance grading of the recovered binder suggested that the WMA produced using Sasobit aged at a slightly reduced rate than the HMA, as indicated by decreased stiffening. No difference in performance grade was measured between the HMA and WMA produced using the Evotherm emulsion. Comparisons of historical data, core data, and ground-penetrating radar scans illustrated that each may indicate a slightly different pavement structure.

From the results of this 2-year investigation, in general, WMA and HMA should be expected to perform equally. Any instances of improved performance of WMA (as compared to HMA) will depend on the WMA technology employed. Some WMA technologies may contribute to reduced in-service binder aging, depending on production temperatures and the nature of the technology. Further evaluation of WMA technologies developed since the inception of this work is recommended to determine their potential for leading to improved performance.

During the period from February through October 2009, VDOT let maintenance contracts using HMA surface mixtures valued at approximately $101 million. If, conservatively, one-tenth of these mixtures were replaced with WMA produced using technologies having beneficial aging characteristics and the apparent trend of a 1-year reduction in the rate of aging continued, resulting in a 1-year deferment of repaving, VDOT could realize a one-time cost savings of approximately $1.15 million.

17 Key Words: Warm-mix asphalt, hot mix asphalt, moisture susceptibility, rutting, fatigue, mechanistic-empirical pavement design guide	18. Distribution Statement: No restrictions. This document is available to the public through NTIS, Springfield, VA 22161.

19. Security Classif. (of this report): Unclassified	20. Security Classif. (of this page): Unclassified	21. No. of Pages: 44	22. Price:

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

FINAL REPORT

PERFORMANCE OF VIRGINIA'S WARM-MIX ASPHALT TRIAL SECTIONS

Stacey D. Diefenderfer, Ph.D., P.E.
Research Scientist

Amy J. Hearon
Graduate Research Assistant

In Cooperation with the U.S. Department of Transportation
Federal Highway Administration

Virginia Transportation Research Council
(A partnership of the Virginia Department of Transportation
and the University of Virginia since 1948)

Charlottesville, Virginia

February 2010
VTRC 10-R17

DISCLAIMER

ABSTRACT

Three trial sections using two warm-mix asphalt (WMA) technologies were constructed in various locations in Virginia in 2006, and experiences with these trial sections were used in the development of the Virginia Department of Transportation's special provision to allow the use of WMA.

WMA for two of the sections was produced using Sasobit, an organic additive (developed by Sasol Wax), and WMA for the third section was produced using Evotherm ET (developed by MeadWestvaco Asphalt Innovations) as the modification method. The sections were evaluated over a 2-year period to assess the initial performance of the WMA and compare it with that of hot-mix asphalt (HMA) control sections constructed at the same time. Coring and visual inspections were performed during the initial construction and at intervals of 3 months, 6 months, 1 year, and 2 years. The cores were tested to determine air-void contents and permeability prior to undergoing extraction and recovery of the asphalt binder for performance grading. In addition, for the two Sasobit trial sites, historic data, core data, and ground-penetrating radar scans were collected and compared to provide documentation of the pavement structure for future analysis.

Visual surveys indicated no significant distresses in either the WMA or HMA sections during the first 2 years in service. Evaluations of the core air-void contents indicated that generally the contents for the WMA and HMA were not significantly different in each trial. The air-void contents at different ages were significantly different in a few instances; however, no trends concerning air voids were observed. Permeability measurements did not indicate any trends concerning permeability over time. Performance grading of the recovered binder suggested that the WMA produced using Sasobit aged at a slightly reduced rate than the HMA, as indicated by decreased stiffening. No difference in performance grade was measured between the HMA and WMA produced using the Evotherm emulsion. Comparisons of historical data, core data, and ground-penetrating radar scans illustrated that each may indicate a slightly different pavement structure.

From the results of this 2-year investigation, in general, WMA and HMA should be expected to perform equally. Any instances of improved performance of WMA (as compared to HMA) will depend on the WMA technology employed. Some WMA technologies may contribute to reduced in-service binder aging, depending on production temperatures and the nature of the technology. Further evaluation of WMA technologies developed since the inception of this work is recommended to determine their potential for leading to improved performance.

During the period from February through October 2009, VDOT let maintenance contracts using HMA surface mixtures valued at approximately $101 million. If, conservatively, one-tenth of these mixtures were replaced with WMA produced using technologies having beneficial aging characteristics and the apparent trend of a 1-year reduction in the rate of aging continued, resulting in a 1-year deferment of repaving, VDOT could realize a one-time cost savings of approximately $1.15 million.

FINAL REPORT

PERFORMANCE OF VIRGINIA’S WARM-MIX ASPHALT TRIAL SECTIONS

Stacey D. Diefenderfer, Ph.D., P.E.
Research Scientist

Amy J. Hearon
Graduate Research Assistant

INTRODUCTION

Overview

Rising energy costs and increased environmental awareness have brought attention to the potential benefits of warm-mix asphalt (WMA) in the United States. WMA is produced by incorporating additives or water into asphalt mixtures to allow production and placement of the mixture at 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. Lower production temperatures may also increase mixture durability by reducing production aging of the mixture. Recently, there has been a surge in WMA research and development, although knowledge of the long-term impact of WMA technologies on mixture performance is very limited.

Three WMA trial sections using two WMA technologies were constructed in Virginia in 2006. WMA for two of the sections was produced using the Sasobit additive (developed by Sasol Wax); WMA for the third trial section was produced using Evotherm ET (developed by MeadWestvaco Asphalt Innovations) as the modification method. The experiences gained during the construction and initial evaluation of these sections were documented in Diefenderfer et al. (2007) and Diefenderfer and Hearon (2008) and were used by the Virginia Department of Transportation (VDOT) in the development of specifications to address the use of WMA. These specifications, Supplemental Section 211—Asphalt Concrete and Supplemental Section 315—Asphalt Concrete Pavement are provided in the Appendix.

PURPOSE AND SCOPE

The purpose of this study was to assess the short-term performance of the three VDOT WMA trial sections constructed in Virginia in 2006 to provide the initial information necessary for the future evaluation of the lifetime performance of WMA.

Specifically, the study evaluated the three WMA trial installations over a period of 2 years to gather short-term performance data to serve as a basis for the evaluation of WMA as a long-term pavement solution.

METHODS

To assess the short-term performance of the three WMA trial sections, seven tasks were performed:

1. Visual site assessments of the pavement surface of the trial sections were conducted.

2. Cores were taken from randomly chosen locations in each of the three trial sections.

3. To determine the rate of mixture densification under traffic, the air-void content of the cores was determined.

4. To evaluate changes in the permeability of the asphalt mixtures over time, the permeability of the cores was determined.

5. To evaluate the progression of aging, binder was recovered from the cores and graded.

6. To determine the underlying structure of the trial sections, historic VDOT data were collected, lift thicknesses were measured, and ground-penetrating radar (GPR) scans were conducted on the two sections located in Highland and Rappahannock counties.

7. Statistical analyses of air void and permeability data were conducted to compare the performance of the WMA and control (HMA) mixtures.

Summary of 2006 Construction of the Three Warm-Mix Asphalt Trial Sections

The three trial sections of WMA were constructed in Highland County, Rappahannock County, and York County, Virginia. Full information about the methods used during construction is provided by Diefenderfer et al. (2007); a summary is presented here.

Trial A: Sasobit

Trial A was constructed on August 11, 2006, as part of a larger pavement rehabilitation project. A 1.5-in overlay was placed on a new base mixture on the eastbound lane of US 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 a 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.

The mixture used in this trial was an SM-9.5A (9.5 mm nominal maximum aggregate size [NMAS] 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 mixture design were made.

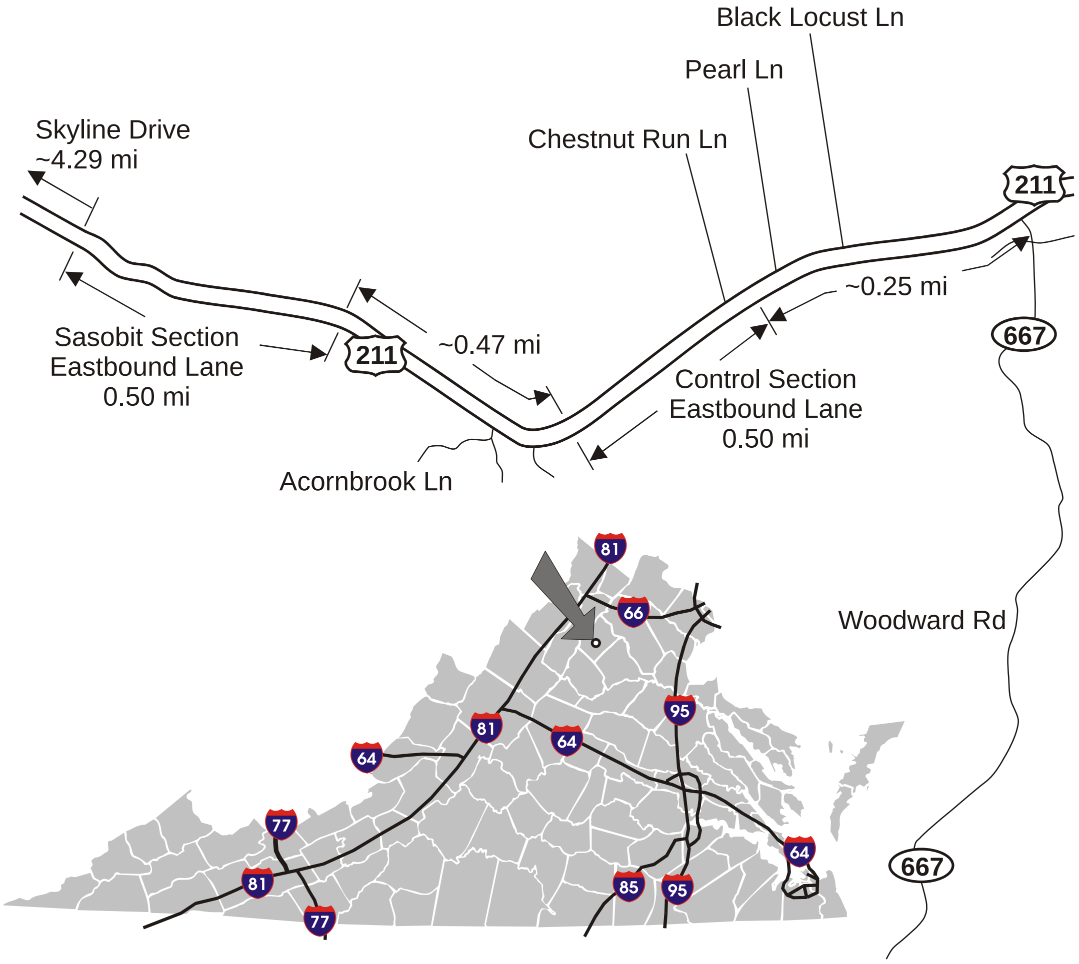


Figure 1. Location of Trial A (Sasobit) in Rappahannock County

Trial B: Sasobit

Trial B was constructed as a 1.5-in overlay on the southbound lane of US 220 in Highland County, Virginia, on August 14 and 15, 2006, by B&S Construction Inc. The overlay was placed over a variable-depth leveling course on moderately rutted and distressed pavement. 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 2. This project considered the application of WMA in long-haul conditions, as the plant was located approximately 45 mi from the paving site. 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 45 min across several mountains.

The mixture used in this trial was an SM-12.5A (12.5 mm NMAS 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. No other changes were made to the mixture design during the production of WMA.

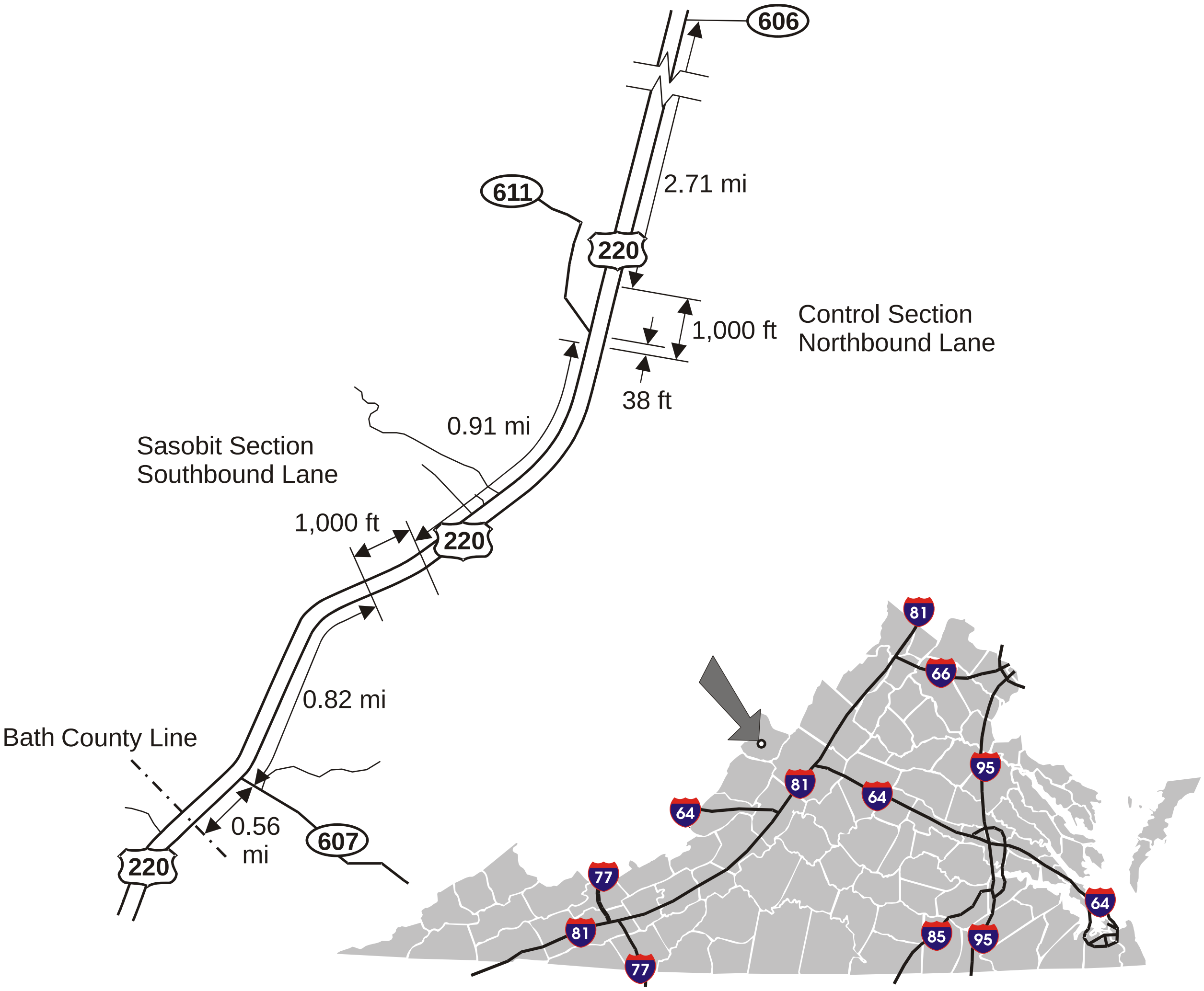


Figure 2. Location of Trial B (Sasobit) in Highland County

Trial C: Evotherm

Trial C was constructed as a 1.5-in overlay over a milled surface on State 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 3.

The mixture used in this trial was an SM-9.5D (9.5 mm NMAS 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 was produced using a PG 70-22 base binder and contained antistrip additives.

Figure 3. Location of Trial C (Evotherm) in York County

Visual Site Assessments

A visual assessment of the surface condition of each site was performed during site visits to obtain cores.

Coring

Sets of six cores were taken from randomly chosen locations in each section during construction and at 3 months, 6 months, 1 year, and 2 years of service

Determination of Air-Void Contents

Air-void contents were determined in accordance with AASHTO T269, Percent Air Voids in Compacted Dense and Open Asphalt Mixtures (AASHTO, 2007).

Permeability Testing

Permeability testing was performed in accordance with Virginia Test Method 120, Method of Test for Measurement of Permeability of Bituminous Paving Mixtures Using a Flexible Wall Permeameter (VDOT, 2007).

Asphalt Binder Recovery and Grading

Asphalt binder was extracted and recovered from cores in accordance with AASHTO T164, Quantitative Extraction of Asphalt Binder from Hot Mix Asphalt Method A, and AASHTO T170, Recovery of Asphalt from Solution by Abson Method (AASHTO, 2007). Recovered binder was graded in accordance with AASHTO M320, Performance-Graded Asphalt Binder (AASHTO, 2007).

Determination of Underlying Structure

VDOT maintains records on all of its pavements, including details such as construction date, mixture type, and layer thickness. These records were gathered from VDOT’s Highway Transportation Records and Inventory System (HTRIS) database for all test sections. The data from these records are referred to herein as “VDOT historic data.”

In addition, full-depth cores were taken after construction and the lift thicknesses were measured using calipers. Similar mixture types may have been measured together; as a result, the layer thicknesses may not match the historic data.

GPR was the final method used to evaluate layer thicknesses. GPR uses electromagnetic energy to determine relative dielectric constants (Sonyok and Zhang, 2008). Different pavement materials have slightly different dielectric constants, which allows the layer boundaries to be identified. GPR data were collected for two sections using an air-launched horn antenna having a central frequency of 2.0 GHz. The data were collected at a rate of one scan per foot.

Statistical Analyses

Statistical analyses were performed to determine if HMA and WMA air void and permeability measurements from each of the three trial sections were statistically different. The *F*-test was used to identify significant differences in data variance. The *t*-test was used to evaluate sample means to identify significant differences.

RESULTS AND DISCUSSION

Visual Assessment

For Trial A (Sasobit), no differences in surface condition were observed between the HMA and WMA sections during the first year of service. Cracking along the centerline of the pavement was observed during the 2-year visit. This was primarily located in the HMA section, although some was observed in the WMA section. The presence of cracking in both sections indicated that the cracking was unlikely to be materials related. Visual assessments performed during visits to the Trial B (Sasobit) and Trial C (Evotherm) sites did not indicate any difference in performance between the HMA and WMA sections at either site over the 2-year evaluation period.

Air Void and Permeability Measurements

Cores were taken at each test section site to evaluate the changes in the asphalt mixture density and permeability over time. Sets of six cores were taken during construction and at 3 months, 6 months, 1 year, and 2 years of service. The measurements taken at construction are referred to as the “initial” measurements. Permeability testing was performed on the cores to assess changes in the mixture permeability over time, which can indicate the potential for future susceptibility to moisture-related damage.

To investigate whether any differences in the measured air voids between various pairs of sample sets were significant, a series of *t*-tests was conducted at a level of significance of $\alpha = 0.05$. Prior to the *t*-tests, *F*-tests were used to evaluate the variance of each pair of comparisons to determine their equivalence so that the appropriate *t*-test assumptions would be applied. Comparisons of the HMA and WMA air voids over time and comparisons of the differences in properties between the two mixtures at each coring interval were performed.

Table 1 summarizes the core air-void contents from Trial A (Sasobit). The results from the statistical analyses are presented in Tables 2 and 3. The HMA appears to have compacted further during the first year as evident from the decreasing air voids. However, this trend was

Table 1. Summary of Core Air-void Contents for Trial A: Sasobit

Mixture	Average Air Voids (%)	Standard Deviation
HMA		
Initial	7.7	1.1
3-Month	6.0	0.9
6-Month	6.2	0.7
1-Year	5.5	0.7
2-Year	7.1	1.2
WMA		
Initial	6.7	1.8
3-Month	6.8	1.9
6-Month	7.8	1.4
1-Year	7.4	1.9
2-Year	7.5	1.1

HMA = hot-mix asphalt; WMA = warm-mix asphalt.

Table 2. Comparisons of Air Voids Over Time for Trial A: Sasobit

Comparison[a]	HMA		WMA	
	Variance	**Means**	**Variance**	**Means**
Initial vs. 3-Month	Equal	Not equal	Equal	Equal
Initial vs. 6-Month	Equal	Not equal	Equal	Equal
Initial vs. 1-Year	Equal	Not equal	Equal	Equal
Initial vs. 2-Year	Equal	Equal	Equal	Equal
3-Month vs. 6-Month	Equal	Equal	Equal	Equal
3-Month vs. 1-Year	Equal	Equal	Equal	Equal
3-Month vs. 2-Year	Equal	Equal	Equal	Equal
6-Month vs. 1-Year	Equal	Equal	Equal	Equal
6-Month vs. 2-Year	Equal	Equal	Equal	Equal
1-Year vs. 2-Year	Equal	Not equal	Equal	Equal

HMA = hot-mix asphalt; WMA = warm-mix asphalt.

[a] Comparisons were made at the level of significance of $\alpha = 0.05$.

Table 3. Comparisons of Air Voids Between HMA and WMA for Trial A: Sasobit

Comparison[a]	Variance	Means
All Cores	Not equal[b]	Not equal[b]
Initial	Equal	Equal
3-Month	Equal	Equal
6-Month	Equal	Not equal
1-Year	Not equal	Equal
2-Year	Equal	Equal

HMA = hot-mix asphalt; WMA = warm-mix asphalt.

[a] Comparisons were made at the level of significance of $\alpha = 0.05$.

[b] Inequalities were not highly significant (*p*-value = 0.0501).

not seen with the 2-year cores. Statistically, the results for the initial HMA cores were different from those of cores taken at the 3-month, 6-month, and 1-year intervals. In addition, the results for the 1-year and 2-year cores were statistically different. All other comparisons indicated that the air-void contents did not change significantly between the ages of 3 months and 1 year. For the WMA, air voids increased slightly up to an age of 6 months, when the trend leveled off. However, statistically, the results for the WMA core sets were not different. The air-void contents were plotted versus the core location to determine if these results were correlated with the wheelpath or non-wheelpath locations of the cores; the results indicated no such influence.

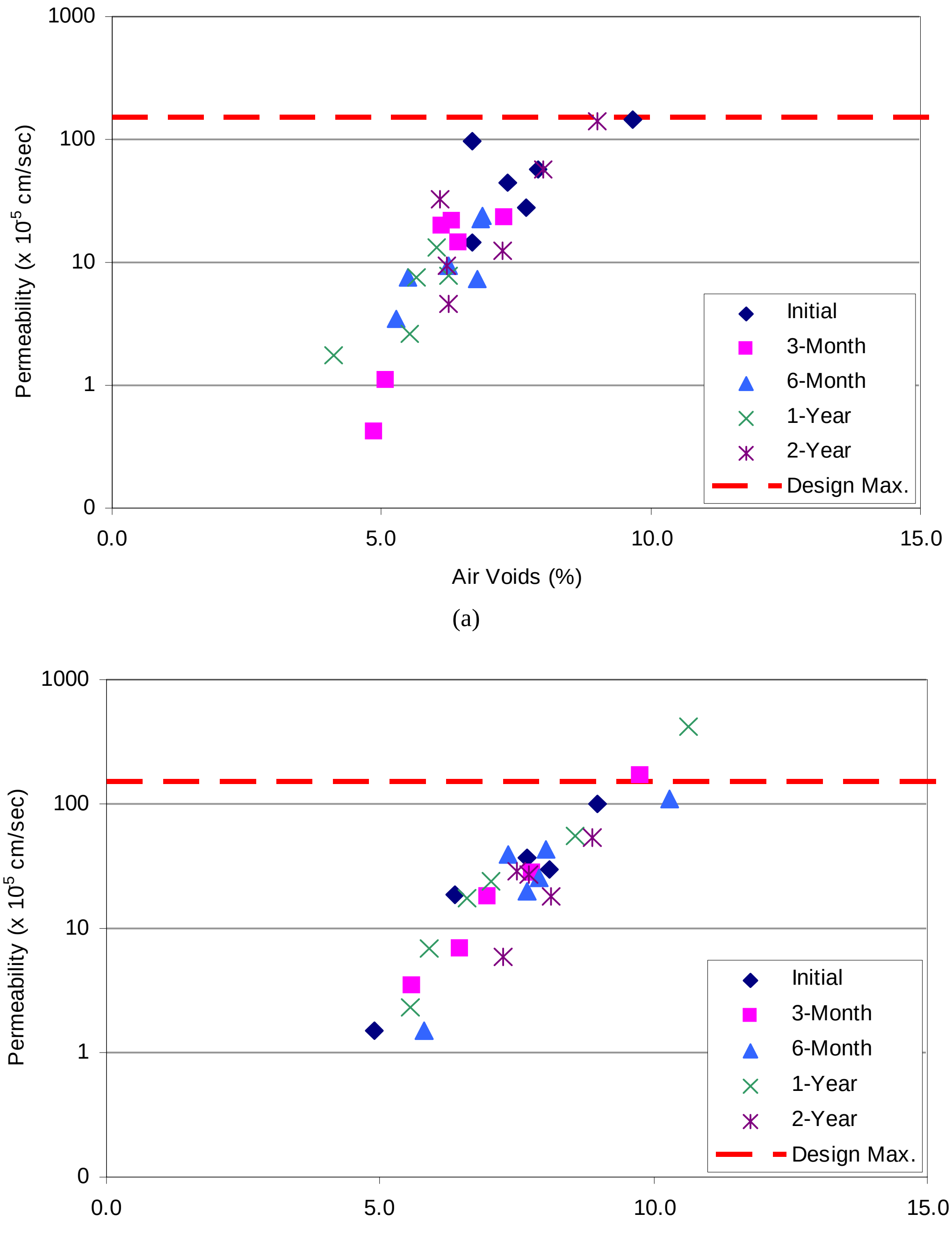
Table 3 summarizes the comparisons between the HMA and WMA cores at each coring interval and over all cores. Although the statistical test indicated a difference between the average air-void contents and variance of all HMA and WMA cores, the difference can be thought of as minimally significant, as the *p*-value for both tests was 0.0501; this indicates that the difference just met the target level of significance for differences using the $\alpha = 0.05$ level of significance. The analysis also indicated a significant difference in the average air-void contents between the HMA and WMA cores taken at 6 months of service and a significant difference in the variance of cores taken at 1 year of service.

The results of the permeability tests are shown in Figure 4. No changes over time were found. An investigation of trends indicated that the permeability of the HMA crossed the design maximum value of 150×10^{-5} cm/sec at an air-void content of approximately 9.0% whereas that of the WMA crossed at an air-void content of approximately 9.75%.

The results of the core testing on Trial B (Sasobit) are presented in Table 4. The air-void contents for both the WMA and HMA decreased over time, with the exception of the 2-year measurement for the HMA. It is unclear why such a substantial increase in air voids is shown for the HMA between 1 and 2 years. As with Trial A (Sasobit), the analysis indicated no correlation between the air-void content and the core location (wheelpath or non-wheelpath). The results of the statistical analysis are presented in Table 4.

As with Trial A (Sasobit), comparisons of the HMA and WMA compaction values for Trial B (Sasobit) over time and comparisons of the differences in void content at each coring interval were performed. The results of this analysis are shown in Table 5. An *F*-test showed equal variances for all comparisons except four: 3-month versus 6-month HMA, 6-month versus 1-year HMA, initial versus 1-year WMA, and 3-month versus 1-year WMA. A *t*-test using the appropriate variance assumption was performed using a level of significance of $\alpha = 0.05$ for all comparisons. For the HMA, air voids generally decreased over time, with the exception of the first 3 months. However, the only statistically significant differences in measured air voids were seen for the HMA between the initial and 1-year samples, 3-month and 1-year samples, and 1-year and 2-year samples. The rest of the comparisons showed statistically equivalent air voids. The trend for the WMA air-void measurements was similar that that for the HMA (decreasing air voids over time); but the changes were not significant. Further, as shown in Table 6, there were no significant differences in air voids between the HMA and WMA until the 2-year samples.

Figure 5 shows the permeability measurements for all cores. Again, there were no clear trends over time. Although the WMA results indicate a greater dispersion of measurements, both sections crossed the design maximum value of 150×10^{-5} cm/sec at air-void contents of approximately 9.5%.



(a)

(b)

Figure 4. Core Permeability Measurements for Trial A: Sasobit: (a) HMA, (b) WMA

Table 4. Summary of Core Air-Void Contents for Trial B: Sasobit

Mixture	Average Air Voids (%)	Standard Deviation
HMA		
Initial	9.2	1.3
3-Month	9.4	2.5
6-Month	8.4	2.1
1-Year	6.6	0.9
2-Year	9.6	1.2
WMA		
Initial	8.1	2.5
3-Month	8.3	2.7
6-Month	7.9	1.5
1-Year	7.3	0.8
2-Year	7.4	1.5

HMA = hot-mix asphalt; WMA = warm-mix asphalt.

Table 5. Comparisons of Air Voids Over Time for Trial B: Sasobit

Comparison[a]	HMA		WMA	
	Variance	Means	Variance	Means
Initial vs. 3-Month	Equal	Equal	Equal	Equal
Initial vs. 6-Month	Equal	Equal	Equal	Equal
Initial vs. 1-Year	Equal	Not equal	Not equal	Equal
Initial vs. 2-Year	Equal	Equal	Equal	Equal
3-Month vs. 6-Month	Equal	Equal	Equal	Equal
3-Month vs. 1-Year	Not equal	Not equal	Not equal	Equal
3-Month vs. 2-Year	Equal	Equal	Equal	Equal
6-Month vs. 1-Year	Not equal	Equal	Equal	Equal
6-Month vs. 2-Year	Equal	Equal	Equal	Equal
1-Year vs. 2-Year	Equal	Not equal	Equal	Equal

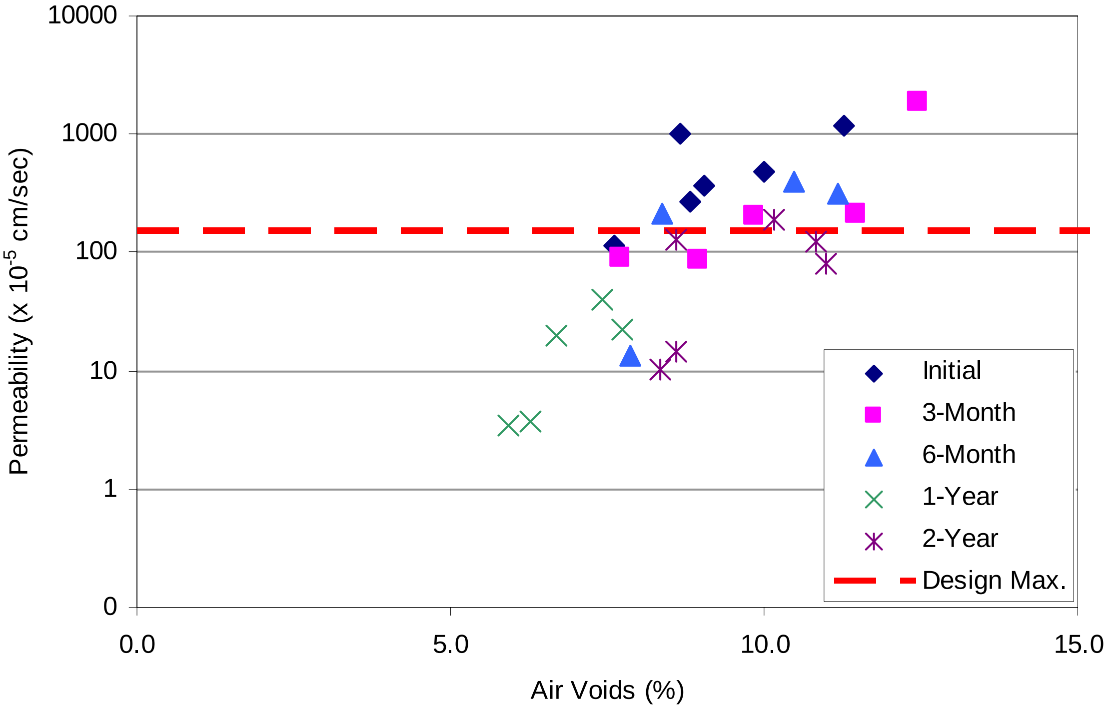
HMA = hot-mix asphalt; WMA = warm-mix asphalt.

[a] Comparisons were made at the level of significance of $\alpha = 0.05$.

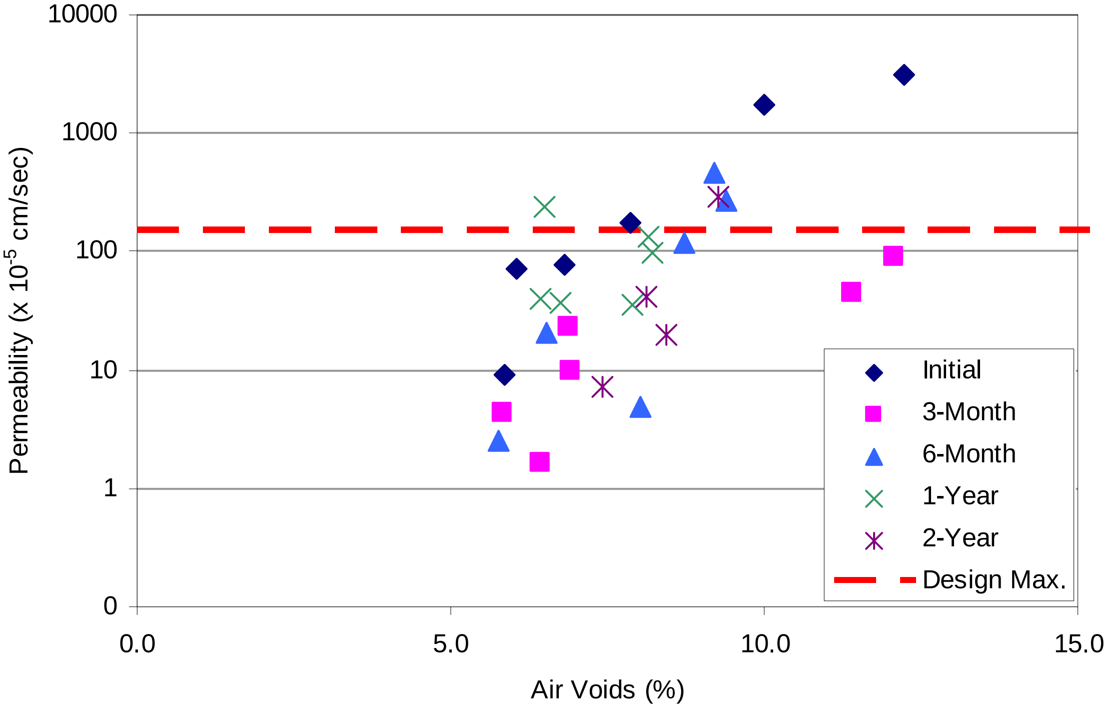
Table 6. Comparisons of Air Voids Between HMA and WMA, Trial B: Sasobit

Comparison[a]	Variance	Means
All Cores	Equal	Equal
Initial	Equal	Equal
3-Month	Equal	Equal
6-Month	Equal	Equal
1-Year	Equal	Equal
2-Year	Equal	Not equal

[a] Comparisons were made at the level of significance of $\alpha = 0.05$.



(a)



(b)

Figure 5. Core Permeability Measurements for Trial B: Sasobit: (a) HMA, and (b) WMA

Table 7 summarizes the results from core testing for Trial C (Evotherm). There was a considerable increase in air-void content for the HMA from the initial cores to the 3-month cores and a 1% increase for the WMA between the 1-year and 2-year cores. Examination of the data gave no indication of why the increases occurred. Analysis indicated no correlation between air-void content and core location (wheelpath or non-wheelpath). The overall trend with time for both sections was decreasing air-void contents, aside from the two exceptions.

Analysis of the HMA and WMA compaction values for Trial C (Evotherm) over time was performed to compare the differences in void content over time. Results of this analysis are shown in Table 8. The only significant differences were for the 3-month versus 2-year HMA cores. All other comparisons indicated that although the air-void contents were decreasing, the changes were not statistically significant. Table 9 summarizes the comparisons between the HMA and WMA at each coring interval and indicates there were no significant differences in the air-void contents for the HMA and WMA sections.

Table 7. Summary of Core Air-Void Contents, Trial C: Evotherm

Mixture	**Average Air Voids (%)**	**Standard Deviation**
HMA		
Initial	7.6	1.6
3-Month	9.6	1.8
6-Month	7.1	2.4
1-Year	7.0	2.7
2-Year	6.3	0.8
WMA		
Initial	9.4	3.5
3-Month	9.2	3.0
6-Month	7.4	2.1
1-Year	7.6	1.9
2-Year	8.6	2.7

Table 8. Comparisons of Air Voids Over Time, Trial C: Evotherm

Comparison[a]	**HMA**		**WMA**	
	Variance	**Means**	**Variance**	**Means**
Initial vs. 3-Month	Equal	Equal	Equal	Equal
Initial vs. 6-Month	Equal	Equal	Equal	Equal
Initial vs. 1-Year	Equal	Equal	Equal	Equal
Initial vs. 2-Year	Equal	Equal	Equal	Equal
3-Month vs. 6-Month	Equal	Equal	Equal	Equal
3-Month vs. 1-Year	Equal	Equal	Equal	Equal
3-Month vs. 2-Year	Not equal	Not equal	Equal	Equal
6-Month vs. 1-Year	Equal	Equal	Equal	Equal
6-Month vs. 2-Year	Not equal	Equal	Equal	Equal
1-Year vs. 2-Year	Not equal	Equal	Equal	Equal

HMA = hot-mix asphalt; WMA = warm-mix asphalt.

[a] Comparisons were made at the level of significance of $\alpha = 0.05$.

Table 9. Comparisons of Air Voids Between HMA and WMA, Trial C: Evotherm

Comparison[a]	Variance	Means
All Cores	Equal	Equal
Initial	Equal	Equal
3-Month	Equal	Equal
6-Month	Equal	Equal
1-Year	Equal	Equal
2-Year	Not equal	Equal

HMA = hot-mix asphalt; WMA = warm-mix asphalt.

[a] Comparisons were made at the level of significance of $\alpha = 0.05$.

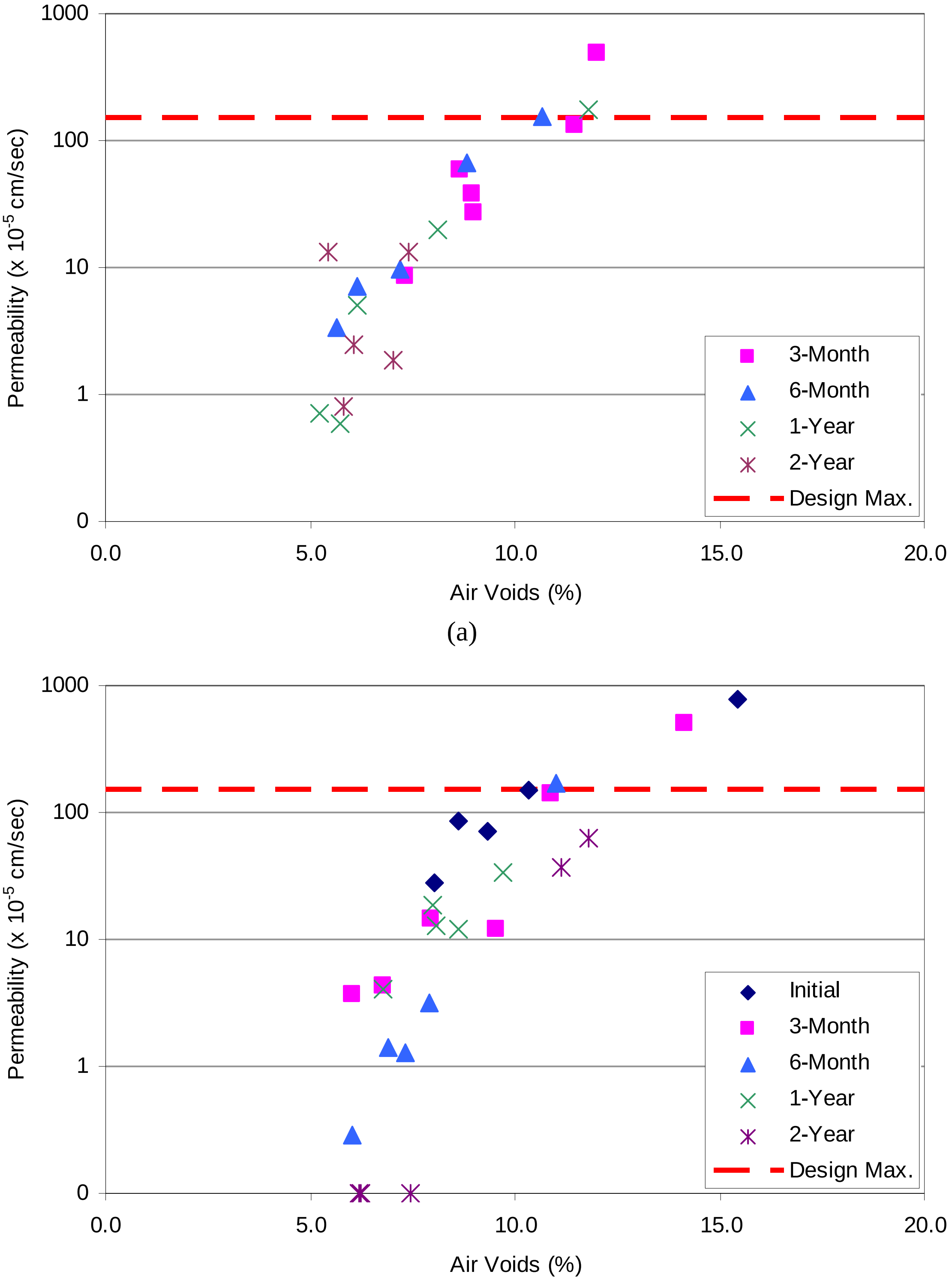
Permeability measurements for Trial C (Evotherm) are presented in Figure 6. As with Trials A and B, no clear trends with time were seen. The WMA data showed a slightly greater dispersion of measurements than did the HMA data. Investigation of the air-void content with regard to where each section reaches the design maximum permeability indicated that the HMA crossed at approximately 11% air voids and the WMA crossed at approximately 12%.

Asphalt Binder Evaluation

As previously discussed, the asphalt binder was extracted and recovered from cores taken at each time interval and then tested to determine its properties. True grade data were not available for all binders and are not reported. Table 10 shows the data for samples taken for Trial A (Sasobit). The virgin binder was known to be a PG 64-22. The effects of production aging and the recovery process on the binder properties can be seen from the initial HMA results; the binder graded as a PG 70-22. Comparatively, the WMA graded as a PG 76-22, gaining two high temperature grades attributable to production and the stiffening effect of the Sasobit WMA additive. It is interesting to note, however, that although the HMA continues to age, as indicated by the increasing stiffening and gain in high temperature grade, the WMA stiffness remained relatively the same throughout the initial 2 years of service. On the low temperature end, the WMA stiffness increased sooner than with the HMA, going from a –22 grade to a –16 at 1 year of service, compared to 2 years for the HMA.

Table 11 presents the binder test data from Trial B (Sasobit). Again, the virgin binder was a PG 64-22 binder. In this case, both the HMA and WMA increased one high temperature grade and lost one low temperature grade after production and construction, resulting in a binder grade of PG 70-16. Both sections showed increasing stiffness at higher temperatures: the HMA binder graded as a PG 76-16 after 1 year of service, and the WMA binder graded as a PG 76-16 after 2 years of service.

Binder test data from Trial C (Evotherm) are presented in Table 12. Trial C was produced using the Evotherm emulsion system produced using a PG 70-22 base binder, although test data for the base binder were not available. The high and low temperature grades for the HMA and WMA were consistent throughout the sampling period as PG 76-22, with the exception of the low temperature grade for the 2-year WMA, which increased one grade to be a PG 76-16.



(a)

(b)

Figure 6. Core Permeability Measurements for Trial C: Evotherm: (a) HMA, (b) WMA

Table 10. Test Results for Binder Recovered from Trial A: Sasobit Cores (AASHTO M320)

Test	Virgin Binder	HMA				WMA			
		Initial	6 Mo	1 Yr	2 Yr	Initial	6 Mo	1 Yr	2 Yr
Dynamic Shear on RTFO-aged Binder									
G*/sin δ, 64°C	4.817					12.88			
G*/sin δ, 70°C	2.226	3.98	4.925			5.886	4.834	6.657	
G*/sin δ, 76°C		1.914	2.376	5.461	4.67	2.778	2.293	3.115	2.638
G*/sin δ, 82°C				2.769	2.274			1.524	1.293
G*/sin δ, 88°C				1.24					
Dynamic Shear on PAV-aged Binder									
G*sin δ, 22°C	4520							8260	
G*sin δ, 25°C	3028	4952	4409	5011		4893	4255	5796	
G*sin δ, 28°C		3428	3032	3616	5359	3445	2968	4128	4425
G*sin δ, 31°C					3974	2379		2819	3097
Creep Stiffness, 60 sec									
S, -6°C					172			150	132
M, -6°C					0.329			0.347	0.336
S, -12°C	210	235	235	252	350	244	229	308	294
M, -12°C	0.339	0.332	0.32	0.315	0.27	0.31	0.302	0.299	0.28
S, -18°C				494					
M, -18°C				0.277					
Binder Grade	PG 64-22	PG 70-22	PG 76-22	PG 82-22	PG 82-16	PG 76-22	PG 76-22	PG 76-16	PG 76-16
HMA = hot-mix asphalt; WMA = warm-mix asphalt; RTFO = rolling thin film oven; PAV = pressure aging vessel.									

Table 11. Test Results for Binder Recovered from Trial B (Sasobit) Cores (AASHTO M320)

Test	Virgin Binder	HMA				WMA			
		Initial	6 Mo	1 Yr	2 Yr	Initial	6 Mo	1 Yr	2 Yr
Dynamic Shear on RTFO-aged Binder									
G*/sin δ, 64°C	3.56								
G*/sin δ, 70°C	1.652	3.257	3.594	5.627		3.405	4.032	4.58	
G*/sin δ, 76°C		1.567	1.71	2.668	3.329	1.569	1.951	2.121	2.645
G*/sin δ, 82°C				1.304	1.632				1.269
Dynamic Shear on PAV-aged Binder									
G*sin δ, 22°C	4325	7097				6051			
G*sin δ, 25°C	2959	4909	3871	7015		4256	5292	5862	
G*sin δ, 28°C			2652	4876	5366		3659	4103	5033
G*sin δ, 31°C					3870				3534
Creep Stiffness, 60 sec									
S, -6°C				153	162		136	132	143
M, -6°C				0.343	0.314		0.343	0.321	0.309
S, -12°C	178	225	187	304	307	246	269	281	244
M, -12°C	0.304	0.285	0.281	0.293	0.257	0.268	0.290	0.280	0.233
Binder Grade	PG 64-22	PG 70-16	PG 70-16	PG 76-16	PG 76-16	PG 70-16	PG 70-16	PG 70-16	PG 76-16
HMA = hot-mix asphalt; WMA = warm-mix asphalt; RTFO = rolling thin film oven; PAV = pressure aging vessel.									

Table 12. Test Results for Binder Recovered from Trial C (Evotherm) Cores (AASHTO M320)

Test	Virgin Binder	HMA				WMA			
		Initial	3 Mo	6 Mo	2 Yr	Initial	3 Mo	6 Mo	2 Yr
Dynamic Shear on RTFO-aged Binder									
G*/sin δ, 64°C									
G*/sin δ, 70°C		5.209	4.782	4.724			5.504	6.871	
G*/sin δ, 76°C		2.59	2.344	2.335	2.205	2.683	2.687	3.363	2.874
G*/sin δ, 82°C			1.14		1.118	1.395		1.704	1.468
G*/sin δ, 88°C									
Dynamic Shear on PAV-aged Binder									
G*sin δ, 22°C									
G*sin δ, 25°C		5183	4100	4117	4285	4204	4443	4918	6295
G*sin δ, 28°C		3614	2866	2857	3032	2868	3088	3416	4511
G*sin δ, 31°C		2493							
Creep Stiffness, 60 sec									
S, -6°C									129
M, -6°C									0.332
S, -12°C		240	198	198	202	271	224	279	277
M, -12°C		0.327	0.313	0.319	0.302	0.316	0.317	0.308	0.290
S, -18°C					406				
M, -18°C					0.264				
Binder Grade	PG 70-22	PG 76-22	PG 76-22	PG 76-22	PG 76-22	PG 76-22	PG 76-22	PG 76-22	PG 76-16

HMA = hot-mix asphalt; WMA = warm-mix asphalt; RTFO = rolling thin film oven; PAV = pressure aging vessel.

Determination of Underlying Structure

As discussed in the “Methods” section, historic VDOT data, core measurements, and GPR data were used to determine the underlying structure of each pavement section. An example of the GPR data collected is shown in Figure 7. In processing the data, the user manually identifies where the layer interfaces appear and the software calculates the dielectric constant from which the thickness is determined. The output consists of layer thicknesses; Figure 8 shows such an analysis indicating four discrete layers. The complete sets of GPR data for Trial A (Sasobit) and Trial B (Sasobit) are available upon request from the authors.

The total layer thickness for each pavement layer was taken as the average thickness for that layer across the test section. The results for Trial A (Sasobit) are shown in Table 13. The three methods showed consistent measurements for the surface layer. Core data did not accurately identify the thickness of Layer 4, although this could have been attributable to the depth of coring being less than the total pavement thickness. GPR data identified the total pavement thickness, but the measurements for Layers 2, 3, and 4 showed discrepancies when compared to the historic and core data. This may have occurred because of similarities and differences in the dielectric constants of the layers.

The results for Trial B (Sasobit) are presented in Table 14. The surface measurements were all consistent. The three slurry seals appear to have been measured as one in both the cores and GPR data. This is likely because the GPR was unable to differentiate between similar materials because of the similar dielectric constants and very thin layer thicknesses.

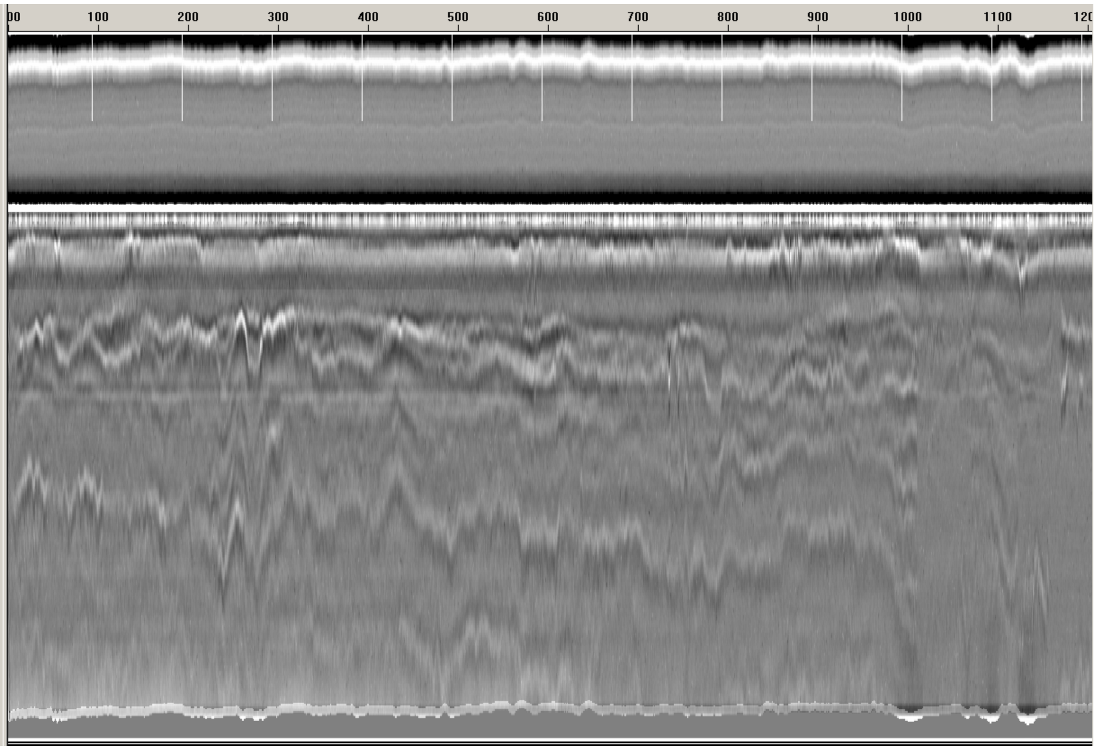


Figure 7. Ground-penetrating Radar Raw Data Scan for Warm-Mix Asphalt in Trial A: Sasobit

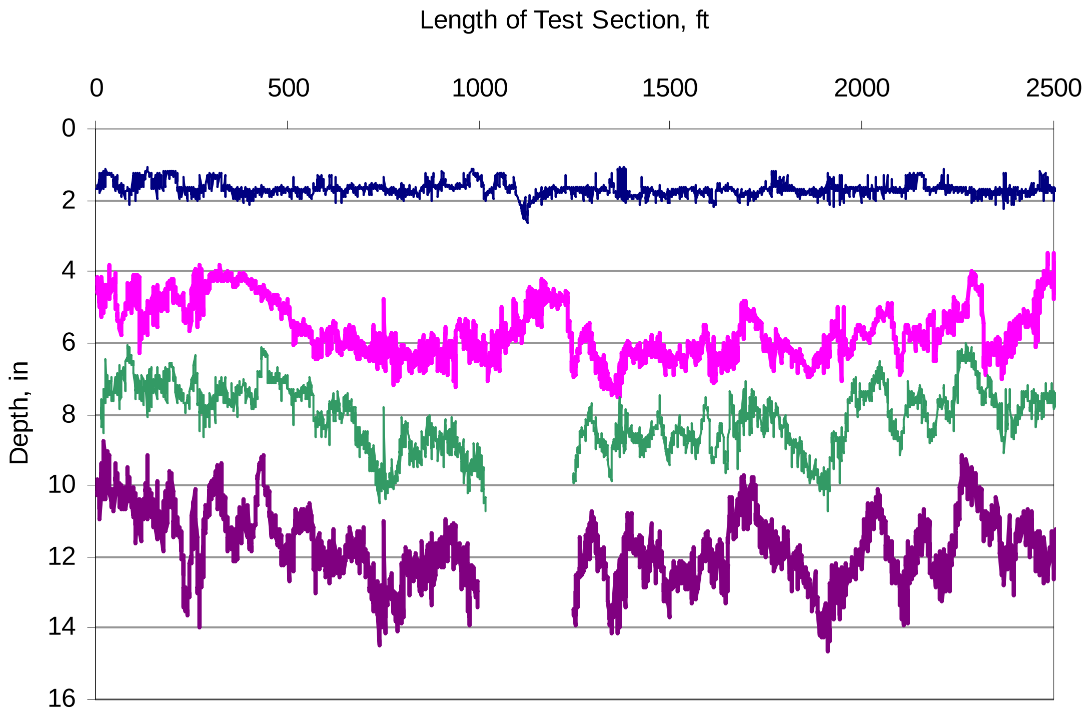


Figure 8. Ground-penetrating Radar Analyzed Data Plot for Warm-Mix Asphalt in Trial A: Sasobit

Table 13. Underlying Structure of Trial A: Sasobit

Historic Data		HMA		WMA	
		Core Measurements[a]	GPR Data	Core Measurements[a]	GPR Data
Surface Layer	1.5 in	1.29 in	1.82 in	1.29 in	1.68 in
	HMA/WMA				
Layer 2	3.0-3.5 in	3.35 in	4.79 in	3.35 in	3.94 in
	25.0 mm NMAS base mixture				
Layer 3	1.7 in	1.14 in		1.14 in	5.24
	9.5 mm NMAS surface mixture				
Layer 4	4 in	0.89 in	2.09 in	0.89 in	
	37.5 mm NMAS base mix		0.52 in 3.49 in		
Subgrade					

HMA = hot-mix asphalt; WMA = warm-mix asphalt; GPR = ground-penetrating radar; NMAS = nominal maximum aggregate size.

[a] Measurements were from cores taken immediately after construction of the trial section in 2006.

Table 14. Underlying Structure of Trial B: Sasobit

		HMA		WMA	
Historic Data		Core Measurements[a]	GPR Data	Core Measurements[a]	GPR Data
Surface Layer	2.0 in	2.12 in	2.5 in	2.27 in	2.77 in
	HMA/WMA				
Layer 2	0.24 in	1.17 in	2.0 in	1.17 in	1.68 in
	Slurry seal				
Layer 3	No thickness given				
	Slurry seal				
Layer 4	No thickness given				
	Slurry seal				
Layer 5	1.3 in	0.8 in	2.72 in	-	2.77 in
	Cold mixture				
Subgrade					

HMA = hot-mix asphalt; WMA = warm-mix asphalt; GPR = ground-penetrating radar; NMAS = nominal maximum aggregate size.

[a] Measurements were from cores taken immediately after construction of the trial section in 2006.

There are discrepancies among the results for all methods. The underlying structure of each test section dates back to 1975 for Trial A (Sasobit) and 1978 for Trial B (Sasobit), and construction records for these lengths of time are not always available. Cores will not always produce an accurate representation of the continuous underlying structure. If any past maintenance went unrecorded or if the initial construction deviated from the plan, this may not be shown by the core. GPR data are difficult to analyze since the presence of a layer constant depends on a difference in the material dielectric constant. In addition, moisture will have an impact on the dielectric constant and may make the layer appear thicker than it actually is. Considered separately, each method has advantages and drawbacks. However, when combined, they provide a more complete indication of the underlying structure of the pavement.

GPR analysis was not performed for Trial C (Evotherm) and core data were not available; however, the historic data were compiled and are shown in Table 15.

Table 15. Underlying Structure of Trial C: Evotherm

Historic Data	
Surface Layer	1.5 in
	HMA/WMA
Layer 1	1.5 in
	9.5 mm NMAS surface mixture
Layer 2	No thickness given
	Slurry seal
Layer 3	No thickness given, typically 1.1-1.5 in
	9.5 mm NMAS surface mixture
Layer 4	No thickness given, typically 1.1-1.5 in
	9.5 mm NMAS surface mixture
Subgrade	

HMA = hot-mix asphalt; WMA = warm-mix asphalt; NMAS = nominal maximum aggregate size.

SUMMARY OF FINDINGS

- In general, the HMA and WMA sites evaluated in this study performed similarly through the first 2 years of service.

- The evaluation of core air voids indicated that few significant differences existed between the HMA and WMA in each trial. Significant differences were seen in a few comparisons of core voids at different ages; however, no trends were observed. The presence of these differences is likely to have been influenced by the small sample size.

- The evaluation of core permeability measurements indicated slight differences in permeability between the HMA and WMA mixtures, but the differences did not appear to be impacting performance.

- Performance grading of the recovered binder indicated that the rate of stiffness gain after construction was reduced in the WMA produced using Sasobit as compared to the HMA. This gain in stiffness is related to the in-service aging of the binder. No difference in performance grade was apparent for the WMA produced using the Evotherm emulsion and the HMA control, except for an increase of one low temperature grade in the WMA at 2 years of service.

- Comparisons of historical data, core data, and GPR scans showed that each data set may indicate slightly different pavement structure; however, the differences would not be expected to affect greatly the outcomes of further analyses of the structures. In the case of core data, this is due to the difficulty in visually determining layer interfaces and the isolated nature of cores. For the GPR data, discrepancies may be seen when the difference in dielectric constant between layers is not great enough for the layers to be detected as separate layers.

CONCLUSIONS

- *HMA and WMA should be expected to perform equally*. Improved WMA performance (as compared to HMA) will depend on the technology used to produce the WMA.

- *Some WMA technologies may contribute to a reduced rate of in-service binder aging.* This is likely related to the technology chemistry and production temperatures and thus is somewhat project dependent. Further evaluation throughout the life of the surface mixture is necessary to validate this conclusion.

RECOMMENDATIONS

1. *The Virginia Transportation Research Council (VTRC) should monitor the performance of additional WMA sites constructed with different WMA technologies to assess their lifetime*

performance. Different technologies affect WMA production processes in different ways; only through lifetime monitoring can the ultimate effect on performance be evaluated.

2. *VTRC should monitor the performance of additional WMA sites constructed under different traffic conditions and with high RAP contents (above 20%) to assess their lifetime performance.* The locations evaluated in this study did not have high levels of traffic, and this effect on performance should be evaluated. The use of WMA with higher RAP contents should be evaluated to assess the impact of lower production temperatures on the production, construction, and performance of such mixtures.

3. *VTRC should continue to monitor the performance of the WMA sites addressed in this study to gather further performance data across the lifetime of the applied mixture.* Initial findings indicate that WMA appears to undergo aging at a reduced rate. However, this can be verified only after the section has reached the end of its life cycle.

COSTS AND BENEFITS ASSESSMENT

Based on two previous studies of the trial sections addressed in this report (Diefenderfer et al., 2007; Diefenderfer and Hearon, 2008), VDOT has implemented changes to Sections 211 and 315 of the *Road and Bridge Specifications* (see the Appendix) to permit the use of approved WMA processes. As more projects are constructed, there will be opportunities to validate conclusively the benefits of WMA. The costs of continuing WMA research can be estimated to be approximately $100,000 per year, based on the prior projects conducted.

This study assessed the initial (2-year) performance of WMA sections. Based on these initial performance results, WMA produced with one technology (Sasobit) appears to undergo an initial reduction in the rate of aging equivalent to approximately 1 year of service. If this initial reduction in aging holds true throughout the life of the overlay and effectively extends the life by 1 year over what is typically expected of HMA, the use of this WMA technology, or any WMA technology having the same benefit, on a project only once could save VDOT the equivalent of 1 year of deferred costs for repaving that segment of roadway. The present discounted value of periodic resurfacings (LCC), at a unit cost of C per resurfacing, may be expressed as:

$$\mathrm{LCC} = \mathrm{C} \times \frac{(1+\mathrm{r})^{\mathrm{T}}}{(1+\mathrm{r})^{\mathrm{T}} - 1} \qquad \text{[Eq. 1]}$$

where r is the discount rate and T is the service life.

If a WMA resurfacing technology with a 1-year life extension is chosen instead of HMA for a single application, the benefits may be determined. Drawing from the definition of LCC, the one-time cost of using HMA ($\mathrm{OTC}_{\mathrm{HMA}}$) is equivalent to:

$$\mathrm{OTC}_{\mathrm{HMA}} = \mathrm{C}_{\mathrm{HMA}} + \frac{\mathrm{LCC}_{\mathrm{HMA}}}{(1+\mathrm{r})^{\mathrm{T}_{\mathrm{HMA}}}} \qquad \text{[Eq. 2]}$$

where $\mathrm{OTC}_{\mathrm{HMA}}$ is the one-time cost of an HMA overlay, $\mathrm{C}_{\mathrm{HMA}}$ is the HMA resurfacing unit cost, $\mathrm{LCC}_{\mathrm{HMA}}$ is the life cycle cost of all future HMA resurfacings, and $\mathrm{T}_{\mathrm{HMA}}$ is the average expected life of a HMA overlay. Similarly, the one-time cost of using WMA can be determined as:

$$\mathrm{OTC}_{\mathrm{WMA}} = \mathrm{C}_{\mathrm{WMA}} + \frac{\mathrm{LCC}_{\mathrm{HMA}}}{(1+\mathrm{r})^{\mathrm{T}_{\mathrm{WMA}}}} \qquad \text{[Eq. 3]}$$

where $\mathrm{OTC}_{\mathrm{WMA}}$ is the one-time cost of an WMA overlay, $\mathrm{C}_{\mathrm{WMA}}$ is the WMA resurfacing unit cost, and $\mathrm{T}_{\mathrm{WMA}}$ is the average expected life of a HMA overlay. This determination conservatively assumes that future resurfacings are done with HMA.

In absolute terms, the monetary impact of using WMA for a single application is equal to:

$$\mathrm{OTC}_{\mathrm{HMA}} - \mathrm{OTC}_{\mathrm{WMA}} = \mathrm{C}_{\mathrm{HMA}} - \mathrm{C}_{\mathrm{WMA}} + \frac{\mathrm{LCC}_{\mathrm{HMA}}}{(1+\mathrm{r})^{\mathrm{T}_{\mathrm{HMA}}}} - \frac{\mathrm{LCC}_{\mathrm{HMA}}}{(1+\mathrm{r})^{\mathrm{T}_{\mathrm{WMA}}}} \qquad \text{[Eq. 4]}$$

Conveniently, this may be separated into a “cost” increment (the present cost additions attributable to the choice of WMA), which is equal to $\mathrm{C}_{\mathrm{HMA}} - \mathrm{C}_{\mathrm{WMA}}$, and a “benefit” increment comprised of the future cost savings attributable to longer service life. The cost increment is project specific and dependent on the choice of WMA technology. The benefit increment depends only on the assumption of an extension of life and is determined as:

$$\text{Benefit Increment} = \frac{\mathrm{LCC}_{\mathrm{HMA}}}{(1+\mathrm{r})^{\mathrm{T}_{\mathrm{HMA}}}} - \frac{\mathrm{LCC}_{\mathrm{HMA}}}{(1+\mathrm{r})^{\mathrm{T}_{\mathrm{WMA}}}} \qquad \text{[Eq. 5]}$$

If it is assumed that $r = 0.02$, $\mathrm{T}_{\mathrm{HMA}} = 8$, and $\mathrm{T}_{\mathrm{WMA}} = 9$, the “benefit” increment (the future cost savings attributable to longer service life) of a single application of WMA can be calculated as:

$$\text{Benefit Increment} = \frac{\mathrm{LCC}_{\mathrm{HMA}}}{(1.02)^{8}} - \frac{\mathrm{LCC}_{\mathrm{HMA}}}{(1.02)^{9}} = \frac{\mathrm{C}_{\mathrm{HMA}}}{1.02^{8}-1} - \mathrm{C}_{\mathrm{HMA}} \times \frac{1.02^{-1}}{1.02^{8}-1} = 0.114 \times \mathrm{C}_{\mathrm{HMA}}$$

[Eq. 6]

During the period from February through October 2009, VDOT let maintenance contracts using HMA surface mixtures valued at approximately \$101 million. If, conservatively, one-tenth of these mixtures were replaced with WMA produced using technologies having beneficial aging characteristics and the apparent trend of a 1-year reduction in the rate of aging were to continue, the 1-year deferment of repaving could result in a one-time cost savings to VDOT of approximately \$1.15 million.

ACKNOWLEDGMENTS

This study would not have been possible without the support of the personnel from the VDOT Materials Division, Culpeper District Materials Office, Staunton District Materials Office, Warrenton Residency, Rappahannock Area Headquarters, Verona Residency, and Monterey Area Headquarters. The authors also appreciate the assistance of Troy Deeds, Ken Elliton, Donnie Dodds, and the VTRC Asphalt Laboratory staff in the collection and testing of samples. Thanks are extended to Brian Diefenderfer for collecting and assisting with the analysis of the GPR data. Appreciation is also extended to the project review panel, composed of William Bailey, Lorenzo Casanova, Brian Diefenderfer, G. W. "Bill" Maupin, Richard Schreck, Haroon Shami, Trenton Clark and Chaz Weaver, for their guidance during this project. Finally, the authors thank Jim Gillespie for assistance with the cost and benefits analysis and Randy Combs, Ed Deasy, and Linda Evans for their support in the graphics and editorial process.

REFERENCES

American Association of State Highway and Transportation Officials. *Standard Specifications for Transportation and Methods of Sampling and Testing*, 27th ed. Washington, DC, 2007.

Diefenderfer, S.D., and Hearon, A.J. *Laboratory Evaluation of a Warm Asphalt Technology for Use in Virginia.* VTRC 09-R11. Virginia Transportation Research Council, Charlottesville, 2008.

Diefenderfer, S.D., McGhee, K.K., and Donaldson, B.M. *Installation of Warm Mix Asphalt Projects in Virginia*. VTRC 07-R25. Virginia Transportation Research Council, Charlottesville, 2007.

Sonyok, D.R., and Zhang, J. Ground Penetration Radar for Highway Infrastructure Condition Diagnostics: Overview of Current Applications and Future Development. Paper No. 08-2983. Presented at the 87th Annual Meeting of the Transportation Research Board, Washington, DC, 2008.

Virginia Department of Transportation. *Virginia Test Methods*. http://www.virginiadot.org/business/resources/bu-mat-VTMs070704.pdf. Accessed October 3, 2007.

APPENDIX

SUPPLEMENTAL SPECIFICATIONS ADDRESSING THE USE OF WARM-MIX ASPHALT

VIRGINIA DEPARTMENT OF TRANSPORTATION
2007 ROAD AND BRIDGE SUPPLEMENTAL SPECIFICATIONS

SUPPLEMENTAL SECTION 211—ASPHALT CONCRETE

SECTION 211—ASPHALT CONCRETE of the Specifications is amended as follows:

Section 211.01—Description is replaced with the following:

Asphalt concrete shall consist of a combination of mineral aggregate and asphalt material mixed mechanically in a plant specifically designed for such purpose.

An equivalent single-axle load (ESAL) will be established by the Engineer, and SUPERPAVE mix types may be specified as one of the types listed as follows:

Mix Type	Equivalent Single-Axle Load (ESAL) Range (millions)	Minimum Asphalt Performance Grade (PG)[2]	Aggregate Nominal Maximum Size[1]
SM-9.0A	0 to 3	64-16	3/8 in
SM-9.0D	3 to 10	70-16	3/8 in
SM-9.0E	Above 10	76-22	3/8 in
SM-9.5A	0 to 3	64-16	3/8 in
SM-9.5D	3 to 10	70-16	3/8 in
SM-9.5E	Above 10	76-22	3/8 in
SM-12.5A	0 to 3	64-16	1/2 in
SM-12.5D	3 to 10	70-16	1/2 in
SM-12.5E	Above 10	76-22	1/2 in
IM-19.0A	Less than 10	64-16	3/4 in
IM-19.0D	10 to 20	70-16	3/4 in
IM-19.0E	20 and above	76-22	3/4 in
BM-25.0A	All ranges	64-16	1 in
BM-25.0D	Above 10	70-16	1 in

[1] **Nominal Maximum Size** is defined as one sieve size larger than the first sieve to retain more than 10 percent aggregate.

[2] **Minimum Asphalt Performance Grade (PG)** is defined as the minimum binder performance grade for the job mixes as determined by AASHTO T170 or AASHTO M320.

Asphalt concrete shall conform to the requirements for the mix type designated.

At the Contractor’s option, Warm Mix Asphalt (WMA) additive or process may be used in lieu of the appropriate Hot Mix Asphalt (HMA).

Section 211.02(h) **antistripping additive** is amended by adding the following to the second paragraph:

When a Warm Mix Asphalt (WMA) additive or process, as described in 211.02(i) of the Specifications, is used in lieu of Hot Mix Asphalt (HMA) in the production of asphalt concrete, the minimum TSR requirement shall be 0.80 for the design and production tests.

Section 211.02—Materials is amended by adding the following:

(k) **Warm Mix Asphalt (WMA)** additives or processes shall be approved by the Department prior to use. Approved materials and processes shall be obtained from the Department’s approved list which is included in the Materials Division’s Manual of Instructions.

Section 211.03—Job-Mix Formula is amended to replace the first and second paragraph of (f) with the following:

(f) A determination will be made that any asphalt concrete mixture being produced conforms to the job-mix formula approved by the Department. The Department and Contractor will test the mixture using samples removed from production. The following tests will be conducted to determine the properties listed:

Property	**Test**
Asphalt content	VTM-102, (VTM-36 when approved)
Gradation	AASHTO T-30
SUPERPAVE properties	AASHTO R35
Asphalt cement material	AASHTO T316 or T-201

For Warm Mix Asphalt (WMA), SUPERPAVE properties will be determined by the Department and Contractor once the WMA has been allowed to cool to 100 degrees F or less and reheated based on the mix designation in Section 211.03(d)6 of the Specifications.

The Department will perform rut testing in accordance with the procedures detailed in VTM-110. If the results of the rut testing do not conform to the following requirements, the Engineer reserves the right to require adjustments to the job-mix formula:

Mix Designation	Maximum Rut Depth, mm
A	7.0
D	5.5
E, (S)	3.5

After calibration of the gyratory compactor is completed, adjustments to the job-mix formula may be required by the Engineer.

TABLE II-12A AGGREGATE PROPERTIES is amended to add **Mix Type IM-19.0E** as follows:

TABLE II-12A
Aggregate Properties

	Coarse Aggregate Properties				
	CAA		ASTM D4791		
	1 fractured	2 fractured	F & E "(5:1)	Fine Aggregate Properties	
Mix Type	face	faces	% by weight	SE	FAA
IM-19.0 E	95% min.	90% min.	10% max.[1]	45% min.	45% min.

TABLE II-13 ASPHALT CONCRETE MIXTURES: DESIGN RANGE is amended to add **Mix Type IM-19.0E** to IM-19.0 A,D as follows:

TABLE II-13
Asphalt Concrete Mixtures: Design Range[1]

	Percentage by Weight Passing Square Mesh Sieves										
Mix Type	2 in	1 1/2 in	1 in	3/4 in	1/2 in	3/8 in	No. 4	No. 8	No. 30	No. 50	No. 200
IM-19.0 A,D,**E**			100	90-100	90 max.	--	--	28-49			2-8

TABLE II-14 MIX DESIGN CRITERIA is replaced with the following:

TABLE II-14
Mix Design Criteria

Mix Type	VTM (%) Production	VFA (%)	VFA (%) Production	Min. VMA	Fines/Asphalt Ratio	No. of Gyrations			Density (%) at
	(Note 1)	Design	(Note 2)	(%)	(Note 3)	N Design	N Initial	N Max	N Initial
SM-9.0A $^{\text{Notes 1,2,3}}$	2.0-5.0	75-80	70-85	16	0.6-1.3	65	7	100	≤ 90.5
SM-9.0D $^{\text{Notes 1,2,3}}$	2.0-5.0	75-80	70-85	16	0.6-1.3	65	7	100	≤ 89.0
SM-9.0E $^{\text{Notes 1,2,3}}$	2.0-5.0	75-80	70-85	16	0.6-1.3	65	7	100	≤ 89.0
SM-9.5A $^{\text{Notes 1,2,3}}$	2.0-5.0	73-79	68-84	15	0.6-1.2	65	7	100	≤ 90.5
SM-9.5D $^{\text{Notes 1,2,3}}$	2.0-5.0	73-79	68-84	15	0.6-1.2	65	7	100	≤ 89.0
SM-9.5E $^{\text{Notes 1,2,3}}$	2.0-5.0	73-79	68-84	15	0.6-1.2	65	7	100	≤ 89.0
SM-12.5A $^{\text{Notes 1,2,3}}$	2.0-5.0	70-78	65-83	14	0.6-1.2	65	7	100	≤ 90.5
SM-12.5D $^{\text{Notes 1,2,3}}$	2.0-5.0	70-78	65-83	14	0.6-1.2	65	7	100	≤ 89.0
SM-12.5E $^{\text{Notes 1,2,3}}$	2.0-5.0	70-78	65-83	14	0.6-1.2	65	7	100	≤ 89.0
IM-19.0A $^{\text{Notes 1,2,3}}$	2.0-5.0	69-76	64-81	13	0.6-1.2	65	7	100	≤ 90.5
IM-19.0D $^{\text{Notes 1,2,3}}$	2.0-5.0	69-76	64-81	13	0.6-1.2	65	7	100	≤ 89.0
IM-19.0E $^{\text{Notes 1,2,3}}$	2.0-5.0	69-76	64-81	13	0.6-1.2	65	7	100	≤ 89.0
BM-25.0A $^{\text{Notes 2,3,4}}$	1.0-4.0	67-87	67-92	12	0.6-1.3	65	7	100	≤ 89.0
BM-25.0D $^{\text{Notes 2,3,4}}$	1.0-4.0	67-87	67-92	12	0.6-1.3	65	7	100	≤ 89.0

[1] SM = Surface Mixture; IM = Intermediate Mixture; BM = Base Mixture.

Note 1: Asphalt content should be selected at 4.0 % Air Voids,

Note 2: During production of an approved job mix, the VFA shall be controlled within these limits.

Note 3: Fines-asphalt ratio is based on effective asphalt content.

Note 4: Base mix shall be designed at 2.5% air voids. BM-25.0 A shall have a minimum asphalt content of 4.4% unless otherwise approved by the Engineer. BM-25.0D shall have a minimum asphalt content of 4.6% unless otherwise approved by the Engineer.

TABLE II-14A RECOMMENDED PERFORMANCE GRADE OF ASPHALT is replaced with the following:

TABLE II-14A
Recommended Performance Grade of Asphalt Cement

Mix Type	Percentage of Reclaimed Asphalt Pavement (RAP) in Mix		
	%RAP ≤ 20.0%	20.0% < %RAP ≤ 30%	20.0% < %RAP ≤ 35%
SM-9.0A, SM-9.5A, SM-12.5A	PG 64-22	PG 64-22	
SM-9.0D, SM-9.5D, SM-12.5D	PG 70-22	PG 64-22	
IM-19.0A	PG 64-22	PG 64-22	
IM-19.0D	PG 70-22	PG 64-22	
BM-25.0A	PG 64-22		PG 64-22
BM-25.0D	PG 70-22		PG 64-22

Section 211.04—Asphalt Concrete Mixtures is amended by replacing (b) with the following:

(b) **Types IM-19.0A, IM-19.0D, and IM-19.0E asphalt concrete** shall consist of crushed stone, crushed slag, or crushed gravel and fine aggregate, slag or stone screenings, or a combination thereof combined with asphalt cement.

NOTE: At the discretion of the Engineer, an intermediate mix may be designated as either SM-19.0A or SM-19.0D. When designated as such, no more than 5 percent of the aggregate retained on the No. 4 sieve may be polish susceptible. All material passing the No. 4 sieve may be polish susceptible.

Section 211.04—Asphalt Concrete Mixtures is amended to replace (e) with the following:

(e) **Type SM-9.5, SM-12.5, IM-19.0 and BM-25.0 asphalt concrete** may be designated E (polymer modified), or stabilized (S). Asphalt concrete mixtures with the E designation may not be stabilized.

1. **Type E asphalt mixtures** shall consist of mixes incorporating a neat asphalt material with polymer modification complying with the requirements of PG 76-22 and have a rolling thin film oven test residue elastic recovery at 77 degrees F of a minimum of 70 percent when tested in accordance with ASTM D 6084 procedure A. E designated mixtures shall not contain more than 15 percent reclaimed asphalt pavement (RAP) material.

2. **Type (S) asphalt mixtures** shall consist of mixes incorporating a stabilizing additive from the Department’s approved list found in the Materials Division’s Manual of Instructions. These mixes shall be

designated with an (S) following the standard mix designation. The minimum required additive shall be as specified on the Department's approved list found in the Materials Division's Manual of Instructions.

3. **Type L asphalt mixtures** will be allowed to contain a 100 percent polishing coarse and fine aggregate. These mixes shall be designated with a L following the standard mix designation.

Section 211.06—Tests is amended to replace the second and third paragraphs with the following:

Abson recovery samples shall be PG graded according to the requirements of AASHTO M 320-05. Samples meeting the required grades specified in Section 211.01 of the Specifications shall be acceptable.

Section 211.15—Initial Production is amended to replace the first sentence with the following:

(a) **Warm Mix Asphalt (WMA):** At the start of production, the Contractor shall place no more than 500 tons or up to one day's production as directed by the Engineer at an approved site, which may be the project site, so the Engineer can examine the process control of the mixing plant, the Contractor's placement procedures, surface appearance of the mix, compaction patterns of the Contractor's roller(s), and correlation of the nuclear density device.

(b) **Hot Mix Asphalt (HMA):** At the start of production of a mix not previously used on a state roadway, the Contractor shall place 100 to 300 tons or up to one day's production as directed by the Engineer at an approved site, which may be the project site, so the Engineer can examine the process control of the mixing plant, the Contractor's placement procedures, surface appearance of the mix, compaction patterns of the Contractor's roller(s), and correlation of the nuclear density device. The material shall be placed at the specified application rate and will be paid for at the contract unit price for the specified mix type. The Engineer will determine the disposition of material that was not successfully produced and/or placed due to negligence in planning, production, or placement by the Contractor.

VIRGINIA DEPARTMENT OF TRANSPORTATION
2007 ROAD AND BRIDGE SUPPLEMENTAL SPECIFICATIONS

SUPPLEMENTAL SECTION 315—ASPHALT CONCRETE PAVEMENT

SECTION 315—ASPHALT CONCRETE PAVEMENT of the Specifications is amended as follows:

Section 315.01—Description is amended by adding the following:

At the Contractor's option, Warm Mix Asphalt (WMA) additive or process may be used in lieu of the appropriate Hot Mix Asphalt (HMA).

Section 315.02(d) **Liquid asphalt coating (emulsion) for rumble strip** is replaced with the following:

(d) **Liquid asphalt coating (emulsion) for rumble strip** shall conform to the requirements of Section 210 of the Specifications. For centerline rumble strips, CSS-1h or CQS-1h conforming to Section 210 of the Specifications shall be used. The CSS-1h or CQS-1h may be diluted by up to 30 percent at the emulsion manufacture's facility.

Section 315.03(a) **Hauling Equipment** is replaced with the following:

(a) **Hauling Equipment:** Trucks used for hauling asphalt mixtures shall have tight, clean, smooth metal or other non-absorptive/inert material bodies equipped with a positive locking metal tailgate. Surfaces in contact with asphalt mixtures shall be given a thin coat of aliphatic hydrocarbon invert emulsion release agent (nonpuddling), a lime solution, or other material on the Department's list of approved release agents. Except where a nonpuddling release agent is used, the beds of dump trucks shall be raised to remove excess agent prior to loading. Only a nonpuddling agent shall be used in truck beds that do not dump. Each truck shall be equipped with a tarpaulin or other cover that will protect the mixture from moisture and foreign matter and prevent the rapid loss of heat during transportation.

Section 315.03—Equipment is amended by adding the following:

(e) **Material Transfer Vehicle (MTV):** When required in the Contract, a MTV shall be a self-propelled storage unit capable of receiving material from trucks, storing the material and transferring the material from the unit to a paver hopper insert via a conveyor system. The required paver hopper insert and unit shall have a combined minimum storage capacity of 15 tons. Prior to placing the asphalt material on the roadway surface, the storage unit or paver hopper insert must be able to remix the material in order to produce a uniform, non-segregated mix, having a uniform temperature.

Section 315.04—Placement Limitations is replaced with the following:

Asphalt concrete mixtures shall not be placed when weather or surface conditions are such that the material cannot be properly handled, finished, or compacted. The surface upon which asphalt mixtures are to be placed shall be free of standing water, dirt, and mud and the base temperature shall conform to the following:

(a) **Warm Mix Asphalt (WMA):**

1. **When the base temperature is above 40 degrees F**, laydown will be permitted at any temperature below the maximum limits given in Section 211.08 of the Specifications.

2. **When the laydown temperature is between 301 degrees F and 325 degrees F**, the number of compaction rollers will be the same number as required for 300 degrees F or less.

(b) **Hot Mix Asphalt (HMA):**

1. **When the base temperature is above 80 degrees F,** mixture laydown will be permitted at any temperature conforming to the limits specified in Section 211 of the Specifications.

2. **When the base temperature is between 40 degrees F and 80 degrees F**, the Nomograph, Table III-2, shall be used to determine the minimum laydown temperature of the asphalt concrete mixes. At no time should the minimum base temperature for base (BM) and intermediate (IM) mixes be less than 40 degrees F. At no time should the minimum laydown temperature for base (BM) and intermediate (IM) mixes be less than 250 degrees F.

   For surface mixes (SM), at no time should the minimum base and laydown temperatures be less than the following:

PG Binder/Mix Designation	Percentage of Reclaimed Asphalt Pavement (RAP) Added to Mix	Minimum Base Temperature	Minimum Placement Temperature
PG 64-22 (A)	<=20%	40 °F	250 °F
PG 64-22 (A)	>20%	50 °F	270 °F
PG 70-22 (D)	<=30%	50 °F	270 °F
PG 76-22 (E)	<=15%	50 °F	290 °F
PG 64-22 (S)	<=30%	50 °F	290 °F

(3) **When the laydown temperature is between 301 degrees F and 325 degrees F,** the number of compaction rollers will be the same number as required for 300 degrees F.

Intermediate and base courses that are placed at rates of application that exceed the application rates shown in Table III-2 shall conform to the requirements for the maximum application rate shown for 8-minute and 15-minute compaction rolling as per number of rollers used.

Should the Contractor be unable to complete the compaction rolling within the applicable 8-minute or 15-minute period, the placing of asphalt mixture shall either cease until sufficient rollers are used or other corrective action is taken to complete the compaction rolling within the specified period.

Compaction rolling shall be completed prior to the mat cooling down to 175 degrees F. Finish rolling may be performed at a lower mat temperature.

The final asphalt pavement finish course shall not be placed until construction pavement markings are no longer required.

Section 315.05(b) **Conditioning Existing Surface** is replaced with the following:

(b) **Conditioning Existing Surface:** When the surface of the existing pavement or base is irregular, it shall be brought to a uniform grade and cross section as directed by the Engineer. The surface on which the asphalt concrete is to be applied shall be prepared in accordance with the requirements of the applicable specifications and shall be graded and compacted to the required profile and cross section.

When specified, prior to placement of asphalt concrete, longitudinal and transverse joints and cracks shall be sealed by the application of an approved joint sealing compound.

Contact surfaces of curbing, gutters, manholes, and other structures projecting into or abutting the pavement and cold joints of asphalt shall be painted with a thick, uniform coating of asphalt prior to placement of asphalt mixture.

A tack or prime coat of asphalt will be required as specified below and shall conform to the applicable requirements of Section 310 and Section 311 of the Specifications. Asphalt classed as cutbacks or emulsions shall be applied ahead of the paving operations, and the time interval between applying and placing the paving mixture shall be sufficient to ensure a tacky residue providing maximum adhesion of the paving mixture to the base. The mixture shall not be placed on tack or prime coats that have been damaged by traffic or contaminated by foreign material. Traffic shall be excluded from such sections.

1. **Priming and Tacking:**

    a. **Priming aggregate base or subbase:** Unless otherwise specified in the contract documents, priming with asphalt material will not be required on aggregate subbase or base material prior to the placement of asphalt base, intermediate or surface layers.

    b. **Tacking:** Application of tack at joints, adjacent to curbs, gutters, or other appurtenances, shall be applied with a hand wand or with spray bar at the rate of 0.2 gallon per square yard. At joints, the tack applied by the hand wand or a spray bar shall be 2 feet in width with 4 to 6 inches protruding beyond the joint for the first pass. Tack for the adjacent pass shall completely cover the vertical face of the mat edge, so that slight puddling of asphalt occurs at the joint, and extend a minimum of 1 foot into the lane to be paved.

       Milled faces that are to remain in place shall be tacked in the same way for the adjacent pass. Use of tack at the vertical faces of longitudinal joints will not be required when paving in echelon.

       On rich sections or those that have been repaired by the extensive use of asphalt patching mixtures, the tack coat shall be eliminated when directed by the Engineer.

       Tack shall not be required atop asphalt stabilized open-graded material drainage layers.

       Tack shall be applied between the existing asphalt surface and each asphalt course placed thereafter.

2. **Removing depressions and elevating curves:** Where irregularities in the existing surface will result in a course more than 3 inches in thickness after compaction, the surface shall be brought to a uniform profile by patching with asphalt concrete and thoroughly tamping or rolling until it conforms with the surrounding surface. The mixture used shall be the same as that specified for the course to be placed.

   When the Contractor elects to conduct operations to eliminate depressions, elevate curves, and place the surface course simultaneously, he shall furnish such additional spreading and compacting equipment as required to maintain the proper interval between the operations.

Section 315.05(c) **Placing and Finishing** is amended to replace the second paragraph with the following:

A continuous line to mark the edge of pavement and provide proper control of pavement width and horizontal alignment will not be required for this contract.

And to add the following paragraphs:

Prior to application of tack coat and commencement of paving operations the Contractor shall clean the existing pavement surface of all accumulated dust, mud, or other debris that may affect the bond of the new overlay, as determined by the Engineer. The Contractor shall ensure the surface remains clean until commencement and during paving operations. The cost for cleaning and surface preparation shall be included in the bid price for asphalt concrete.

When required in the Contract, a MTV shall be used during the placement of designated asphalt mixes on full lane width applications.

Section 315.05(d) **Compacting** is amended by replacing the fifth paragraph with the following:

Rolling shall begin at the sides and proceed longitudinally parallel with the center of the pavement, each trip overlapping at least 6 inches, gradually progressing to the crown of the pavement. When abutting a previously placed lane, rolling shall begin at the outside unconfined side and proceed toward the previously placed lane. On superelevated curves, rolling shall begin at the low side and proceed to the high side by overlapping of longitudinal trips parallel with the centerline.

Section 315.05(e) **Density—Table III-3 Density Requirements and its footnote** are replaced with the following:

TABLE III-3
Density Requirements

Mixture Type	**Min. Control Strip Density (%)**
SM-9.5A, 12.5A	92.5
SM-9.5D, 12.5D	92.2
SM-9.5E, 12.5E	92.2
IM-19.0A, IM-19.0D, IM-19.0E	92.2
BM-25.0A, BM-25.0D	92.2

Note: The control strip density requirement is the percentage of theoretical maximum density of the job-mix formula by Superpave Mix Design or as established by the Engineer based on two or more production maximum theoretical density tests.

Section 315.05(e)2 **Surface, Intermediate and Base Courses** is replaced with the following:

2. **Surface, intermediate, and base courses** not having a sufficient quantity of material to run a nuclear density roller pattern and control strip shall be compacted to a minimum density of **91.5** percent of the theoretical maximum density as determined in accordance with the requirements of VTM-22. The Contractor shall be responsible for cutting cores or sawing plugs for testing by the Department. If the density is less than **91.5** percent, payment will be made in accordance with the requirements of Table III-5.

   For asphalt patching, the minimum density of 91.5 percent of the maximum theoretical density will be determined in accordance with the requirements of VTM-22. The Contractor shall be responsible for cutting cores or sawing plugs. One set of plugs/cores shall be obtained within the first 20 tons of patching material and every 500 tons thereafter for testing by the Contractor or the Department. Core/plug locations shall be randomly selected. If the density is less than the 91.5 percent, payment will be made on the tonnage within the 20 or 500 ton lot in accordance with the requirements of Table III-5.

TABLE III-5

Payment Schedule for Surface, Intermediate and Base Courses (Not sufficient quantity to perform nuclear density roller pattern and control)

% Theoretical Maximum Density	% of Payment
Greater than or equal to 91.5	100
90.2-91.4	95
88.3-90.1	90
Less than 88.2	75

Any section in which a mixture (e.g., SM-9.0) is being placed at an application rate of less than 125 pounds per square yard, based on 110 pounds per square yard per inch, that does not have a sufficient quantity of material for a nuclear density roller pattern and control strip shall be compacted by rolling a minimum of three passes with a minimum 8-ton roller. No density testing will be required.

Section 315.05(g) **Rumble Strips** is amended to replace fourth paragraph with the following:

Following the cutting and cleaning of the depressions of waste material, the entire rumble strip area shall be coated with liquid asphalt coating (emulsion) using a pressure distributor. For rumble strips installed on the shoulder, the approximate application rate shall be 0.1 gallons per square yard. For rumble strips installed in a new asphalt concrete surface (new construction or overlay) along the centerline, no sealing of the rumble strip area shall be performed. When the rumble strip is installed along the centerline in an existing asphalt concrete surface (i.e. more than one year since placement), the approximate application rate shall be 0.05 gallons per square yard. The application temperature shall be between 160 degrees F and 180 degrees F. For shoulder rumble strips only, overspray shall not extend more than 2 inches beyond the width of the cut depressions and/or shall not come in contact with pavement markings.

Section 315.08—Measurement and Payment is amended to include the following:

Material Transfer Vehicle (MTV), when required in the Contract, will not be measured for separate payment. The cost for furnishing and operating the MTV shall be included in the price bid for other appropriate items.

Warm Mix Asphalt (WMA) additive or process will not be measured for separate payment, the cost of which, shall be included in the price bid for other appropriate items.