Final Report

Evaluating Constructability and Properties of Warm Mix Asphalt

Submitted to

The Office of Materials and Research
The Georgia Department of Transportation

Prepared By

Dr. James Tsai and Dr. James Lai
Georgia Institute of Technology
Atlanta, Georgia 30332-0355
Tel: (912) 963-6777; (770) 416-9805

June 2010

1. Report No.: FHWA-GA-10-0904	2. Government Accession No.:	3. Recipient's Catalog No.:

4. Title and Subtitle: Evaluating Constructability and Properties of Warm Mix Asphalt	5. Report Date: June 2010 6. Performing Organization Code:
7. Author(s): James S. Lai, James Y. Tsai and Zhaohua Wang	8. Performing Organ. Report No.: 09-04
9. Performing Organization Name and Address: Dr. James Lai and Dr. James Tsai Georgia Institute of Technology Atlanta, Georgia 30332-0355	10. Work Unit No.: 11. Contract or Grant No.:
12. Sponsoring Agency Name and Address: Georgia Department of Transportation Office of Materials & Research 15 Kennedy Drive Forest Park, GA 30297-2534	13. Type of Report and Period Covered: Final; September 2009 – June 2010 14. Sponsoring Agency Code:

15. Supplementary Notes:

16. Abstract:

This report presents the second pilot study initiated by the Georgia Department of Transportation (GDOT) for assessing the potential use of warm mix asphalt (WMA) mixes in Georgia highway pavements. The pilot study included paving three different WMA mixes (the Evotherm WMA (developed by MeadWestvaco Co.), the Rediset WMA (developed by AkzoNobel) and the Cecabase RT WMA (developed by CECA)) and a 9.5 mm Superpave control mix. The three WMA mixes for the test sections used the same 9.5 mm Superpave mix design. The main objective of this research study was to assess the constructability of these three WMA mixture types.

All the asphalt mixes were produced by an Astec continuous drum plant with a production rate of 220 tons per hour. The production temperature for the 9.5 mm Superpave mix was 310 °F and that for the Evotherm, Rediset and Cecabase RT WMA were 260 °F, 280 °F and 260 °F respectively.

The paving of 9.5mm Superpave mix was quite smooth and without any problem. The paving of Evotherm WMA mix was also considered acceptable though occasional blemish occurred. The paving of Rediset WMA mix was considered unacceptable with many blemishes occurring behind the paver. Material Transfer Vehicle (MTV) was used during the paving of the Evotherm WMA and the Rediset WMA. No MTV was used during the paving of Cecabase RT WMA mix and many cold asphalt clumps were presented in the hopper and auger chamber. The reasons that the three WMA test sections didn't achieve the desired paving quality as the control section might be due to the fact that either the WMA additive dosage rates used were insufficient or the introduction of WMA additive during the mixing process was ineffective.

A series of laboratory tests were performed on the three WMA mixes and the control mix that were collected from the asphalt plant during the construction, and the cores that were taken from the four test sections after construction. The tests and mix properties evaluated included, basic mix properties, moisture susceptibility, APA rutting tests, Hamburg tests, fatigue tests, and bond strength tests.

Recommendations for improving the quality of the WMA paving operation and performance were offered.

17. Key Words: Warm Mix Asphalt, Bituminous Construction	18. Distribution Statement:

19. Security Classification (of this report): Unclassified	20. Security Classification (of this page): Unclassified	21. Number of Pages: 130	22. Price:

Form DOT 1700.7 (8-69)

TABLE OF CONTENTS

GLOSSARY OF ABBREVIATIONS

AC – Asphalt Content

ANOVA – ANalysis Of VAriance

APA – Asphalt Pavement Analyzer

CO – Carbon Monoxide

CO_2 – Carbon Dioxide

DAT – Dispersed Asphalt Technology

ET – Emulsion Technology

Evotherm 3G – Third Generation Evotherm

G* – Complex shear modulus

G*/sinδ – Elastic portion of complex shear modulus. δ is the phase angle

G_{mb} – Bulk specific gravity

G_{mm} – Maximum specific density

HMA – Hot Mix Asphalt

IRI – International Roughness Index

JMF – Job Mix Formula

MTV – Material Transfer Vehicle

N_{design} – The design number of gyrations required to produce a sample with the same density as that expected in the field

$N_{initial}$ – The number of gyrations used as a measure of mixture compactability during construction

N_{max} – The number of gyrations required to produce a laboratory density that should never be exceeded in the field.

NOx – Nitrous Oxides

PG – Performance Grading

RAP – asphalt pavement

SO_2 – Sulfur Dioxide

S.S.D – Saturated, Surface Dry

TSR – Tensile Strength Ratio

VFA – Voids Filled with Asphalt

VMA – Voids in Mineral Aggregate

VOC – Volatile Organic Compounds

VTM – Voids in Total Mix

WMA – Warm Mix Asphalt

wt% – Weight Percent

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Background

Rising energy costs and increased awareness of emission problems in the production of Hot Mix Asphalt (HMA) have brought attention to the potential benefits of Warm Mix Asphalt (WMA) in the United States. A number of new WMA processes and products have become available that have the capability of reducing the temperatures at which asphalt mixes are produced and paved without compromising the performance of the pavement. These new products can reduce production temperatures by as much as 50°F or more. Lower plant mixing temperatures would reduce the fuel consumption by as much as 30 percent or more and thus reduce the operation costs. Lower plant mixing temperatures would also reduce gas emission, which represents significant cost savings to an asphalt plant for its emission control facility. WMA will also allow longer haul distances and a longer construction season than if the mixes are produced at normal operating temperatures. Lowering the mixing temperature would reduce oxidative hardening of the asphalt and thus could result in improving the pavement's performance by reduced thermal cracking and block cracking.

However, lowering the mix temperatures, in drying the aggregates and in the mixing operation, could potentially cause WMA to be more susceptible to moisture damage and rutting. These potential distresses as well as the issues related to the constructability of WMA are important and need to be carefully evaluated to ensure the viability and long term performance of WMA mixes.

Objective of Proposed Research Program

The research study presented in this report was the second pilot study initiated by the Georgia Department of Transportation (GDOT) for assessing the potential use of WMA in Georgia highway pavements. The pilot study included placing pavement test sections using the following three WMA mixes (the Evotherm WMA (developed by MeadWestvaco Co.), the Rediset WMA (developed by AkzoNobel) and the Cecabase RT WMA (developed by CECA)) and a 9.5 mm Superpave control mix. The three WMA test sections and the control section were a part of the 9.5 mm Superpave mix overlay construction project on State Route 42 in Monroe County, Georgia. The project consists of 12.091 miles of milling, inlay, HMA resurfacing, and shoulder reconstruction on State Route 42 beginning North of State Route 74 and extending to State Route 18.

The objective of this research study was to assess these three WMA mixtures through (1) assessing the constructability of the WMA mixes, (2) evaluating the properties of the WMA mixes through laboratory testing of the mixes produced during the construction of the test sections, and (3) conducting initial assessment of the performance of the WMA pavements.

Major Findings

(1) The three WMA mixes studied in this pilot project used the same 9.5 Superpave mix design. The reason for using the same mix design was that the amount of additives used in these three mixes was very small and should not affect the mix characteristics.

(2) The asphalt mixes for the four test sections were produced by the Astec continuous drum plant with a production rate of 220 tons per hour. The relevant mix production and paving data for the four mixes are summarized in Table A below. The quality control testing was performed on the mixes produced in the asphalt plant, and the test results indicated that deviations from the Job Mix Formula (JMF) for the asphalt content and aggregate gradation were within the acceptance limits for all four tested mixes.

Table A Summary of Asphalt Plant Production and Paving Data

	Results			
Mix Type	**9.5 mm Superpave**	**Evotherm**	**Rediset**	**Cecabase RT**
Paving Date	10/30/2009	10/29/2009	11/3/2009	11/4/2009
Tonnage produced	1098.7 ton	1715 ton	1592.05 ton	1696.32 ton
Additive dosage, wt% of mix	n/a	0.6%	0.2%	0.44%
Fuel consumption, gal / ton	Not available	Not available	Not available	Not available
Mix Temperatures ^{o}F				
-Production	315	260	280	260
-At load out	300	240 - 255	265 - 270	265 - 260
-Behind screed	295	230 – 250	240 - 255	230 - 245
Length of paved test section	0.7 miles	1.3 miles	0.3 miles	1.8 miles
Use MTV	no	yes	yes	no
Compacted mat thickness	1 ¼ inch	1 ¼ inch	1 ¼ inch	1 ¼ inch
In-place VTM	5.7%	7.1%	5.8%	5.8%
Surface defects	no	Occasional blemishes	Frequent blemishes, pulling and stripping	Frequent blemishes and pulling
Time when opened to traffic	2 hrs.	2 hrs.	2 hrs.	2 hrs.
Pavement smoothness	623 mm/km	732 mm/km	845 mm/km	821 mm/km

(3) Paving of the 9.5 mm Superpave mix control section was successful and did not encounter any problems during the paving operation. Paving of the Evotherm WMA mix was considered acceptable. A Material Transfer Vehicle (MTV) was used in the paving train and had helped improving the paving operation. Even with that, some blemishes still occurred on the asphalt mat behind the screed requiring some hand work to correct them. An MTV was used also in the paving train during the paving of the Rediset WMA mix. However, the paving quality was in general unsatisfactory. Blemishes occurred more frequently behind the screed than the case when Evotherm

mix was used. Paving of the Cecabase RT WMA mix did not utilize an MTV. The quality of paving with the mix produced at 260 ^{o}F was poor with a large number of cold mix clumps present in the hopper requiring the paving crew to remove the clumps. Severe blemishes and pulling were observed on the asphalt mat behind the screed.

(4) Compared with the first pilot study conducted in 2008, blemishes occurred much less frequently for the Evotherm WMA mix test section. Other than the different WMA additive used in this pilot study, use of an MTV in the paving operation had improved the paving quality. However, compared with the 9.5 mm Superpave control section, blemish and pulling still occurred. This would indicate that the WMA additives used in this pilot project were inadequate toward producing the intended effects. This could be due to either of the following two reasons: (1) the applied dosage rates could be insufficient for the three WMA additives used in this pilot project. The adequate dosage rates recommended by the additive suppliers should be validated in a laboratory prior to the field implementation; or (2) the methods for introducing the Rediset and Cecabase RT additives into the mixing operation could be ineffective.

(5) Laboratory tests were performed on the asphalt mix collected from the asphalt plant during the construction and the cores taken from the four test sections. Table B summarizes the post-construction laboratory test results.

Table B Summary of Post-Construction Laboratory Test Results

	9.5 mm Superpave	**Evotherm WMA**	**Rediset WMA**	**Cecabase RT WMA**
Volumetric Properties				
-% AC	5.46	5.81	5.88	5.83
-VTM, %	2.3	1.6	1.4	1.9
-VMA, %	14.5	14.7	13.0	13.4
Recovery Binder				
-Viscosity, poises	5646	5343	5272	5671
Moisture Susceptibility				
-Tensile splitting-control, psi	110.6	85.3	76.9	80.9
-Tensile splitting-conditioned, psi	120.5	99.2	89.7	87.8
-TSR, %	109	116	116	109
APA Rutting, mm	5.78	6.55	5.79	5.93
Hamburg test, Rut @ 10000 cyl., in.	0.40	0.20	0.35	0.53
Bond Strength, psi	208.6	132.2	115.5	127.2
Fatigue Testing				
-cyls. to failure	14773	13470	22490	29813
-Stiffness, MPa	1585	2323	1139	951

- The air voids for all three WMA mixes compacted at N_{design} (design number of gyrations) of 65 were less than 2.0%, much less than the 4.0% design air voids. Therefore, rutting susceptibility should be closely monitored in the next summer or two on these test sections. The control mix compacted under the same conditions having VTM (Voids in Total Mix) at 2.3% would also indicate this mix has marginal rutting resistance.

- The dynamic shear Rheometer tests were performed on the asphalt binders recovered from the mixes produced at the plant. The results in terms of G* and G*/sinδ indicate that there is no significant difference between the asphalt binder of the control mix and that of the three WMA mixes after the short term aging during the production of the mixes in the asphalt plant.

- Results of the GDT-66 moisture susceptibility tests indicate that the 9.5 mm Superpave control mix has a higher tensile stability values for both the unconditioned (control) specimens and the conditioned specimens than that of the WMA mixes. The test results also indicate that the moisture conditioned specimens have higher stability values than that of the unconditioned (control) specimens for each type of the mixes used in this pilot test program, including the 9.5 mm Superpave control mix and the three WMA mixes. Thus, the Tensile Strength Ratio (TSR) values are over 100% for each of the four mixes. Regarding the unusual TSR values, one engineer in OMR explained that it happens at times on finer and “tender” mixes such as 9.5 mm mix. It was thought that the conditioning of the testing pills actually stiffens the mix to some extent. In the meantime, given the higher AC contents in conjunction with hydrated lime, the tensile stability for the conditioned specimen becomes higher. The Cecabase RT mix shows moderate stripping with considerable stripping on coarse particles and moderate stripping on fine particles. The other mixes shows only slight stripping. According the GDOT standard (Section 828), all these mixes meet the acceptance requirements with a minimum tensile strength of 60 psi and a minimum TSR of 80%.

- Results from the APA (Asphalt Pavement Analyzer) rutting tests indicate that all four mixes meet the GDOT acceptance requirements. Evotherm WMA mix has a slightly higher rut depth value than the other three mixes.

- Results from the Hamburg tests indicate that the Evotherm WMA mix has the lowest rutting and the highest stripping inflection point, and Cecabase RT WMA mix has the highest rutting and the stripping inflection point was close to what Rediset has, which is the lowest one. This indicates that the Cecabase RT WMA mix could be more susceptible to moisture than the other mixes, which is consistent with the finding from the GDT-66 moisture susceptibility tests. Results from this testing showed the Evotherm WMA has much lower total rutting at 10,000 cycles than the other mixes, which is opposite to the finding from the APA rutting test results.

- Results of the bond strength testing show the bond strengths from all the four mixes all exceed 100 psi. The control mix has the highest value of 208 psi and the three WMA mixes have the strengths around 115 psi to 132 psi. Average bond strength of 100 psi is the typical bond strength between HMA pavement layers against slippage failure.

- The fatigue tests were performed on all four mixes following the AASHTO T321-07 standard. The rankings of cycles to failure from high to low among these four mixes are: Cecabase RT mix, Rediset mix, Control mix and Evotherm mix. An ANOVA was performed on the cycles to failure among the four mixes. The significance level of the ANOVA was 0.05. The result showed that the p-value, about 0.03, is less than the significance threshold of 0.05, but is not exceptionally low (less than 0.01). Thus, we can say that the cycles to failure among the 4 mixes show a statistical difference at a moderate significant level.

(6) A preliminary study was conducted by Georgia Tech Research Institute (GTRI) to evaluate the relative magnitude of Volatile Organic Compounds (VOC) emissions during the production of WMA and the control mix at the asphalt plant and during the paving operations. Results of the VOC emissions measurements for the four mixes indicate that VOC emissions generated from any of the WMA mixes used in this project at the asphalt plant and at the paving site are not significantly different from that of the control mix.

Recommendations

The following recommendations are offered with an aim toward better understanding and improving the quality of the WMA paving operation and performance.

(1) Continuous pavement condition monitoring on the test sections is highly needed to thoroughly evaluate the actual performance. It is especially important to closely monitor the rutting susceptibility in the next summer or two.

(2) There was problem mixing the additives uniformly into the mixing drum during the test of Rediset. It is recommended to develop a test method to quantitatively measure the percentage of additive applied right after the additives are fully mixed in the drum to ensure the right percentage of additives is introduced uniformly into the drum in the plant.

(3) When WMA is used in a paving project, the following information in addition to that stipulated under GDOT Standard Specifications Section 400.1.03 should be included when the contractor submits the JMF after the contract has been awarded:

    - The amount of WMA additive as percent of net binder used in the mix or the percent of the total mix weights used, particularly when Reclaimed Asphalt Pavement (RAP) is used.

- A viscosity vs. temperature chart for the binder incorporating the specified WMA additive dosage.
- The procedure for incorporating the WMA additive into the mix, the mixing temperature and mixing process in the laboratory mixing operations.
- Temperature and duration of aging, if different from the standard for aged at 135^{o}C (275^{o}F) in an oven for 2 hours after mixing and prior to compaction.
- Any deviation from the Superpave mix design procedures.

(4) Submit the proposed JMF for approval at least 4 weeks (instead of 2 weeks) before the beginning the asphalt plant mixing operation. This would allow the Office of Materials and Research (OMR) sufficient time to conduct more thorough mix design verification testing.

(5) It would be desirable to request that the WMA additive supplier conduct the mix design verification testing based on the JMF, the aggregates, and the binder submitted by the contractor, and forward the verification mix design results to the OMR. It would be highly desirable that the WMA additive suppliers also provide the following information for using the WMA additive during the construction.

- Minimum threshold mix temperature behind the screed
- Maximum allowable storage time in silo
- Maximum allowable storage time in truck

(6) OMR should perform mix design verification testing based on the JMF, aggregates, and binder submitted by the contractor and compare the results with those from the WMA additive suppliers. The mixing temperature and the compaction temperature as suggested by the WMA additive suppliers should be carefully evaluated during the laboratory mix design. Workability of the mix should also be carefully evaluated.

(7) It may be desirable to intentionally vary the temperatures of the mix at load out, behind the screed, and during the holding time to assess the sensitivity of the temperatures and the storage time on the constructability of the WMA mix in the test section of a construction project. This would provide valuable information for the contractor and for the Quality Control Technician during the mainline paving. If the results indicate that the WMA mix used is too sensitive to the temperature variations, the project engineer perhaps should consider requesting the contractor to use a MTV to mitigate the temperature sensitivity of the WMA mix used for the project.

(8) OMR and the Office of Maintenance should cooperate to place additional WMA sections to gain experience of using different types of WMA mixes. The proposed research program for this pilot study presented in this report, including the Post-Construction Laboratory Testing and Evaluation Program, can be used to evaluate the constructability and the properties of the mixes.

Chapter 1 INTRODUCTION

1.1 Background

Rising energy costs and increased awareness of emission problems in the production of Hot Mix Asphalt (HMA) have brought attention to the potential benefits of Warm Mix Asphalt (WMA) in the United States. A number of new WMA processes and products have become available that have the capability of reducing the temperature at which asphalt mixes are produced and paved without compromising the performance of the pavement. These new products can reduce production temperatures by as much as 50°F or more (*1-6*). Lower plant mixing temperatures would reduce fuel consumption by as much as 30 percent or more and thus reduce the operation costs. Lower plant mixing temperatures would also reduce gas emission by as much as 90 percent (*4*). The typical expected reductions of various emissions as presented in (*6*) were: 30 to 40 percent for Carbon Dioxide (CO_2) and Sulfur Dioxide (SO_2), 50 percent for Volatile Organic Compounds (VOC), 10 to 30 percent for Carbon Monoxide (CO), 60 to 70 percent for Nitrous Oxides (NOx), and 20 to 25 percent for dust. Lowering the emissions represents a significant cost savings to an asphalt plant for its emission control facility. Lower emissions may allow asphalt plants to be built in non-attainment areas, where there are strict air pollution regulations. WMA will also allow longer haul distances and a longer construction season than the mixes that are produced at normal operating temperatures. Lowering the mixing temperature would reduce oxidative hardening of the asphalt and thus could result in improving the pavement's performance by reduced thermal cracking and block cracking. There are some other benefits, such as allowing more Reclaimed Asphalt Pavement (RAP) to be incorporated in the mixes.

However, lowering the operation temperature, in drying the aggregates and in the plant mixing operation, could potentially cause WMA to be more susceptible to moisture damage and rutting (*2-4*). These potential distresses are important and need to be carefully evaluated to ensure the viability and long term performance of WMA.

WMA was originated in Europe in late 1990 and introduced to the U.S in 2002 when a study tour to Europe to examine WMA technologies was conducted by the National Asphalt Pavement Association (NAPA) (*6*). A WMA Technical Working Group (TWG) was formed by the Federal Highway Administration (FHWA) and NAPA to oversee WMA investigations and field trials in the U.S., which is led by the experts from NAPA, the State Departments of Transportation (DOTs), FHWA, the National Center for Asphalt Technology (NCAT), and the American Association of State Highway and Transportation Officials (AASHTO) (http://www.warmmixasphalt.com). Up to now, many State highway agencies and even some municipalities in the U.S. have placed trial WMA sections.

The following list some warm mix additives and processes available in the U.S. (*5*, http://www.warmmixasphalt.com/WmaTechnologies.aspx):

- Advera, a synthetic zeolite.

- Aspha-min, a zeolite additive that releases small amount of water into the mix.
- Astec foamed-asphalt, small quantities of water injected into the liquid asphalt stream of an Astec Double-Barrel plant.
- Cecabase RT, a surface active agent.
- Evotherm, a chemical additive that includes ingredients to improve coating and workability, adhesion promoters, and emulsification agents (the chemical is delivered in an emulsion).
- Rediset, a warm mix additive that also functions as an anti-strip agent.
- REVIX, the additives (broadly encompassing surfactants, polymers, acids, processing aids, waxes, etc.) incorporated into the asphalt binder that would improve coating and spreading over aggregate surfaces at reduced temperatures.
- Sasobit, a wax based additive.
- Aquablack WMA, a WMA system using Microbubble foaming technology.
- EcoFoam-II, a WMA system for continuous flow plants using the static inline vortex asphalt blender.
- Low-Energy Asphalt, a sequential mixing process.
- Shell Thiopave, a system that utilizes pelletized, sulphur based product as an asphalt binder extender, mixture modifier and a WMA technology.

1.2 Objective and Pilot Test Program

The research study presented in this report was the second pilot study initiated by the Georgia Department of Transportation (GDOT) for assessing the potential use of WMA in Georgia highway pavements. This pilot study included placing test sections using three different WMA mixes (the Evotherm WMA (developed by MeadWestvaco Co.), the Rediset WMA (developed by AkzoNobel) and the Cecabase RT WMA (developed by CECA)) and a 9.5 mm Superpave control mix. The three WMA test sections and the control section were a part of the 9.5 mm Superpave mix overlay construction project on State Route 42 in Monroe County.

The objective of this research study was to assess these three WMA mixtures through (1) assessing the constructability of the WMA mixes, (2) evaluating the properties of the WMA mixes through laboratory testing of the mixes that are produced during the construction of the test sections, and (3) conducting initial assessment of the performance of the WMA pavements. The proposed work for this study consists of following 4 tasks:

Task 1: Pre-construction Preparation: This task consists of preparing a detailed plan covering all phases of the pilot study.

Task 2: Assessing WMA Constructability during Construction: Efforts will be made in this task to obtain as completely as possible the construction related information, subject to the availability of resources and time permitted during the construction. This would provide important information related to the performance of the WMA test sections and the control section.

Task 3: Coordinate Post-Construction Evaluation: This task consists of coordinating the laboratory testing and evaluation properties of the WMA mixes and the control mix collected in the asphalt plant during the construction and the cores taken from the test sections.

Task 4: Prepare a Final Report: This task consists of preparing a final report documenting all the work performed in this pilot study.

1.3 Organization of Report

This report is divided into 6 chapters. Chapter 2 presents the work performed under Task 1, preparing a detailed plan covering all phases of the pilot study and collecting pertinent properties of the aggregates and the mix designs. Chapter 3 presents the work proposed under Task 2 for assessing the constructability, including the asphalt plant production operations and the paving operations, of the three WMA test sections and the control section. The laboratory testing and evaluation program proposed under Task 3 are summarized in Chapter 4. Chapter 5 summarizes the findings of the VOC emissions during the production of WMA and the control mix at the asphalt plant and during the paving operations. Conclusions and recommendations are presented in Chapter 6.

Chapter 2 PREPARATION AND PRE-CONSTRUCTION ACTIVITIES

This chapter presents the work performed under Task 1 – Pre-construction Preparation.

2.1 Development of Pilot Test Plan

A detailed plan covering all phases of the pilot study was prepared and submitted to OMR on September 11, 2009. The plan included the activities for evaluating WMA technology in the following three phases.

- Pre-construction data collection and laboratory evaluation of material properties.
- Evaluating mix production, paving and compaction operations, and performing quality control during the construction of the test sections.
- Post-construction evaluations of the performance of the WMA test sections and the control section.

The activities conducted and the results obtained during the pre-construction phase are presented in this chapter, and those during the construction phase and post-construction phases are presented in later chapters.

2.2 Description of Evotherm, Rediset and Cecabase RT WMA Mixes

Evotherm WMA

The Evotherm WMA additive was co-developed in Europe by MeadWestvaco Co. and Eurovia in 2003. MeadWestvaco reports that field testing has demonstrated a 100° F reduction in production temperatures. MeadWestvaco also reports that the decreased production temperatures of the Evotherm process can lead to plant energy savings of 55 percent; a 45 percent reduction in CO_2 and SO_2 emissions, a 60% reduction in NOx, a 41% reduction in total organic material, and benzene soluble fractions below detectable limits.

Three versions of Evotherm additives are available: 1) Evotherm ET (Emulsion Technology); 2) Evotherm DAT (Dispersed Asphalt Technology); and 3) Evotherm 3G (third generation). Evotherm ET is a high Asphalt Content (AC) content and water-based asphalt emulsion (around 70% solids). It requires no plant modifications for using this product and simply replaces the liquid asphalt in the HMA design. Evotherm DAT is a concentrated solution of additives in-line injected at the mix plant. Evotherm 3G was co-developed by MeadWestvaco, Paragon Technical Services and Mathy Technology & Engineering. This water-free form of additive is suitable to be introduced at the mix plant or asphalt terminal. The Evotherm 3G was used in producing the WMA mix in this project. The Evotherm additive was introduced into the liquid asphalt at the asphalt terminal and was delivered to the hot mix plant in a ready-to-use form. The quantity of

Evotherm used in producing the WMA mix in this project was 0.6% by weight of total asphalt mix.

Rediset WMA

The Rediset WMA additive was developed by AkzoNobel. Rediset uses surfactants and organic additives in pellet form. The surfactants improve the wetting ability of the asphalt for better coating with the aggregates, and the organic additives provide a reduction of the binder viscosity and a lubricating effect for easier coating and compaction. Rediset can be blended directly into the asphalt or directly into the mixing drum near where the asphalt is introduced. The HMA plant does not have to be modified. Studies have shown that Rediset WMA can lower the mix production temperature by 54° F and reduce fuel consumption by at least 20%. The dosage is around 1 to 2% of the binder. The mix design does not need to be modified because Rediset can maintain the Performance Grading (PG) of the binder. The quantity of Rediset used in producing the WMA mix in this project was 0.2% by weight of total mix.

Cecabase RT WMA

Cecabase RT WMA additive is a relative new product developed in 2006 by CECA. It is a liquid chemical additive that can be directly added into the binder at a dosage rate from 0.2 to 0.5 weight percent (wt%) of bitumen. It is claimed that Cecabase RT can lower mix production temperature by 122° F. The dosage rate used in producing the WMA mix in this project was 0.44% by weight of total asphalt mix.

2.3 WMA and HMA Material Sources and Properties

The three WMA test sections used the same aggregates and asphalt binder that was used for the 9.5 mm Superpave mix for this project. The source and properties of aggregate and asphalt binder, and the mix properties are presented below.

Aggregate

All the aggregates used for producing the mixes were from Aggregates USA at the Hitchcock Quarry (GDOT QPL Source Code 028C) at Postell, Georgia. The general character of the aggregates is Mylonite Gneiss/Amphibolite, and is classified as Group II aggregate in accordance with GDOT Spec 800.2.01.A. The properties of the aggregates are summarized in Table 2-1.

Table 2-1 Property of Aggregates

Specific Gravity			Percent Absorption	LA Abrasion Loss, %	Mg-Sulfate Soundness Loss, %
Bulk	S.S.D.	App.			
2.693	2.709	2.736	0.059	17	1.1

Asphalt Binder

The asphalt binder used was a PG 67-22 from NuStar at Savannah Plant (GDOT QPL Source Code 0002).

Reclaimed Asphalt Pavement (RAP)

The RAP used in all three mixes was from the Reeves Construction Co. Postell Plant (GDOT QPL Source Code 004R)

2.4 Mix Design

9.5 mm Superpave Mix

The control section, which is a part of the normal overlay construction project on State Route 42 in Monroe County, used a 9.5 mm Superpave mix. The amount of different sizes of aggregates and the RAP used for the mix is shown in Table 2-2. The aggregate gradation and optimum ACs used for the mix design are shown in Table 2-3. The Job Mix Formula (JMF) for this mix submitted by Reeves Construction Company to the OMR is included in Table A-1 in Appendix A of this report. Table 2-4 summarizes some key mix design parameters that are also shown in Table A-2 in Appendix A. Note that the AC (5.6%) in the JMF submitted by Reeves was 0.46% higher than that of the original approved mix design (5.14%).

Table 2-2 Aggregates Used for the Mixes

RAP	15%
#7	5%
#89	34%
M10	21%
W10	37%
Hydrated Lime	1.0%

Table 2-3 Aggregate Gradation and Asphalt Contents

Sieve Size, mm	JMF, % Passing
19.0	100
12.5	99
9.5	92
4.75	66
2.36	45
0.075	7
Optimum AC, %	**5.6**

Table 2-4 Volumetric Mix Design Data

% AC	G_{mm}	% G_{mb} @ $N_{initial}$	% G_{mb} @ N_{design}	G_{mb}	% Air Voids	VMA	VFA	Dust Ratio
5.00	2.525	88.7	95.6	2.413	4.4	16.1	72.5	1.05
5.50	2.506	90.5	97.0	2.429	3.0	16.0	80.9	0.96
5.14					4.0			

- Optimum Asphalt Cement (AC) Content = 5.14%
- Air Voids at Optimum AC = 4.0%
- Aggregate Effective Specific Gravity = 2.732
- $N_{initial}$ = 6
- N_{design} = 65

Mix Design for Evotherm, Rediset and Cecabase RT Mixes

The three WMA mixes in this pilot study used the same 9.5 Superpave mix design. The reason for using the same mix design was that the amount of additives used in these three WMA mixes was very small and should not affect the mix characteristics. However, other research studies (*4*) indicated that the air voids could be affected under the same compaction efforts, even with adjusting the mixing and compaction temperatures to account for the improved workability when using the WMA additives. Chapter 3 and Chapter 4 of this report will present the results and comparisons of the characteristics of the three WMA mixes and the control mix.

Chapter 3 ASSESSING ASPHALT PLANT AND PAVING OPERATIONS DURING CONSTRUCTION

3.1 Locations of Test Section Sites

The three WMA test sections and the control test section were a part of the 9.5 mm Superpave mix overlay construction project on State Route 42 in Monroe County, Georgia. The project consists of 12.091 miles of milling, inlay, plant mix resurfacing and shoulder reconstruction on State Route 42 beginning North of State Route 74 and extending to State Route 18. The locations of the construction project and the test sections are shown in Figure 3-1. The milepost range for each test section can also be found in Table 3-1. Reeves Construction Co. was the project contractor. The Evotherm WMA test section was constructed on October 29, 2009. The control section was constructed on October 30, 2009. The Rediset WMA test section was then placed on November 3, 2009. On November 4, 2009, the Cecabase RT test section was completed. The pavement sections that were constructed on rainy days were not counted. The weather during the construction of these test sections was sunny, and the temperature was about 50°F in the early morning and increased to about 70°F in the afternoon.

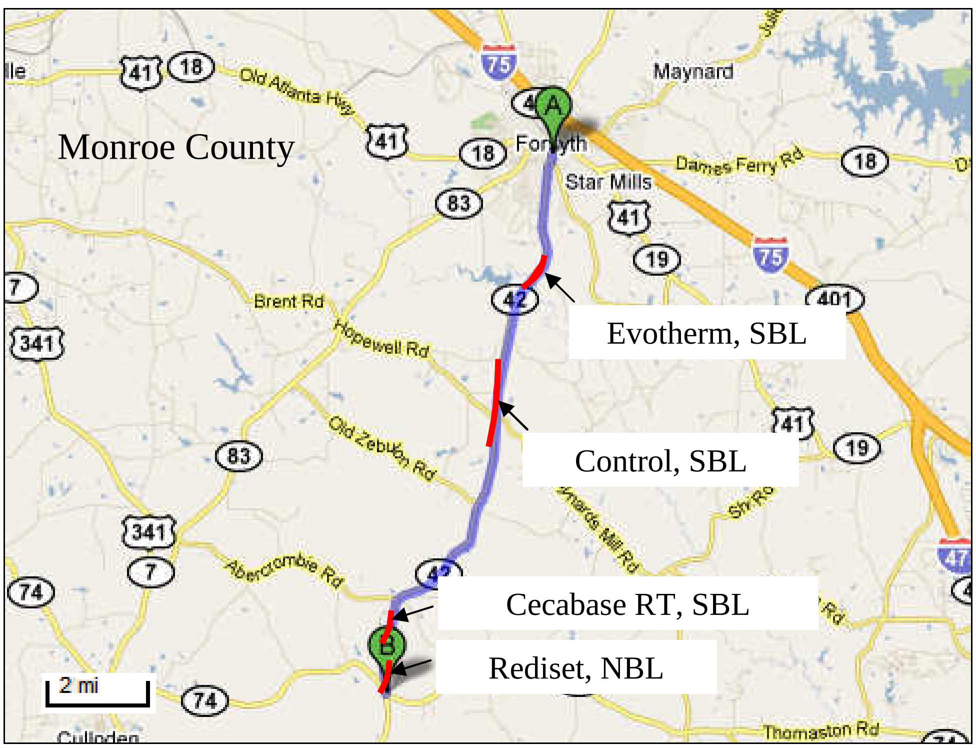

Figure 3-1 Locations of test sections

Table 3-1 Construction Dates and Locations of Test Sections

Date	Test Section	Milepost From	Milepost To	Orientation
10/29/2009	Evotherm	11.5	10.2	Southbound (SB)
10/30/2009	Control	9.3	8.4	SB
11/3/2009	Rediset	2.5 (SB)	2.2 (NB)	SB then NB
11/4/2009	Cecabase RT	3.4	5.2	Northbound (NB)

3.2 Asphalt Plant and Mix Production

The asphalt plant was located at Postell, Georgia, about 40 miles from the test section sites, see Figure 3-2. It would take about 1 hour for the truck to deliver the mix from the asphalt plant to the test section sites.

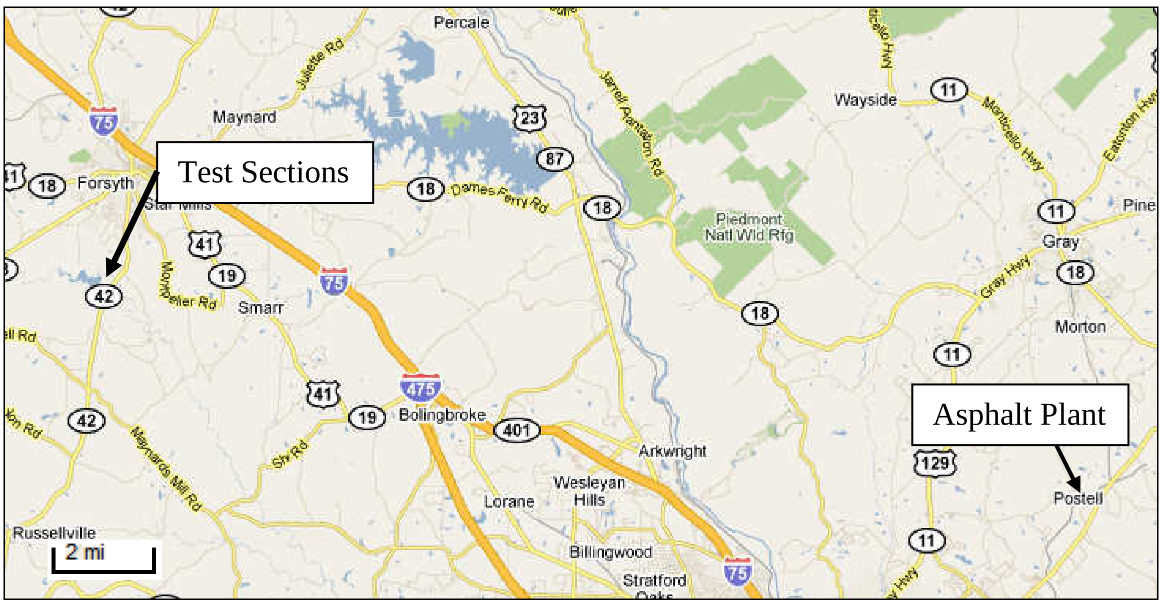

Figure 3-2 Locations of asphalt plant and test section sites

The asphalt mixes were produced by an Astec continuous drum plant with a production rate of 220 tons per hour. As mentioned in Section 2.3, all the aggregates used for producing the mixes were from Rinker Materials Co. at the Hitchcock Quarry at Postell, Georgia. The moisture contents of the aggregate stockpile were determined, and the results are presented in Table 3-2.

Table 3-2 Aggregate Stockpile Moisture Contents

Aggregate Type	Moisture Contents, %
#7	0.1
#89	1.1
W10	5.7
M10	2.3
RAP	0.8

9.5 mm Superpave Mix

Table 3-3 summarizes the 9.5 mm Superpave mix plant production related information collected on October 30, 2009. The mix discharge temperature was about 310^{o}F. The average fuel consumption for producing this mix was not available. There was no visible moisture problem in the baghouse. Results of the quality tests for the asphalt content and aggregate gradation of the mix at the plant are summarized in Table 3-4. A copy of the data sheet recording the quality control test results for the mix is included in Table A-3 in Appendix A of this report. The deviations from the JMF of the AC and aggregate gradation shown in Table 3-4 are within the acceptance limits. Fifteen 5-gallon buckets of the mix were collected from the plant and sent to OMR and NCAT (5 buckets) for testing the properties of the mix as described in Chapter 4.

Table 3-3 9.5 mm Superpave Mix Plant Production Information

Information Required	Results / Remarks
9.5 mm Superpave Mix (Control)	October 30, 2009
Tonnage produced	1098.7 ton
Use of silo and typical storage time	15 minutes
Mix discharge temperature	310 ^{o}F
Report regular QC testing results	See Table 3-4
Fuel consumption data	Accurate data not available
Baghouse moisture problem, if any	none

Table 3-4 9.5 mm Superpave Mix QC Test Results at Asphalt Plant

Sieve Size, mm	Percent passing		
	JMF	Average (1)	Deviation
19.0	100	100	0
12.5	99	98.2	0.8
9.5	92	91.9	0.1
4.75	66	67	1
2.36	45	46.2	1.2
0.075	7	6.9	0.1
Optimum AC, %	**5.60**	**5.66**	**0.06**

Note (1): Average of 2 samples, see Table A-3 in Appendix A

Evotherm WMA Mix

Production of the Evotherm WMA mix at the asphalt plant was started at about 7 a.m. on October 29, 2009. The plant operation for producing this mix was the same as that for producing the 9.5 mm Superpave mix, except the temperatures were lower. Table 3-5 summarizes the plant production related information collected during the production of this mix. The mix discharge temperature was about 260^{o}F, about 50^{o}F lower than that for the 9.5 mm Superpave mix. The average fuel consumption was not available. There was no visible moisture problem in the baghouse. Results of the quality tests for the asphalt content and aggregate gradation of the mix at the plant are summarized in Table 3-6. A copy of the data sheet recording the quality control test results for the mix is included in Table A-4 in Appendix A of this report. The deviations from the JMF of the asphalt content and aggregate gradation shown in Table 3-6 are within the acceptance limits. Fifteen 5-gal buckets of the mix were collected from the plant and sent to the GDOT OMR laboratory and NCAT (5 buckets) for testing the properties of the mix as described in Chapter 4.

Table 3-5 Evotherm WMA Mix Plant Production Information

Information Required	**Results / Remarks**
Evotherm Warm Mix Asphalt	October 29, 2009
Tonnage produced	1715 ton
Method of introducing additive to the mix	Mixed with Liquid Asphalt
Use of silo and typical storage time	15 minutes
Mix discharge temperature	260^{o}F
Report regular QC testing results	See Table 3-6
Fuel consumption data	Accurate data not available
Baghouse moisture problem, if any	none

Table 3-6 Evotherm WMA Mix QC Test Results at Asphalt Plant

Sieve Size, mm	Percent passing		
	JMF	Average (1)	Deviation
19.0	100	100	0
12.5	99	97	2
9.5	92	90.8	1.2
4.75	66	62.6	3.4
2.36	45	41.9	3.1
0.075	7	6.2	0.8
Optimum AC, %	**5.60**	**5.59**	**0.01**

Note (1): Average of 3 samples, see Table A-4

Rediset WMA Mix

Production of the Rediset WMA mix at the plant started at about 7 a.m. on November 3, 2009. The plant operation for producing this mix was the same as that for producing the 9.5 mm Superpave mix, except that the temperatures were lower. Table 3-7 summarizes the plant production related information collected during the production of this mix. The mix discharge temperature was about 280^{o}F, about 30^{o}F lower than that for the 9.5 mm Superpave mix. The average fuel consumption was not available. There was no visible moisture problem in the baghouse. Results of the quality tests for the asphalt content and aggregate gradation of the mix at the plant are summarized in Table 3-8. A copy of the data sheet recording the quality control test results for the mix is included in Table A-5 in the Appendix A. The deviations from the JMF of the asphalt content and aggregate gradation shown in Table 3-8 are within the acceptance limits. Fifteen 5-gal buckets of the mix were collected from the plant and sent to OMR and NCAT (5 buckets) for testing the properties of the mix as described in Chapter 4.

Table 3-7 Rediset WMA Mix Plant Production Information

Information Required	Results / Remarks
Rediset Warm Mix Asphalt	November 3, 2009
Tonnage produced	1592.05 ton
Method of introducing additive to the mix	Mixed with Liquid Asphalt
Use of silo and typical storage time	15 minutes
Mix discharge temperature	280^{o}F
Report regular QC testing results	See Table 3-8
Fuel consumption data	Accurate data not available
Baghouse moisture problem, if any	none

Table 3-8 Rediset WMA Mix QC Test Results at Asphalt Plant

Sieve Size, mm	Percent passing		
	JMF	**Average (1)**	**Deviation**
19.0	100	100	0
12.5	99	98	1
9.5	92	91.7	0.3
4.75	66	64.7	1.3
2.36	45	44.8	0.2
0.075	7	7	0
Optimum AC, %	**5.60**	**5.65**	**0.05**

Note (1) Average of 3 samples, see Table A-5

Cecabase RT WMA Mix

Production of the Cecabase RT WMA mix at the plant started at about 7 a.m. on November 4, 2009. The plant operation for producing this mix was the same as that for producing the 9.5 mm Superpave mix, except that the temperatures were lower. Table 3-9 summarizes the plant production related information collected during the production of this mix. The mix discharge temperature was about 280^{o}F, about 30^{o}F lower than that for the 9.5 mm Superpave mix. The average fuel consumption was not available. There was no visible moisture problem in the baghouse. Results of the quality tests for the asphalt content and aggregate gradation of the mix at the plant are summarized in Table 3-10. A copy of the data sheet recording the quality control test results for the mix is included in Table A-6 in the Appendix A. The deviations from the JMF of the asphalt content and aggregate gradation shown in Table 3-10 are within the acceptance limits. Fifteen 5-gal buckets of the mix were collected from the plant and sent to OMR and NCAT (5 buckets) for testing the properties of the mix as described in Chapter 4.

Table 3-9 Cecabase RT WMA Mix Plant Production Information

Information Required	Results / Remarks
Cecabase RT Warm Mix Asphalt	November 4, 2009
Tonnage produced	1696.32 ton
Method of introducing additive to the mix	Mixed with Liquid Asphalt
Use of silo and typical storage time	15 minutes
Mix discharge temperature	280^{o}F
Report regular QC testing results	See Table 3-10
Fuel consumption data	Accurate data not available
Baghouse moisture problem, if any	none

Table 3-10 Cecabase RT WMA Mix QC Test Results at Asphalt Plant

Sieve Size, mm	Percent passing		
	JMF	Average (1)	Deviation
19.0	100	100	0
12.5	99	98.3	0.7
9.5	92	90	2
4.75	66	63.7	2.3
2.36	45	43.9	1.1
0.075	7	6.8	0.2
Optimum AC, %	**5.60**	**5.57**	**0.03**

Note (1) Average of 3 samples, see Table A-6

3.3 Paving Operations of Test Sections

Paving for the test sections started on October 29, 2009. The Evotherm WMA was first paved in the Morning of October 29 and continued to the afternoon. The 9.5 mm Superpave control section was paved on October 30. Due to raining, the paving operation was suspended until November 3. The Rediset WMA section was paved on November 3 and the Cecabase RT WMA section on November 4. Locations of the test sections are shown in Figure 3-1 and Table 3-1. The weather and the temperatures during the paving of each test section are listed in Table 3-11.

.

Table 3-11 Weather Condition during Construction

Date	Temperature (^oF)			Weather
	Lowest	Highest	Mean	
10/29/2009	57	81	67	Sunny
10/30/2009	58	80	65	Cloudy - Raining
11/3/2009	42	76	56	Sunny
11/4/2009	42	76	57	Sunny

Paving operations on all WMA test sections and the control section were about the same, except that the temperatures of the mixes at load out and behind the screed were different.

Table 3-12 summarizes the common paving operation information collected during the construction. Tandem end-dump trucks were used for hauling the asphalt mixes. The hauling distance from the asphalt plant to the paving sites was about 40 miles and the hauling time was somewhere between 1 hour to 1 hour and 30 minutes. The mixes in the trucks were properly covered with tarpaulins during the hauling and waiting to be discharged into the paver. The PG 67-22 paving grade asphalt was used for the tack coat and the tack rate was between 0.04 and 0.06 gal/yd^2. With the lesson learned in the first pilot study, contractor used a Material Transfer Vehicle (MTV) for paving the Evotherm and Rediset test sections but not the Cecabase RT WMA test section because the MTV was unexpectedly out of order on November 4. The compacted mat thickness for all sections was 1 ¼ inch.

Table 3-12 Summary of Laydown /Compaction Information for All Sections

Information Required	Results / Remarks
Project location	SR 42 Monroe Co.
Contractor	Reeves Construction Company
Truck type	Tandem end-dump trucks
Haul distance/Haul time	40 miles, 1 hr to 1 hr 30 min
Release agent used (if any)	#1 Asphalt Release, Comp Technologies
Material sticking in truck beds?	No
Use of transfer vehicles	Yes, SB-2500 Road Tec (for Evotherm and Rediset WMA mixes)
Paver type and model	Blaw-Knox PF-3200
Use vibratory screed / heated screed?	Yes/ Yes
Compacted mat thickness	1 ¼ inch
Roller Train	2 vibratory rollers, 1 pneumatic roller,
-Vibratory roller / pattern	Ingersoll Rand DD-130 4 passes of vibration rolling
-Pneumatic roller	Ingersoll Rand PT-125 Continuous rolling
Time when opened to traffic	About 2 hours after compaction

Paving operations and information related to the quality of paving for each test sections are presented below.

Paving Evotherm Test Section

Paving of Evotherm test section started on the southbound lane at about 10:00 am on October 29, 2009. The starting milepost was MP 13.4. At the beginning, the mix production temperature in the plant was the same as that for the conventional HMA, about 310 ^{o}F. After 22 truck loads, the mix production temperature was lowered to 280 ^{o}F. The temperature was further lowered to 260 ^{o}F after the 57th truck load. The corresponding milepost range for the WMA at 260 ^{o}F was between MP 11.5 and 10.2. When the mix was produced at the high temperature, the placement and compaction of the WMA mix were similar to that of the conventional HMA. Hence, the focus was on observing the characteristics and quality of paving and compaction operations of the mix produced at this lower temperature (260 ^{o}F).

During the paving operation, temperatures of the mix at load out and behind the screed were frequently monitored. For the mix produced at 260 ^oF, temperatures of the mix at the load out were between 240^oF and 255^oF and those behind the screed were between 230^oF and 250^oF. These were about 40^oF to 50^oF lower than that for the paving of the conventional 9.5 mm Superpave mix. The paving operation was quite smooth. Occasional blemishes were occurring as shown in Figure 3-3 to Figure 3-6, and requiring hand work to correct them by taking mix out of the spreader box and shoveling it onto the blemished areas to repair the mat. However, the situation was not as bad when compared with the blemish problem that occurred during the paving of the same WMA mix in the first pilot study in 2008. Several engineers from GDOT at the paving site considered the paving quality acceptable.

In addition to taking the temperature readings at various locations using a digital thermometer, infrared images were also taken at the truck load out and behind the screed. Figure 3-7 shows the temperature distribution of the mix at the truck load crust. This infrared image indicated the highest temperature at the crust was about 187 ^oF, and about 157 ^oF near the edges. Figure 3-8 is the infrared image of the uncompacted mat behind the screed. The highest temperature was about 236 ^oF with about 13 ^oF temperature difference between the high and the low across the mat.

Compaction of the mat was followed immediately behind the paver. A 15-ton Ingersoll Rand DD-130 vibratory roller was used for the breakdown rolling, which consisted of 4 passes of vibratory compaction. Then a pneumatic tire roller was used for the intermediate rolling, and the rolling was completed with a steel wheel roller.

Density of the compacted mat was determined using a nuclear density gage. A total of 5 gage readings were taken, and the air voids for these 5 readings were from 5.9 % to 7.7% with the averaged air voids of 7.1 % (see Table A-9). Pavement smoothness was measured using the laser road profiler at every 0.1 mile. The average value was 732 mm/km (the smoothness test result can also be found in Appendix A-7). Table 3-13 summarizes the pertinent data related to the construction of the Evotherm test section.

Figure 3-3 Blemishes from throw back (Evotherm mix)

Figure 3-3 Blemishes from throw back (Evotherm mix)

Figure 3-4 Blemishes from throw back (Evotherm mix)

Figure 3-5 Blemishes from throw back (Evotherm mix)

Figure 3-6 Blemishes from throw back (Evotherm mix)

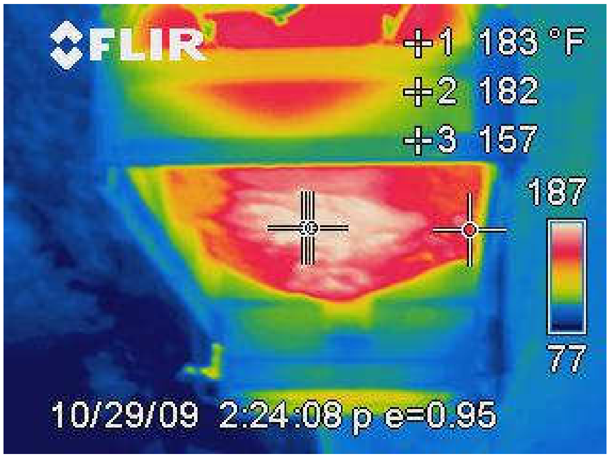

Figure 3-7 IR image on truck load crust (Evotherm mix)

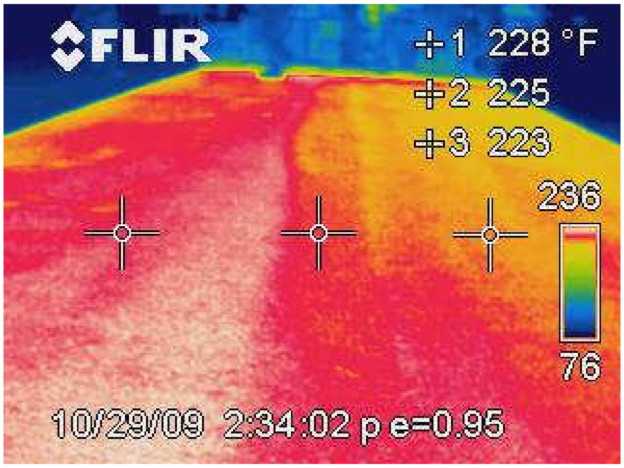

Figure 3-8 IR image of Evotherm mix behind screed

Table 3-13 Summary of Evotherm WMA Mix Test Section Paving Information

Information Required	Results / Remarks
Paving date and time	10/29/2009, 10 am to 3:00 pm
Temperature range at load out	240 to 255°F
Mix temperature behind screed	230 to 250°F
Test section length paved	1.3 miles
Compacted mat thickness	1 ¼ inch
Quality of compacted pavement surface	
-In-place density by nuclear gage	Avg. air voids 7.1%
-Any surface defects	Occasional blemishes due to cold clumps dragging
Time when opened to traffic	2 hr. after paving
Pavement smoothness	732 mm/km

Paving Rediset Test Section

Paving of the Rediset test section started on the southbound lane at about 9:00 am on November 3. The starting milepost was MP 4.6. The starting production temperature was the same as that of the conventional HMA. Then, the temperature at the plant was lowered to 280 °F and the corresponding pavement section was from southbound lane MP 2.5 to the south end, then back to MP 2.2 on northbound lane. However, the quality of the asphalt mat paved with this low temperature was poor. Therefore, the contractor decided not to further lower the mix production temperature. The following observations were based on the Rediset WMA produced at 280 °F.

During the paving process, temperatures of the mix at load out and behind the screed were frequently monitored. Temperatures of the mix at the load out were between 265°F and 270°F and behind the screed between 240°F and 255°F. These were about 20°F to 30°F lower than that for the paving of the conventional 9.5 mm Superpave mix. The paving quality was in general unsatisfactory. Figure 3-9 shows the effect of pulling on the mat by the right extension screed, and Figure 3-10 shows the effects of the gear box stripping. Blemishes happened more frequently on this test section as shown in Figure 3-11 to Figure 3-13. These construction defects have severely affected the paving quality and required extensive corrective actions. At about 3:00 pm, the contractor decided to raise the production temperature to 310 °F after the 56th truck load of the mix was paved.

In addition to taking the temperature readings at various locations using a digital thermometer, infrared images were also taken at the truck load out and behind the screed. Figure 3-14 shows the mat temperature distribution at the truck load crust. This infrared image indicated that the highest temperature at the crust was about 284 °F and the temperature at the edges about 180 °F. The temperature distribution of the uncompacted mat behind the screed is shown in Figure 3-15. The highest temperature was about 256 °F and there was about 20 °F temperature difference on the mat.

Compaction of the mat was immediately followed behind the paver. The same rollers and patterns were used as that for compacting the Evotherm test section. The density of the compacted mat was determined using a nuclear density gage. A total of 5 gage readings were taken, and the air voids ranged from 4.7% to 6.6% with the averaged air voids of 5.8 % (see Table A-10). Pavement smoothness was measured using the laser road profiler at every 0.1 mile. The average value was 845 mm/km (the smoothness test result can also be found in Appendix A-7). Table 3-14 summarizes the pertinent data related to the construction of the Rediset test section.

Table 3-14 Summary of Rediset WMA Mix Test Section Paving Information

Information Required	Results / Remarks
Paving date and time	November 3, 2009, 9 am to 3:00 pm
Temperature range at load out	265 to 270^{o}F
Mix temperature behind screed	240 to 255^{o}F
Test section length paved	0.3 miles
Compacted mat thickness	1 ¼ inch
Quality of compacted pavement surface	
- In-place density by nuclear gage	Avg. air voids 5.8%
- Any surface defects	Frequent blemishes due to cold clumps dragging, pulling and gearbox stripping
Time when opened to traffic	2 hr. after paving
Pavement smoothness	845 mm/km

Figure 3-9 Pulling on Rediset WMA test section

Figure 3-10 Gearbox stripping on Rediset WMA test section

Figure 3-11 Blemish on Rediset WMA test section

Figure 3-12 Blemish on Rediset WMA test section

Figure 3-13 Blemish on Rediset WMA test section

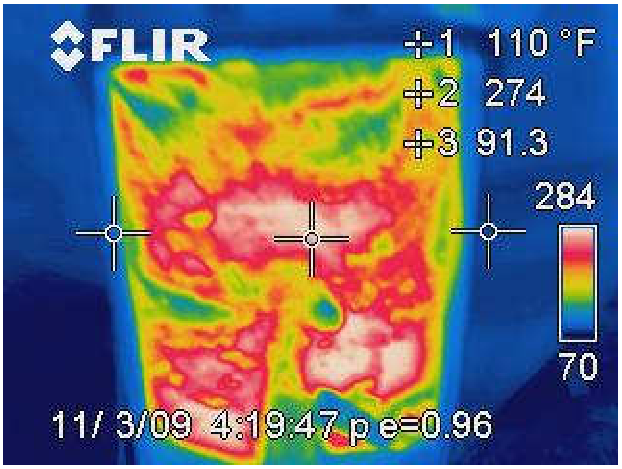

Figure 3-14 IR image on truck load crust (Rediset WMA)

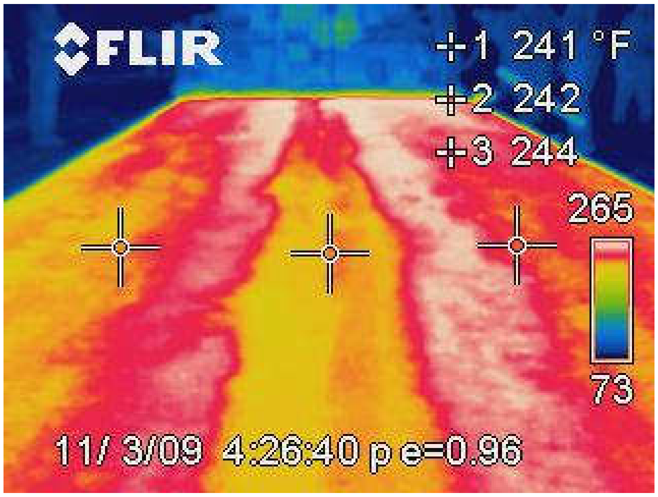

Figure 3-15 IR image of Rediset WMA behind screed

Paving Cecabase RT Test Section

Paving of the Cecabase RT test section started on the northbound lane at about 9:00 am on November 4. The starting milepost was MP 2.2. Although a total of 1,696 ton of the mix was produced, only 4 truck loads (from 33^{rd} to 36^{th} truck load) had the production temperature of 260 ^{o}F while the major portion of the mix was produced at higher temperatures. The following observation was based on the paving operation in the segment where the production temperature was at 260 ^{o}F

One change of the paving process was that the MTV was not used because it was unexpectedly out of order. Temperatures of the mix at the load out were between 245^{o}F and 260^{o}F and that behind the screed between 230^{o}F and 245^{o}F. These were about 20^{o}F to 50^{o}F lower than that for the paving of the conventional 9.5 mm Superpave mix. A large amount of cold mix clumps were present in the hopper and the paving crew had to stop the paver and remove those clumps from the hopper as shown in Figure 3-17. These had caused severe blemish and pulling problems on the mat behind the screed as shown in Figure 3-18 to Figure 3-20.

During the paving process, infrared images were taken at the truck load surface and at the mat behind the screed. Figure 3-21 shows the temperature distribution of truck load when mix was being unloaded. It shows a large number of small clumps of mix with temperature at about 200 ^{o}F. The highest temperature was about 268 ^{o}F. The temperature distribution of the asphalt mat behind the screed is shown in Figure 3-22. The highest temperature was about 250 ^{o}F with about 30 ^{o}F temperature difference across the mat.

Compaction of the mat was immediately followed behind the paver. The same rollers and patterns were used as the Evotherm test section. The density of the compacted mat was determined using a nuclear density gage. A total of 5 gage readings were taken, and the air voids ranged from 5.0% to 6.1% with the averaged air voids of 5.8 % (see Table A-11). Pavement smoothness was measured using the laser road profiler at every 0.1 mile. The average value was 821 mm/km (the smoothness test result can also be found in Appendix A-7). Table 3-15 summarizes the pertinent data related to the construction of the Cecabase RT test section.

Figure 3-16 Cold mix clumps of Cecabase RT WMA in hopper

Figure 3-17 Removal of cold Cecabase RT WMA clumps from hopper

Figure 3-18 Blemish on Cecabase RT test section

Figure 3-19 Blemish on Cecabase RT test section

Figure 3-20 Pulling on Cecabase RT test section

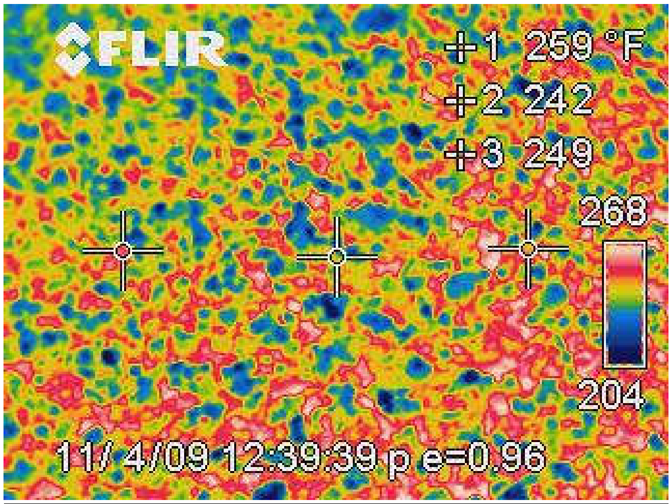

Figure 3-21 IR image on truck load when Cecabase mix was being unloaded

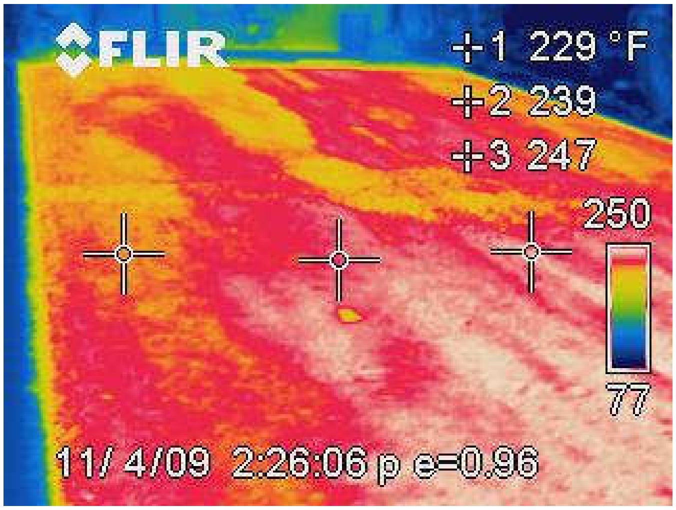

Figure 3-22 IR image of Cecabase mix behind screed

Table 3-15 Summary of Cecabase RT WMA Mix Test Section Paving Information

Information Required	Results / Remarks
Paving date and time	November 4, 2009, 9 am to 3 pm
Temperature range at load out	245 to 260 ^{o}F
Mix temperature behind screed	230 to 245 ^{o}F
Test section length paved	1.8 miles
Compacted mat thickness	1 ¼ inch
Quality of compacted pavement surface	
- In-place density by nuclear gage	Avg. air voids 5.8%
- Any surface defects	Frequent blemishes due to cold clumps dragging and pulling
Time when opened to traffic	2 hr. after paving
Pavement smoothness	821 mm/km

Paving 9.5 mm Superpave Mix Control Section

Paving of the 9.5 mm Superpave mix control section was on October 30, 2009. Regrettably the researchers were not there during the construction of this control section. Since it was still raining in the morning of the day and the contractor was uncertain if the weather would allow for the paving operation, the researchers left the construction site. By the time the researchers were informed that the construction was resumed it was too late for them to rush back to the site. Therefore, the information pertaining to the construction operations for this test section was provided by Mark Bruce in OMR.

Temperatures of the mix at the load out were about 300 ^{o}F and that behind the screed about 295 ^{o}F. Figure 3-23 and Figure 3-24 show the IR images of the mix at the truck load out and the asphalt mat behind the screed. The paving progressed quite smoothly, and no noticeable defects were observed. The mat was quite uniform and smooth and no blemish was observed during the entire paving of the control section, see Figure 3-25.

Compaction of this section was identical to that of the WMA test sections. Density of the compacted mat was determined using a nuclear density gage. A total of 5 gage readings were taken, and the air voids ranged from 5.3% to 6.1% with the averaged air voids of 5.7 % (see Table A-8). Pavement smoothness was measured using the laser road profiler at every 0.1 mile. The average smoothness was 623 mm/km (the smoothness test result can also be found in Appendix A-7). Table 3-16 summarizes the pertinent data related to the construction of the control test section.

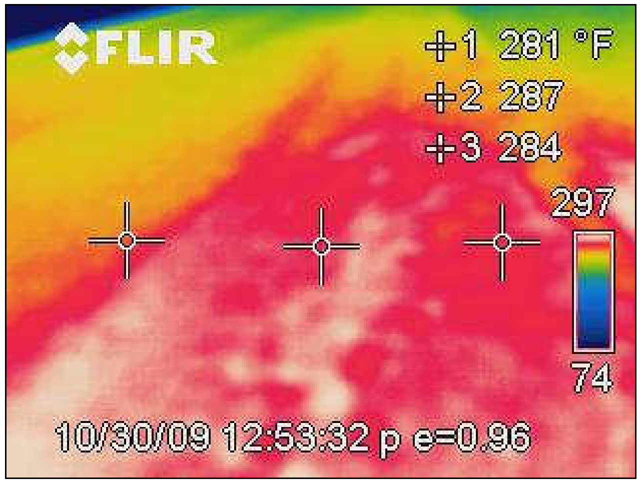

Figure 3-23 IR image on truck load when mix was unloaded

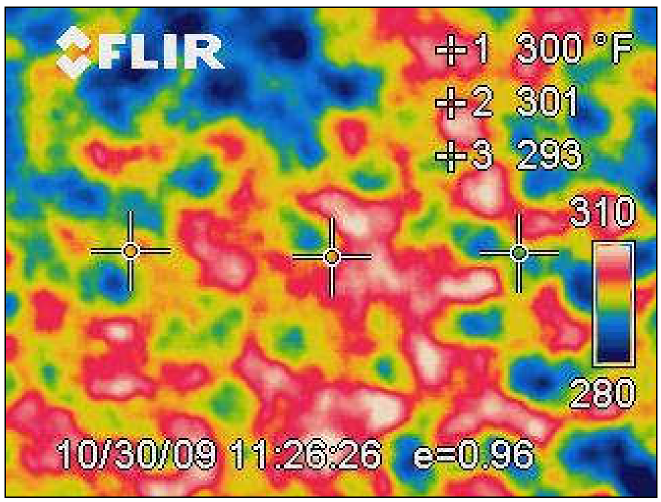

Figure 3-24 IR image on placement mat behind the screed

Figure 3-25 Paving of 9.5 mm Superpave mix

Table 3-16 Summary of 9.5 Superpave Mix Control Section Paving Information

Information Required	Results / Remarks
Paving date and time	October 30, 2009
Temperature range at load out	300 ^oF
Mix temperature behind screed	295 ^oF
Test section length paved	0.7 miles
Compacted mat thickness	1 ¼ inch
Quality of compacted pavement surface	
- In-place density	Gauge avg. 5.7% air voids Core avg. 5.08% air voids
- Any surface defects	Few blemishes from throw back
Time when opened to traffic	2 hr. after paving
Pavement smoothness	623 mm/km

3.4 Discussions and Conclusions

Paving of the 9.5 mm Superpave mix control section was successful and no problems were encountered during the paving operation. Temperature of the mix at the load out was about 300 ^oF and that behind the screed was about 295 ^oF.

For the Evotherm mix produced at 260 ^oF, the temperature of the mix at load out was about 240^oF- 255^oF and that behind the screed was about 230^oF - 250^oF. An MTV was used, which had helped to improve the paving operation. Even with that, some blemishes still occurred on the asphalt mat behind the screed requiring some hand work to correct them. However, the situation was not as bad compared to the blemish problem presented in the first pilot study. Several engineers from GDOT at the paving site considered the paving quality acceptable.

The production temperature for Rediset WMA mix was only lowered to 280 ^oF. The paving quality at this temperature was unacceptable and the contractor decided not to further lower the production temperature. Temperature of the mix at the load out was between 265^oF and 270^oF and that behind the screed was between 240^oF and 255^oF. With the mix produced at 280 ^oF, the paving quality was generally unsatisfactory even with the use of an MTV in the paving train. Blemishes occurred on the asphalt mat behind the screed more frequently than the Evotherm WMA mix described above.

The production temperature of Cecabase RT mix was 260 ^oF and no MTV was used during the paving. Temperature of the mix at the load out was between 245^oF and 260^oF and behind the screed between was 230^oF and 245^oF. A large number of cold mix clumps were present in the hopper requiring the paving crew to remove the clumps. Without having the MTV to remix and break up and remixing the cold mix clumps had no doubt worsen the problem. Severe blemishes and pulling were observed on the asphalt mat behind the screed. Because of the seriousness of the problems, only 4 truckloads of the mix produced at 260 ^{o}F were paved in this test section. If the MTV were used in this paving operation, the quality of the paving could have been improved, although it is doubtful if all the problems observed could have been completely eliminated.

Table 3-17 summarizes the quality of the test sections in terms of the air voids measured by the nuclear gage and the smoothness measured by the laser road profiler. The 9.5 mm Superpave control section has the lowest International Roughness Index (IRI) reading and the least variations of air voids determined using the nuclear density gage. Among the three WMA test sections, the Cecabase RT section seems to have the lowest variations in the air voids. But one must recognize that only a small portion of this test section (4 truckloads of the mix) had the production temperature of 260 ^{o}F. The production temperatures for the mix used in the remaining portion of this test section were higher. On the other hand, no MTV was used in this test section.

Compared with the first pilot study conducted in 2008, blemishes occurred much less frequently for the Evotherm WMA mix test section. Other than the different WMA additive used in this pilot study, use of an MTV in the paving operation had improved the paving quality. Use of an MTV in the paving train could help break up the cold mix clumps during the load out and thus reduce, if not completely eliminate, the cold mix clumps in the hopper and the auger chamber, and also reduce the blemishes developed behind the screed. However, compared with the 9.5 mm Superpave test section, blemish and pulling still occurred. This would indicate that the WMA additives used in this pilot project were still inadequate toward producing the intended effects. This could be due to either of the following two reasons:

(1) The applied dosage rates could be insufficient for the three WMA additives used in this pilot project. Without sufficient dosage of WMA additives, the viscosity of asphalt binder cannot be reduced sufficiently at the prescribed temperatures at the load out and in the auger chamber to allow for smooth paving operation to proceed. The dosage rates used in this pilot project were 0.6%, 0.2%, and 0.44% by weight of the total mix respectively for Evotherm, Rediset and Cecabase RT. The adequate dosage rates recommended by the additive suppliers should be validated in laboratory prior to the field implementation.
(2) The methods for introducing the Rediset and Cecebase RT additives into the mixing operation could be ineffective. One GDOT engineer mentioned that there were some problems with mixing Rediset uniformly in the drum, which delayed the production for 8 hours.

Table 3-17 Compare Paving Quality of WMA Mixes with Control mix

	9.5 mm Superpave	Evotherm WMA	Rediset WMA	Cecabase RT WMA (1)
Additive dosage by wt% of mix	-	0.6%	0.2%	0.44%
Mix Temperatures				
- Production	315°F	260 °F	280 °F	260 °F (1)
- At load out	300°F	240-255 °F	265-270 °F	245-260 °F
- Behind screed	295°F	230-250 °F	240-255 °F	230-245 °F
Use of MTV	No	Yes	Yes	No
Cold mix clumps in Hopper	No	Some	Many	Many
Blemishes behind screed	No	Some	Severe	Severe
% Air Void, by nuclear gage				
- Average	5.7	7.1	5.8	5.8
- Range	0.8	1.8	1.9	1.1
Smoothness (mm/km)	623	732	845	821

(1) Only 4 truckloads of Cecabase RT WMA mix was produced at 260°F. The remaining large portion of the mix was produced at higher temperatures.

Chapter 4 POST-CONSTRUCTION EVALUATION

Certain pertinent properties of the WMA mixes and the control mix were evaluated by performing a series of laboratory tests with the samples prepared in the laboratory using the mixes collected from the asphalt plant during the construction and from the cores taken from the test sections. Table 4-1 summarizes the laboratory tests performed in this study.

Table 4-1 Laboratory Test Programs

Item	Test / Information Required
1	Obtain and determine basic mix properties
2	Moisture susceptibility tests (GDT-66)
3	Prepare 6-150 mm dia. samples for APA tests
4	Perform APA tests (GDT-115)
5	Prepare 4-150 mm dia. samples for Hamburg tests
6	Conduct Hamburg tests by NCAT
7	Conduct fatigue testing by NCAT
8	Cut 10-150 mm dia. cores from test section
9	Conduct bond strength tests
10	Test recovered binder to assess aging effect

4.1 Basic Asphalt Mix Properties

These tests were to determine the basic asphalt mix properties including the Maximum Specific Gravity (G_{mm}), AC, VTM (Voids in Total Mix), VMA (Voids in Mineral Aggregate), VFA (Voids Filled with Asphalt) and aggregate gradation. The tests were conducted at the GDOT OMR laboratory using the asphalt mixes collected in the asphalt plant during the construction. The detailed test results are presented in Appendix B.

Test results of basic volumetric mix properties

Table 4-2 summarizes the basic volumetric mix properties determined from the laboratory test. The detailed test results are presented in Table B-1 to Table B-4 in Appendix B. According to Table A-2 for the 9.5 mm Superpave mix design, the N_{design} was 65. Therefore, 65 number of gyration, which is corresponding to the N_{design} for the approved Superpave mix, was used for preparing the samples reported in Table B-1 to Table B-4.

According to Table A-2 for the 9.5 mm Superpave mix design, the VTM should be at 4.0%; and according to GDOT Standard Specifications Section 828.2.02, VMA should be ≥15 and VFA between 65 and 80 for a 9.5 mm Superpave mix. The results shown in Table 4-2 indicate that the VTM values for all four mixes (between 2.3% and 1.4%) are much lower than the 4%. These low VTM values have contributed to the lower VMA (between 13.0 and 14.7) and higher VFA (between 84.1 and 89.2) than those are permitted by the GDOT Specifications referenced above. Based on the Superpave mix design criteria, VTM should be no less than 2.0% when the samples were compacted to the N_{max}. The results shown in Table 4-2 indicated that the VTM for all three WMA mixes compacted at N_{design} of 65 have the VTM values less than 2.0 %, which was much less than the 4.0% design air voids. It would indicate that these mixes could be susceptible to rutting under the design traffic load. Even for the control mix with the VTM at 2.3% for the samples compacted at the same conditions could indicate the control mix is also marginal for rutting resistance.

Table 4-2 Basic Volumetric Mix Properties

Mix Type	% AC	G_{mm}	G_{mb}	G_{se}	VTM, %	VMA,%	VFA,%
Control	5.46	2.493	2.436	2.715	2.3	14.5	84.1
Evotherm	5.81	2.479	2.440	2.714	1.6	14.7	89.1
Rediset	5.88	2.490	2.455	2.731	1.4	13.0	89.2
Cecabase RT	5.83	2.477	2.430	2.713	1.9	13.4	85.8

Aggregate gradation

Table 4-3 summarizes the tested aggregate gradations for all test mixes. According to the GDOT standard (Section 828), the aggregation gradations for all test mixes meet the acceptance requirements.

Table 4-3 Aggregation Gradation

Sieve Size, mm	Control, % Passing	Evotherm, %Passing	Rediset, %Passing	Cecabase RT, %Passing	JMF, % Passing
19.0	100.0	100.0	100.0	100	100
12.5	98.6	98.2	99.1	98.4	99
9.5	92.0	91.5	91.4	94.3	92
4.75	66.6	61.6	64.4	69.0	66
2.36	45.9	42.1	44.1	46.5	45
1.18	32.7	30.3	31.5	32.8	31
0.600	24.3	22.8	23.7	24.3	22
0.300	18.0	17.0	17.9	18.1	16
0.150	12.8	12.1	12.8	12.8	10
0.075	7.7	7.6	7.8	8.0	7.0

4.2 Moisture Susceptibility Tests

This test is intended to address the concern of potential moisture issues due to the lower temperature of WMA mix that may not completely dry out the aggregates. The tests were performed on the laboratory-compacted specimens at the OMR laboratory. The mixes were collected in the asphalt plant during the construction. The specimens were prepared with the air voids within the 7.0±1.0 % ranges. The test procedure followed the GDOT standard (GDT 66). For each type of mix, 6 specimens were tested, which were divided into two groups, control group and conditioned group. The results of the diametral tensile strengths and the Tensile Strength Ratios (TSR) are summarized in Table 4-4. The detailed test results are presented in Table B-5 to Table B-8

Table 4-4 Moisture Susceptibility Test

Mix Type	Tensile Strength, psi		TSR, %	Stripping
	Control	Conditioned		
Control	110.6	120.5	108.9	Slight
Evotherm	85.3	99.2	116.3	Slight
Rediset	76.9	89.7	116.5	Slight
Cecabase RT	80.9	87.8	108.5	Moderate

The results shown in Table 4-4 indicate that the control mix has the highest tensile strength for both the control specimens and the conditioned specimens than that of the WMA mixes. The TSR values for the control mix and that for the WMA mixes are comparable and are all over 100%. The Cecabase RT mix shows moderate stripping with considerable stripping on coarse particles and moderate stripping on fine particles. The other mixes show only slight stripping. According to the GDOT standard (Section 828), all these mixes meet the acceptance requirements with a minimum tensile strength of 60 psi and a minimum TSR of 80%.

4.3 APA Test

This test is to evaluate the rutting susceptibility of asphalt concrete mixtures using the Asphalt Pavement Analyzer (APA). The tests were performed on the laboratory-compacted specimens prepared at the OMR laboratory. The mixes were collected in the asphalt plant during the construction. The specimens were prepared with the air voids within the 5.0±1.0 % ranges. The test procedure followed the GDOT standard (GDT 115). Table 4-5 summarizes the testing results. The detailed test results are presented in Table B-9 to Table B-12 in Appendix B.

The rutting results for all types of mixes meet the GDOT acceptance requirements (Section 828). Evotherm WMA mix has the highest rut depth value among the 4 mixes tested. The rut depths for other two types of WMA mixes are almost same as that of the control mix.

Table 4-5 Rutting Susceptibility Test

Mix Type	Rutting, mm
Control	5.78
Evotherm	6.55
Rediset	5.79
Cecabase RT	5.93

4.4 Bond Strength Test

This test is intended to assess the adhesive strength between the newly paved resurfacing mixes and the existing pavement surface. Six 6-inch-diameter cores were cut from each test sections two months after the construction. The bond strength tests were performed in the OMR laboratory using the Marshall Tester fitted with a shear head. The tests were performed at the loading speed of 2 in./min and at 77 ^{o}F temperature. Some core samples contained a thin layer of surface treatment material between the existing pavement and the resurfacing layer. Presence of the surface treatment layer at the interface could have affected the bond strength. Actually, some cores taken from the Rediset test section were disintegrated due to the poor bonding at the interface, and 5 new cores had to be re-cut from the Rediset test section for the bond strength testing. Table 4-6 summarizes the bond strength testing results for the four mixes. The results indicate that the control mix had higher bond strength than that of the WMA mixes. The bond strengths among the three WMA mixes are about the same. According to the NCAT study (*9*), average bond strength of 100 psi is the typical bond strength between HMA pavement layers against slippage failure.

Table 4-6 Bond Strength Test Results

Mix Type	Shear Strength, psi							
	#5	#6	#7	#8	#9	#10	Average	Std. Dev.
Control	170.6	333.5	148.7	123.8	145.7	329.3	208.6	87.89
Evotherm	156.0	122.5	127.2	112.6	135.0	140.0	132.2	13.76
Rediset	125.9	126.7	120.2	111.3	101.4	107.7	115.5	9.42
Cecabase RT	156.3	107.5	114.8	116.0	125.2	143.4	127.2	17.23

4.5 Assessment of Short Term Aging Effect of Asphalt Binders

This test is intended to assess the short term aging effect of the asphalt binders used in the control mix and in the WMA mixes during the production of the mixes at the plant. The Abson recovery test was conducted for recovering the asphalt binders from the mixes collected at the asphalt plant. The Dynamic Shear Rheometer test was then performed on the recovered binders. The tests were performed at the OMR laboratory using Bohlin Dynamic Shearing Rheometer. Two samples were tested for each type of asphalt binder. Table 4-7 summarizes the testing results. The detailed test results are presented in Table B-13 to Table B-20 in Appendix B. The results in terms of G^* and $G^*/\sin\delta$ show that there is no significant difference between the asphalt binder of the control mix and that of the three WMA mixes after the short term aging during the production of the mixes at the asphalt plant. This indicates that incorporating the WMA additives in the asphalt binder and the mixing of the WMA mixes at lower temperature did not cause "reduced aging effect" of the binder properties. This would imply that the WMA mixes probably would have no effects in terms of improving rutting resistance, nor reducing low temperature cracking and block cracking compared with the control mix.

Table 4-7 Dynamic Shearing Rheometer Test

Mix Type	G*, Pascal		G*/sinδ, Pascal	
	Sample 1	Sample 2	Sample 1	Sample 2
Control	5599	5333	5637	5371
Evotherm	5348	5337	5389	5378
Rediset	5271	5273	5353	5353
Cecabase RT	5620	5722	5736	5841

Test parameters:

- Strain controlled at the amplitude = 10.00 percent
- Plate diameter = 25.0 mm;
- Plate gap = 1.000 mm
- Test temperature = 60 ^{o}C
- Equilibrium time = 10 minutes

4.6 Fatigue Test

This test was performed by NCAT. Three beam samples for each type of mixes were fabricated using the asphalt mixes collected in the asphalt plant during the construction. The testing procedures follow the AASHTO standard (AASHTO T321-07). The following are some key parameters for this test:

- Air voids of the compacted beam samples: 6.0 ± 0.5%
- Test temperature: 20 ^{o}C ± 0.5 ^{o}C
- Controlled strain amplitude: 800 μs
- Number of samples to be tested: 3

The cycles to failure were computed according to both the AASHTO T321-07 and ASTM D 7460-08. Table 4-8 and Figure 4-1 summarize the testing results. The rankings of cycles to failure from high to low among these 4 mixes are: Cecabase RT mix, Rediset mix, Control mix and Evotherm mix. An ANOVA was performed on the cycles to failure among the 4 mixes. The significance level of the ANOVA was 0.05. The result showed that the p-value, about 0.03, is less than the significance threshold of 0.05, but is not exceptionally low (less than 0.01). Thus, we can say that the cycles to failure among the four mixes show a statistical difference at a moderate significant level.

Table 4-8 Fatigue Test

Mix Type	Sample ID	Air Voids, %	Cycles to Failure (AASHTO)	Cycles to Failure (ASTM)	Initial Stiffness MPa	Termination Stiffness MPa
Control	1	6.5	8740	11160	6023	1506
	4	6.4	9850	18860	6754	1689
	5	6.3	10150	14300	6239	1560
Average		**6.4**	**9580**	**14773**	**6339**	**1585**
Std. Dev.		**0.10**	**742.8**	**3871.8**	**375.6**	**93.9**
Evotherm	3	7.8	7700	16300	5531	1383
	4	7.6	7120	11300	5076	1269
	5	6.3	7370	12810	5392	1348
Average		**7.2**	**7397**	**13470**	**5333**	**1333.3**
Std. Dev.		**0.81**	**290.9**	**2564.5**	**233.2**	**58.3**
Rediset	3	7.5	17020	22670	4521	1130
	6	7.2	12490	31620	4491	1123
	7	7.1	12020	13180	4653	1163
Average		**7.3**	**13843**	**22490**	**4555**	**1139**
Std. Dev.		**0.21**	**2761.1**	**9221.3**	**86.2**	**21.5**
Cecabase RT	1	6.3	27400	45820	3352	838
	3	6.8	17110	26160	3782	946
	4	7.1	12650	17460	4280	1070
Average		**6.7**	**19053**	**29813**	**3805**	**951**
Std. Dev.		**0.40**	**7564.6**	**14528.7**	**464.4**	**116.1**

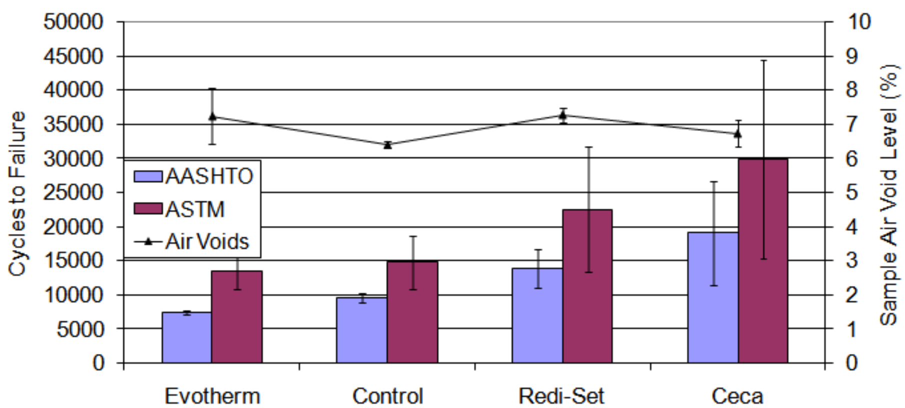

Figure 4-1 Fatigue test results

4.7 Hamburg Wheel-Tracking Test

This test was performed to assess the moisture susceptibility and rutting susceptibility of the mixes. Four 6-inch-diameter cores taken from each test section were tested. The tests were performed by NCAT. The testing procedures followed the AASHTO standard (AASHTO T324-04).

The test results are presented in Table 4-9 and Figure 4-2. On average, Evotherm WMA mix has the lowest rutting and the highest stripping inflection point, and Cecabase RT WMA mix has the highest rutting and the stripping inflection point was close to what Rediset has, which is the lowest one. This indicates that Cecabase RT WMA mix could be more susceptible moisture to than the other mixes. This also confirms the moisture susceptibility test results presented in Section 4.2. In this test the Evotherm WMA has much lower total rutting at 10,000 cycles than the other mixes, while the APA test results have shown the opposite.

Table 4-9 Hamburg Test

Sample ID	Mix Type	Sample Air Voids (%)	Average Air Voids (%)	Rutting Rate, in/hr	Total Rutting @ 10,000, in	Stripping Inflection Point, cycles
CC1	Cecabase RT	5.2	5.4	0.099	0.394	4400
CC4	Cecabase RT	5.5				
CC2	Cecabase RT	6.8	7.5	0.168	0.666	4600
CC3	Cecabase RT	8.1				
Cecabase	**Average**			**0.134**	**0.530**	**4500**
CS2	Control	6.3	5.6	0.122	0.484	5560
CS4	Control	4.9				
CS1	Control	4.7	4.4	0.077	0.307	4650
CS3	Control	4.1				
Control	**Average**			**0.100**	**0.396**	**5105**
EV1	Evotherm	7.7	7.8	0.067	0.267	5450
EV3	Evotherm	7.8				
EV2	Evotherm	7.5	7.8	0.032	0.128	6750
EV4	Evotherm	8.1				
Evotherm	**Average**			**0.050**	**0.198**	**6100**
RS1	Rediset	4.5	6.6	0.089	0.352	4000
RS3	Rediset	8.6				
RS2	Rediset	6.1	6.0	0.086	0.342	4775
RS4	Rediset	5.9				
Rediset	**Average**			**0.088**	**0.347**	**4388**

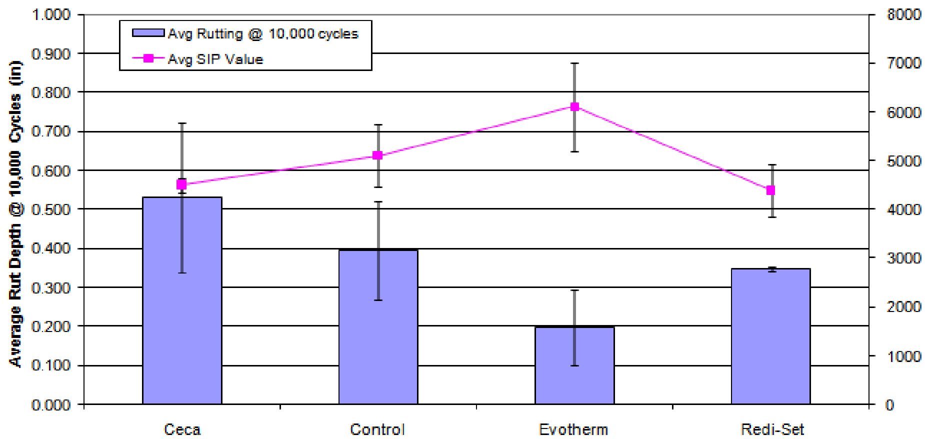

Figure 4-2 Hamburg test results

4.8 Discussions and Conclusions

Table 4-10 summarizes the post-construction laboratory test results.

Table 4-10 Summaries of Post-Construction Laboratory Test Results

	Sample Source	9.5 mm Superpave	Evotherm WMA	Rediset WMA	Cecabase RT WMA
Volumetric Properties	Plant				
-% AC		5.46	5.81	5.88	5.83
-VTM, %		2.3	1.6	1.4	1.9
-VMA, %		14.5	14.7	13.0	13.4
Recovery of Binder	Plant				
-Viscosity, poises		5646	5343	5272	5671
Moisture Susceptibility	Plant				
-Tensile splitting-control, psi		110.6	85.3	76.9	80.9
-Tensile splitting-conditioned, psi		120.5	99.2	89.7	87.8
-TSR, %		109	116	116	109
APA Rutting, mm	Plant	5.78	6.55	5.79	5.93
Hamburg test, Rut @ 10000 cyl, in.	Core	0.40	0.20	0.35	0.53
Bond Strength, psi	Core	208.6	132.2	115.5	127.2
Fatigue Testing	Plant				
-Cyls. to failure		14773	13470	22490	29813
-Stiffness, MPa		1585	2323	1139	951

Determination of the basic asphalt mix properties from the asphalt mixes collected in the asphalt plant during construction indicated that the air voids for all three WMA mixes compacted at N_{design} of 65 were less than 2.0%, much less than the 4.0% design air voids.

Therefore, rutting susceptibility should be closely monitored in the next summer or two on these test sections. The control mix compacted under the same conditions has the VTM at 2.3% and would also indicate that this mix has marginal rutting resistance. The aggregate gradations from all four mixes determined from the mixes produced at the plant were very close to that determined from the quality control tests of the mixes conducted at the plant and both sets of the aggregate gradations are very close to that of the JMF submitted by the contractor.

The dynamic shear Rheometer tests were performed on the asphalt binders recovered from the mixes produced at the plant. The results in terms of G^* and $G^*/\sin\delta$ indicate that there is no significant difference between the asphalt binder of the control mix and that of the three WMA mixes after the short term aging during the production of the mixes in the asphalt plant. This indicates that incorporating the WMA additives in the asphalt binder and the mixing of the WMA mixes at lower temperature did not cause "reduced aging effect" of the binder properties.

Results of the GDT-66 moisture susceptibility tests indicate the 9.5 mm Superpave control mix has higher tensile stability values for both the unconditioned (control) specimens and the conditioned specimens than that of the WMA mixes. The test results also indicate that the moisture conditioned specimens have higher stability values than that of the unconditioned (control) specimens for each type of the mixes used in this pilot test program, including the 9.5 mm Superpave control mix and the 3 WMA mixes. Thus, the TSR values are over 100% for each of the four mixes. Regarding the unusual TSR values, one engineer in OMR explained that it happens at times on finer and "tender" mixes such as 9.5 mm mix. It was thought that the conditioning of the testing pills actually stiffens the mix to some extent. In the meantime, given the higher AC contents in conjunction with hydrated lime, the tensile stability for the conditioned specimen becomes higher. The Cecabase RT mix shows moderate stripping with considerable stripping on coarse particles and moderate stripping on fine particles. The other mixes show only slight stripping. According to the GDOT standard (Section 828), all these mixes meet the acceptance requirements with a minimum tensile strength of 60 psi and a minimum TSR of 80%.

Results from the APA rutting tests indicate that all four mixes meet the GDOT acceptance requirements. Evotherm WMA mix has a slightly higher rut depth value compared with the other three mixes. The rut depths for the other two types of WMA mixes are almost same as that of the control mix.

Results from the Hamburg tests indicated that Evotherm WMA mix has the lowest rutting and the highest stripping inflection point, and Cecabase RT WMA mix has the highest rutting and the stripping inflection point was close to what Rediset has, which is the lowest one. This indicates that Cecabase RT WMA mix would be more susceptible to moisture than the other mixes, which is consistent with the finding from the GDT-66 moisture susceptibility tests. Results from this testing showed that the Evotherm WMA has much lower total rutting at 10,000 cycles than the other mixes, which is opposite to the finding from the APA rutting test results.

Results of the bond strength testing show the bond strengths from the four mixes all exceed 100 psi, with the control mix having the highest value of 208 psi and the three WMA mixes having the strengths around 115 psi to 132 psi. According to the NCAT study (*9*), average bond strength of 100 psi is the typical bond strength between HMA pavement layers against slippage failure.

The fatigue tests were performed on all 4 mixes collected at the asphalt plant. The testing procedures followed the AASHTO standard (AASHTO T321-07). The rankings of cycles to failure from high to low among these 4 mixes are: Cecabase RT mix, Rediset mix, Control mix and Evotherm mix. An ANOVA was performed on the cycles to failure among the 4 mixes. The significance level of the ANOVA was 0.05. The result showed that the p-value, about 0.03, is less than the significance threshold of 0.05, but is not exceptionally low (less than 0.01). Thus, we can say that the cycles to failure among the 4 mixes show a statistical difference at a moderate significant level.

Chapter 5 EVALUATION OF WARM MIX HYDROCARBON EMISSION

This chapter presents the results of a preliminary study that was conducted by Alexander Samoylov and Michael Rodgers of Georgia Tech Research Institute (GTRI) for evaluating the relative magnitude of VOC emissions during the production of WMA and the control mix at the asphalt plant and during the paving operations. A report entitled, "Warm-Mix Asphalt Hydrocarbon Emissions Scoping Study," submitted by the investigators is included in Appendix C of this report.

5.1 Introduction

One of the important considerations in using WMA is the potential for reducing the emissions of VOC that are important precursors to photochemical smog and the creation of secondary fine particulate matter (PM2.5). Therefore, it is important to be able to assess the extent of the reduction of the pollutants for using WMA and compare that with the conventional HMA during the construction of asphalt pavements.

However, determination of absolute emissions rates from industrial processes, including the production of asphalt mixtures in the plant and the paving operations, is normally a time consuming, costly and difficult process as these emission rates are often strongly impacted by local environmental conditions and normal variations in the process being measured. For this reason, scoping studies are often undertaken to ascertain whether emissions from a new process are likely to be substantially different from the one that it replaces. This study was conceived as a scoping study to determine and compare VOC emissions from the WMA mixtures used in the pilot project and the control mix.

5.2 Measurement Approach

The basic study approach was to compare the observed VOC concentrations just above surface of various WMA mixes with those associated with a control mix using both free air and an open topped chamber (cone). Measurements of surface fluxes using near surface concentration measurements normally require the use of eddy correlation, gradient or Bowen ratio methods that require substantial ancillary micrometeorological measurements in addition to the concentration measurements. In the case of asphalt mixtures, this need for extensive supporting meteorological measurements is greatly reduced since the surface temperature of the asphalt mix (260 to 300 ^{o}F) is much higher than that of the ambient air and the near surface energy balance is almost completely controlled by the asphalt mix at least so long as the surface winds are not too high. Thus, for this scoping study, measurements were limited to the evaluation of the near surface concentration gradients and exhaust concentrations from the open topped chambers based on the assumption that ventilation rates induced by the surface temperature conditions were comparable for all the mixtures.

All VOC concentration measurements made during the study were performed using a Siemens Ultramat 23® Non-Dispersive Infrared (NDIR) detector equipped with a heated type 316 stainless steel inlet system. Measurements were made at distances 1, 3, 10, 30, and 100 cm above the surface of the asphalt mixtures in open air and at the exhaust from a variety of simple open-topped chambers with a six second measurement update cycle. These VOC concentration measurements were conducted at the asphalt plant when these mixes were produced and at the paving during the paving operations.

Regarding the VOC measurement protocol, Michael Rodgers further explained as follows: "Current AP-42 emissions factors for asphalt paving are still based on a series of grab sample enclosure measurements conducted during the 1970's. Since then EPA has issued substantial technical guidance on conducting stack emissions testing at asphalt plants but has not provided any guidance or standard protocols for field testing of emissions from asphalt transport and pavements. In the mid 1990's NSF and the National Strategic Highway Research Program sponsored a study conducted in collaboration with the South Coast Air Quality Management District and the University of Southern California to establish a protocol for pavement emissions measurements but the resulting protocol, based on grab sampling and gas chromatographic testing, was never adopted by U.S. EPA. The NDIR measurement techniques used in this study are derived from EPA standard methods used for dynamometer testing of vehicle emissions (EPA-75 test procedure) and are considered EPA equivalent methods for this purpose."[1]

Asphalt Plant Measurements

The VOC measurements at the asphalt plant were made within 1-2 minutes after the mix was discharged from the silo into the truck. All measurements were made near the center of the truck bed at distances of 1, 3, 10, 30, and 100 centimeters from the asphalt surface using a heated stainless steel line and a Siemens Ultramat 23® NDIR detector. In addition to these open air measurement some semi-controlled measurements were performed using open topped chambers (cones) resting on the asphalt surface. Several measurements were excluded from the data set because delay between truck loading and the time the vehicle was made available for the measurements was too long (i.e. more than 20 minutes).

Paving Site Measurements

Measurements at the paving site were conducted using the same general approach as that used for at the asphalt plant. In this case the stainless steel inlet was placed close to the centerline of the freshly paved asphalt mat. Measurements were performed in two separate stages, on the uncompacted asphalt mat immediately behind the screed and after the rollers had compacted the mat at least once.

[1] The explanation on the VOC measurement protocol was provided by Michael Rodgers when the final report was reviewed by GDOT. It was not included in the Appendix C that is the report prepared by Michael Rodgers.

Table 5-1 shows more specific information regarding the measurement program including the measurement day, general environmental conditions, asphalt temperatures and pavement status.

Table 5-1 VOC Emission Study Conditions

Day#	Date	Additive Measured	Temp Morning, (deg F)	Temp Afternoon, (deg F)	Wind Conditions	Humidity	Asphalt Temperature (deg F)			Pavement Rolled	Pavement Unrolled
							300	280	260		
1	10/29/2009	Evotherm	40-45	55-60	Strong	Medium	X	X	X		
2	10/30/2009	Low Rediset / Control Mix	40-45	50-55	Light	High	X			X	X
3	11/3/2009	Rediset	40-45	55-60	Moderate	Medium	X	X		X	X
4	11/4/2009	CECA	45-50	60-65	Light	Medium	X	X	X	X	X

5.3 Results

Evotherm Additive

The Evotherm WMA mix was tested on October 29th 2009. In the morning hours, ambient temperatures ranged from 40-45 °F and were associated with the very strong winds. The wind moderated significantly in the afternoon and ambient temperatures rose to 55-60 °F. VOC concentration measurements were conducted at three different WMA temperatures: 300°F, 280°F and 260°F and were conducted only at the asphalt plant. The results of the measurements are summarized in Table 5-2.

Table 5-2 VOC Measurements at Asphalt Plant – Evotherm WMA

Temperature °F	**Distance, cm**					**Cone**
	1	**3**	**10**	**30**	**100**	
260	19	18	15	12	10	17
280	26	25	18	15	13	21
300	11	9	11	9	7	-

Control Mix

Measurements of the control mix were performed on October 30th. Weather conditions for that day were considerably different from the day before. Temperatures were between 45 °F and 55 °F with high humidity and light drizzle that became light rain at times. Winds were very light.

Results of the VOC concentration measurements at the plant and at the paving site are presented in Table 5-3. Results of the VOC measurements on uncompacted and compacted mat at the paving site are very similar. Compacted mat appears to generate a slightly stronger source of VOC emission but given the variability of external conditions and the small absolute difference, the differences between uncompacted and compacted conditions are minimal.

Table 5-3 VOC Measurements at Asphalt Plant and Paving Site–Control Mix

Temperature °F	**Distance, cm**					**Cone**
	1	**3**	**10**	**30**	**100**	
Plant						
300 °F	14.3	12.3	9.2	7.3	6.1	13.2
Paving Site						
Uncompacted	-	-	27	26	24	29
Compacted	-	-	27	26	27	28

Rediset Additive

The Rediset WMA mix was first produced in the morning of October 30. By 10 a.m. the weather turned to light drizzle and paving was switched to the conventional mix. It became apparent the next day that an incorrect proportion, only about 30% of the required dosage of Rediset additive was used for the mix. Paving of Rediset WMA mix was resumed on November

3rd, and the correct dosage rate of Rediset additive was tested. In the morning of November 3rd, temperatures were 40 °F -45 °F with very light wind conditions and in the afternoon reached 55 °F - 60°F with the wind increasing and becoming moderate.

The VOC measurements at the asphalt plant were performed at two temperatures: 300 °F and 280 °F. Results of these measurements, along with the measurements made on October 30 are summarized in Table 5-4. Measurements were also conducted at the paving site. Results of the VOC measurements at the uncompacted and compacted asphalt mats are also presented in Table 5-4 indicating no significant differences of VOC emission between the 280 °F and 300 °F production temperatures at the plant and no difference between the uncompacted and compacted conditions at the paving site.

Table 5-4 Rediset Additive VOC Measurements

Measurement	**Distance, cm**					**Cone**			
	1	**3**	**10**	**30**	**100**	**Cone1**	**Cone 2**	**Cone 3**	**Cone 4**
Plant									
260 °F	-	-	-	-	-	-	-	-	-
280 °F	24	27	24	25	25	27	27	25	26
300 °F	20	20	19	19	18	25	28	28	28
Incorrect,300 °F	14	10	9	8	10	14	-	-	-
Paving Site									
Uncompacted	-	-	18	20	20	17	-	20	18
Compacted	-	-	19	20	20	-	-	-	-

Cecabase RT Additive

VOC concentration measurements of Cecabase RT WMA mix were carried out on November 4th. Temperatures in the morning hours were between 45 °F - 50 °F and in the afternoon between 60 °F - 65°F with light wind conditions. VOC concentration measurements were made at the asphalt plant at three temperatures: 300°F, 280°F, and 260°F. VOC concentration measurements were made at the paving site at 260°F and at 300°F. The results are summarized in Table 5-5. The results show no significant differences for the mix produced at 260 °F, 280 °F and 300 °F, and no difference between the uncompacted and compacted conditions at the paving site.

Table 5-5 Cecabase RT Additive VOC Measurements

Measurement	Distance, cm					Cone		
	1	3	10	30	100	Cone1	Cone 3	Cone 4
Plant								
260 ^oF	27	28	27	29	27	28	29	28
280 ^oF	26	25	26	24	24	27	27	27
300 ^oF	24	24	24	20	19	25	25	24
Paving Site								
Uncomp, 260 ^oF	-	-	25	21	25	26	27	26
Uncomp, 300 ^oF	-	-	27	28	27	26	25	29
Compact, 260 ^oF	-	-	27	26	26	-	-	-
Compact, 300 ^oF	-	-	27	27	28	-	-	-

5.4 Conclusions

This study was designed as a screening test to examine if there were significant variations in VOC emissions from the 3 different WMA mixes and the control mix. Based on the results presented in this chapter, it appears that VOC emissions generated from any of the WMA mixes used in this project are not significantly different (more than a factor of two) from that of the control mix under the same environmental conditions. Further, the results show only very small and likely insignificant differences between the mixes using 3 different WMA additives in terms of observed VOC concentrations, making it unlikely that VOC emissions would be an important factor in the selection of a preferred WMA additive among the 3 candidate WMA additives used in this project.

Michael Rodgers further provided an explanation and suggestion on the testing result as follows: "While there are a variety of theoretical reasons to believe that WMA should have lower VOC emissions than conventional mix, the current measurements were unable to establish that the emissions were different. While these results could indicate that, in fact, the emissions are the same, we believe that it is more likely due to one or more other factors. For example, the gradient method used in these measurements is sensitive to differences in horizontal winds which differed significantly from day to day during the measurement period and could be only partially corrected for. Additionally, asphalt is a complex mixture and day-to-day variations in the mixture could contribute to measurement uncertainty. The absence of replicate measurements on different batches of nominally the same mixture makes evaluation of this variability difficult. There are, of course, a variety of other possibilities as well, most of which are associated with the limited experimental controls used for the current study. We would recommend that future studies of these emissions also include controlled studies (e.g. closed chamber studies on test plots) and additional replicates for each of the mixtures to ensure that these uncertainties can be more fully accounted for."[2]

[2] The explanation and suggestion on the testing result was provided by Michael Rodgers when the final report was reviewed by GDOT. It was not included in the Appendix C that is the report prepared by Michael Rodgers.

Chapter 6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The following conclusions are offered based on the work that has been performed for this study.

(1) The asphalt mixes for the four test sections were produced by the Astec continuous drum plant with a production rate of 220 tons per hour. The relevant mix production and paving data for the four mixes are summarized in Table 6-1 below. The quality control testing was performed on the mixes produced in the asphalt plant, and the test results indicated that deviations from the JMF for the asphalt content and aggregate gradation were within the acceptance limits for all four mixes tested.

Table 6-1 Summary of Asphalt Plant Production and Paving Data

	Results			
Mix Type	**9.5 mm Superpave**	**Evotherm**	**Rediset**	**Cecabase RT**
Paving Date	10/30/2009	10/29/2009	11/3/2009	11/4/2009
Tonnage produced	1098.7 ton	1715 ton	1592.05 ton	1696.32 ton
Additive dosage, wt% of mix		0.6%	0.2%	0.44%
Fuel consumption, gal / ton	Not available	Not available	Not available	Not available
Mix Temperatures ^{o}F				
-Production	315	260	280	260
-At load out	300	240 - 255	265 - 270	265 - 260
-Behind screed	295	230 – 250	240 - 255	230 - 245
Test section length paved	0.7 miles	1.3 miles	0.3 miles	1.8 miles
Use of MTV	no	yes	yes	no
Compacted mat thickness	1 ¼ inch	1 ¼ inch	1 ¼ inch	1 ¼ inch
In-place VTM	5.7%	7.1%	5.8%	5.8%
Surface defects	no	Occasional blemishes	Frequent blemishes, pulling and stripping	Frequent blemishes and pulling
Time opened to traffic	2 hrs.	2 hrs.	2 hrs.	2 hrs.
Pavement smoothness	623 mm/km	732 mm/km	845 mm/km	822 mm/km

(2) Paving of the 9.5 mm Superpave mix control section was successful and did not encounter any problems during the paving operation. Paving of the Evotherm WMA mix was considered acceptable. An MTV was used in the paving train and that had helped improve the paving operation. Even with that, some blemishes still occurred on the asphalt mat behind the screed and required some hand work to correct them. An MTV was used also in the paving train during the paving of the Rediset WMA mix. However, the paving quality was generally unsatisfactory. Blemishes occurred on the asphalt mat behind the screed more

frequently than occurred on the Evotherm mix. Paving of the Cecabase RT WMA mix did not utilize an MTV. The quality of paving with the mix produced at 260 ^{o}F was poor with a large number of cold mix clumps present in the hopper requiring the paving crew to remove the clumps. Severe blemishes and pulling was observed on the asphalt mat behind the screed.

(3) Compared with the first pilot study conducted in 2008, blemishes occurred much less frequently for the Evotherm WMA mix test section. Other than the different WMA additive used in this pilot study, use of an MTV in the paving operation had improved the paving quality. However, compared with the 9.5 mm Superpave control section, blemish and pulling still occurred. This would indicate that the WMA additives used in this pilot project were inadequate toward producing the intended effects. This could be due to either of the following two reasons: (1) the applied dosage rates could be insufficient for the three WMA additives used in this pilot project. The adequate dosage rates recommended by the additive suppliers should be validated in the laboratory prior to the field implementation; or (2) the methods for introducing the Rediset and Cecabase RT additives into the mixing operation could be ineffective.

(4) Laboratory tests were performed on the asphalt mix collected from the asphalt plant during the construction and the cores taken from the four test sections. Table 6-2 summarizes the post-construction laboratory test results.

Table 6-2 Summaries of Post-Construction Laboratory Test Results

	9.5 mm Superpave	Evotherm WMA	Rediset WMA	Cecabase RT WMA
Volumetric Properties				
-% AC	5.46	5.81	5.88	5.83
-VTM, %	2.3	1.6	1.4	1.9
-VMA, %	14.5	14.7	13.0	13.4
Recovery of Binder				
-Viscosity, poises	5646	5343	5272	5671
Moisture Susceptibility				
-Tensile splitting-control, psi	110.6	85.3	76.9	80.9
-Tensile splitting-conditioned, psi	120.5	99.2	89.7	87.8
-TSR, %	109	116	116	109
APA Rutting, mm	5.78	6.55	5.79	5.93
Hamburg test, Rut @ 10000 cyl. , in.	0.40	0.20	0.35	0.53
Bond Strength, psi	208.6	132.2	115.5	127.2
Fatigue Testing				
-cyls. to failure	14773	13470	22490	29813
-Stiffness, MPa	1585	2323	1139	951

- The air voids for all three WMA mixes compacted at N_{design} of 65 were less than 2.0%, much less than the 4.0% design air voids. Therefore, rutting susceptibility should be closely monitored in the next summer or two on these test sections. The control mix compacted under the same conditions has the VTM at 2.3% and would also indicate this mix has marginal rutting resistance.

- The dynamic shear Rheometer tests were performed on the asphalt binders recovered from the mixes produced at the plant. The results in terms of G^* and $G^*/\sin\delta$ indicate that there are no significant differences between the asphalt binder of the control mix and that of the three WMA mixes after the short term aging during the production of the mixes in the asphalt plant.

- Results of the GDT-66 moisture susceptibility tests indicate the 9.5 mm Superpave control mix has higher tensile stability values for both the unconditioned (control) specimens and the conditioned specimens than that of the WMA mixes. The test results also indicate that the moisture conditioned specimens have higher stability values than that of the unconditioned (control) specimens for each type of the mixes used in this pilot test program, including the 9.5 mm Superpave control mix and the three WMA mixes. Thus, the TSR values are over 100% for each of the four mixes. Regarding the unusual TSR values, one engineer in OMR explained that it happens at times on finer and "tender" mixes such as 9.5 mm mix. It was thought that the conditioning of the testing pills actually stiffens the mix to some extent. In the meantime, given the higher AC contents in conjunction with hydrated lime, the tensile stability for the conditioned specimen becomes higher. The Cecabase RT mix shows moderate stripping with considerable stripping on coarse particles and moderate stripping on fine particles. The other mixes show only slight stripping. According to the GDOT standard (Section 828), all these mixes meet the acceptance requirements with a minimum tensile strength of 60 psi and a minimum TSR of 80%.

- Results from the APA rutting tests indicated that all 4 mixes meet the GDOT acceptance requirements. Evotherm WMA mix has a slightly higher rut depth value compared with the other three mixes.

- Results from the Hamburg tests indicated that the Evotherm WMA mix has the lowest rutting and the highest stripping inflection point, and Cecabase RT WMA mix has the highest rutting and the stripping inflection point was close to what Rediset has, which is the lowest one. This indicates that Cecabase RT WMA mix could have more moisture susceptibility than the other mixes, which is consistent with the finding from the GDT-66 moisture susceptibility tests. Results from this testing showed that the Evotherm WMA has much lower total rutting at 10,000 cycles than the other mixes, which is opposite to the finding from the APA rutting test results.

- Results of the bond strength testing showed that the bond strengths from all the 4 mixes exceed 100 psi, with the control mix having the highest value of 208 psi and the 3 WMA mixes having the strengths around 115 psi to 132 psi. Average bond strength of 100 psi is the typical bond strength between HMA pavement layers against slippage failure.

- The fatigue tests were performed on all 4 mixes following the AASHTO T321-07 standard. The rankings of cycles to failure from high to low among these 4 mixes are:

Cecabase RT mix, Rediset mix, Control mix and Evotherm mix. An ANOVA was performed on the cycles to failure among the four mixes. The significance level of the ANOVA was 0.05. The result showed that the p-value, about 0.03, is less than the significance threshold of 0.05, but is not exceptionally low (less than 0.01). Thus, we can say that the cycles to failure among the 4 mixes show a statistical difference at a moderate significant level.

(5) A preliminary study was conducted by GTRI to evaluate the relative magnitude of VOC emissions during the production of WMA and the control mix at the asphalt plant and during the paving operations. Results of the VOC emissions measurements for the four mixes indicate that VOC emissions generated from any of the WMA mixes used in this project at the asphalt plant and at the paving site are not significantly different from that of the control mix.

6.2 Recommendations

The following recommendations are offered with an aim toward better understanding and improving the quality of the WMA paving operation and performance.

(1) Continuous pavement condition monitoring on the test sections is highly needed to thoroughly evaluate the actual performance. It is especially important to closely monitor the rutting susceptibility in the next summer or two.

(2) There was problem mixing the additives uniformly into the mixing drum during the test of Rediset. It is recommended to develop a test method to quantitatively measure the percentage of additive applied right after the additives are fully mixed in the drum to ensure the right percentage of additives is introduced uniformly into the drum in the plant.

(3) When WMA is used in a paving project, the following information in addition to that stipulated under GDOT Standard Specifications Section 400.1.03 should be included when the contractor submits the JMF after the contract has been awarded:

- The amount of WMA additive as percent of net binder used in the mix or the percent of the total mix weights used, particularly when RAP is used.
- A viscosity vs. temperature chart for the binder incorporating the specified WMA additive dosage.
- The procedure for incorporating the WMA additive into the mix, the mixing temperature and mixing process in the laboratory mixing operations.
- Temperature and duration of aging, if different from the standard for aged at 135^{o}C (275^{o}F) in an oven for 2 hours after mixing and prior to compaction.
- Any deviation from the Superpave mix design procedures.

(4) Submit the proposed JMF for approval at least 4 weeks (instead of 2 weeks) before the beginning of the asphalt plant mixing operation. This would allow the OMR sufficient time to conduct more thorough mix design verification testing.

(5) It would be desirable to request the WMA additive supplier to conduct the mix design verification testing based on the JMF, the aggregates, and the binder submitted by the contractor, and forward the verification mix design results to the OMR. It would be highly desirable that WMA additive suppliers also provide the following information for using the WMA additive during the construction.

- Minimum threshold mix temperature behind the screed
- Maximum allowable storage time in silo
- Maximum allowable storage time in truck

(6) OMR should perform mix design verification testing based on the JMF, aggregates, and binder submitted by the contractor and compare the results with those from the WMA additive suppliers. The mixing temperature and the compaction temperature as suggested by the WMA additive suppliers should be carefully evaluated during the laboratory mix design. Workability of the mix should also be carefully evaluated.

(7) It may be desirable to intentionally vary the temperatures of the mix at load out, behind the screed, and during the holding time to assess the sensitivity of the temperatures and the storage time on the constructability of the WMA mix in the test section of a construction project. This would provide valuable information for the contractor and for the Quality Control Technician during the mainline paving. If the results indicate that the WMA mix used is too sensitive to the temperature variations, the project engineer perhaps should consider requesting the contractor to use an MTV to mitigate the temperature sensitivity of the WMA mix used for the project.

(8) OMR and the Office of Maintenance should cooperate in using additional WMA sections to gain experience of using different types of WMA mixes. The proposed research program for this pilot study presented in this report, including the Post-Construction Laboratory Testing and Evaluation Program, can be used to evaluate the constructability and the properties of the mixes.

REFERENCES

1. Hurley, G.C. and B. D. Prowell. "Evaluation of Potential Processes for Warm Mix Asphalt," Presented at the 2006 Annual Meeting of the Association of Asphalt Paving Technologists.
2. Prowell, B.D., Hurley, G.C., and Crews, E. "Field Performance of Warm Mix Asphalt at the NCAT Test Track" Presented at the 86th Annual Meeting of the Transportation Research Board, January 21-25, 2007, Washington, DC.
3. Hurley, G.C. and B. D. Prowell. "Field Performance of Warm Mix Asphalt," Presented at the TRB 2008 Annual Meeting.
4. Muench, Stephen T., et al. "Assessing the Potential for Warm Mix Asphalt Technology Adoption," TRB 2007 Annual Meeting. January 2007.
5. Brown, D. C. "Warm Mix: the Lights are Green, Hot Mix Asphalt Technology," Jan/Feb 2008.
6. Corrigan, M., et al. "Warm-Mix Asphalt: European Practice," Federal Highway Administration Technical Report, FHWA-PL-08-007, February 2008.
7. Diefenderfer, S.D., K.K. McGhee, and B.M. Donaldson. "Installation of Warm Mix Asphalt Projects in Virginia," Virginia Transportation Research Council, Report No FHWA/VTRC 07-R25, April 2007.
8. Swanson, Malcolm. "Double Barrel Green System – An Equipment Means to Produce Warm Mix," a PowerPoint Presentation, ASTEC Industrial, Inc.
9. West, R.C., J. Zhang, and J. Moore, "Evaluation of Bond Strength between pavement Layers," NCAT Report 05-08, National Center for Asphalt Technology, Dec 2005.

APPENDIX A MIX DESIGN AND PRODUCTION

Table A-1 9.5 mm Superpave Mix Job Mix Formula
Submitted by Reeves Construction Co.

Table A-2 9.5 mm Superpave Mix Design

Table A-3 9.5 mm Superpave Mix Asphalt Plant QC Test Results

Table A-4 Evotherm WMA Mix Asphalt Plant QC Test Results

Table A-5 Rediset WMA Mix Asphalt Plant QC Test Results

Table A-6 Cecabase RT WMA Mix Asphalt Plant QC Test Results

Table A-7 Smoothness Test Result

Table A-8 9.5 mm Superpave Mix Compaction QC Test Results

Table A-9 Evotherm WMA Mix Compaction QC Test Results

Table A-10 Rediset WMA Mix Compaction QC Test Results

Table A-11 Cecabase RT WMA Mix Compaction QC Test Results

Table A-1 9.5 mm Superpave Mix Job Mix Formula
Submitted by Reeves Construction Co.

REEVES CONSTRUCTION CO.

REQUEST FOR APPROVAL/REVISION OF ASPHALTIC CONCRETE JOB MIX FORMULA

TYPES OF MIX(ES): 9.5SP II 9.5SP RAP II

PROJECT: CSSTP-M003-00(837)01 COUNTY: MONROE

CONTRACT I.D. NUMBER: B13260-08-000-0 DATE: 4/23/2009

FROM: REEVES CONSTRUCTION COMPANY CONTRACTOR/SUBCONTRACTOR

FIELD BCE MARK BRUCE

TO: AREA ENGINEER BRINK STOKES PLANT LOCATION POSTELL

PERSON(S) RESPONSIBLE FOR QUALITY CONTROL: TONY YOUGHN

MATERIALS DATA

TYPE MIX	MIX I.D. NO.	AGG. SIZE	%	SOURCE #	SOURCE / LOCATION
9.5SP II	28-9.5SP-47-7	7	7	028C	RINKER MAT'LS @ POSTELL, GA
		89	34	028C	RINKER MAT'LS @ POSTELL, GA
		M10	21	028C	RINKER MAT'LS @ POSTELL, GA
		W10	37	028C	RINKER MAT'LS @ POSTELL, GA
		LIME	1.00%		
9.5SP RAP II	28R-9.5SP-39-7	RAP	15	004R	04-2002-2
		7	5	028C	RINKER MAT'LS @ POSTELL, GA
		89	35	028C	RINKER MAT'LS @ POSTELL, GA
		M10	15	028C	RINKER MAT'LS @ POSTELL, GA
		W10	29	028C	RINKER MAT'LS @ POSTELL, GA
		LIME	'.925		
GRADE AC	PG67-22			4	REEVES TERMINAL, PERRY, GA
TYPE OF ANTI-STRIP, ADD.:	L/QD:	X		6	TENN-LUTRELL, MACON, GA

MIXTURE DATA

SIEVE SIZE	TYPE MIX 9.5SP II	TYPE MIX	TYPE MIX 9.5SP R II
11/2" OR 37.5MM			
1" OR 25MM			
3/4" OR 19MM	100		100
1/2" OR12.5MM	99		99
3/8" OR 9.5MM	92		92
NO. 4 OR 4.75MM	66		66
NO. 8 OR 2.36MM	45		45
NO. 50 OR 300UM			
NO. 200 OR 0.75UM	7		7
PERCENT AC	5.6		5.6
THEO. SP. GRAV.	2.502		2.502
ACT. SP. GRAV.	2.429		2.432
TEMP. (F)(C)	310		310

APPROVED: ✓ DISAPPROVED: ______ BY: Mark B DATE: 4/23/05

REMARKS: SR-42 407178

Table A-2 9.5 mm Superpave Mix Design

Department of Transportation - State of Georgia
Asphaltic Concrete Design Report

Date: 11/28/2006

Mix Type: 9.5mmSP   Mix I.D. No.: 28R-9.5SP-39-7   Design Lab: Reeves

This design is approved for use contingent upon approval by the Engineer of a Job Mix Formula. A change in materials properties or unacceptable field performance may invalidate this design.

Materials

Aggregate	Size, Grade Type (code)	%Used With Lime	%Used W.out Lime	Group	Source Code	Source Name
	RAP	15			004R	Reeves Construction Co. (RAP) @ Postell 3,000 T 11/27/0
	7	5		IIA	028C	Rinker Materials, Postell
	89	35		IIA	028C	Rinker Materials, Postell
	M10	15		IIA	028C	Rinker Materials, Postell
	W10	29		IIA	028C	Rinker Materials, Postell
Mineral Filler						Approved Source
Asph. Cement	67-22				0002	Citgo @ Savannah
Hydr. Lime		0.925				Approved Source
Additive						Approved Source

Hydrated Lime ☑ Additive ☐ Nini: 6 Nmax: Ndes: 65

% AC	GMM	GmmIni	GmmNdes	%Air Voids	VMA	VFA	DustRatio	GMB
5.00	2.525	88.7	95.6	4.4	16.1	72.5	1.05	2.413
5.50	2.506	90.5	97.0	3.0	16.0	80.9	0.96	2.429
		< 91.5	96	4.0	> 16.0	72 - 76	0.8 - 1.6	

Aggregate Gradations

Type	37.5mm	25.0mm	19.0mm	12.5mm	9.5mm	4.75mm	2.36mm	1.18mm	600µm	300µm	150µm	75µm
RAP	100	100	100	93	86	72	56	43	33	24	17	11.0
7	100	100	100	95	52	2	1	0	0	0	0	0.0
89	100	100	100	100	96	26	5	2	0	0	0	0.0
M10	100	100	100	100	100	99	81	55	42	32	22	12.0
W10	100	100	100	100	100	99	75	50	33	22	12	3.0
Lime:	0	0	0	0	0	0	0	0	0	0	100	100
CmbGrd	100	100	100	99	94	64	45	31	22	16	10	5.2

Diametral Tensile Splitting

	Lime	Liquid
Conditioned (kPa)	695.6	
Control (kPa)	856.9	
Retained Stability	81.2	

Job Mix Formula Critera

	Optimum AC %	Film Thick
Ndes	5.14	8.52
LWT (mm)	2.71	
Aggr. Eff. Gravity	2.732	

Remarks: Type II
Checkpoint Design based on Mix ID# 028X151_9.5SP-21-007L.
RAP = 14.9% aggregate & 0.8% AC; RAP AC = 5.70%.
Stockpile No. 004-2-2000* Reeves Construction @ Postell.
Calibration factor =-0.28%.
* 4-2-2000 (1R2006)

Sheila L. Hines (MC)

State Bituminous Construction Engineer

Table A-3 9.5 mm Superpave Mix Asphalt Plant QC Test Results

GDOT 159 - Asphaltic Concrete Lot Worksheet (ENGLISH)

Plant Number: 004 **Project ID: CSSTP-M003-00(837)01** **Type Mix: 9.5mm SP** **Level: N/A** **Lot Number: 07**

Contract ID:	B13260-08-000-0	Date:	10/30/2009	Tech ID:	523
Mix ID:	28R-9.5SP-39-7	Contractor ID:	2RE390	County Number:	207
District Number:	3	Corrected copy:	N	Blend:	RAP
Type course:	S	Completed report:	Y		

AC Grade: PG67-22 AC Source No: 0002 Hyd. Lime: Y Liq. Add.: N Quan. This report (tons): 1098.7 Void Spec: Y

Control Strip Density(lb/ft³)	In Place Density (lb/ft³)	ReEval IPD	% Comp	% Comp ReEval	% Voids	ReEval % Voids	Strip Test Time	% Ret	Lime Checks %
	145.7				5.9				0.91
	146.0				5.7				
	145.5				6.1				
	146.7				5.3				
	146.4				5.5				

Target Density (lb/ft³)		Max Air Voids:		Avg:	5.7	AC C.F.:	
Theo. Density (lb/ft³)	154.9	Max Practical Air Voids:	7.0	Range	0.8	Temp. C.F.:	

Sam No	Sample Date	Load No	Time	Temp °F	Total Mass(g)	Begin Mass(g)	Final Mass(g)	AggDry Mass(g)		1 1/2 in	1 in	3/4 in	1/2 in	3/8 in	No. 4	No. 8	No. 50	No. 200	A.C.	UW C.F.
									JMF:			100.0	99.0	92.0	66.0	45.0		7.0	5.60	
523-439	10/30/2009	16	9:00 AM	310	2011.9			1898.2	Mass(g):			0.0	28.8	143.1	580.7	977.0		1803.6	125:Y	2.00
									%Pass:			100.0	98.5	92.5	69.4	48.5		7.0	5.78	IA:N
523-440	10/30/2009	44	12:48 PM	330	2015.4			1909.7	Mass(g):			0.0	40.0	166.6	678.6	1071.1		1819.2	125:Y	2.00
									%Pass:			100.0	97.9	91.3	64.5	43.9		6.7	5.53	IA:N
									Avg. % Dev:			0.0	0.8	0.6	2.5	2.3		0.1	0.13	

Indicated Pay Factors

Voids: 1.00 Range: 1.00 Extr: 1.00 Sieve: 1.00 AC: 1.00

End Results: Y Remarks: second lot of suface mix

Appll Pay Factor: 1.00

Verified By: TJW

Table A-4 Evotherm WMA Mix Asphalt Plant QC Test Results

GDOT 159 - Asphaltic Concrete Lot Worksheet (ENGLISH)

Plant Number: 004 **Project ID: CSSTP-M003-00(837)01** **Type Mix: 9.5mm SP** **Level: N/A** **Lot Number: 06**

Contract ID:	B13260-08-000-0	Date:	10/29/2009	Tech ID:	523
Mix ID:	28R-9.5SP-39-7	Contractor ID:	2RE390	County Number:	207
District Number:	3	Corrected copy:	N	Blend:	RAP
Type course:	S	Completed report:	Y		

AC Grade: PG67-22 AC Source No: 0002 Hyd. Lime: Y Liq. Add.: N Quan. This report (tons): 1715 Void Spec: Y

Control Strip Density(lb/ft³)	In Place Density (lb/ft³)	ReEval IPD	% Comp	% Comp ReEval	% Voids	ReEval % Voids	Strip Test Time	% Ret	Lime Checks %
	144.2				6.9				0.89
	141.7				8.5				
	143.2				7.6				
	141.5				8.7				
	141.6				8.6				

Target Density (lb/ft³)		Max Air Voids:		Avg:	8.1	AC C.F.:	
Theo. Density (lb/ft³)	154.9	Max Practical Air Voids:	7.0	Range	1.8	Temp. C.F.:	

Sam No	Sample Date	Load No	Time	Temp °F	Total Mass(g)	Begin Mass(g)	Final Mass(g)	AggDry Mass(g)		1 1/2 in	1 in	3/4 in	1/2 in	3/8 in	No. 4	No. 8	No. 50	No. 200	A.C.	UW C.F.
									JMF:			100.0	99.0	92.0	66.0	45.0		7.0	5.60	
523-436	10/29/2009	3	7:46 AM	325	1712.7			1621.9	Mass(g):			0.0	43.2	131.1	587.2	929.9		1546.2	125:Y	2.00
									%Pass:			100.0	97.3	91.9	63.8	42.7		6.7	5.54	IA:N
523-437	10/29/2009	45	12:01 PM	285	2005.9			1882.3	Mass(g):			0.0	54.2	167.9	744.6	1128.7		1807.4	125:Y	2.00
									%Pass:			100.0	97.1	91.1	60.4	40.0		6.0	5.64	IA:N
523-438	10/29/2009	78	3:56 PM	260	1936.0			1822.7	Mass(g):			0.0	60.8	190.7	662.2	1040.6		1748.9	125:Y	2.00
									%Pass:			100.0	96.7	89.5	63.7	42.9		6.0	5.60	IA:N
									Avg. % Dev:			0.0	2.0	1.2	3.4	3.1		0.8	0.03	

Indicated Pay Factors

Voids: 0.90 Range: 1.00 Extr: 1.00 Sieve: 1.00 AC: 1.00

End Results: Y Remarks: fisrt lot of surface mix in adjustment period

Appl Pay Factor: 1.00

Verified By: TJW

Table A-5 Rediset WMA Mix Asphalt Plant QC Test Results

GDOT 159 - Asphaltic Concrete Lot Worksheet (ENGLISH)

Plant Number: 004 **Project ID: CSSTP-M003-00(837)01** **Type Mix: 9.5mm SP** **Level: N/A** **Lot Number: 09**

Contract ID:	B13260-08-000-0	Date:	11/3/2009	Tech ID:	523
Mix ID:	28R-9.5SP-39-7	Contractor ID:	2RE390	County Number:	207
District Number:	3	Corrected copy:	N	Blend:	RAP
Type course:	S	Completed report:	Y		

AC Grade: PG67-22 AC Source No: 0002 Hyd. Lime: Y Liq. Add.: N Quan. This report (tons): 1592.05 Void Spec: Y

Control Strip Density(lb/ft³)	In Place Density (lb/ft³)	ReEval IPD	% Comp	% Comp ReEval	% Voids	ReEval % Voids	Strip Test Time	% Ret	Lime Checks %
	145.0				6.4				0.95
	146.3				5.6				
	146.1				5.7				
	144.7				6.6				
	147.6				4.7				

Target Density (lb/ft³)		Max Air Voids:		Avg: 5.8	AC C.F.:
Theo. Density (lb/ft³)	154.9	Max Practical Air Voids:	7.0	Range 1.9	Temp. C.F.:

Sam No	Sample Date	Load No	Time	Temp °F	Total Mass(g)	Begin Mass(g)	Final Mass(g)	AggDry Mass(g)		1 1/2 in	1 in	3/4 in	1/2 in	3/8 in	No. 4	No. 8	No. 50	No. 200	A.C.	UW C.F.
									JMF:			100.0	99.0	92.0	66.0	45.0		7.0	5.60	
523-447	11/3/2009	27	11:04 AM	280	1686.4			1594.4	Mass(g):			0.0	29.6	116.5	543.0	865.3		1513.9	125:Y	2.00
									%Pass:			100.0	98.1	92.7	65.9	45.7		7.0	5.68	IA:N
523-448	11/3/2009	41	12:03 PM	283	1672.6			1585.1	Mass(g):			0.0	38.3	139.7	562.1	874.8		1505.2	125:Y	2.00
									%Pass:			100.0	97.6	91.2	64.5	44.8		7.0	5.55	IA:N
523-449	11/3/2009	79	3:27 PM	330	1548.9			1462.6	Mass(g):			0.0	23.1	130.4	529.8	820.0		1389.6	125:Y	2.00
									%Pass:			100.0	98.4	91.1	63.8	43.9		7.0	5.71	IA:N
									Avg. % Dev:			0.0	1.0	0.8	1.2	0.7		0.0	0.08	

Indicated Pay Factors

Voids: 1.00 Range: 1.00 Extr: 1.00 Sieve: 1.00 AC: 1.00

Appl Pay Factor: 1.00 End Results: Y Remarks: fourth lot of surface mix

Verified By: TJW

Table A-6 Cecabase RT WMA Mix Asphalt Plant QC Test Results

GDOT 159 - Asphaltic Concrete Lot Worksheet (ENGLISH)

Plant Number: 004 **Project ID: CSSTP-M003-00(837)01** **Type Mix: 9.5mm SP** **Level: N/A** **Lot Number: 10**

Contract ID:	B13260-08-000-0	Date:	11/4/2009	Tech ID:	523
Mix ID:	28R-9.5SP-39-7	Contractor ID:	2RE390	County Number:	207
District Number:	3	Corrected copy:	N	Blend:	RAP
Type course:	S	Completed report:	Y		

AC Grade: PG67-22 AC Source No: 0002 Hyd. Lime: Y Liq. Add.: N Quan. This report (tons): 1696.32 Void Spec: Y

Control Strip Density(lb/ft³)	In Place Density (lb/ft³)	ReEval IPD	% Comp	% Comp ReEval	% Voids	ReEval % Voids	Strip Test Time	% Ret	Lime Checks %
	145.7				5.9				0.93
	145.4				6.1				
	145.7				5.9				
	145.7				5.9				
	147.1				5.0				

Target Density (lb/ft³)		Max Air Voids:		Avg:	5.8	AC C.F.:	
Theo. Density (lb/ft³)	154.9	Max Practical Air Voids:	7.0	Range	1.1	Temp. C.F.:	

Sam No	Sample Date	Load No	Time	Temp °F	Total Mass(g)	Begin Mass(g)	Final Mass(g)	AggDry Mass(g)		1 1/2 in	1 in	3/4 in	1/2 in	3/8 in	No. 4	No. 8	No. 50	No. 200	A.C.	UW C.F.
									JMF:			100.0	99.0	92.0	66.0	45.0		7.0	5.60	
523-450	11/4/2009	13	8:46 AM	255	1831.9			1724.3	Mass(g):			0.0	24.5	149.4	600.6	950.7		1644.7	125:Y	2.00
									%Pass:			100.0	98.6	91.3	65.2	44.9		6.6	5.80	IA:N
523-451	11/4/2009	41	12:07 PM	295	1510.4			1430.5	Mass(g):			0.0	32.2	185.8	551.3	824.9		1363.9	125:Y	2.00
									%Pass:			100.0	97.7	87.0	61.5	42.3		6.7	5.48	IA:N
523-452	11/4/2009	69	2:11 PM	330	2051.2			1940.2	Mass(g):			0.0	26.4	162.3	691.6	1077.8		1840.2	125:Y	2.00
									%Pass:			100.0	98.6	91.6	64.4	44.4		7.2	5.43	IA:N
									Avg. % Dev:			0.0	0.7	2.0	2.3	1.1		0.3	0.16	

Indicated Pay Factors

Voids: 1.00 Range: 1.00 Extr: 1.00 Sieve: 1.00 AC: 1.00

End Results: Y Remarks: fifth lot of surface mix

Appll Pay Factor: 1.00

Verified By: TJW

Table A-7 Smoothness Test Result

FINAL TOPPING RIDE SUMMARY WORKSHEET

SUMMARY OF PAVEMENT SMOOTHNESS

Date 02/11/10 District 3 Area Number 1

District Engineer David B. Millen, P.R.L.S.
Area Engineer Michael Presley
Profiler Operator Lea Ward

Project No. CSSTP-M003-00(837)01

County Monroe

Run Type FINAL State Route 42 Contract ID B13260-08-000-0

Total Lane Miles	24.2

Project Limits Resurfacing on SR 42 from SR 74 to SR 18

Contractor Name Reeves Construction Company

Contractor No. 2RE390

Mix	9.5mm SP
Spec. Target	900
Spec. Corrective	1025

PROJECT AVERAGES			
Preconst.		New	Resurface
1020			731
MTV		28%Change	

Test Limits		Direct. NL1	M/F			Direct. NL2	M/F			Direct. SL1	M/F			Direct. SL2	M/F		
From	To	SI	Tar.	Corr.	Date	SI	Tar.	Corr	Date	SI	Tar.	Corr.	Date	SI	Tar.	Corr.	Date
2.11	3.00	848	M	M	11/10/09					845	M	M	02/11/10				
3.00	4.00	812	M	M	11/10/09					606	M	M	11/10/09				
4.00	5.00	832	M	M	11/10/09					592	M	M	11/10/09				
5.00	6.00	719	M	M	11/10/09					694	M	M	11/10/09				
6.00	7.00	612	M	M	11/10/09					599	M	M	11/10/09				
7.00	8.00	628	M	M	11/10/09					665	M	M	11/10/09				
8.00	9.00	654	M	M	11/10/09					623	M	M	11/10/09				
9.00	10.00	660	M	M	11/10/09					639	M	M	11/10/09				
10.00	11.00	712	M	M	11/10/09					732	M	M	10/30/09				
11.00	12.00	646	M	M	11/10/09					706	M	M	10/30/09				
12.00	13.00	735	M	M	02/11/10					726	M	M	10/30/09				
13.00	13.57	791	M	M	02/11/10					672	M	M	10/30/09				

M = MEETS F = FAILS SI = SMOOTHNESS INDEX

COMMENTS:

Table A-8 9.5 mm Superpave Mix Compaction QC Test Results

GDOT150 - Control Strip and Asphaltic Compaction (ENGLISH)

Plant 4 **Project** CSSTP-M003-00(837)01 **Type** 9.5mm SP
Level: N/A **Lot** 07

County	207	District Number:	3	Sample	10/30/2009
Contract ID:	B13260-08-000-0	Contractor	2RE390	Ctr. Name:	REEVES
		Area Engineer	314	Item No.:	400
Tech. ID:	3H				
		Blend:	RAP		
Plant	MACON				
Percent	5.6				

Gauge No.:	24991	Mode (inches):	BS		
Density Standard	2349	Correction Factor :	31	Corrected Std.	2380
Calibration Factor 1:	-1.812613	Calibration Factor	1.272415		
Control Strip:	N	Max % air voids:	7.8		
Use Nuclear Or Core	Nuclear	Theo.	154.9	Target Density	

Test #	Tech ID	Sam. #	Year	Begin (ft.)	End (ft.)	Length (ft)	Lane Location	Rnd. No.	Rnd Sta. (ft)	Trans. Loc
1	3H	705	2009				SBL		9+88	

Nuclear Results	Left	Center	Right	Average	DensityCR	Density(lb/ft³)	%	% Void
	599	615	602	605	0.2543	145.7		5.9
Core Results	WtAir (g)	WtSurf (g)	WtWater(g)	Diff (g)	SpecGrav	Density(lb/ft³)	%	% Void

Test #	Tech ID	Sam. #	Year	Begin (ft.)	End (ft.)	Length (ft)	Lane Location	Rnd. No.	Rnd Sta. (ft)	Trans. Loc
2	3H	706	2009				SBL		9+73	

Nuclear Results	Left	Center	Right	Average	DensityCR	Density(lb/ft³)	%	% Void
	588	602	615	602	0.2528	146.1		5.7
Core Results	WtAir (g)	WtSurf (g)	WtWater(g)	Diff (g)	SpecGrav	Density(lb/ft³)	%	% Void

Test #	Tech ID	Sam. #	Year	Begin (ft.)	End (ft.)	Length (ft)	Lane Location	Rnd. No.	Rnd Sta. (ft)	Trans. Loc
3	3H	707	2009				SBL		9+45	

Nuclear Results	Left	Center	Right	Average	DensityCR	Density(lb/ft³)	%	% Void
	591	612	622	608	0.2556	145.5		6.1
Core Results	WtAir (g)	WtSurf (g)	WtWater(g)	Diff (g)	SpecGrav	Density(lb/ft³)	%	% Void

Test #	Tech ID	Sam. #	Year	Begin (ft.)	End (ft.)	Length (ft)	Lane Location	Rnd. No.	Rnd Sta. (ft)	Trans. Loc
4	3H	708	2009				SBL		8+85	

Nuclear Results	Left	Center	Right	Average	DensityCR	Density(lb/ft³)	%	% Void
	578	600	605	594	0.2497	146.7		5.3
Core Results	WtAir (g)	WtSurf (g)	WtWater(g)	Diff (g)	SpecGrav	Density(lb/ft³)	%	% Void

Test #	Tech ID	Sam. #	Year	Begin (ft.)	End (ft.)	Length (ft)	Lane Location	Rnd. No.	Rnd Sta. (ft)	Trans. Loc
5	3H	709	2009				SBL		8+69	

Nuclear Results	Left	Center	Right	Average	DensityCR	Density(lb/ft³)	%	% Void
	588	600	606	598	0.2513	146.4		5.5
Core Results	WtAir (g)	WtSurf (g)	WtWater(g)	Diff (g)	SpecGrav	Density(lb/ft³)	%	% Void

% of Theo.		Average	5.7
		Range %	0.8
Remarks		Testing Group	Testing Management
		Meets	Pass

Verified By BLJ

Table A-9 Evotherm WMA Mix Compaction QC Test Results

GDOT150 - Control Strip and Asphaltic Compaction (ENGLISH)

Plant 4 **Project** CSSTP-M003-00(837)01 **Type** 9.5mm SP
Level: N/A **Lot** 06

County	207	District Number:	3	Sample	10/29/2009
Contract ID:	B13260-08-000-0	Contractor	2RE390	Ctr. Name:	REEVES
		Area Engineer	314	Item No.:	400
Tech. ID:	3H				
		Blend:	RAP		
Plant	MACON				
Percent	5.6				

Gauge No.:	24991	Mode (inches):	BS		
Density Standard	2349	Correction Factor :	-63	Corrected Std.	2286
Calibration Factor 1:	-1.812613	Calibration Factor	1.272415		
Control Strip:	N	Max % air voids:			
Use Nuclear Or Core	Nuclear	Theo.	154.9	Target Density	

Test #	Tech ID	Sam. #	Year	Begin (ft.)	End (ft.)	Length (ft)	Lane Location	Rnd. No.	Rnd Sta. (ft)	Trans. Loc
1	3H	687	2009				SBL		13+00	

	Left	Center	Right	Average	DensityCR	Density(lb/ft³)	%	% Void
Nuclear Results	585	571	589	582	0.2544	145.7		5.9
Core Results	WtAir (g)	WtSurf (g)	WtWater(g)	Diff (g)	SpecGrav	Density(lb/ft³)	%	% Void

Test #	Tech ID	Sam. #	Year	Begin (ft.)	End (ft.)	Length (ft)	Lane Location	Rnd. No.	Rnd Sta. (ft)	Trans. Loc
2	3H	688	2009				SBL		12+12	

	Left	Center	Right	Average	DensityCR	Density(lb/ft³)	%	% Void
Nuclear Results	612	616	601	610	0.2667	143.1		7.6
Core Results	WtAir (g)	WtSurf (g)	WtWater(g)	Diff (g)	SpecGrav	Density(lb/ft³)	%	% Void

Test #	Tech ID	Sam. #	Year	Begin (ft.)	End (ft.)	Length (ft)	Lane Location	Rnd. No.	Rnd Sta. (ft)	Trans. Loc
3	3H	689	2009				SBL		11+84	

	Left	Center	Right	Average	DensityCR	Density(lb/ft³)	%	% Void
Nuclear Results	587	582	607	592	0.2590	144.7		6.6
Core Results	WtAir (g)	WtSurf (g)	WtWater(g)	Diff (g)	SpecGrav	Density(lb/ft³)	%	% Void

Test #	Tech ID	Sam. #	Year	Begin (ft.)	End (ft.)	Length (ft)	Lane Location	Rnd. No.	Rnd Sta. (ft)	Trans. Loc
4	3H	690	2009				SBL		11+36	

	Left	Center	Right	Average	DensityCR	Density(lb/ft³)	%	% Void
Nuclear Results	606	602	626	611	0.2674	143.0		7.7
Core Results	WtAir (g)	WtSurf (g)	WtWater(g)	Diff (g)	SpecGrav	Density(lb/ft³)	%	% Void

Test #	Tech ID	Sam. #	Year	Begin (ft.)	End (ft.)	Length (ft)	Lane Location	Rnd. No.	Rnd Sta. (ft)	Trans. Loc
5	3H	691	2009				SBL		10+48	

	Left	Center	Right	Average	DensityCR	Density(lb/ft³)	%	% Void
Nuclear Results	609	610	613	611	0.2671	143.0		7.7
Core Results	WtAir (g)	WtSurf (g)	WtWater(g)	Diff (g)	SpecGrav	Density(lb/ft³)	%	% Void

% of Theo. Average 7.1
Range % 1.8

Remarks	FIRST LOT OF ADJUSTMENT	Testing Group	Testing Management
		Meets	Pass
Verified By	BLJ		

Table A-10 Rediset WMA Mix Compaction QC Test Results

GDOT150 - Control Strip and Asphaltic Compaction (ENGLISH)

Plant 4 **Project** CSSTP-M003-00(837)01 **Type** 9.5mm SP
Level: N/A **Lot** 09

County	207	District Number:	3	Sample	11/3/2009
Contract ID:	B13260-08-000-0	Contractor	2RE390	Ctr. Name:	REEVES
		Area Engineer	314	Item No.:	400
Tech. ID:	3H				
		Blend:	RAP		
Plant	MACON				
Percent	5.6				

Gauge No.:	24991	Mode (inches):	BS		
Density Standard	2352	Correction Factor :	31	Corrected Std.	2383
Calibration Factor 1:	-1.812613	Calibration Factor	1.272415		
Control Strip:	N	Max % air voids:	7.8		
Use Nuclear Or Core	Nuclear	Theo.	154.9	Target Density	

Test #	Tech ID	Sam. #	Year	Begin (ft.)	End (ft.)	Length (ft)	Lane Location	Rnd. No.	Rnd Sta. (ft)	Trans. Loc
1	3H	715	2009				SBL		4+46	
2	3H	716	2009				SBL		3+91	
3	3H	717	2009				SBL		3+37	
4	3H	718	2009				SBL		3+05	
5	3H	719	2009				SBL		2+59	

Nuclear Results

Test #	Left	Center	Right	Average	DensityCR	Density(lb/ft³)	%	% Void
1	599	625	617	614	0.2575	145.0		6.4
2	630	588	580	599	0.2515	146.3		5.5
3	617	589	600	602	0.2526	146.1		5.7
4	626	617	609	617	0.2591	144.7		6.6
5	599	588	571	586	0.2459	147.6		4.7

Core Results (each test)

WtAir (g)	WtSurf (g)	WtWater(g)	Diff (g)	SpecGrav	Density(lb/ft³)	%	% Void

% of Theo. Average 5.8
Range % 1.9

Remarks

Testing Group	Testing Management
Meets	Pass

Verified By BLJ

Table A-11 Cecabase RT WMA Mix Compaction QC Test Results

GDOT150 - Control Strip and Asphaltic Compaction (ENGLISH)

Plant **4** **Project** **CSSTP-M003-00(837)01** **Type** **9.5mm SP**
Level: **N/A** **Lot** **10**

County	207	District Number:	3	Sample	11/4/2009
Contract ID:	B13260-08-000-0	Contractor	2RE390	Ctr. Name:	REEVES
		Area Engineer	314	Item No.:	400
Tech. ID:	3H				
		Blend:	RAP		
Plant	MACON				
Percent	5.6				

Gauge No.:	24991	Mode (inches):	BS		
Density Standard	2342	Correction Factor :	31	Corrected Std.	2373
Calibration Factor 1:	-1.812613	Calibration Factor	1.272415		
Control Strip:	N	Max % air voids:	7.8		
Use Nuclear Or Core	Nuclear	Theo.	154.9	Target Density	

Test #	Tech ID	Sam. #	Year	Begin (ft.)	End (ft.)	Length (ft)	Lane Location	Rnd. No.	Rnd Sta. (ft)	Trans. Loc
1	3H	720	2009				NBL		2+50	

	Left	Center	Right	Average	DensityCR	Density(lb/ft³)	%	% Void
Nuclear Results	610	611	590	604	0.2544	145.7		5.9
Core Results	WtAir (g)	WtSurf (g)	WtWater(g)	Diff (g)	SpecGrav	Density(lb/ft³)	%	% Void

Test #	Tech ID	Sam. #	Year	Begin (ft.)	End (ft.)	Length (ft)	Lane Location	Rnd. No.	Rnd Sta. (ft)	Trans. Loc
2	3H	721	2009				NBL		2+59	

	Left	Center	Right	Average	DensityCR	Density(lb/ft³)	%	% Void
Nuclear Results	588	610	622	607	0.2557	145.4		6.1
Core Results	WtAir (g)	WtSurf (g)	WtWater(g)	Diff (g)	SpecGrav	Density(lb/ft³)	%	% Void

Test #	Tech ID	Sam. #	Year	Begin (ft.)	End (ft.)	Length (ft)	Lane Location	Rnd. No.	Rnd Sta. (ft)	Trans. Loc
3	3H	722	2009				NBL		3+21	

	Left	Center	Right	Average	DensityCR	Density(lb/ft³)	%	% Void
Nuclear Results	589	622	601	604	0.2545	145.7		5.9
Core Results	WtAir (g)	WtSurf (g)	WtWater(g)	Diff (g)	SpecGrav	Density(lb/ft³)	%	% Void

Test #	Tech ID	Sam. #	Year	Begin (ft.)	End (ft.)	Length (ft)	Lane Location	Rnd. No.	Rnd Sta. (ft)	Trans. Loc
4	3H	723	2009				NBL		3+28	

	Left	Center	Right	Average	DensityCR	Density(lb/ft³)	%	% Void
Nuclear Results	588	625	600	604	0.2547	145.7		6.0
Core Results	WtAir (g)	WtSurf (g)	WtWater(g)	Diff (g)	SpecGrav	Density(lb/ft³)	%	% Void

Test #	Tech ID	Sam. #	Year	Begin (ft.)	End (ft.)	Length (ft)	Lane Location	Rnd. No.	Rnd Sta. (ft)	Trans. Loc
5	3H	724	2009				NBL		3+86	

	Left	Center	Right	Average	DensityCR	Density(lb/ft³)	%	% Void
Nuclear Results	588	590	588	589	0.2481	147.1		5.0
Core Results	WtAir (g)	WtSurf (g)	WtWater(g)	Diff (g)	SpecGrav	Density(lb/ft³)	%	% Void

	% of Theo.	Average		5.8
		Range %		1.1
Remarks		Testing Group	Testing Management	
		Meets	Pass	

Verified By BLJ

APPENDIX B LABORATORY TEST RESULTS

Table B-1 GDOT Basic Mix Volumetric Test – Control Mix

Asphalt Content	
Test Result:	5.18%
Calibration Factor:	-0.28%
Adjusted %AC:	**5.46%**

AASHTO T-209 Test Results Theorectical Max. Specific Gravity, Bowl Determination		
Binder Content, %AC	5.46%	5.46%
Bowl Number	1	2
Weight of Bowl in Air, g	2192	2197.1
Weight of Bowl in Water, g	1383.9	1387
Test Weights		
Weight of Sample + Bowl in Air, g	3711.8	3713.3
Weight of Sample + Bowl in Water, g	2293	2295.9
Calculations		
Weight of Sample in Air, g	1519.8	1516.2
Weight of Sample in Water, g	909.1	908.9
Theoretical Max. Specific Gravity, Gmm	2.489	2.497
Average Gmm	**2.493**	

Effective Stone Gravity Calculations (Gse)	
Binder Content, %AC	5.46%
Specific Gravity of AC	1.031
Theoretical Max. Specific Gravity, Gmm	2.493
Effective Stone Gravity, Gse	**2.715**

AASHTO T-166 Test Results Bulk Specific Gravity of Compacted Bituminous Mixtures		
Binder Content, %AC	5.46%	5.46%
Dry Weight in Air, g	4803.0	4798.5
Submerged Weight, g	2836.3	2834.0
SSD Weight, g	4808.5	4803.6
Bulk Specific Gravity, Gmb	2.435	2.436
% Water Absorbed by Volume	0.28%	0.26%
Theoretical Max. Specific Gravity, Gmm	2.493	2.493
% Voids in Total Mix (VTM)	**2.3**	**2.3**

Gradation Test Results	
Sieve Size	**% Passing**
37.5mm (1.5")	100.0
25mm (1")	100.0
19mm (3/4")	100.0
12.5mm (1/2")	98.6
9.5mm (3/8")	92.0
4.75mm (No.4)	66.6
2.36mm (No.8)	45.9
1.18mm (No.16)	32.7
600um (No.30)	24.3
300um (No.50)	18.0
150um (No.100)	12.8
75um (No.200)	7.7

Table B-2 GDOT Basic Mix Volumetric Test – Evotherm Mix

Asphalt Content	
Test Result:	5.53%
Calibration Factor:	-0.28%
Adjusted %AC:	**5.81%**

AASHTO T-209 Test Results Theorectical Max. Specific Gravity, Bowl Determination		
Binder Content, %AC	5.81%	5.81%
Bowl Number	1	2
Weight of Bowl in Air, g	2192	2197.1
Weight of Bowl in Water, g	1383.9	1387
Test Weights		
Weight of Sample + Bowl in Air, g	3707.6	3712.6
Weight of Sample + Bowl in Water, g	2287.5	2291.7
Calculations		
Weight of Sample in Air, g	1515.6	1515.5
Weight of Sample in Water, g	903.6	904.7
Theoretical Max. Specific Gravity, Gmm	2.476	2.481
Average Gmm	**2.479**	

Effective Stone Gravity Calculations (Gse)	
Binder Content, %AC	5.81%
Specific Gravity of AC	1.031
Theoretical Max. Specific Gravity, Gmm	2.479
Effective Stone Gravity, Gse	**2.714**

AASHTO T-166 Test Results Bulk Specific Gravity of Compacted Bituminous Mixtures		
Binder Content, %AC	5.81%	5.81%
Dry Weight in Air, g	5046.0	5042.2
Submerged Weight, g	2978.5	2983.9
SSD Weight, g	5050.2	5046.7
Bulk Specific Gravity, Gmb	2.436	2.444
% Water Absorbed by Volume	0.20%	0.22%
Theoretical Max. Specific Gravity, Gmm	2.479	2.479
% Voids in Total Mix (VTM)	**1.7**	**1.4**

Gradation Test Results	
Sieve Size	**% Passing**
37.5mm (1.5")	100.0
25mm (1")	100.0
19mm (3/4")	100.0
12.5mm (1/2")	98.2
9.5mm (3/8")	91.5
4.75mm (No.4)	61.6
2.36mm (No.8)	42.1
1.18mm (No.16)	30.3
600um (No.30)	22.8
300um (No.50)	17.0
150um (No.100)	12.1
75um (No.200)	7.6

Table B-3 GDOT Basic Mix Volumetric Test – Rediset Mix

Asphalt Content	
Test Result:	5.60%
Calibration Factor:	-0.28%
Adjusted %AC:	**5.88%**

AASHTO T-209 Test Results Theorectical Max. Specific Gravity, Bowl Determination		
Binder Content, %AC	5.88%	5.88%
Bowl Number	1	2
Weight of Bowl in Air, g	2192	2197.1
Weight of Bowl in Water, g	1383.9	1387
Test Weights		
Weight of Sample + Bowl in Air, g	3709.3	3714
Weight of Sample + Bowl in Water, g	2291.5	2295
Calculations		
Weight of Sample in Air, g	1517.3	1516.9
Weight of Sample in Water, g	907.6	908
Theoretical Max. Specific Gravity, Gmm	2.489	2.491
Average Gmm	**2.490**	

Effective Stone Gravity Calculations (Gse)	
Binder Content, %AC	5.88%
Specific Gravity of AC	1.031
Theoretical Max. Specific Gravity, Gmm	2.490
Effective Stone Gravity, Gse	**2.731**

AASHTO T-166 Test Results Bulk Specific Gravity of Compacted Bituminous Mixtures		
Binder Content, %AC	5.88%	5.88%
Dry Weight in Air, g	4800.7	4800.8
Submerged Weight, g	2850.8	2848.5
SSD Weight, g	4805.6	4805.3
Bulk Specific Gravity, Gmb	2.456	2.453
% Water Absorbed by Volume	0.25%	0.23%
Theoretical Max. Specific Gravity, Gmm	2.490	2.490
% Voids in Total Mix (VTM)	**1.4**	**1.5**

Gradation Test Results	
Sieve Size	% Passing
37.5mm (1.5")	100.0
25mm (1")	100.0
19mm (3/4")	100.0
12.5mm (1/2")	99.1
9.5mm (3/8")	91.4
4.75mm (No.4)	64.4
2.36mm (No.8)	44.1
1.18mm (No.16)	31.5
600um (No.30)	23.7
300um (No.50)	17.9
150um (No.100)	12.8
75um (No.200)	7.8

Table B-4 GDOT Basic Mix Volumetric Test – Cecabase RT Mix

Asphalt Content	
Test Result:	5.55%
Calibration Factor:	-0.28%
Adjusted %AC:	**5.83%**

AASHTO T-209 Test Results Theorectical Max. Specific Gravity, Bowl Determination		
Binder Content, %AC	5.83%	5.83%
Bowl Number	1	2
Weight of Bowl in Air, g	2192	2197.1
Weight of Bowl in Water, g	1383.9	1387
Test Weights		
Weight of Sample + Bowl in Air, g	3710.3	3713
Weight of Sample + Bowl in Water, g	2289.4	2290.7
Calculations		
Weight of Sample in Air, g	1518.3	1515.9
Weight of Sample in Water, g	905.5	903.7
Theoretical Max. Specific Gravity, Gmm	2.478	2.476
Average Gmm	**2.477**	

Effective Stone Gravity Calculations (Gse)	
Binder Content, %AC	5.83%
Specific Gravity of AC	1.031
Theoretical Max. Specific Gravity, Gmm	2.477
Effective Stone Gravity, Gse	**2.712**

AASHTO T-166 Test Results Bulk Specific Gravity of Compacted Bituminous Mixtures		
Binder Content, %AC	5.83%	5.83%
Dry Weight in Air, g	4801.5	4799.4
Submerged Weight, g	2829.4	2830.0
SSD Weight, g	4806.1	4804.1
Bulk Specific Gravity, Gmb	2.429	2.431
% Water Absorbed by Volume	0.23%	0.24%
Theoretical Max. Specific Gravity, Gmm	2.477	2.477
% Voids in Total Mix (VTM)	**1.9**	**1.8**

Gradation Test Results	
Sieve Size	% Passing
37.5mm (1.5")	100.0
25mm (1")	100.0
19mm (3/4")	100.0
12.5mm (1/2")	98.4
9.5mm (3/8")	94.3
4.75mm (No.4)	69.0
2.36mm (No.8)	46.5
1.18mm (No.16)	32.8
600um (No.30)	24.3
300um (No.50)	18.1
150um (No.100)	12.8
75um (No.200)	8.0

Table B-5 GDOT Moisture Susceptibility Test– Control Mix

	Control				Conditioned		
Sample Number	**2**	**3**	**4**		**1**	**5**	**6**
Binder Content, %	5.46%	5.46%	5.46%		5.46%	5.46%	5.46%
Height (mm)	95.0	95.0	95.1		95.0	95.0	95.0
Dry Weight in Air	3792.8	3789.0	3787.7		3786.3	3788.0	3791.4
Submerged Weight	2183.8	2162.6	2169.4		2173.9	2171.7	2176.6
SSD Weight	3821.3	3811.7	3811.9		3813.5	3813.6	3815.5
Bulk Specific Gmb	2.316	2.298	2.306		2.309	2.307	2.313
Theoretical Gmm	2.493	2.493	2.493		2.493	2.493	2.493
% Voids (VTM)	7.077	7.823	7.485		7.355	7.444	7.191

	Control				Conditioned			
Sample	**2**	**3**	**4**		**1**	**5**	**6**	
Stability (lbs)	3886	3847	3967		3880	4415	4447	
Height (inches)	3.74	3.74	3.74		3.74	3.74	3.74	
Strip Rating	-	-	-		1	1	1	
PSI	110.237	109.131	112.417	110.595	110.067	125.244	126.152	120.487
				Average				Average

%Retained	108.9%

Table B-6 GDOT Moisture Susceptibility Test– Evotherm Mix

	Control				Conditioned			
Sample Number	**3**	**4**	**5**		**1**	**2**	**6**	
Binder Content, %	5.81%	5.81%	5.81%		5.81%	5.81%	5.81%	
Height (mm)	95.0	95.0	95.1		95.0	95.0	95.0	
Dry Weight in Air	3793.7	3791.2	3789.2		3789.7	3789.2	3789.5	
Submerged Weight	2172.2	2170.1	2164.5		2174.4	2166.8	2168.0	
SSD Weight	3820.6	3808.1	3806.1		3814.8	3806.5	3807.4	
Bulk Specific Gmb	2.301	2.315	2.308		2.310	2.311	2.312	
Theoretical Gmm	2.479	2.479	2.479		2.479	2.479	2.479	
% Voids (VTM)	7.156	6.628	6.882		6.801	6.774	6.749	

	Control				Conditioned			
Sample	**3**	**4**	**5**		**1**	**2**	**6**	
Stability (lbs)	3384	2836	2803		3578	3215	3693	
Height (inches)	3.74	3.74	3.74		3.74	3.74	3.74	
Strip Rating	-	-	-		1	1	1	
PSI	95.997	80.451	79.431	85.293	101.500	91.202	104.762	99.155
				Average				Average

%Retained	**116.3%**

Table B-7 GDOT Moisture Susceptibility Test– Rediset Mix

	Control				Conditioned			
Sample Number	**2**	**3**	**4**		**1**	**5**	**6**	
Binder Content, %	5.88%	5.88%	5.88%		5.88%	5.88%	5.88%	
Height (mm)	95.0	95.0	95.1		95.0	95.0	95.0	
Dry Weight in Air	3795.0	3790.4	3789.5		3789.5	3789.2	3787.3	
Submerged Weight	2187.1	2178.9	2183.9		2184.0	2178.9	2177.3	
SSD Weight	3820.2	3815.9	3815.2		3812.6	3811.0	3813.3	
Bulk Specific Gmb	2.324	2.315	2.323		2.327	2.322	2.315	
Theoretical Gmm	2.490	2.490	2.490		2.490	2.490	2.490	
% Voids (VTM)	6.671	7.006	6.704		6.549	6.757	7.026	

	Control				Conditioned			
Sample	**2**	**3**	**4**		**1**	**5**	**6**	
Stability (lbs)	3133	2499	2506		3163	3127	3191	
Height (inches)	3.74	3.74	3.74		3.74	3.74	3.74	
Strip Rating	-	-	-		1	1	1	
PSI	88.876	70.891	71.015	76.927	89.727	88.706	90.522	89.652
				Average				Average

%Retained	**116.5%**

Table B-8 GDOT Moisture Susceptibility Test– Cecabase RT Mix

	Control				Conditioned			
Sample Number	**1**	**3**	**6**		**2**	**5**	**4**	
Binder Content, %	5.83%	5.83%	5.83%		5.83%	5.83%	5.83%	
Height (mm)	95.0	95.0	95.1		95.0	95.0	95.0	
Dry Weight in Air	3790.8	3788.2	3785.7		3791.7	3788.8	3789.4	
Submerged Weight	2170.2	2168.2	2163.8		2169.4	2167.6	2170.9	
SSD Weight	3812.6	3808.8	3804.9		3812.0	3810.1	3811.2	
Bulk Specific Gmb	2.308	2.309	2.307		2.308	2.307	2.310	
Theoretical Gmm	2.477	2.477	2.477		2.477	2.477	2.477	
% Voids (VTM)	6.815	6.777	6.867		6.805	6.870	6.731	

	Control				Conditioned			
Sample	1	3	6		2	5	4	
Stability (lbs)	3268	2695	2597		3208	3054	3020	
Height (inches)	3.74	3.74	3.74		3.74	3.74	3.74	
Strip Rating	-	-	-		2	1	2	
PSI	92.706	76.451	73.594	80.917	91.004	86.635	85.671	87.770
				Average				Average

%Retained	**108.5%**

Table B-9 GDOT Rutting Susceptibility Test (APA) – Control Mix

Testing temp, C	64

Sample Number	1	2	3	4	5	6
Height, mm	75.0	75.0	75.0	75.0	75.0	75.0
Dry Weight in Air, g	3050.1	3043.8	3043.3	3041.3	3042.7	3043.5
Submerger Weight, g	1773.8	1762.7	1763.5	1758.9	1761.3	1764.8
SSD Weight, g	3065.0	3057.7	3057.2	3052.7	3055.0	3057.2
Gmb	2.362	2.350	2.352	2.351	2.352	2.355
Gmm	2.493	2.493	2.493	2.493	2.493	2.493
Air Voids, %	5.2	5.7	5.6	5.7	5.6	5.5

POSITION	LEFT PILLS					CENTER PILLS					RIGHT PILLS				
SAMPLE #	1		6		AVG.	2		4		AVG.	3		5		AVG.
READING	FWD	FWD CTR	AFT CTR	AFT	RUT	FWD	FWD CTR	AFT CTR	AFT	RUT	FWD	FWD CTR	AFT CTR	AFT	RUT
0	12.35	12.34	12.27	12.12		12.06	12.16	13.06	13.24		12.70	13.17	12.79	12.85	
8000	6.71	7.72	6.55	6.33		7.25	7.70	7.92	8.24		5.91	5.63	5.66	6.13	
DEF, mm	5.64	4.62	5.72	5.79	5.44	4.81	4.46	5.14	5.00	4.85	6.79	7.54	7.13	6.72	7.05

AVERAGE DEFORMATION=	5.78	mm

Table B-10 GDOT Rutting Susceptibility Test (APA) – Evotherm Mix

Testing temp, C	64

Sample Number	1	2	3	4	5	6
Height, mm	75.0	75.0	75.0	75.0	75.0	75.0
Dry Weight in Air, g	3047.9	3044.9	3045.6	3044.9	3044.0	3044.3
Submerger Weight, g	1761.9	1759.8	1759.8	1760.9	1756.4	1756.9
SSD Weight, g	3057.6	3053.7	3053.7	3053.8	3053.9	3052.3
Gmb	2.352	2.353	2.354	2.355	2.346	2.350
Gmm	2.479	2.479	2.479	2.479	2.479	2.479
Air Voids, %	5.1	5.1	5.0	5.0	5.4	5.2

POSITION	LEFT PILLS					CENTER PILLS					RIGHT PILLS				
SAMPLE #	1		2		AVG.	3		6		AVG.	4		5		AVG.
READING	FWD	FWD CTR	AFT CTR	AFT	RUT	FWD	FWD CTR	AFT CTR	AFT	RUT	FWD	FWD CTR	AFT CTR	AFT	RUT
0	11.02	12.18	12.63	12.82		12.50	12.31	12.94	13.33		12.26	12.37	12.65	13.08	
8000	6.09	6.63	6.63	7.14		7.09	7.09	6.81	7.14		4.30	4.52	3.59	4.45	
DEF, mm	4.93	5.55	6.00	5.68	5.54	5.41	5.22	6.13	6.19	5.74	7.96	7.85	9.06	8.63	8.38

AVERAGE DEFORMATION=	6.55	mm

Table B-11 GDOT Rutting Susceptibility Test (APA) – Rediset Mix

Testing temp, C	64

Sample Number	1	2	3	4	5	6
Height, mm	75.0	75.0	75.0	75.0	75.0	75.0
Dry Weight in Air, g	3043.1	3037.6	3039.6	3043.7	3041.0	3042.3
Submerger Weight, g	1760.6	1755.3	1753.1	1760.3	1759.3	1763.5
SSD Weight, g	3055.6	3048.1	3048.8	3052.0	3051.7	3053.2
Gmb	2.350	2.350	2.346	2.356	2.353	2.359
Gmm	2.490	2.490	2.490	2.490	2.490	2.490
Air Voids, %	5.6	5.6	5.8	5.4	5.5	5.3

POSITION	LEFT PILLS					CENTER PILLS					RIGHT PILLS				
SAMPLE #	1		2		AVG.	3		5		AVG.	4		6		AVG.
READING	FWD	FWD CTR	AFT CTR	AFT	RUT	FWD	FWD CTR	AFT CTR	AFT	RUT	FWD	FWD CTR	AFT CTR	AFT	RUT
0	11.65	12.57	12.71	12.67		12.46	12.62	12.98	12.96		11.88	11.91	12.91	12.99	
8000	6.66	7.72	6.59	6.69		7.07	6.74	6.30	6.66		6.54	6.27	6.52	7.02	
DEF, mm	4.99	4.85	6.12	5.98	5.49	5.39	5.88	6.68	6.30	6.06	5.34	5.64	6.39	5.97	5.84

AVERAGE DEFORMATION=	5.79	mm

Table B-12 GDOT Rutting Susceptibility Test (APA) – Cecabase RT Mix

Testing temp, C	64

Sample Number	1	2	3	4	5	6
Height, mm	75.0	75.0	75.0	75.0	75.0	75.0
Dry Weight in Air, g	3044.1	3043.4	3044.8	3050.3	3042.2	3040.8
Submerger Weight, g	1755.6	1755.8	1758.0	1761.4	1753.2	1750.7
SSD Weight, g	3053.7	3051.9	3053.4	3057.3	3049.8	3048.0
Gmb	2.345	2.348	2.350	2.354	2.346	2.344
Gmm	2.477	2.477	2.477	2.477	2.477	2.477
Air Voids, %	5.3	5.2	5.1	5.0	5.3	5.4

POSITION	LEFT PILLS					CENTER PILLS					RIGHT PILLS				
SAMPLE #	1		6		AVG.	2		5		AVG.	3		4		AVG.
READING	FWD	FWD CTR	AFT CTR	AFT	RUT	FWD	FWD CTR	AFT CTR	AFT	RUT	FWD	FWD CTR	AFT CTR	AFT	RUT
0	13.49	13.49	13.49	13.49		12.61	11.93	10.77	10.89		11.94	11.94	12.78	12.66	
8000	7.01	7.67	6.94	7.39		7.35	7.04	5.47	6.19		5.55	5.53	5.48	6.76	
DEF, mm	6.48	5.82	6.55	6.10	6.24	5.26	4.89	5.30	4.70	5.04	6.39	6.41	7.30	5.90	6.50

AVERAGE DEFORMATION=	5.93	mm

Table B-13 GDOT DSR Test – Control Mix (1)

Bohlin DSR Project - SHRP Pass/Fail Mode (Strain Controlled)
Instrument Serial No: 99/008000/BOH/A/007 Temp. Control: Water Bath
Summary Sheet: SHRP Software: Version 5.07

File Name: C:\DSR\00010001.ARP

Parameters:

Measurement Type:	High Temperature Range
Target Temperature:	60.0 °C
Strain Amplitude:	10.00 percent
Plate Diameter:	25.0 mm
Plate Gap:	1.000 mm
Equilibration Time:	10.0 minutes

Ancillary Info:

Operator ID:	Operator 001
Sample ID:	Sample0001
Sample Type:	Original Binder
Test Number:	0001

Measurement Results: 11/7/2009 11:00:03 AM

Modulus (G*):	5.5992E3 Pascal
Phase Angle (delta):	83.3 degrees
G*/sin(delta):	5.6375E3 Pascal
Strain Amplitude:	10.39 percent
Final Temperature:	60.0 °C
Osc. Frequency:	10.08 radians/second
Test Status:	PASSED

Operator Notes:
Title: Bohlin DSR Software Version 5.05
Conventional Mix 10/30
/09 15%
CSSTP-M003-00(837)01 Monroe
Reeves Construction 9.5 II

DOT 170
SAMPLE CARD FOR ALL MATERIAL

Date Received NOV 05 2009 OMR Sample # 20905573
Project No. CSSTP-M003-00(837)01 County Monroe
Material 9.5 II Size or Type
Date Sampled 10-30-09 Sample No.
Sampled From Truck Sample Represents 15%
Producer or Property Owner
Location Reeves Postell
Contractor Reeves Construction
Examined For Oblon Recovery Pay Item No. 402
Used In Submitted By Ted Hardeman
Remarks: CID: 813260-09-000-0
Conventional Mix for Warm Mix Research

Table B-14 GDOT DSR Test – Control Mix (2)

Bohlin DSR Project - SHRP Pass/Fail Mode (Strain Controlled)
Instrument Serial No: 99/008000/BOH/A/007 Temp. Control: Water Bath
Summary Sheet: SHRP Software: Version 5.07

File Name: C:\DSR\00010002.ARP

Parameters:

Measurement Type:	High Temperature Range
Target Temperature:	60.0 °C
Strain Amplitude:	10.00 percent
Plate Diameter:	25.0 mm
Plate Gap:	1.000 mm
Equilibration Time:	10.0 minutes

Ancillary Info:

Operator ID:	Operator 001
Sample ID:	Sample0001
Sample Type:	Original Binder
Test Number:	0002

Measurement Results: 11/7/2009 11:14:41 AM

Modulus (G*):	5.3325E3 Pascal
Phase Angle (delta):	83.1 degrees
G*/sin(delta):	5.3718E3 Pascal
Strain Amplitude:	10.21 percent
Final Temperature:	60.0 °C
Osc. Frequency:	10.08 radians/second
Test Status:	PASSED

Operator Notes:
Title: Bohlin DSR Software Version 5.05
Conventional Mix 10/30
/09 15%
CSSTP-M003-00(837)01 Monroe
Reeves Construction 9.5 II

DOT 170 SAMPLE CARD FOR ALL MATERIAL

Date Received NOV 05 2009 OMR Sample # 20905573
Project No. CSSTP-M003-00(837)01 County Monroe
Material 9.5 II Size or Type
Date Sampled 10-30-09 Sample No.
Sampled From Truck Sample Represents 15%
Producer or Property Owner
Location Reeves Pastell
Contractor Reeves Construction
Examined For [illegible] Ablon Recovery Pay Item No. 402
Used In Submitted By Ted Harden
Remarks: CID: 813260-0[illegible]-000-0
Conventional Mix for Warm Mix Research

Table B-15 GDOT DSR Test – Evotherm Mix (1)

Bohlin DSR Project - SHRP Pass/Fail Mode (Strain Controlled)
Instrument Serial No: 99/008000/BOH/A/007 Temp. Control: Water Bath
Summary Sheet: SHRP Software: Version 5.07

File Name: C:\DSR\00010001.ARP

Parameters:

Measurement Type:	High Temperature Range
Target Temperature:	60.0 °C
Strain Amplitude:	10.00 percent
Plate Diameter:	25.0 mm
Plate Gap:	1.000 mm
Equilibration Time:	10.0 minutes

Ancillary Info:

Operator ID:	Operator 001
Sample ID:	Sample0001
Sample Type:	Original Binder
Test Number:	0001

Measurement Results: 11/5/2009 11:51:37 AM

Modulus (G*):	5.3483E3 Pascal
Phase Angle (delta):	83.0 degrees
G*/sin(delta):	5.3889E3 Pascal
Strain Amplitude:	10.20 percent
Final Temperature:	60.0 °C
Osc. Frequency:	10.08 radians/second
Test Status:	PASSED

Operator Notes:
Title: Bohlin DSR Software Version 5.05 [Instrument]=INT DSR 00? in SHRP MODE [Sample]=< Enter Sample Details > COMMENTS:
EVO W
arm Mix 10/29/09

Table B-16 GDOT DSR Test – Evotherm Mix (2)

Bohlin DSR Project - SHRP Pass/Fail Mode (Strain Controlled)
Instrument Serial No: 99/008000/BOH/A/007 Temp. Control: Water Bath
Summary Sheet: SHRP Software: Version 5.07

File Name: C:\DSR\00010002.ARP

Parameters:

Measurement Type:	High Temperature Range
Target Temperature:	60.0 °C
Strain Amplitude:	10.00 percent
Plate Diameter:	25.0 mm
Plate Gap:	1.000 mm
Equilibration Time:	10.0 minutes

Ancillary Info:

Operator ID:	Operator 001
Sample ID:	Sample0001
Sample Type:	Original Binder
Test Number:	0002

Measurement Results: 11/5/2009 1:42:08 PM

Modulus (G*):	5.3370E3 Pascal
Phase Angle (delta):	82.9 degrees
G*/sin(delta):	5.3781E3 Pascal
Strain Amplitude:	10.15 percent
Final Temperature:	60.0 °C
Osc. Frequency:	10.08 radians/second
Test Status:	PASSED

Operator Notes:
Title: Bohlin DSR Software Version 5.05 [Instrument]=INT DSR 00? in SHRP_MODE [Sample]=< Enter Sample Details > COMMENTS:
EVO W
arm Mix 10/29/09

Table B-17 GDOT DSR Test – Rediset Mix (1)

Bohlin DSR Project - SHRP Pass/Fail Mode (Strain Controlled)
Instrument Serial No: 99/008000/BOH/A/007 Temp. Control: Water Bath
Summary Sheet: SHRP Software: Version 5.07

File Name: C:\DSR\00010003.ARP

Parameters:

Measurement Type:	High Temperature Range
Target Temperature:	60.0 °C
Strain Amplitude:	10.00 percent
Plate Diameter:	25.0 mm
Plate Gap:	1.000 mm
Equilibration Time:	10.0 minutes

Ancillary Info:

Operator ID:	Operator 001
Sample ID:	Sample0001
Sample Type:	Original Binder
Test Number:	0003

Measurement Results: 11/7/2009 11:29:02 AM

Modulus (G*):	5.2707E3 Pascal
Phase Angle (delta):	80.0 degrees
G*/sin(delta):	5.3527E3 Pascal
Strain Amplitude:	10.05 percent
Final Temperature:	60.0 °C
Osc. Frequency:	10.08 radians/second
Test Status:	PASSED

Operator Notes:
Title: Bohlin DSR Software Version 5.05
Redi- Mix (Warm Mix)
11/03/09 15%
CSSTP-M003-00(837)01 Monroe
Reeves Construction 9
.5 II

DOT 170 — SAMPLE CARD FOR ALL MATERIAL

Date Received NOV 05 2009 — OMR Sample # 20905574
Project No. CSSTP-M003-00(837)01 County Monroe
Material 9.5 II Size or Type
Date Sampled 11-3-09 Sample No.
Sampled From Truck Sample Represents 15%
Producer or Property Owner
Location Reeves Postell
Contractor Reeves Construction
Examined For [illegible] Recovery Pay Item No. 402
Used In Submitted By [illegible]
Remarks: CID: 811260-0[illegible]-000-0
Redi Set Additive for Warm Mix Asphalt

Table B-18 GDOT DSR Test – Rediset Mix (2)

```
Bohlin DSR Project - SHRP Pass/Fail Mode (Strain Controlled)
Instrument Serial No: 99/008000/BOH/A/007  Temp. Control: Water Bath
Summary Sheet:  SHRP Software: Version 5.07

File Name:      C:\DSR\00010004.ARP

Parameters:
    Measurement Type:     High Temperature Range
    Target Temperature:   60.0 °C
    Strain Amplitude:     10.00 percent
    Plate Diameter:       25.0 mm
    Plate Gap:            1.000 mm
    Equilibration Time:   10.0 minutes

Ancillary Info:
    Operator ID:          Operator 001
    Sample ID:            Sample0001
    Sample Type:          Original Binder
    Test Number:          0004

Measurement Results:      11/7/2009 11:39:06 AM
    Modulus (G*):         5.2728E3 Pascal
    Phase Angle (delta):  80.1 degrees
    G*/sin(delta):        5.3526E3 Pascal
    Strain Amplitude:     10.17 percent
    Final Temperature:    60.0 °C
    Osc. Frequency:       10.08 radians/second
    Test Status:          PASSED

Operator Notes:
    Title: Bohlin DSR Software Version 5.05
Redi- Mix  (Warm Mix)
    11/03/09 15%
CSSTP-M003-00(837)01 Monroe
Reeves Construction 9
    .5 II
```

DOT 170 SAMPLE CARD FOR ALL MATERIAL

Date Received NOV 05 2009 OMR Sample # 20905574

Project No. CSSTP-M003-00(837)01 County Monroe

Material 9.5 II Size or Type

Date Sampled 11-3-09 Sample No.

Sampled From Truck Sample Represents 15%

Producer or Property Owner

Location Reeves Postell

Contractor Reeves Construction

Examined For Gradation Recovery Pay Item No. 402

Used In Submitted By Ted Hardiman

Remarks: (ID: 811260-0f-000-0

Redi Set Additive for Warm Mix Asphalt

Table B-19 GDOT DSR Test – Cecabase RT Mix (1)

Bohlin DSR Project - SHRP Pass/Fail Mode (Strain Controlled)
Instrument Serial No: 99/008000/BOH/A/007 Temp. Control: Water Bath
Summary Sheet: SHRP Software: Version 5.07

File Name: C:\DSR\00010005.ARP

Parameters:

Measurement Type:	High Temperature Range
Target Temperature:	60.0 °C
Strain Amplitude:	10.00 percent
Plate Diameter:	25.0 mm
Plate Gap:	1.000 mm
Equilibration Time:	10.0 minutes

Ancillary Info:

Operator ID:	Operator 001
Sample ID:	Sample0001
Sample Type:	Original Binder
Test Number:	0005

Measurement Results: 11/7/2009 11:51:08 AM

Modulus (G*):	5.6202E3 Pascal
Phase Angle (delta):	78.5 degrees
G*/sin(delta):	5.7363E3 Pascal
Strain Amplitude:	10.44 percent
Final Temperature:	60.0 °C
Osc. Frequency:	10.08 radians/second
Test Status:	PASSED

Operator Notes:
Title: Bohlin DSR Software Version 5.05
Ceca- Mix (Warm Mix)
11/04/09 15%
CSSTP-M003-00(837)01 Monroe
Reeves Construction 9
.5 II

DOT 170 SAMPLE CARD FOR ALL MATERIAL

Date Received NOV 05 2009 OMR Sample # 70905575
Project No. CSSTP-M003-00(837)01 County Monroe
Material 9.5 II Size or Type
Date Sampled 11-4-09 Sample No.
Sampled From Truck Sample Represents 15%
Producer or Property Owner
Location Reeves Portell
Contractor Reeves Construction
Examined For Gradation Recovery Pay Item No. 402
Used In Submitted By
Remarks: CID: 81260-04-000-0
Ceca additive for Warm mix Asphalt

Table B-20 GDOT DSR Test – Cecabase RT Mix (2)

Bohlin DSR Project - SHRP Pass/Fail Mode (Strain Controlled)
Instrument Serial No: 99/008000/BOH/A/007 Temp. Control: Water Bath
Summary Sheet: SHRP Software: Version 5.07

File Name: C:\DSR\00010001.ARP

Parameters:

Measurement Type:	High Temperature Range
Target Temperature:	60.0 °C
Strain Amplitude:	10.00 percent
Plate Diameter:	25.0 mm
Plate Gap:	1.000 mm
Equilibration Time:	10.0 minutes

Ancillary Info:

Operator ID:	Operator 001
Sample ID:	Sample0001
Sample Type:	Original Binder
Test Number:	0001

Measurement Results: 11/7/2009 12:12:44 PM

Modulus (G*):	5.7218E3 Pascal
Phase Angle (delta):	78.4 degrees
G*/sin(delta):	5.8408E3 Pascal
Strain Amplitude:	10.37 percent
Final Temperature:	60.0 °C
Osc. Frequency:	10.08 radians/second
Test Status:	PASSED

Operator Notes:
Title: Bohlin DSR Software Version 5.05
Ceca Mix (Warm Mix) 11/
04/09 15%
CSSTP-M0003-00(837)01 9.5 II

DOT 170 **SAMPLE CARD FOR ALL MATERIAL**

Date Received NOV 05 2009 OMR Sample # 7090557S
Project No. CSSTP-M003-00(837)01 County Monroe
Material 9.5 II Size or Type
Date Sampled 11-4-09 Sample No.
Sampled From Truck Sample Represents 15%
Producer or Property Owner
Location Reeves Paitell
Contractor Reeves Construction
Examined For 9.5 mm Recovery Pay Item No. 402
Used In Submitted By Ted Gordon
Remarks: CID: 811260-01-000-0
Ceca additive for Warm mix Research

APPENDIX C WARM-MIX ASPHALT HYDROCARBON EMISSIONS SCOPING STUDY

Report entitled, "Warm-Mix Asphalt Hydrocarbon Emissions Scoping Study" prepared by A. Samoylov and M. Rodgers

Warm-Mix Asphalt Hydrocarbon Emissions Scoping Study

Alexander Samoylov &
Michael Rodgers, Ph.D

Georgia Tech Research Institute
Air Quality Group
Aerospace, Transportation and Advanced Systems Laboratory

February 2010

TABLE OF CONTENTS

Introduction

This report provides results of a preliminary scoping study to determine the relative magnitude of hydrocarbon emissions arising from the use of various warm mix asphalt (WMA) blends being considered for use by the Georgia Department of Transportation. An important consideration in the use of all asphalt mixtures is their potential for emissions of Volatile Organic Compounds (VOC) that are important precursors to photochemical smog and the creation of secondary fine particulate matter (PM2.5). Significant increases or decreases in VOC emissions from these WMA mixtures relative to current asphalts could either positively or negatively impact their desirability as a replacement for current mixtures.

Determination of absolute emissions rates from industrial processes is normally a costly and difficult process as these emissions rates are often strongly impacted by local environmental conditions and normal variations in the process being measured. This natural variability means that obtaining good quantitative results normally requires a large number of replicate measurements across a range of environmental and process conditions with extensive micrometeorological support and specialized instrumentation and apparatus. As a result, these quantitative experiments tend to be time consuming and costly and tend to be limited to those emissions that are both significant and likely to be substantially different from other processes in which the emissions rates are already known. For this reason, scoping studies are often undertaken to ascertain whether emissions from a new process are likely to be substantially different from the one that it replaces. This study was conceived as a “first look” or scoping study to determine whether VOC emissions from these WMA mixtures were significantly higher, lower or comparable to those observed from a current asphalt mix and to ascertain the need for a more comprehensive study.

Measurement Approach

The basic study approach was to compare observed VOC concentrations just above surface of various WMA blends with those associated with a control mix using both free air and an open topped chamber (cone). Measurements of surface fluxes using near surface concentration measurements normally require the use of eddy correlation, gradient or Bowen ratio methods that require substantial ancillary micrometeorological measurements in addition to the concentration measurements. In the case of asphalt mixtures, this need for extensive supporting meteorological measurements is greatly reduced since the surface temperature of the asphalt mix (260 to 300 degrees Fahrenheit) is so high relative to that of the ambient air that the near surface energy balance is almost completely controlled by the asphalt mix at least so long as the surface winds are not too high. Thus for this scoping study measurements were limited to evaluation of the near surface concentration gradients and exhaust concentrations from the open topped chambers based on the assumption that ventilation rates induced by the surface temperature conditions were comparable for all of the mixtures. While, of course, this approximation is not strictly true due to variations in environmental conditions, it is believed to be a sufficiently accurate to determine if the relative emissions from the WMA mixtures were significantly (i.e. more than a factor of two) higher or lower or comparable to that of the control mix.

All VOC measurements made during the study were performed using a Siemens Ultramat 23® Non-Dispersive Infrared (NDIR) detector equipped with a heated type 316 stainless steel inlet system. Measurements were made at distances 3, 10, 30, and 100 cm above the surface of the asphalt mixtures in open air and at the exhaust from a variety of simple open-topped chambers[3] with a six second measurement update cycle.

These VOC measurements were conducted on WMA mixtures containing three different additives as well as a control mixture that was a regular mixture approved by Georgia Department of Transportation for use on state roads. The additives used in the WMA mixtures used in this study were provided by Evotherm, Rediset, and CECA. The VOC measurements on the asphalt mixtures were performed in two separate locations. The first of these locations was at the asphalt plant operated by Aggregate USA near Macon, GA. The second location was at a paving site on State Route 42 near Forsyth, GA. Both locations are illustrated on Figure 1 below.

Figure 1: Location of asphalt plant and paving site used for study measurements

Table 1 gives more specific information regarding the measurement program including measurement day, general environmental conditions, asphalt temperatures and pavement status.

[3] These chambers were employed to reduce the impact of wind conditions. As many of these chambers were standard traffic cones these chambers are marked in this report as cones (See cone description in Appendix A).

Table 3: Study Conditions

Day#	Date	Additive Measured	Temp Morning, (deg F)	Temp Afternoon, (deg F)	Wind Conditions	Humidity	Asphalt Temperature			Pavement Rolled	Pavement Unrolled
							300F	280F	260F		
1	10/29/2009	Evotherm	40-45	55-60	Strong	Medium	X	X	X		
2	10/30/2009	Low Rediset / Control Mix	40-45	50-55	Light	High	X			X	X
3	11/3/2009	Rediset	40-45	55-60	Moderate	Medium	X	X		X	X
4	11/4/2009	CECA	45-50	60-65	Light	Medium	X	X	X	X	X

Asphalt Plant Measurements

The VOC measurements at the asphalt plant shortly after, usually within 1-2 minutes, the asphalt was dispensed from the surge bin to ensure that the deviations between sampling and measured temperatures were minimized. All measurements were made near the center of the truck bed at distances of 1, 3, 10, 30, and 100 centimeters from the asphalt surface using a heated stainless steel line and a Siemens Ultramat 23® NDIR detector[4]. In addition to these open air measurement some semi-controlled measurements were performed using open topped chambers (cones) resting on the asphalt surface. Several measurements were excluded from the data set because delay between truck loading and the time the vehicle was made available for the measurements was too great (i.e. more than 20 minutes).

Figure 2: Reeves Asphalt Plant near Macon, GA

Paving Site Measurements

Measurements at the paving site were done on location by using the same general approach as that used for the asphalt plant measurements. In this case the stainless steel inlet was placed close to the centerline of the freshly dispensed asphalt. Measurements were performed in two separate stages. Stage one (labeled unrolled in the tables) was conducted after the asphalt mix was dispensed from the paver but before rollers had a chance to compact the asphalt. In the second stage (labeled rolled in the tables) was performed after the rollers had completed at least one pass and packed down the asphalt. Figure 3 shows a typical view of the sample paving site location.

---

[4] This NDIR system evaluates hydrocarbon concentrations through optical absorption in the middle infrared spectral region associated with the C-H stretch and reports values in terms of concentration of an equivalent reference gas (n-hexane).

Figure 3: View of paving site near Forsyth, GA

Evotherm Additive

The Evotherm additive WMA was tested on October 29th 2009. In the morning hours, ambient temperature ranged from 40-45 ^oF and were associated with the very strong winds. These winds moderated significantly in the afternoon and ambient temperatures rose to 55-60 ^oF.

VOC measurements were conducted at three different WMA temperature ranges: 300^{o}F, 280^{o}F and 260^{o}F and were conducted only at the asphalt plant. The results of the measurements are shown in Figures 4, 5 and 6 respectively. These data are also tabulated in Tables 2, 3, and 4 in the appendix.

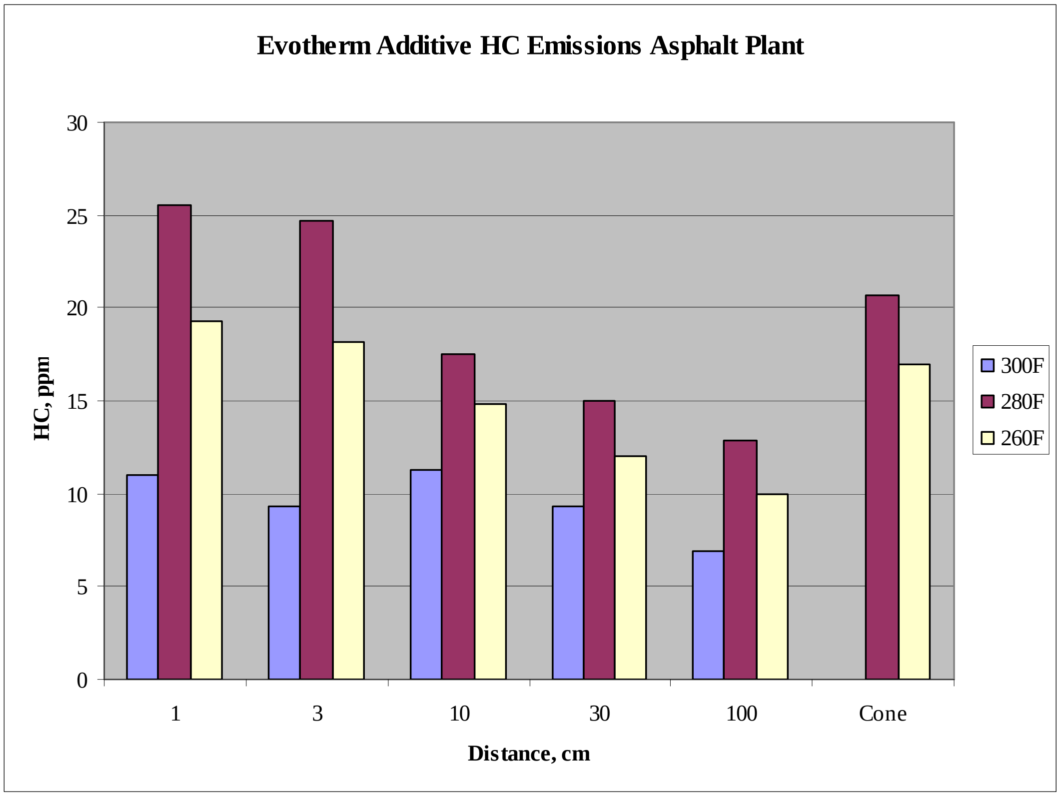

Figure 4: Evotherm Additive VOC concentrations at asphalt plant by temperature

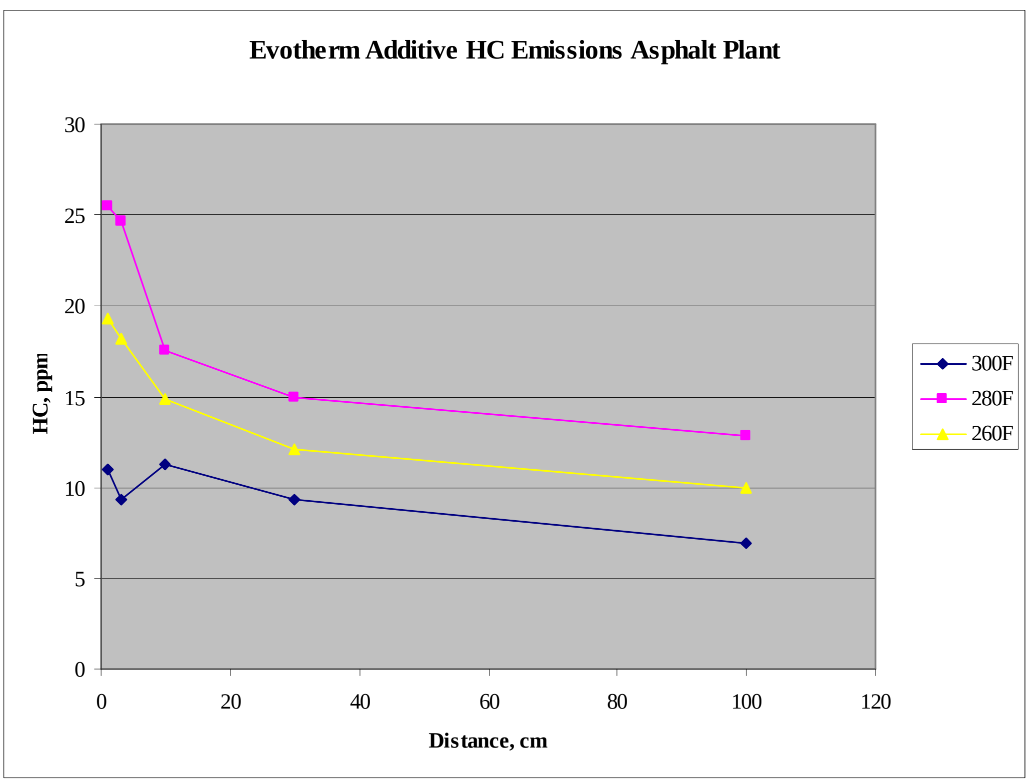

Figure 5: Evotherm Additive VOC concentrations at asphalt plant by distance above asphalt surface

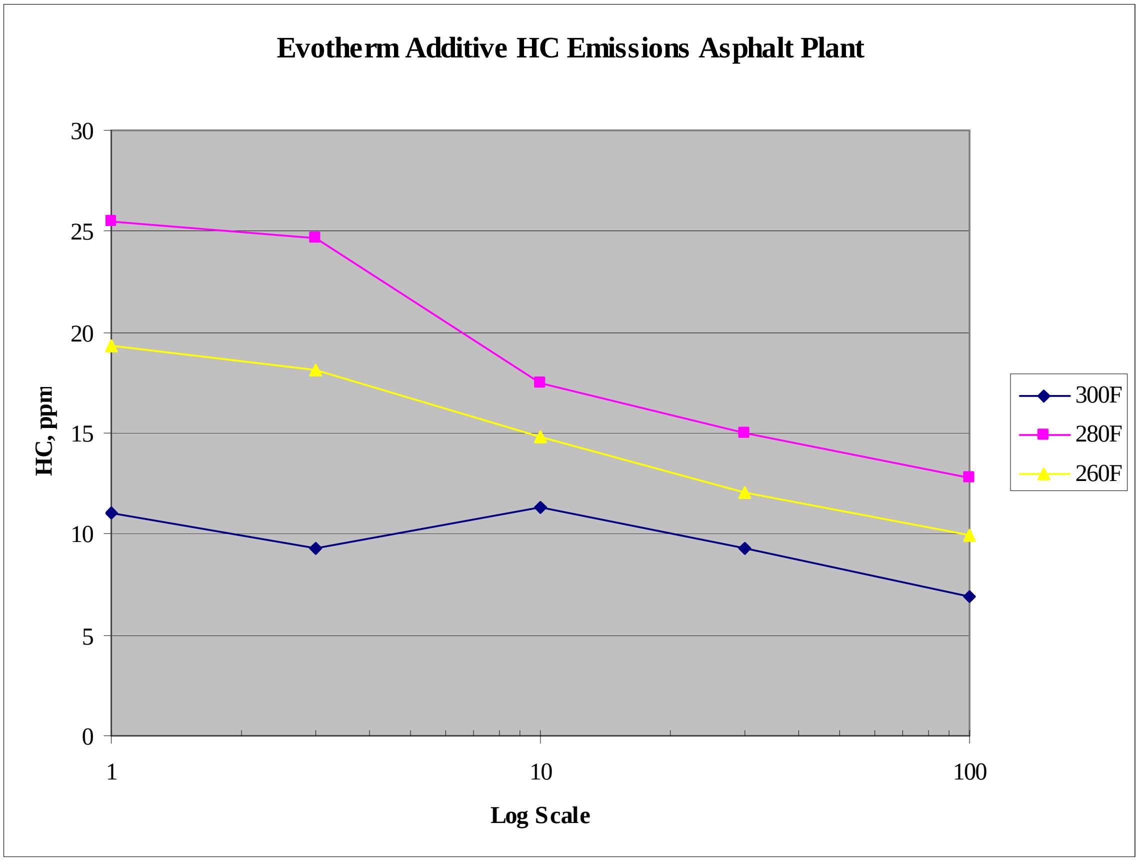

Figure 6: Evotherm Additive asphalt plant VOC concentrations Log Scale

Control Mix and Low Concentration Rediset Additive

Measurements of the control mix and low concentration of Rediset additive were done on October 30th, 2009. Weather conditions for that day were considerably different from the day before. Temperatures were between 45 ^{o}F and 55 ^{o}F with the high humidity and light drizzle that became light rain at times. Winds were very light.

The Rediset Additive WMA mixture at 300 ^{o} F was measured first. However, it became apparent the next day that an incorrect proportion of Rediset additive was added to asphalt mix. Only approximately 30% of Rediset additive dissolved in the asphalt mix. Measurement results for this low Rediset additive can be seen on Figure 7 and in Table 5 of the appendix.

Measurements for the Regular/Control mix were also made in the same day. Results from the control mix are presented in Figures 8 and 9 and in Table 6 of the appendix. As for the low concentration Rediset additive, the control mix was measured only at 300 ^{o} F.

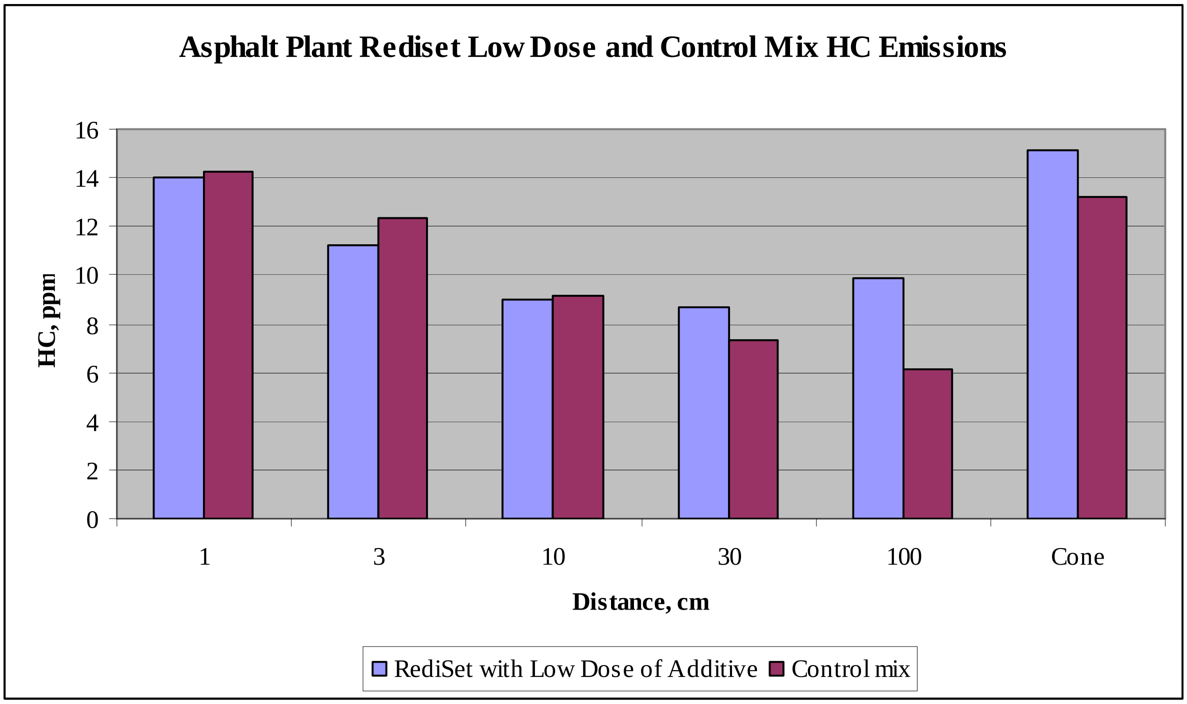

Figure 7: Incorrect Rediset Additive Asphalt Plant VOC Measurements

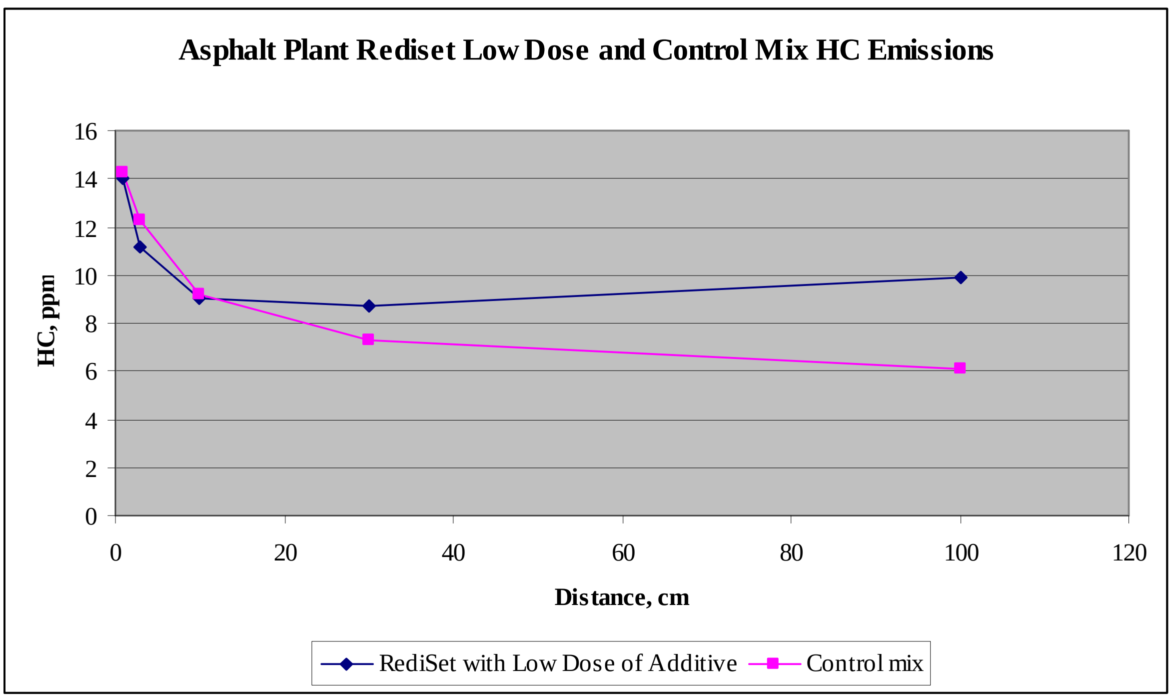

Figure 8: Incorrect Rediset Additive Asphalt Plant VOC Measurements

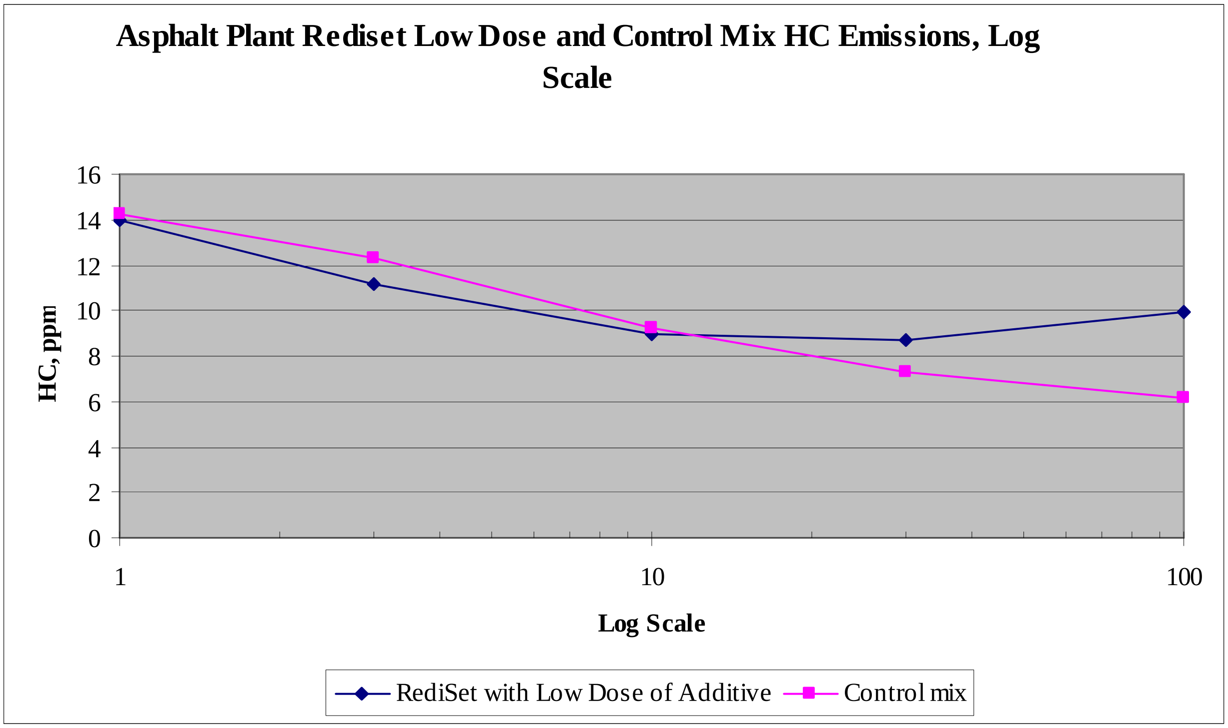

Figure 9: Incorrect Rediset Additive Asphalt Plant VOC Measurements Log Scale

In addition to the asphalt plant measurements, measurements at the paving site were also performed using both open air and chamber measurements. These data are summarized in Figure 10 and in Table 7 and Table 8 of the Appendix.

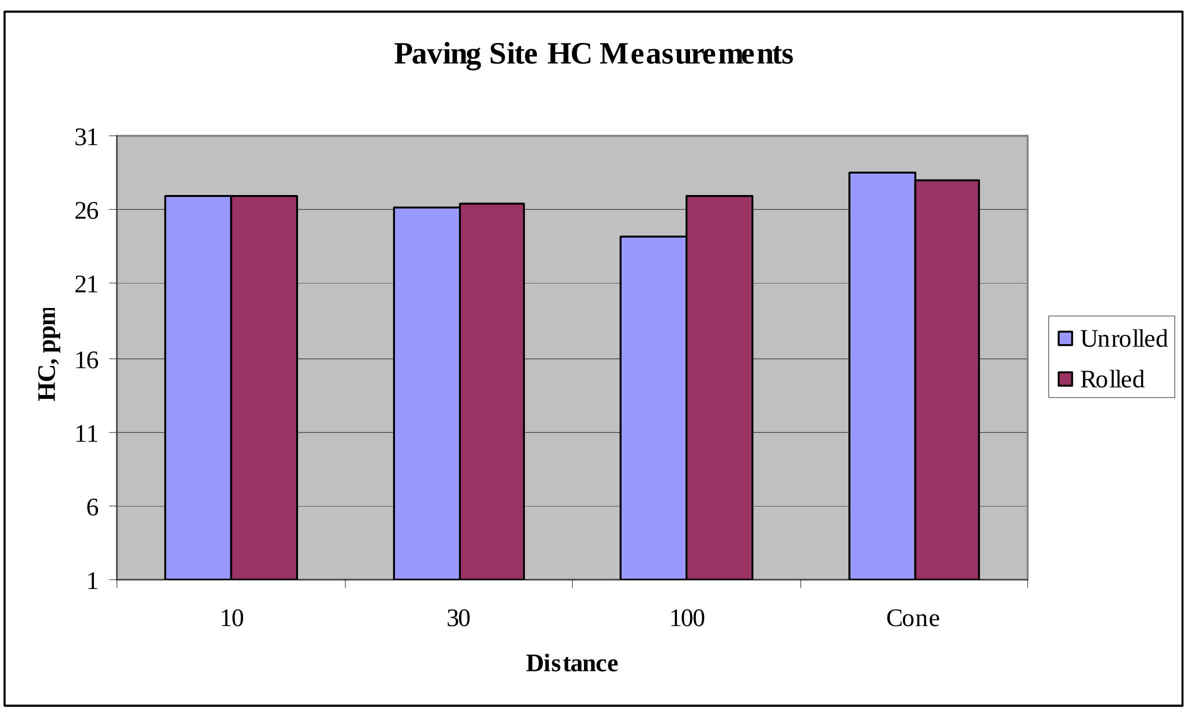

Figure 10: Regular Control Mix Paving Site VOC Measurements

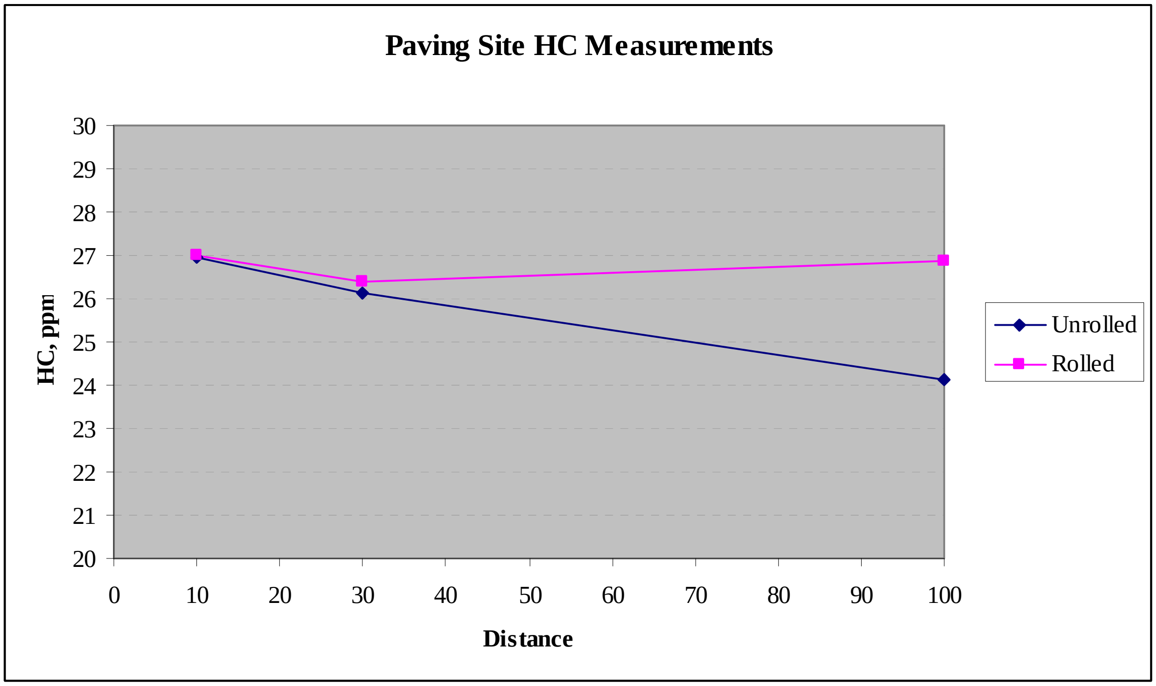

Figure 11: Regular Control Mix Paving Site VOC Measurements

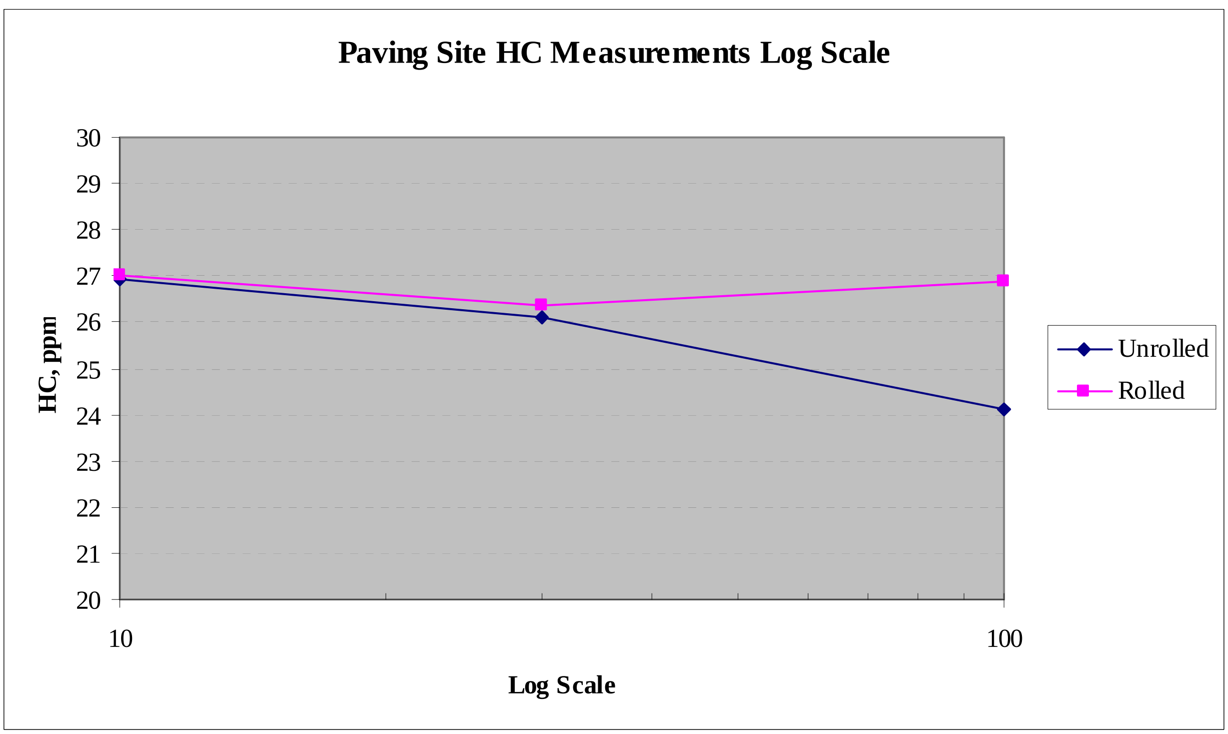

Figure 12: Regular Control Mix Paving Site VOC Measurements Log Scale

These results show a high degree of consistency between the low concentration of Rediset additive and regular mix asphalt from the asphalt plant. In other words, low concentration of the

Rediset additive did not have any measureable effect on VOC concentration compared to the control mix.

When we look at the results from the paving site we also see that rolled and unrolled measurements of VOC concentrations are very similar. Rolled asphalt appears to be a slightly stronger source of VOC emission but given the variability of external conditions and the small absolute difference, the differences between rolled and unrolled asphalt are minimal.

Rediset Additive

The correct concentration of Rediset additive was tested on November 30th, 2009. In the morning temperatures were 40 °F -45 °F with very light wind conditions and in the afternoon it reached 55 °F - 60°F with the wind increasing and becoming moderate.

The Rediset additive asphalt plant VOC measurements were performed at two temperatures points of 300 °F and 280 °F. Results of these measurements are summarized in Figure 13 and in Tables 9 and 10 in the Appendix.

Measurements were also conducted at the paving site. Results from these rolled and unrolled measurements are compared with the plant results in Figures 14 and 15 and in more detail in Table 11 (unrolled) and Table 12 (rolled) in the Appendix.

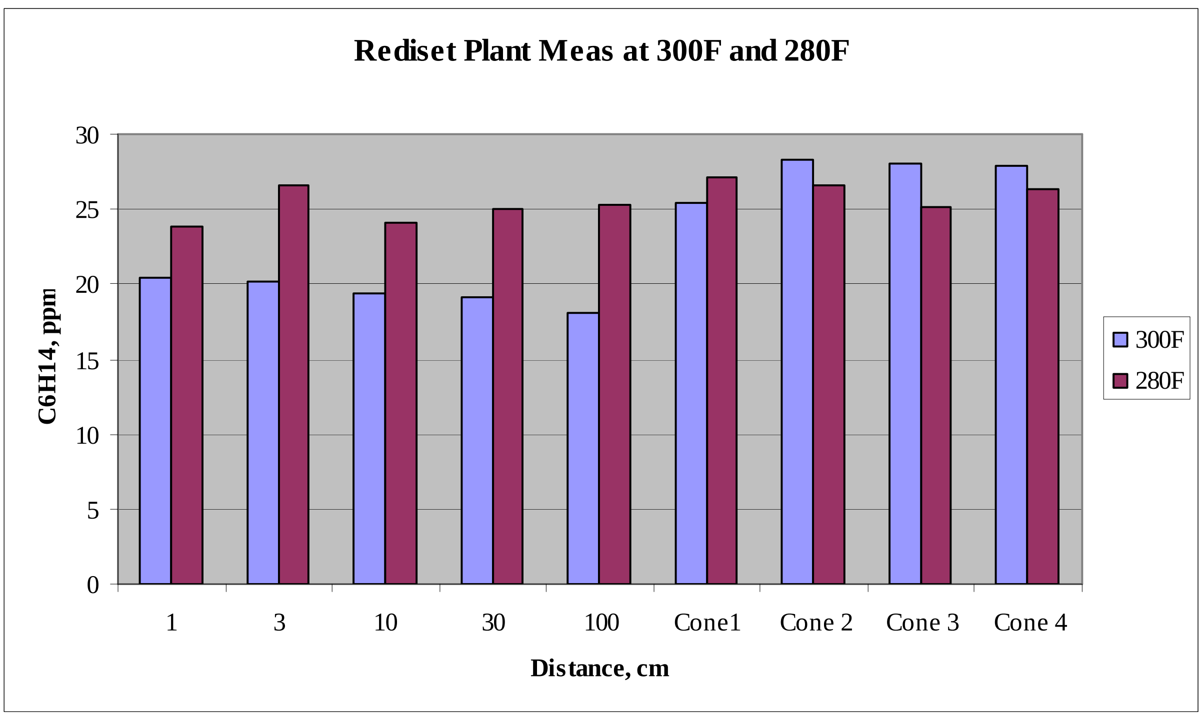

Figure 13:3 Rediset Additive Asphalt Plant VOC Measurements

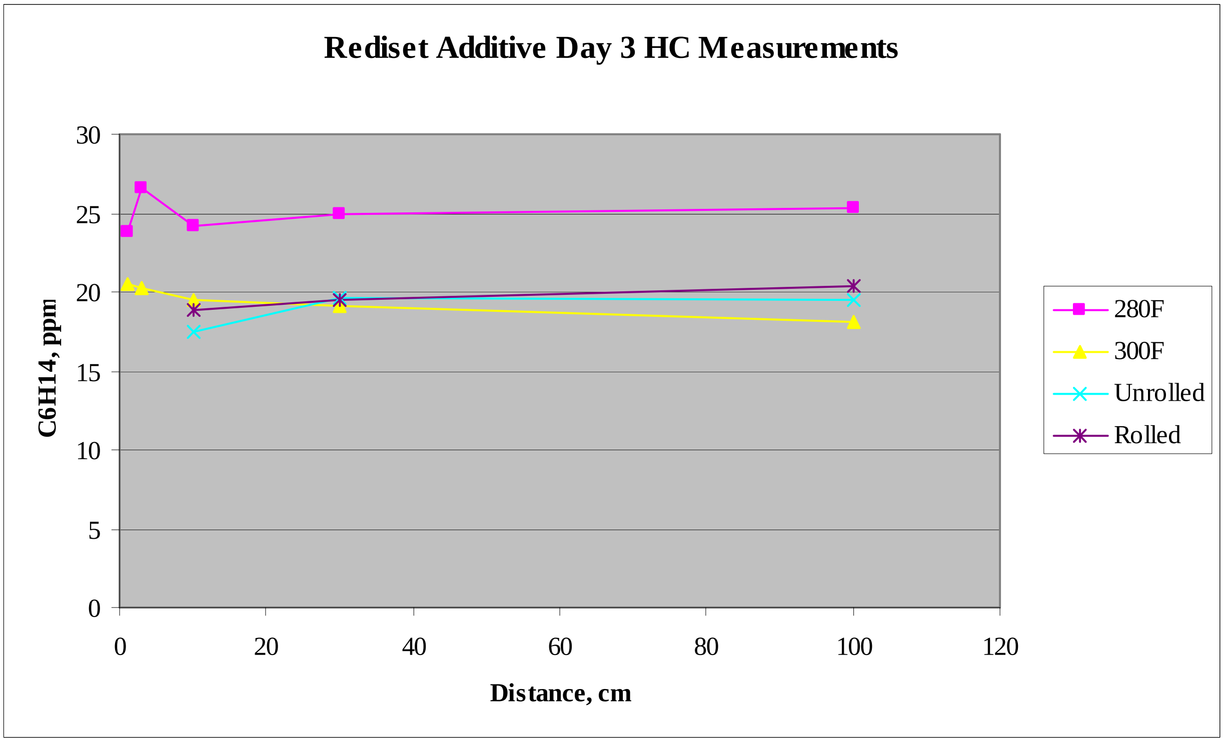

Figure 14: Rediset Additive VOC Measurements

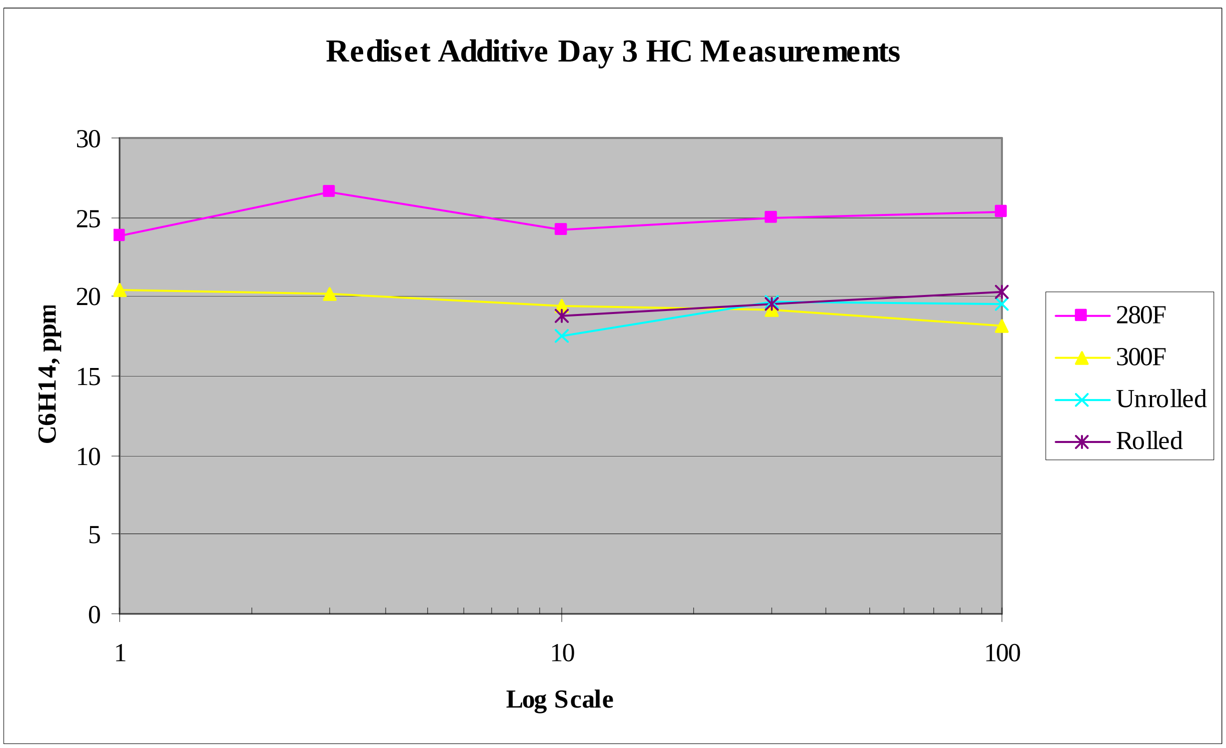

Figure 15: Rediset VOC Measurements Log Scale

From these results we observe no significant differences between the 280 ^{o}F and 300 ^{o}F WMA mixtures with the Rediset additive. Likewise, there was no difference for rolled and unrolled paving conditions.

CECA Additive

CECA additive measurements were carried out on November 4th, 2009. Temperatures in the morning hours were between 45 °F - 50 °F and in the afternoon between 60 °F - 65°F with light wind conditions.

Measurements of asphalt mix containing CECA additive were made at the asphalt plant for all three temperature ranges: 300°F, 280°F, and 260°F (Tables 13, 14, 15 in the Appendix). Open air and results from three different cones are illustrated in Figures 16 and 17.

VOC concentration measurements were made at the paving site for mixtures of CECA additive at 260°F and at 300°F. Detailed results are presented in Tables 16-19 of the Appendix. The same results are shown in Figure 18 (linear height scale) and Figure 19 (log height scale) for the open air measurements. Figure 20 shows results for the cone measurements at the asphalt plant measurements and rolled and unrolled pavement measurements.

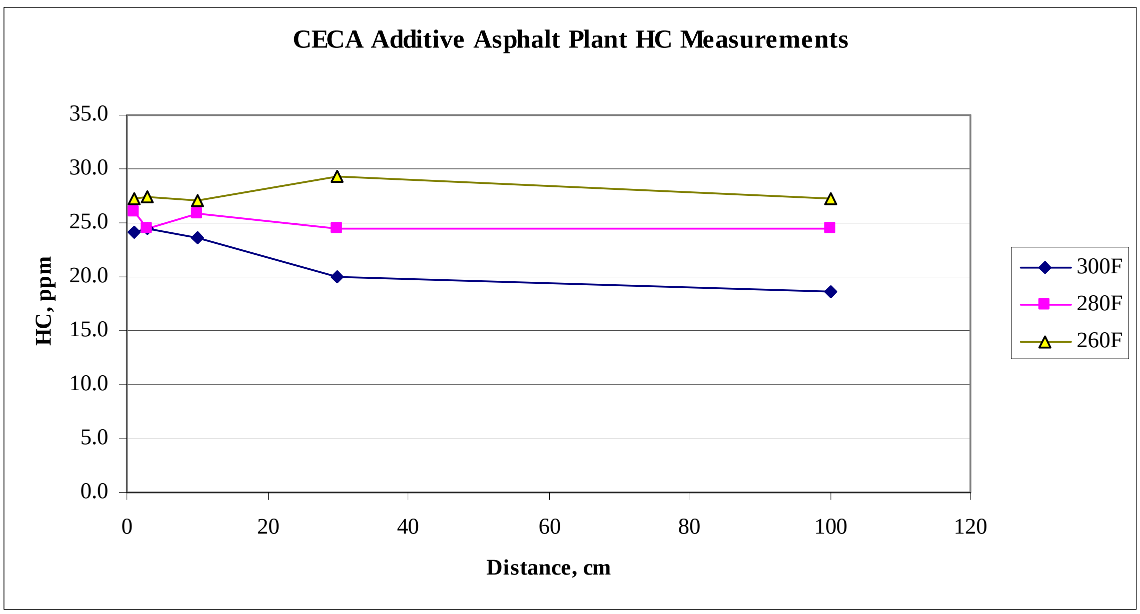

Figure 16: CECA Additive Asphalt Plant VOC Measurements

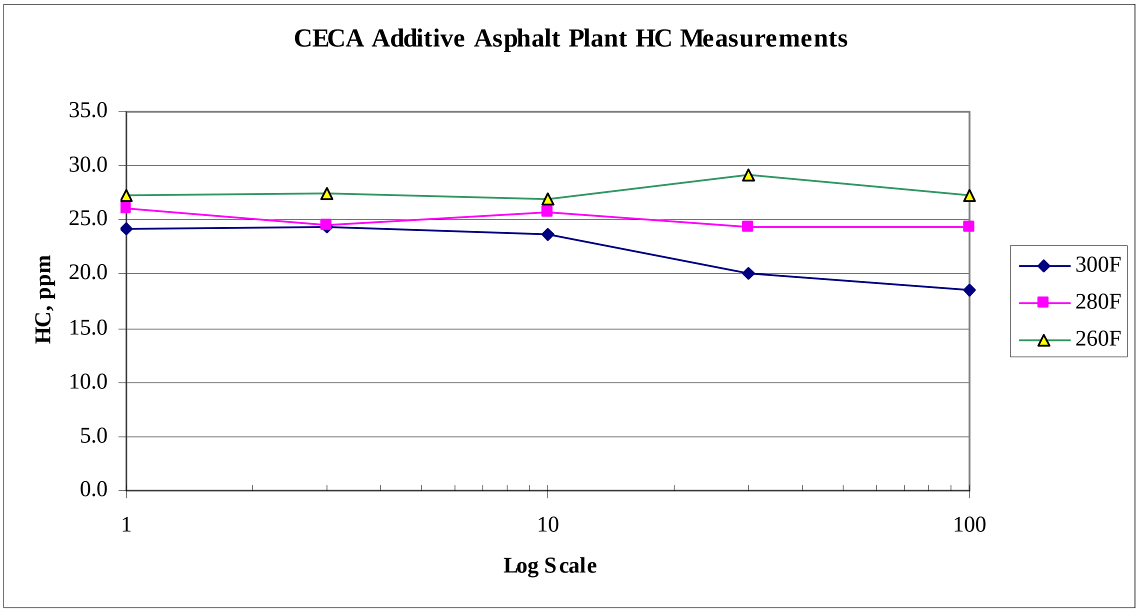

Figure 17: CECA Additive Asphalt Plant VOC Measurements Log Scale

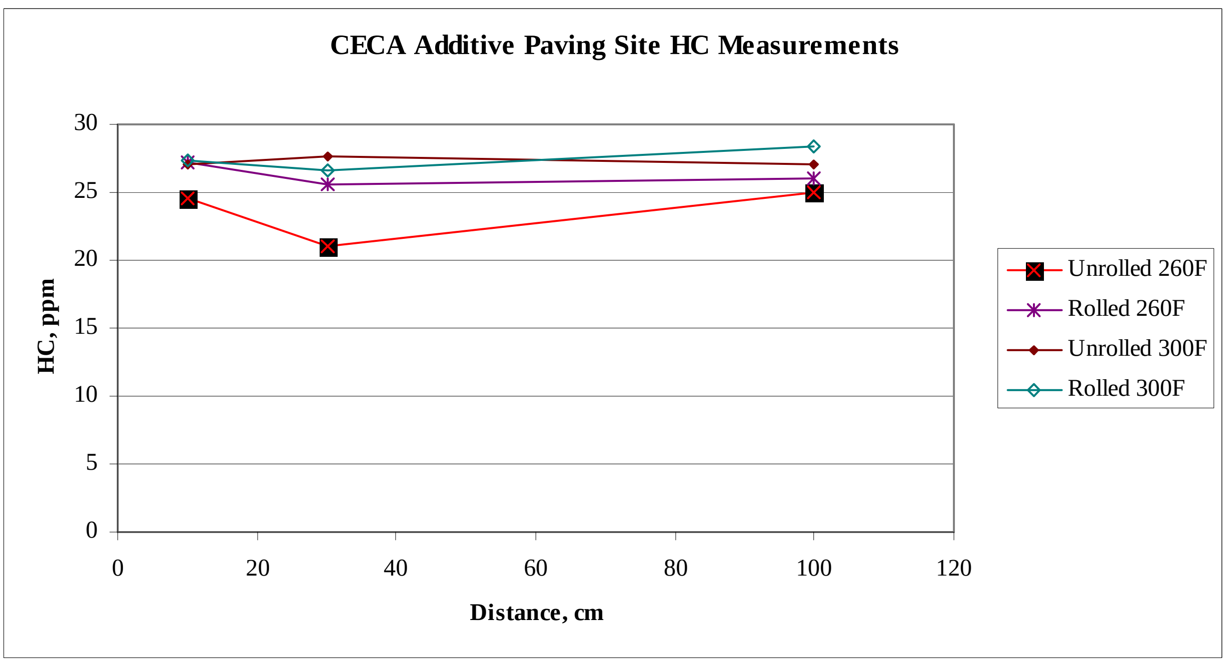

Figure 18: CECA Additive Paving Site VOC Measurements

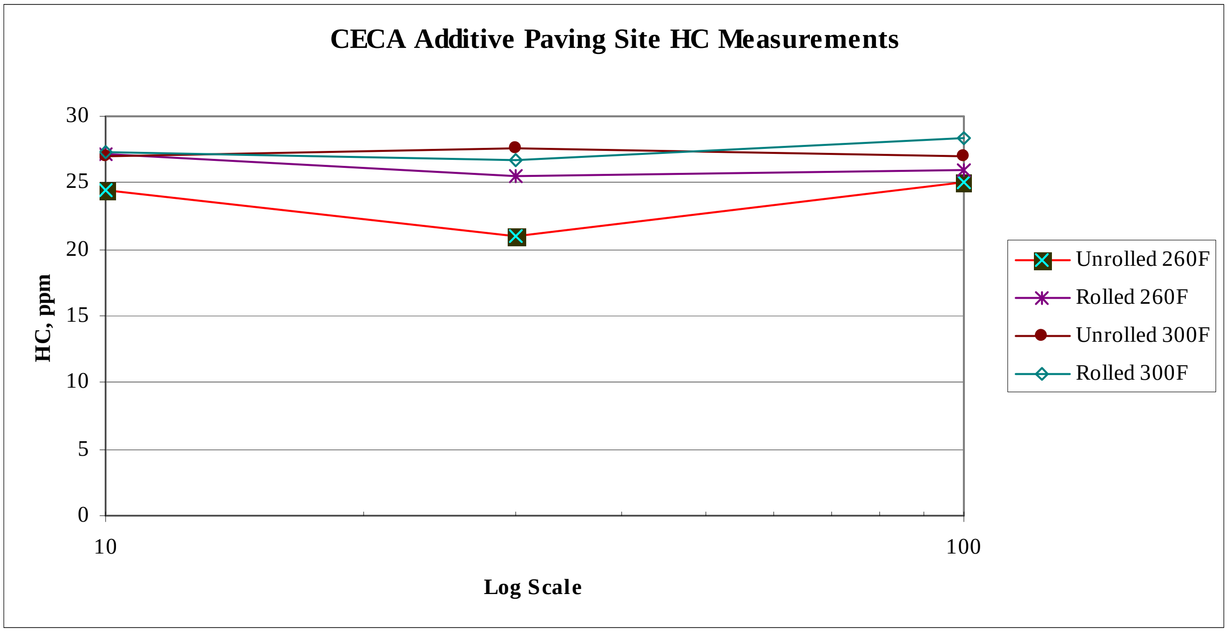

Figure 19: CECA Additive Paving Site VOC Measurements Log Scale

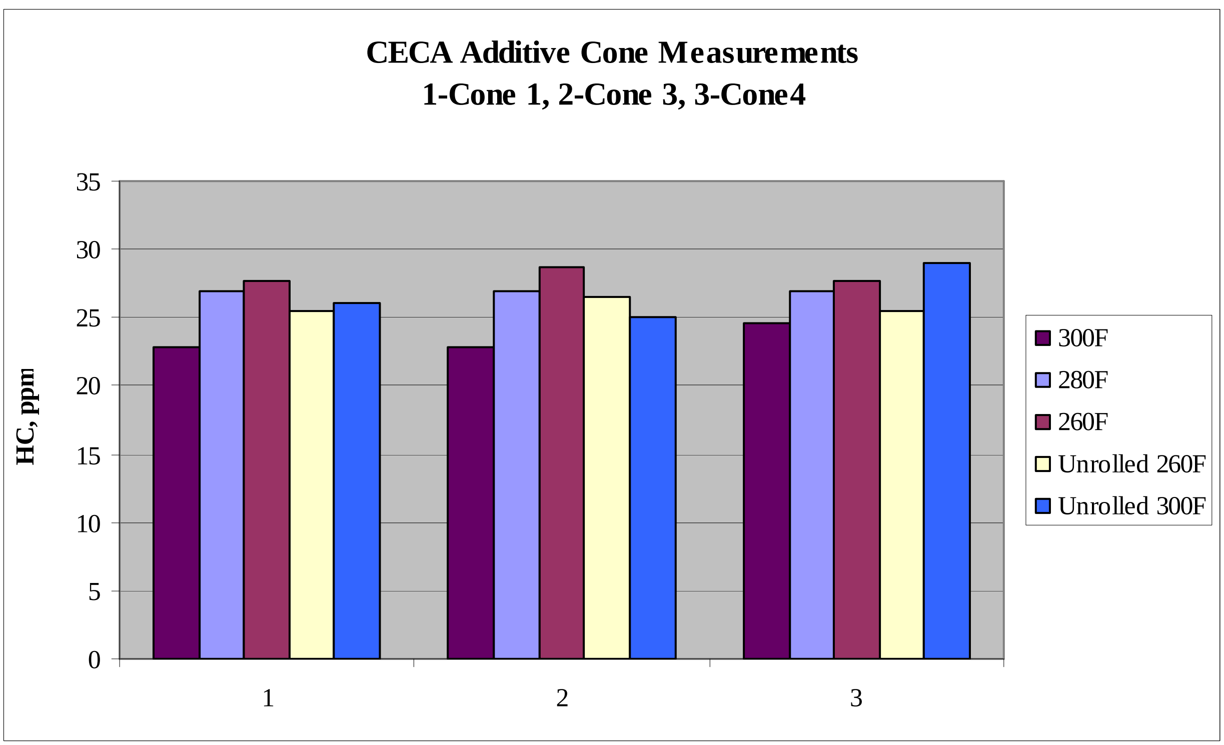

Figure 20: CECA Additive VOC Cone Measurements

Even though some minor differences can be observed between the conditions, these differences are likely to be within the variability between mixtures and thus insignificant from an emissions perspective. CECA additive at different temperatures demonstrated the same VOC emission behaviors.

Conclusions

This study was designed as a screening test to examine if there were significant variations in VOC emissions from different additives such as Evotherm, Rediset, and CECA used to produce WMA and to examine the effect of mixture temperature on emissions from these mixtures. Based on the results of this study, it appears unlikely that any of the WMA mixtures using any of the tested additives VOC emissions are significantly different (more than a factor of two) from the existing control mix for the same environmental conditions. Further, the results show only very small, and likely insignificant, differences between the additives in terms of observed VOC concentrations making it unlikely that VOC emissions would be an important factor in the selection of a preferred additive for a WMA mixture, at least among these candidates, and that the selection should be made based on other characteristics of the mixtures.

Of course, much smaller emissions differences could be important for air quality purposes and additional, more controlled, studies of VOC emissions should be considered once a particular mixture and application temperature are selected. These additional measurements, made under the final selected conditions, are the best way to ensure that accuracy of future air quality emissions inventories.

Appendix

Cone Descriptions

Cone 1 is a 29” traffic cone with the 10” base and 2” top with a 1” top opening.

Cone 1

Cone 2 is a 29” traffic cone with 7” base and 1 ¾ inch top with a 1” top opening.

Cone 2

Cone 3 is a 19” traffic cone with 7” base and 2” top with 1” top opening.

Cone 3

Cone 4 is an inverted 7” tall ceramic flower pot with an 8” base (as shown) and 4.5” top with a 1” top opening.

Cone 4

6.2.1 Data Tables

Table 4 Evotherm Additive at 300 F Asphalt Plant VOC Measurements

Meas #	Distance, cm				
	1	**3**	**10**	**30**	**100**
1	9	10	9	10	10
2	8	13	12	11	10
3	8	8	8	8	7
4	12	8	10	11	6
5	20	9	19	9	3
Average	11	9	11	9	7

Table 5 Evotherm Additive at 280 F Asphalt Plant VOC Measurements

Meas #	Distance, cm					Cone
	1	**3**	**10**	**30**	**100**	
1	26	22	17	16	14	20
2	28	28	26	19	16	20
3	28	28	18	15	13	20
4	27	27	16	13	10	20
5	25	25	12	13	12	19
6	19	18	16	14	12	25
Average	26	25	18	15	13	21

Table 6 Evotherm Additive at 260 F

Meas #	Distance, cm					Cone
	1	3	10	30	100	
1	23	23	21	18	8.6	12
2	18	18	13	8.8	8.8	18
3	20	20	18	12	8.8	18
4	17	16	11	8.6	8.6	17
5	15	14	13	11	8.8	17
6	20	18	14	12	12	14
7	22	18	14	14	14	23
Average	19	18	15	12	10	17

Table 7 Incorrect Portion of Rediset Additive 300F Asphalt Plant VOC Measurements

Meas #	Distance, cm					Cone
	1	3	10	30	100	
1	17		14	7	10	10
2	20	15	12	10	5	15
3	12	12	7	12	10	14
4	9	7	6	6	9	10
5	17	8	9	9	15	13
6	11	11	13	8	13	16
7	12	11	6	6	7	18
Average	14	10	9	8	10	14

Table 8 Regular Control Mix Asphalt Plant VOC Measurements

Meas #	Distance, cm					Cone
	1	3	10	30	100	
1	12.5	8	6	4	4	9
2	12.5	13	6.5	6	6	11
3	13	10	8	6	6	14
4	13	14	8	7.5	5	14
5	15	13	8.5	8	6	14
6	16	13	12.5	9	8	14
7	15	13.5	13	11	8	13.5
8	17	14	11	7	6	16
Average	14.3	12.3	9.2	7.3	6.1	13.2

Below are measurements of VOC from the paving site. They include unrolled and rolled measurements. Unrolled measurements are the data taken after asphalt was distributed to the paving surface from the paver but before rollers had a chance to roll it. Rolled data was taken after rollers passed at least once and between each subsequent roll.

Table 9 Regular Control Mix Paving Site VOC Measurements UNROLLED

Meas #	Distance, cm			Cone
	10	30	100	
1	20.5	21	16	28
2	27	21	19	31
3	25	23	23	
4	25	28	23	
5	32	29	28	27
6	34	33	26	
7	29	27	34	
8	23	27	24	28
Average	27	26	24	29

Table 10 Regular Control Mix Paving Site VOC Measurements ROLLED

Meas #	Distance, cm			Cone
	10	30	100	
1	27	25	23	28
2	20	26	25	
3	31	26	23	
4	21	22	23	
5	34	28	32	
6	29	24	32	
7	25	32	29	
8	29	28	28	
Average	27	26	27	28

Table 11 Rediset Additive 300F VOC Measurements

Meas #	Distance, cm					Cone			
	1	3	10	30	100	Cone1	Cone 2	Cone 3	Cone 4
1	19	21	19	18	18	38	36	44	50
2	21	20	19	23	21	34	38	36	34
3	26	28	28	24	21	22	21	25	28
4	21	20	20	17	18	22	27	24	22
5	17	21	18	17	13	19	22	18	21
6	29	23	24	22	24	26	26	29	23
7	16	17	13	17	16	18		21	26
8	18	15	14	20	17	25		22	17
9	17	17	20	14	15	25		33	30
Average	20	20	19	19	18	25	28	28	28

Table 12 Rediset Additive 280F Asphalt Plant VOC Measurements

Meas #	Distance, cm					Cone			
	1	3	10	30	100	Cone1	Cone 2	Cone 3	Cone 4
1	24	28	23	24	23	34	30	25	30
2	24	35	23	22	27	21	23	21	27
3	23	32	28	27	27	29	29	25	26
4	25	27	26	27	25	26	27	29	25
5	23	22	22	25	28	23	24	27	23
6	21	20	24	24	23	29		27	29
7	27	22	23	26	24	28		22	24
Average	24	27	24	25	25	27	27	25	26

Table 13 Rediset Paving Site VOC Measurements UNROLLED

Meas #	Distance, cm			Cone		
	10	30	100	Cone1	Cone 3	Cone 4
1	16	17	18	17	17	17
2	16.5	21	19.5	17	22	19.5
3	20	21	21			
Average	18	20	20	17	20	18

Table 14 Rediset Paving Site VOC Measurements ROLLED

Meas #	Distance, cm		
	10	30	100
1	19	20	21
2	18.5	18.5	19
3	19	20	21
Average	19	20	20

Table 15 Day 4 CECA Additive 300F Plant VOC measurements

Meas #	Distance, cm					Cone		
	1	3	10	30	100	Cone1	Cone 3	Cone 4
1	27	31	28	16	14	21	25	28
2	23	21	20	20	16	23	23	21
3	26	23	25	21	21	25	23	24
4	21	21	21	22	21	26	25	22
5	24	26	24	21	21	28	27	23
Average	24	24	24	20	19	25	25	24

Table 16 CECA Additive 280F Plant VOC Measurements

Meas #	Distance, cm					Cone		
	1	3	10	30	100	Cone1	Cone 3	Cone 4
1	29	24	25	24	20	28	27	27
2	28	26	23	24	23	28	27	27
3	28	29	26	28	28	28	29	26
4	27	27	28	28	27	30	29	27
5	21	19	23	24	29	23	24	29
6	21	27	23	20	24	24	26	24
7	29	28	28	26	23	32	27	29
8	27	18	28	18	19	21	27	25
9	24	23	28	28	27	29	26	28
Average	26	25	26	24	24	27	27	27

Table 17 CECA Additive 260F Plant VOC Measurements

Meas #	Distance, cm					Cone		
	1	3	10	30	100	Cone1	Cone 3	Cone 4
1	25	28	29	29	27	29	27	28
2	28	28	24	29	26	27	31	29
3	27	28	28	31	29	27	28	27
4	29	26	27	28	27	28	29	27
Average	27	28	27	29	27	28	29	28

Table 18 CECA Additive 260F Paving Site VOC Measurements UNROLLED

Meas #	Distance, cm			Cone		
	10	30	100	Cone1	Cone 3	Cone 4
1	22	21	29	24	29	25
2	27	21	21	27	24	26
Average	25	21	25	26	27	26

Table 19 CECA Additive 260F Paving Site VOC Measurements ROLLED

Meas #	Distance, cm		
	10	30	100
1	28	26	25
2	27	26	26
3	25	23	23
4	28	25	28
5	27	27	26
6	28	25	28
7	27	27	26
Average	27	26	26

Table 20 CECA Additive 300F Paving Site VOC Measurements UNROLLED

Meas #	Distance, cm			Cone		
	10	30	100	Cone1	Cone 3	Cone 4
1	26	27	25	26	25	29
2	26	27	29	26	25	29
3	29	29	27			
Average	27	28	27	26	25	29

Table 21 CECA Additive 300F Paving Site VOC ROLLED

Meas #	Distance, cm		
	10	30	100
1	27	27	29
2	27	25	28
3	28	28	28
Average	27	27	28