Louisiana Transportation Research Center

Final Report 628

Demonstration Project for Enhanced Durability of Asphalt Pavements through Increased In-Place Pavement Density

by

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TECHNICAL REPORT STANDARD PAGE

1. Title and Subtitle
Demonstration Project for Enhanced Durability of Asphalt Pavements through Increased In-Place Pavement Density

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Louisiana Department of Transportation and Development
P.O. Box 94245
Baton Rouge, LA 70804-9245

5. Report No.
FHWA/LA.17/628

6. Report Date
November 2020

7. Performing Organization Code
LTRC Project Number: 18-4B
SIO Number: DOTLT 1000214

8. Type of Report and Period Covered
Final Report
Enter Date: 10/2018 – 9/2019

9. No. of Pages
52

10. Supplementary Notes
Conducted in Cooperation with the U.S. Department of Transportation, Federal Highway Administration

11. Distribution Statement
Unrestricted. This document is available through the National Technical Information Service, Springfield, VA 21161.

12. Key Words
In-place density; Durability; WMA; Evotherm; LWT; SCB; IDT E*

13. Abstract
In-place density of asphalt pavements is an important factor influencing performance and durability. The objective of this project was to evaluate the effects of increasing the initial in-place density of asphalt pavements on their field performance and durability. This study is part of the FHWA demonstration project on *Enhanced Durability through Increased In-Place Pavement Density*. Two approaches for increasing in-place density were adopted: (1) addition of Evotherm warm mix asphalt (WMA) additive at a dosage rate of 0.6% by the weight of mix, and (2) addition 0.2% asphalt binder (Plus AC) to the design optimum asphalt binder content. Three test sections, each consisting of 4,000-ft. long overlay section of control hot mix asphalt (HMA), Evotherm WMA, and Plus AC HMA of binder and wearing course mixtures were constructed. Density measurements were determined in the laboratory from field cores taken at each test section. The high- and intermediate-temperature properties of field cores were evaluated using the Loaded Wheel Tracking and Semi-Circular Bending tests, respectively. Further, indirect tensile dynamic modulus (IDT |E*|) test was conducted for full viscoelastic characterization of the asphalt mixtures. The two approaches considered in this study were successful in increasing field density. Significant increase in densities of the binder course Evotherm WMA and Plus AC HMA mixtures as compared to the control one were measured. Further, increased in-place density resulted in an increase in mixture stiffness as measured by the IDT |E*|.

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LTRC appreciates the dedication of the following Project Review Committee Members in guiding this research study to fruition.

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conducted for
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In-place density of asphalt pavements is an important factor influencing performance and durability. The objective of this project was to evaluate the effects of increasing the initial in-place density of asphalt pavements on their field performance and durability. This study is part of the FHWA demonstration project on *Enhanced Durability through Increased In-Place Pavement Density*. Two approaches for increasing in-place density were adopted: (1) addition of Evotherm warm mix asphalt (WMA) additive at a dosage rate of 0.6% by the weight of mix, and (2) addition 0.2% asphalt binder (Plus AC) to the design optimum asphalt binder content. Three test sections, each consisting of 4,000-ft. long overlay section of control hot mix asphalt (HMA), Evotherm WMA, and Plus AC HMA of binder and wearing course mixtures were constructed. Density measurements were determined in the laboratory from field cores taken at each test section. The high- and intermediate-temperature properties of field cores were evaluated using the Loaded Wheel Tracking and Semi-Circular Bending tests, respectively. Further, indirect tensile dynamic modulus (IDT |E*|) test was conducted for full viscoelastic characterization of the asphalt mixtures. The two approaches considered in this study were successful in increasing field density. Significant increase in densities of the binder course Evotherm WMA and Plus AC HMA mixtures as compared to the control one were measured. Further, increased in-place density resulted in an increase in mixture stiffness as measured by the IDT |E*|.

Acknowledgments

The research work presented in this report was part of the FHWA Demonstration Project for Enhanced Durability of Asphalt Pavements through Increased In-Place Pavement Density. The construction contribution of Coastal Bridge Company, L.L.C. to this project is acknowledged.

Implementation Statement

The results from this field demonstration project has provided guidance to the Louisiana Department of Transportation and Development (DOTD) in reviewing and updating the current field density acceptance criteria for asphalt pavements. Further, it is anticipated that the results will be used by the FHWA to provide national guidance for enhancing durability of asphalt pavements through increased in-place pavement density.

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Introduction

Background

The goal of pavement compaction is to achieve a uniform and smooth surface at a specified air void content that can accommodate current and predicted traffic loadings over the design life of the pavement without undergoing significant levels of distress (i.e., rutting, cracking, etc.) [1]. The in-place density of hot mix asphalt (HMA) after compaction is a significant factor influencing the durability and long-term performance of asphalt pavements [1]. Approximately $35 billion is needed annually by the United States (US) government to preserve the prevailing conditions of bridges and highways through the year 2040 [2]. Aschenbrener et al. estimated that 5 to 25% improvement in pavement performance has the potential to yield annual savings of $1.75 to 8.75 billion [3]. By making more durable roads, these savings could then be reinvested into the United States Highway System to improve conditions [3]. The required level of in-place field density in asphalt layers is achieved by a given number of roller compactor passes. The roller compaction process causes the interlocking of aggregates in an asphalt layer, thereby increasing in-place density. A freshly laid un-compacted asphalt mixture layer behind a paver is a loose and evenly distributed mat with a certain thickness (or depth). The asphalt layer after compaction is a denser one with a reduced thickness, smooth and uniform surface, and a homogenous appearance.

The required in-place density of an asphalt pavement can be achieved through a combination of different activities that include proper design, production, placement, compaction, and quality control of the mixture [1]. The in-place density of an asphalt layer is usually expressed as a percent of its theoretical maximum specific gravity (Gmm). During pavement construction, mixtures behind pavers prior to roller compaction have densities within the range of 80 to 85% of Gmm. Most state highway agencies usually specify an average in-place density of 92 to 93% of Gmm (i.e., the equivalent of 7 to 8% air) for a compacted asphalt pavement [3]. Previous studies([4], [5], and [6]) have shown that as little as 1%increase in in-place density can lead to a 10 to 30% increase in asphalt pavement service life. Tran et al. [7] reported a conservative estimate of 10% increase in service life associated with 1% increase in density which translates into an average of 8.8% cost savings through the life cycle of pavements. Thus, the cost savings expected would be significantly higher than the additional cost to achieve the increased density in the asphalt pavements.

There have been significant advancements in technology and techniques for pavement design and construction. These advancements have the potential to increase asphalt pavement density and improve both durability and cost-effectiveness. Many of these advancements are already being employed; however, in many instances, standards for in-place density have remained unchanged. It is proposed that by using already adopted practices, in-place density targets can be increased. Thus, with enhanced density targets, improved mixture durability, and extended pavement service life can be achieved. Prowell et al. reported that WMA technologies could be used as compaction aids for highly modified stiff asphalt mixtures [8]. Further, Mohammad et al. recently reported improved field compaction of Evotherm WMA mixtures [9].

Objective

The overall objective of this project was to evaluate the effects of increasing the initial in-place density of asphalt pavements in Louisiana on field performance and durability. Specific objectives included:

- Identifying an efficient methodology for achieving the increased in-place density of asphalt pavements with minimal additional costs and without damaging the aggregate structure;
- Constructing a demonstration pavement section that includes a control section (meeting the current minimum density requirement) and a test section (having an average of 1.5% increased in-place density);
- Evaluating volumetric properties of laboratory and field asphalt samples; and
- Evaluating laboratory performance characteristics of laboratory and field asphalt samples.

Scope

A field rehabilitation project in Louisiana was selected for this study, which was part of the FHWA demonstration project on Enhanced Durability Through Increased In-Place Pavement Density [3]. The rehabilitation project consisted of milling off approximately 4-in. of existing asphalt pavement and replacing it with a 2-in. Level 2 binder course mixture followed by a 2-in. Level 2 wearing course mixture meeting the 2016 DOTD *Standard Specifications for Roads and Bridges* [10]. Two techniques were used to increase the in-place density of the binder and wearing course mixtures. The first one required the addition of Evotherm additive at the dosage rate of 0.6% by the weight of mix to both binder and wearing course mixtures. The second approach added 0.2% asphalt binder to the design optimum asphalt content. A styrene butadiene styrene (SBS) polymer-modified asphalt binder meeting Louisiana specifications for PG 76-22M was utilized for both the binder and wearing course mixtures [10]. Three wearing and binder course mixtures (i.e., control with optimum asphalt binder content; Evotherm additive mix; and mix with 0.2% higher asphalt binder content) were placed and compacted at the test sections. Densities of the compacted test sections were evaluated. A suite of laboratory mechanical tests was performed to ascertain the performance and durability of the asphalt mixtures evaluated. The tests conducted include the semi-circular bend (SCB) at intermediate temperature, the loaded wheel test (LWT) at high temperature, and indirect tensile dynamic modulus (IDT |E*|) test at multiple temperatures (i.e., -10°C, 10°C, and 30°C) for full viscoelastic characterization of the asphalt mixtures. Four replicates each were tested in the LWT and the SCB tests, and three replicates were tested in the IDT |E*| test.

Methodology

Project Background and Description

In 2017, the Federal Highway Administration (FHWA) Demonstration Project "Enhanced Durability of Asphalt Pavements through Increased In-place Pavement Density" was created to evaluate the importance of in-place asphalt density in building cost-effective and durable asphalt pavements [3]. The first phase of the project comprised of the construction of demonstration projects in ten states across the US [3]. The ten states constructed a total of 38 test sections, and the National Center for Asphalt Technology (NCAT) compiled the results from these demonstration projects [3]. According to Aschenbrener et al. [3], the states utilized the following methods to achieve increased in-place density: "(1) improving the agency's specification by including or increasing incentives and increasing the minimum percent density requirements; (2) making engineering adjustments to the asphalt mixture design to achieve slightly higher optimum asphalt binder content; (3) improving consistency as measured by the standard deviation; (4) following best practices; and (5) using new technologies."

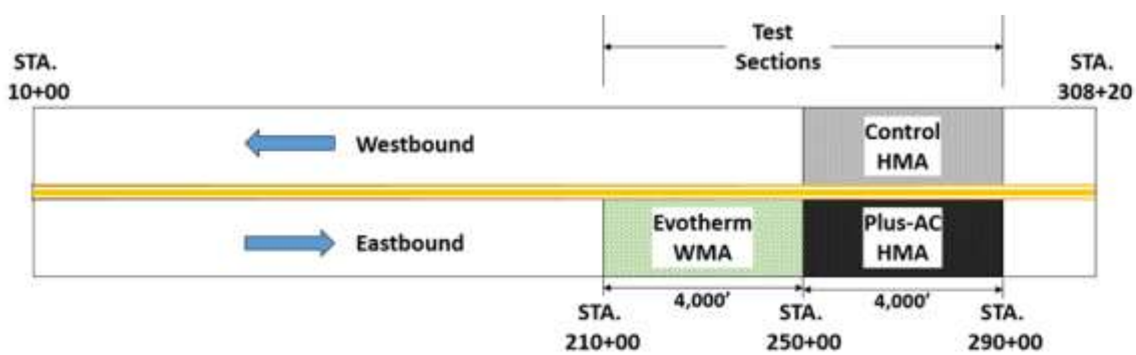
In 2017, FHWA partnered with DOTD as part of a second phase to conduct a field demonstration project and install test sections on a state highway. A primary objective of the demonstration project was to evaluate the possibility of increasing DOTD's in-place density requirements for quality acceptance (QA) in order to enhance the durability of its asphalt pavements using cost-effective methods. DOTD selected an asphalt overlay project on Route US 190 near the city of Walker in Livingston Parish for this demonstration project; see Figure 1.

Figure 1. Project location

The design traffic volume was 3.9 million equivalent single axle loads (ESALs), for which a 2-in. Level 2 binder course and a 2-in. Level 2 wearing course overlays were placed over a milled surface of an existing conventional asphalt pavement. Within 5.69 miles of the entire overlay project, three 4,000-ft.-long test sections were constructed towards the east end of the project on eastbound lane; see Figure 2. A 4,000-ft.-long control section was placed on the westbound lane next to one of the two test lanes. These test sections (two experimental and one control section) comprised of the following:

- Control Section (Control HMA): Conventional HMA concrete overlay on the westbound lane;
- Evotherm Test Section (Evotherm WMA): Evotherm WMA overlay on the eastbound lane; and
- Plus AC Test Section (Plus AC HMA): Plus AC mix section on the eastbound lane.

Figure 2. Layout of test sections



Prior to construction, the Asphalt Institute delivered an "Increased Density Workshop" to the DOTD. The aim of the workshop was to present information on the use of current best practices and new technologies to improve in-place asphalt mixture density. The workshop was attended by personnel from DOTD, LTRC, Louisiana State University, and representatives of the contractor. Topics that were discussed included mix design, pavement design, and construction best practices (equipment and operation) as applicable to the selected project. On-site technical advice was also delivered by LTRC staff to the DOTD prior to the construction of the project.

Project Schedule and Quantities

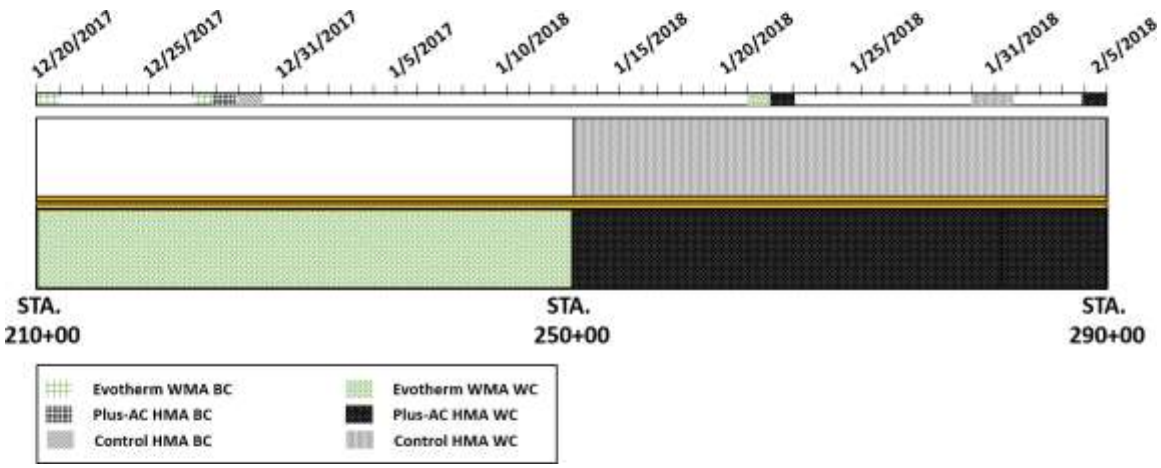
Approximately 4,380 tons of new asphalt mixture was used for the test sections shown in Figure 2. Construction of these test sections were completed from December 21, 2017 to February 5, 2018. For the 2-in. binder course lift, approximately 606 and 660 tons of Evotherm and Plus AC mixtures, respectively, were placed. For the 2-in. wearing course lift, approximately 742 and 564 tons of Evotherm and Plus AC mixtures, respectively, were placed. The amount of conventional binder and wearing course mixtures placed on the control section were about 700 and 1000 tons, respectively, by a rough approximation from daily plant production. Table 1 shows the construction schedule for each workday during construction. Figure 3 presents the layout of the paving schedule on the test sections.

Table 1. Project schedule

Mix Type	Date	Quantity (ton)	Beginning Station	Ending Station	Direction
Control HMA BC	12/29/17 – 2 /30/17	~700	290+00	250+00	WB
Control HMA WC	1/30/18 – 1 /31/18	~1000	290+00	250+00	WB
Evotherm WMA BC	12/21/17 – 12 /28/17	606	210+00	250+00	EB
Evotherm WMA WC	1/21/18 – 1 /22/18	742	207+85	249+17	EB
Plus AC HMA BC	12/29/2017	660	250+00	290+00	EB
Plus AC HMA WC	1/22/17 – 2 /5/18	664	249+17	281+62	EB

HMA: Hot mix asphalt; WMA: Warm mix asphalt; BC: Binder course; WC: Wearing course; Plus AC: Mixture contained 0.2% more asphalt content than the control mix; WB: West bound; EB: East bound ~: Approximate

Figure 3. Layout of paving schedule



Materials

Table 2 lists the asphalt mixture component materials used in this demonstration project. For binder course mixtures, coarse limestone, fine limestone, and fine river sand were used with 23.8% reclaimed asphalt pavement (RAP). Coarse sandstone, coarse limestone, fine limestone, and fine river sand, and 19.1% RAP were utilized in the wearing course mixtures. The asphalt mixtures were prepared using a styrene-butadiene-styrene (SBS) polymer-modified asphalt binder meeting Louisiana specifications for PG 76-22M [10].

Table 2. Asphalt mixture component materials

Mixture Type	Binder Course	Wearing Course
Coarse Sandstone	NA	30.0%
#67 Coarse Limestone	26.7%	NA
#78 Coarse Limestone	16.8%	13.0%
#8 Coarse Limestone	9.1%	14.5%
#11 Fine Limestone (Washed)	12.2%	11.3%
Fine River Pump Sand	11.4%	12.1%
RAP	23.8%	19.1%
Asphalt Binder	76-22M	76-22M

RAP: Recycled asphalt pavement; NA: Not Applicable

Mixture Design

Six Superpave asphalt mixtures were used: three 19.0-mm binder course and three 12.5-mm wearing course mixtures. A Level 2 design (Ninitial = 7, Ndesign = 65, Nfinal = 105 gyrations) was performed in accordance with AASHTO R 35, “Standard Practice for Superpave Volumetric Design for Hot Mix Asphalt (HMA) [11],” AASHTO M 323, “Standard Specification for Superpave Volumetric Mix Design [12],” and Section 502 of the 2016 DOTD *Standard Specifications for Roads and Bridges* [10]. Specifically, the optimum asphalt cement content was determined based on volumetric properties (VTM = 3.0 – 5.0 %, VMA ≥ 13%, VFA = 68% -78%) and densification requirements (%Gmm at Ninitial ≤ 89, %Gmm at Nfinal ≤ 98). Both binder and wearing course mixtures included one conventional HMA, one Evotherm WMA, and one Plus AC HMA. Table 3 presents the design properties of mixtures evaluated. It is noted that the Evotherm WMA additive was incorporated at a dosage rate of 0.6% by the weight of mix to binder and wearing course mixtures, whereas, the Plus AC HMA mixtures included an additional 0.2% asphalt binder to the design optimum asphalt binder content; see Table 3.

Table 3. Mix design volumetrics

Test Sections	Control HMA BC	Control HMA WC	Evotherm WMA BC	Evotherm WMA WC	Plus AC HMA BC	Plus AC HMA WC
%Design AC	4.8	5.0	4.9	5.1	5.0	5.2
Gmm	2.468	2.448	2.464	2.441	2.48	2.441
VMA	14.3	14.6	14.5	15.0	14.7	15.1
VFA	76	76	76	77	76	77
%AV	3.5	3.5	3.5	3.5	3.5	3.5
Metric Sieve (mm)	Gradation (%)	Gradation (%)	Gradation (%)	Gradation (%)	Gradation (%)	Gradation (%)
25	100	100	100	100	100	100
19	97	100	97	100	97	100
12.5	86	93	86	93	86	93
9.5	72	80	72	80	72	80
4.75	42	45	42	45	42	45
2.36	32	35	32	35	32	35
1.18	23	27	23	27	23	27
0.6	18	22	18	22	18	22
0.3	10	12	10	12	10	12
0.15	6	7	6	7	6	7
0.075	4	5	4	5	4	5
Dust Ratio	0.87	1.02	0.85	1.00	0.84	0.98
Pbe (%)	4.7	4.9	4.8	5.0	4.9	5.1

VMA: Voids in the mineral aggregate; AC: Asphalt content; VFA: Voids filled with asphalt; Gmm: Theoretical maximum specific gravity; %AV: Design air voids content; Pbe: Effective binder content; BC: Binder course; WC: Wearing course; Plus AC: Mixture contained 0.2% more asphalt content than the control mix

Mixture Design Validation

The plant produced loose mixtures were tested according to AASHTO M 323, “Standard Specification for Superpave Volumetric Mix Design” [12]. Loose samples of the six asphalt mixtures were taken at the haul truck immediately after loading at the plant to validate the volumetric properties. The voids in mineral aggregates (VMA), voids filled with asphalt (VFA), the Gmm, and the percent air void content (%AV) of the plant mixture were determined and compared with the target laboratory mixture design values. The percent asphalt binder content (%AC) and the aggregate gradation of the plant mixture samples were also validated in accordance with AASHTO T164, “Standard Method of Test for Quantitative Extraction of Asphalt Binder from Hot Mix Asphalt (HMA)” [13].

Construction

Production and Transportation

All asphalt mixtures were produced at the contractor’s plant, which was approximately 27 miles from the construction site. The average one-way haul time from plant to site was approximately 38 minutes during night paving. The mix production plant was equipped with Astec Double Barrel Dryer drum mixer, which can produce an average of 250 tons of asphalt mixtures per an hour. The plant used natural gas as the fuel for the dryer drum mixer. The plant produced asphalt mixtures were transferred to a silo before discharging to a haul truck. The capacity of the silo was approximately 850 tons.

Table 4 summarizes the mix production details. It is worth noting that the contractor opted to produce Evotherm WMA mixtures at the same temperature range as the Control HMA and Plus AC HMA to ensure that the compaction aid effect of WMA additive would not be compensated by the reduced production temperature.

Table 4. Mix production details

Mix Type	Date	Quantity (ton)	Mixing Temp. (°F)	Number of Trucks Utilized	Air Temp. (°F)
Control HMA BC	12/29/17 – 12/30/17	~700	300 - 325	14	50 - 52
Control HMA WC	1/30/18 – 1/31/18	~1000	300 - 325	18	50 - 55
Evotherm WMA BC	12/21/2017 – 12/28/2017	606	300 - 325	9-14	42 - 52
Evotherm WMA WC	1/21/18 – 1/22/18	742	300 - 325	14	60 - 65
Plus AC HMA BC	12/29/2017	660	300 - 325	12-14	34 - 41
Plus AC HMA WC	1/22/2017– 2/5/2018	664	300 - 325	14-17	55 - 65

HMA: Hot mix asphalt; WMA: Warm mix asphalt; BC: Binder course; WC: Wearing course; Plus AC: Mixture contained 0.2% more asphalt content than the control mix; ~: approximate

The air temperature during the binder course paving from December 21 through December 30, 2017, ranged from 34°F to 52°F and during the wearing course paving from January 21 through February 5, 2018, ranged from 50°F to 65°F, respectively. The DOTD *Standard Specifications for Roads and Bridges* requires 40°F minimum temperature for binder course paving and 50°F minimum for wearing course paving. With these requirements, it is worth noting that the Plus AC HMA binder course was paved mostly under the minimum temperature limit, which would negatively affect the final field density. However, the paving of Plus AC HMA binder course layer progressed fairly quickly, minimizing the excessive cooling of freshly laid asphalt mat before the breakdown roller application, due to the efficient operation of haul trucks.

Mixture Placement and Compaction

The existing asphalt pavement surface was milled at approximately 4-in. in depth prior to placement of the new overlay mixture. The milled surface was then cleaned by a power broom in preparation for tack coat application. SS-1 anionic emulsion asphalt was spread on the milled surface by a spray truck at a residual application rate of 0.045 g/sy. A Caterpillar paver (model: CAT AP1055) was used throughout the entire construction. A Roadtec Shuttle Buggy (model: SB-2500) material transfer vehicle (MTV) was utilized during the binder course construction, which was later on replaced with a Caterpillar E2850 (CAT E2850) full-size MTV for the wearing course construction. Surface temperature of the un-compacted asphalt mat behind the paver were periodically monitored. The average mat temperatures of the six different layers (i.e., BC and WC of Control HMA, Evotherm WMA, and Plus AC HMA test sections) ranged from 240°F to 275°F. All paving activities were conducted at night; see Figure 4.

Figure 4. Paving train

Two slightly different models of steel rollers (i.e., CAT CB 534D and CAT CB 434D) were utilized for the compaction process; see Figure 5. The CAT CB 534D was primarily used as a breakdown roller, whereas CAT CB 434D was used as a finish roller. On average, the breakdown roller applied seven to nine passes of compaction over a 100- to 150-ft. long span of asphalt mat with vibration. The finish roller, in general, followed the breakdown roller at an interval (i.e., five to ten minutes behind the breaking roller) while applying five to seven passes of finishing compaction without vibration.

Figure 5. Roller compactors: (a) CAT CB 534D and (b) CAT 434D

Field Density Measurements

Within each of the three 4,000-ft. long experimental sections, 15 locations were randomly chosen along the center of the lane to evaluate field densities. Densities and subsequent air voids were measured according to AASHTO T 166, "Standard Method of Test for Bulk Specific Gravity (Gmb) of Compacted Hot Mix Asphalt (HMA) Using Saturated Surface-Dry Specimens" [14]. Along with field cores, multiple in-situ density measurements were taken using non-destructive density gauges, such as PaveTracker (a non-nuclear type field density gauge) and a Pavement Quality Indicator (PQI, a non-nuclear type field density gauge). The in-situ density measurements were collected on the surface of all three binder course sections (i.e., Control, Evotherm WMA, and Plus AC).

Asphalt Mixture Laboratory Tests

Table 5 presents the asphalt mixture tests performed on field cores from each test section. A brief description of each test is provided below.

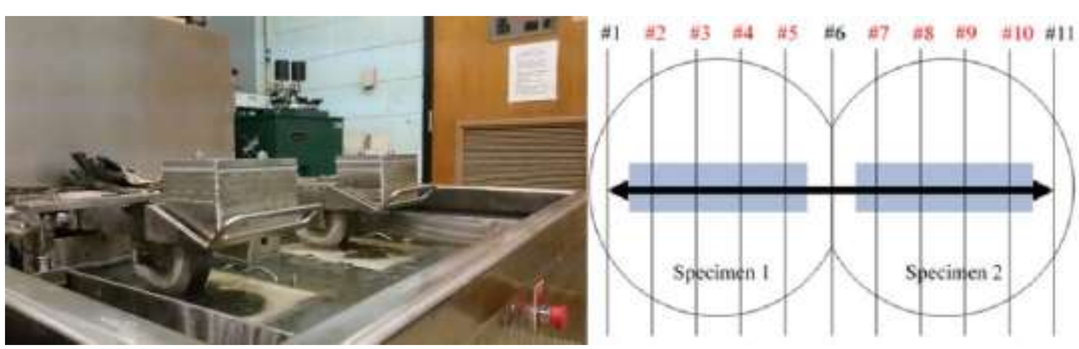
Table 5. Asphalt mixture laboratory tests

Tests	Protocols	Engineering Properties	Specimen Details	No. of Specimens
LWT at 50oC	AASHTO T 324 [15]	Rutting Susceptibility and Moisture Resistance	ϕ150 mm x 60 mm	4
SCB at 25oC	ASTM D 8044 [16]	Intermediate Temperature: Fatigue Cracking Resistance	ϕ150 mm x 57 mm	4
Indirect Tensile Dynamic Modulus Test at Multiple Temperatures (i.e., -10, 10, and 20°C)	AASHTO TP 131 [17]	Viscoelastic Characterization (stiffness and phase angle)	ϕ150 mm x 38-50 mm	3

Loaded Wheel Test (LWT)

The loaded-wheel test was conducted in accordance with AASHTO T 324, "Standard Method of Test for Hamburg Wheel-Track Testing of Compacted Hot Mix Asphalt (HMA)" [15]. This test is considered a torture test that produces damage by rolling a 703 N (158 lb.) steel wheel across the surface of cylindrical specimens (150 mm diameter by 60 mm thick) that are submerged in 50 °C water for 20,000 passes at 52 passes per a minute; see Figure 6. Four specimens (two specimens for each wheel) were tested. Rut depth measurements were recorded at 11 locations across cylindrical specimen until failure; see Figure 6. Then, rut depth measurements at four middle locations were averaged; see Figure 6. Further, rut depth at 20,000 cycles was computed and used in the analysis. This test was done to determine the effect of improved mixture density on the high temperature performance.

Figure 6. Setup for loaded wheel tracking test, 50°C wet



Semi-Circular Bend (SCB) Test

The SCB test was performed according to ASTM D 8044 "Standard Test Method for Evaluation of Asphalt Mixture Cracking Resistance using the Semi-Circular Bend Test

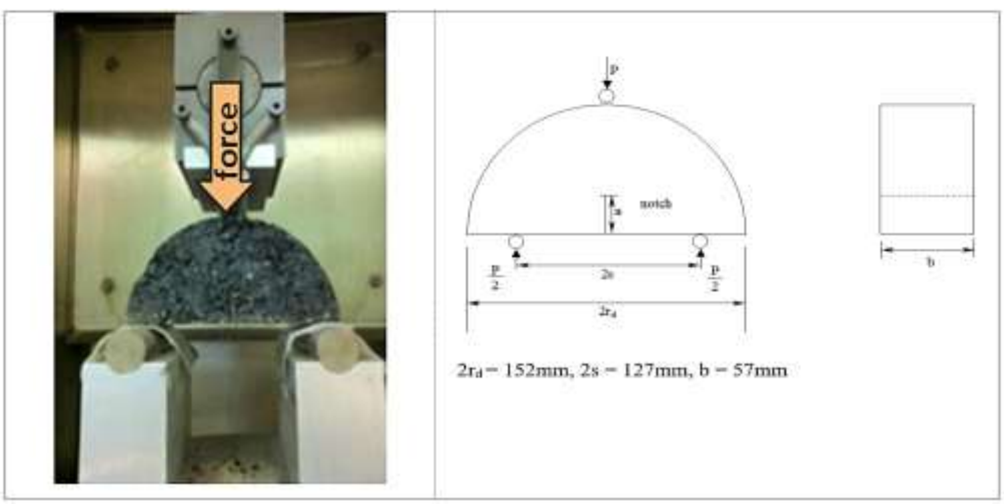
(SCB) at Intermediate Temperatures" [16]. This test characterizes the fracture resistance of asphalt mixtures based on fracture mechanics principals, the critical strain energy release rate, also called the critical value of J-integral, or J_c. To determine J_c, semi-circular specimens with at least two different notch depths need to be tested for each mixture. In this study, two notch depths of 25.4 mm and 38 mm were selected. Test temperature was selected to be 25°C. The semi-circular specimen is loaded monotonically until fracture failure under a constant cross-head deformation rate of 0.5 mm/min in a three-point bending load configuration; see Figure 7. The load and deformation are continuously recorded and J_c is determined using the following equation:

$$\boldsymbol{J_c = \left(\frac{U_1}{b_1} - \frac{U_2}{b_2}\right)\frac{1}{a_2 - a_1}} \qquad (1)$$

where,
J_c = critical strain energy release rate (kJ/m2),
b = sample thickness (m),
a = notch depth (m), and
U = strain energy to failure (kJ)

The higher the J_c value of a mixture, the higher its fracture resistance at intermediate temperatures and vice versa. The cracking resistance of field cores from the asphalt mixture test sections evaluated were determined

Figure 7. Setup for semi-circular bend test



Indirect Tensile Dynamic Modulus (IDT |E*|) Test

The IDT |E*| test was conducted according to AASHTO TP 131, "Proposed Standard Test Method for Determining the Dynamic Modulus of Asphalt Mixtures Using the Indirect Tension Test" [17]. The IDT|E*| test applies a sinusoidal compressive stress to the diametric axis of an unconfined cylindrical field core specimen; see Figure 8. This test was conducted at three temperatures of -10, 10, and 30°C (14, 50, and 86°F) and at five loading frequencies of 10, 5, 1, 0.5, and 0.1 Hz at each of the three temperatures. The compressive stress applied on the test specimen results in tensile stress-strain along the horizontal axis of the specimen. A target tensile strain level of 40 to 60 microstrains was maintained to keep the specimens in the linear viscoelastic region. The dynamic modulus was computed using the following equation:

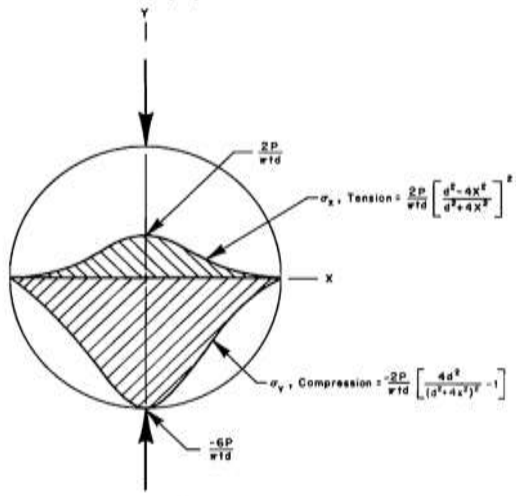
$$|\boldsymbol{E}^*| = \boldsymbol{2}\left(\frac{\boldsymbol{P_0}}{\boldsymbol{\pi a d}}\right)\left(\frac{\boldsymbol{\beta_1\gamma_2 - \beta_2\gamma_1}}{\boldsymbol{\gamma_2 V_0 - \beta_2 U_0}}\right) \quad (2)$$

where,
|E*| = Dynamic complex modulus
P_0 = Load amplitude,
U_0 = Horizontal displacement amplitude,
V_0 = Vertical displacement amplitude,
a = Loading strip width,
d = Specimen diameter,
$\beta_1, \beta_2, \gamma_1$, and γ_2 = geometric constants

The geometric constants are functions of gauge length, specimen diameter, and loading strip width [18]. The dynamic modulus of asphalt mixtures obtained at various frequencies and temperatures were combined into a master curve using the time-temperature superposition principle. The test data were used for full viscoelastic characterization of asphalt mixtures from the three test sections.

Figure 8. (a) IDT|E*| test setup and (b) stress distribution along X-axis

(a)



(b)

Statistical Analysis

The mechanistic performance results of the asphalt mixtures from all test sections were statistically analyzed using analysis of variance (ANOVA) procedure provided in the Statistical Analysis System (SAS) 9.4 program [19]. A multiple comparison procedure (Tukey test) with a confidence level of 95% was performed on the means. The groupings represent the mean for the test results reported by mixture type. The results of the statistical grouping are reported with letters: A, B, C, and so forth, representing statistically distinct performance (i.e., rut depth at 20000 passes and SCB J_c) from best to worst. Multiple letter designations, such as A/B (or A/B/C) indicate that the difference in the means is not statistically significant.

Discussion of Results

Plant Mix Volumetric Results

Table 5 presents the volumetric properties and aggregate gradations of the plant produced mixtures. Compared to the JMF (Table 3) the plant mixtures appeared to have slightly finer gradations, resulting in a slightly higher dust ratios. Further, the extracted %AC of Evotherm WMA BC, Evotherm WMA WC, and Plus AC HMA BC were slightly different from that of the JMF. Specifically, %AC of Evotherm WMA BC and Plus AC HMA BC increased by 0.1% more than the JMF %AC value, while %AC of Evotherm WMA WC also decreased by 0.1%.In general, these differences resulted in marginal reductions in VMA, minimal increases in VFA, and 0.2 to 0.6% reduction in %AV.

Table 6. Plant mix volumetrics

Mixtures	Control HMA BC	Control HMA WC	Evotherm WMA BC	Evotherm WMA WC	Plus AC HMA BC	Plus AC HMA WC
Extracted %AC	4.8	5.0	5.0	5.0	5.1	NP
Gmm	2.473	2.453	2.465	2.452	2.467	NP
VMA	14.0	14.3	14.1	14.4	13.9	NP
VFA	76	77	78	78	80	NP
%AV	3.3	3.3	3.1	3.3	2.9	NP
Metric Sieve (mm)	Gradation (%)	Gradation (%)	Gradation (%)	Gradation (%)	Gradation (%)	Gradation (%)
25.0	100	100	100	100	100	NP
19.0	97	100	96	100	96	NP
12.5	85	95	84	92	85	NP
9.5	71	80	72	79	72	NP
4.75	42	45	42	43	42	NP
2.36	32	35	32	35	31	NP
1.18	22	27	22	25	22	NP
0.6	18	22	19	21	18	NP
0.3	10	12	9	11	10	NP
0.15	6	7	6	7	5	NP
0.075	4.2	5	4.6	5.1	4.2	NP
Dust Ratio	0.92	1.05	0.97	1.05	0.87	NP
Pbe (%)	4.6	4.8	4.8	4.8	4.8	NP

VMA: Voids in the mineral aggregate; AC: Asphalt content; VFA: Voids filled with asphalt; Gmm: Theoretical maximum specific gravity; %AV: Design air voids content; Pbe: Effective binder content; BC: Binder course; WC: Wearing course; Plus AC: Mixture contained 0.2% more asphalt content than the control mix; NP: Not provided

Field Density Results

Figure 9 shows the average air voids of core samples from the test sections evaluated. For the BC test sections, the two methodologies (Evotherm WMA and Plus AC HMA) considered were effective in significantly increasing the in-place densities (i.e., lower air voids) of the Evotherm HMA and the Plus AC test sections as compared to the Control HMA section. For the WC test sections, however, the two increased in-place density techniques resulted in a minimal increase in the in-place densities of the Evotherm WMA and Plus AC HMA test sections as compared to the Control HMA section. The improvement in the in-place densities of the WC test sections was not significant because the Control HMA mixture already had a low air void (i.e., 4.4% air void content); therefore, the two approaches were not expected to reduce the air void content significantly. It is worth noting that the Evotherm WMA and Plus AC BC and WC test sections achieved much higher field densities (i.e., lower air voids) than the FHWA proposed density requirements (i.e., an average of 1.5% increased in-place density) for this project.

Figure 9. Average air voids of test sections

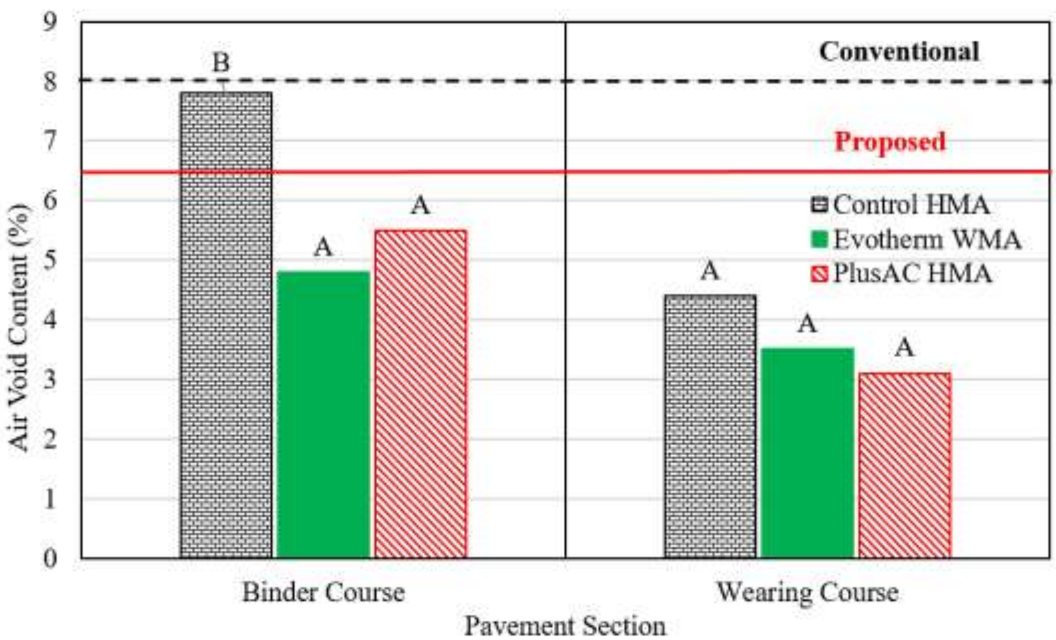
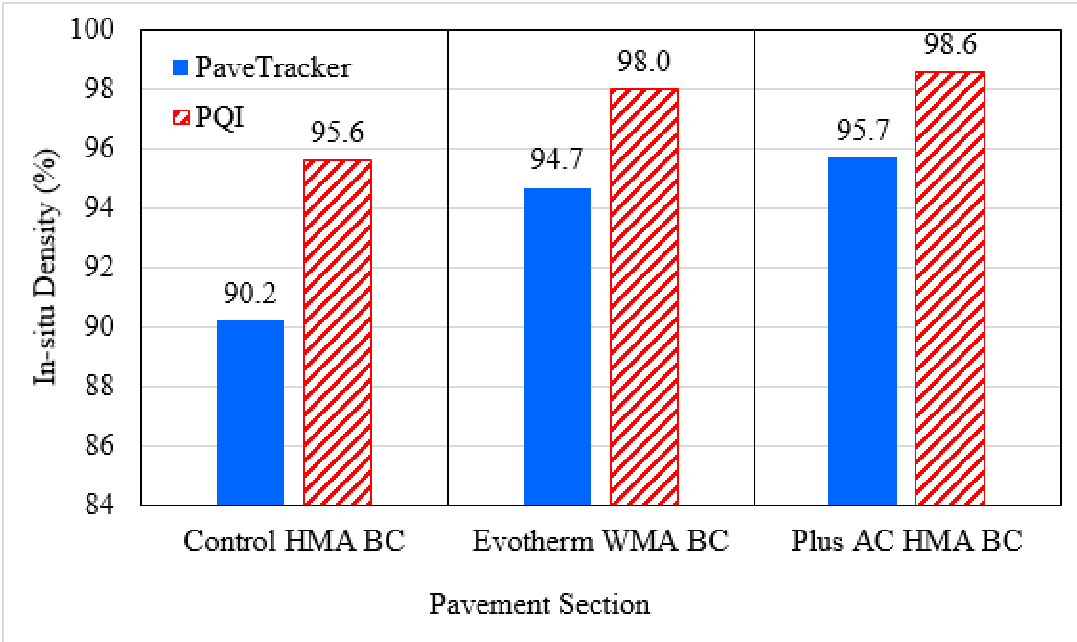


Figure 10 presents the average direct density readings by two different in-situ density gauges for the sections evaluated. The average Coefficient of Variation (CoV) of density measurements using the PaveTracker and the PQI gauges were 3.1% and 1.3%, respectively. The increased density techniques (Evotherm WMA and Plus AC HMA) resulted in increased in-place density of the asphalt pavements as measured by PaveTracker and the PQI gauges, as compared to the control section.

Figure 10. Average density from in-situ density devices

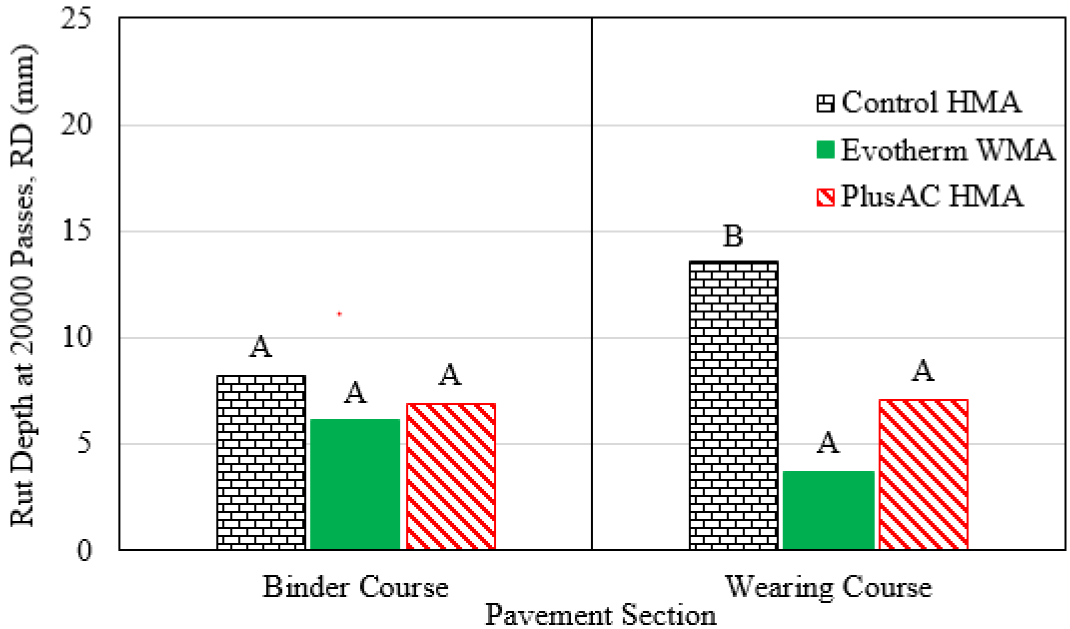


Laboratory Performance Test Results

Loaded Wheel Test (LWT)

Figure 11 presents the LWT test results for the test sections evaluated. The average coefficient of variation (COV) of the rut depths at 20000 passes from the LWT tests was 17%. For the BC test sections, increased in-place densities (Evotherm WMA and Plus AC HMA) resulted in lower LWT rut depths as compared to the Control HMA section, though not significant. Further, Evotherm WMA and Plus AC HMA wearing course mixtures had significantly lower LWT rut depths as compared to the control section. Thus, the two increased in-place density approaches considered in this study were effective in improving rutting performance as measured by LWT test.

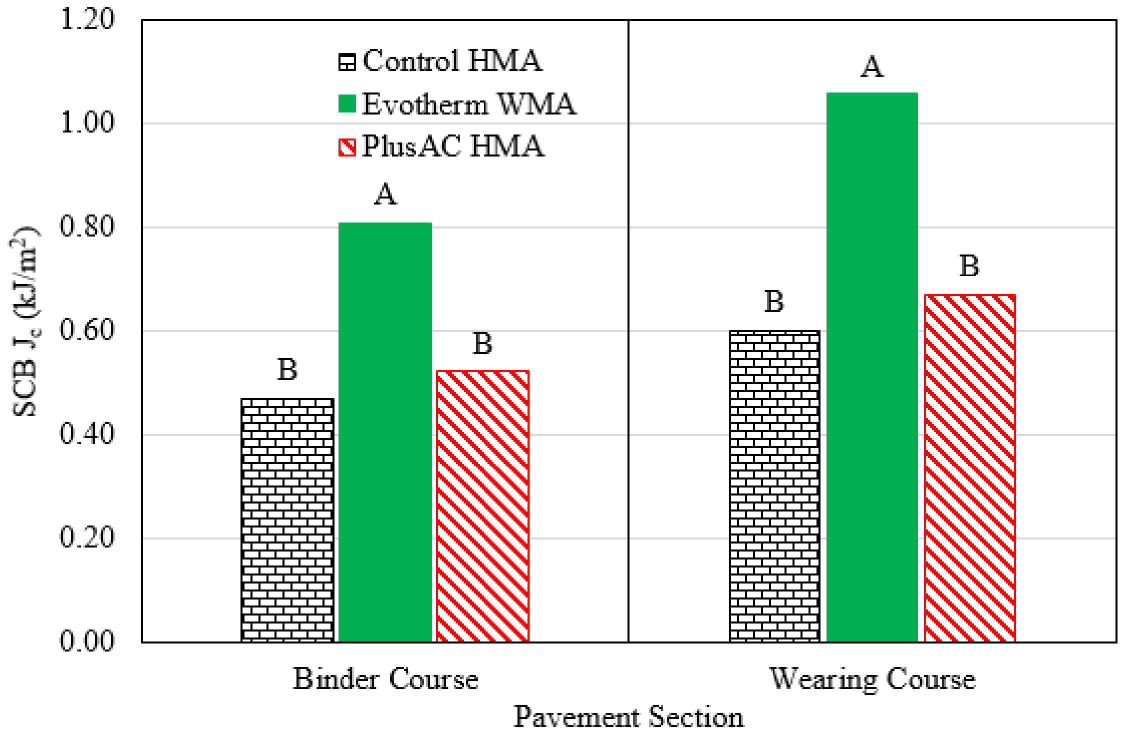
Figure 11. LWT test results, 50°C wet



Semi-Circular Bend (SCB) Test

Figure 12 shows the intermediate temperature fracture resistance (J_c) of the six asphalt mixture evaluated. The average CoV of the J_c values from the SCB tests was 18%. For the BC test sections, the increased in-place density methodologies (Evotherm WMA and Plus AC HMA) resulted in a significant increase in SCB J_c of the Evotherm WMA test section and a marginal increase in the SCB J_c of the Plus AC test section as compared to the control section. A similar observation was made in the wearing course test sections. The Evotherm WMA technology resulted in a significant increase in the SCB J_c of the Evotherm WMA WC test section whereas the Plus AC HMA approach resulted in a marginal increase in the SCB J_c of the Plus AC HMA wearing course test section as compared to the control one. Thus, the two increased in-place density approaches considered in this study were effective in improving intermediate temperature cracking performance as measured by SCB test.

Figure 12. SCB test results, 25°C



Indirect Tensile Dynamic Modulus (IDT |E*|) Test

Figures 13(a) and 13(b) present the dynamic modulus master curves for the six asphalt mixture test sections evaluated. Master curves were constructed at the reference temperature of 10 °C. A rule of thumb expectation from the master curve is that a stiffer asphalt mixture at the low reduced frequency range (approximately from 10-5 Hz to 10-3 Hz) would result in low rutting [20]. For the BC test sections, the two increased in-place density techniques (i.e., Evotherm WMA and Plus AC HMA) resulted in increased stiffness (i.e., higher |E*|) at the low reduced frequency range (i.e., 10-5 Hz to 10-3 Hz) for the Evotherm and the Plus AC test section as compared to the Control HMA section. A similar observation was made in the wearing course test sections. The Evotherm WMA and the Plus AC increased in-placed density techniques were effective in increasing the stiffness of the Evotherm WMA and Plus AC WC test sections at the low-reduced frequency range as compared to the Control HMA WC section. This observation is consistent with results obtained from the LWT test.

Figure 13. Dynamic modulus master curves for (a) binder course, and (b) wearing course test sections

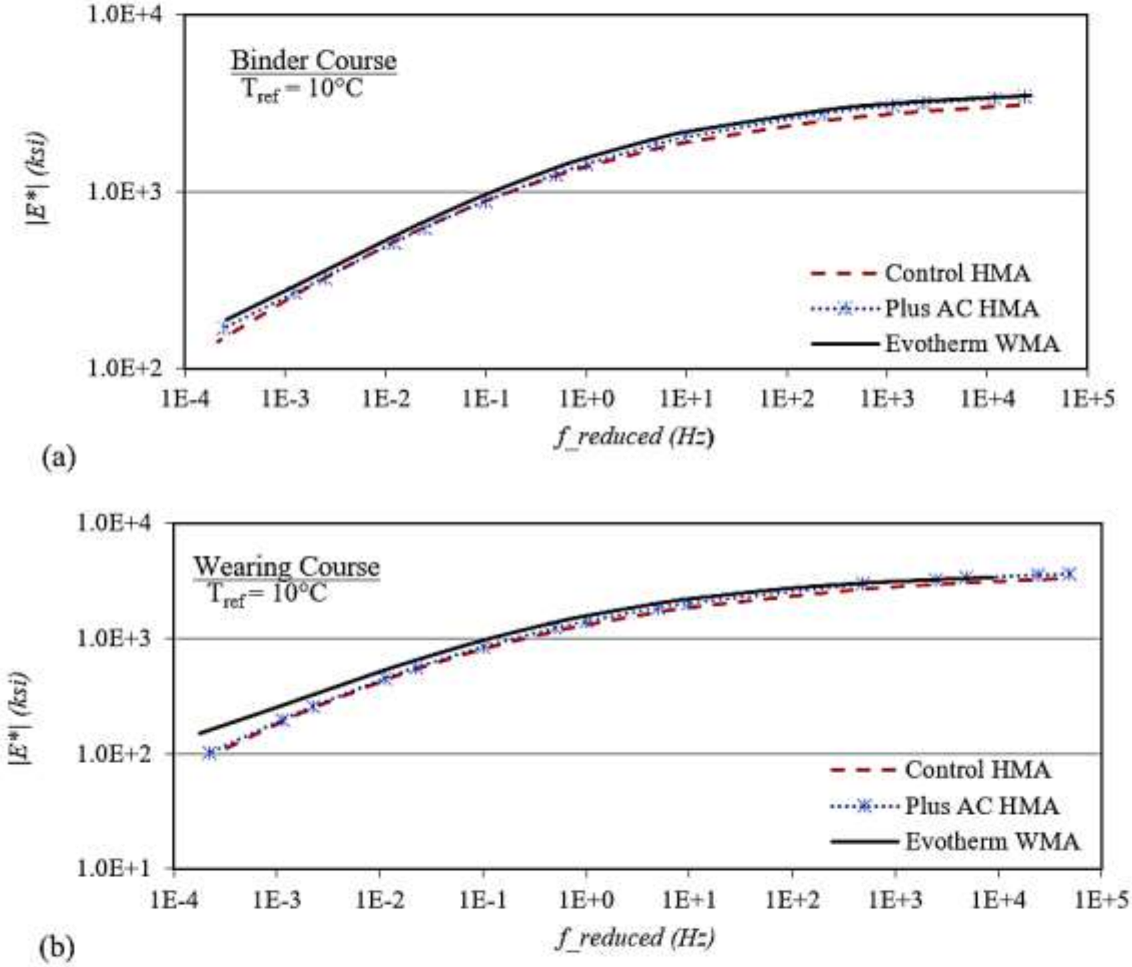
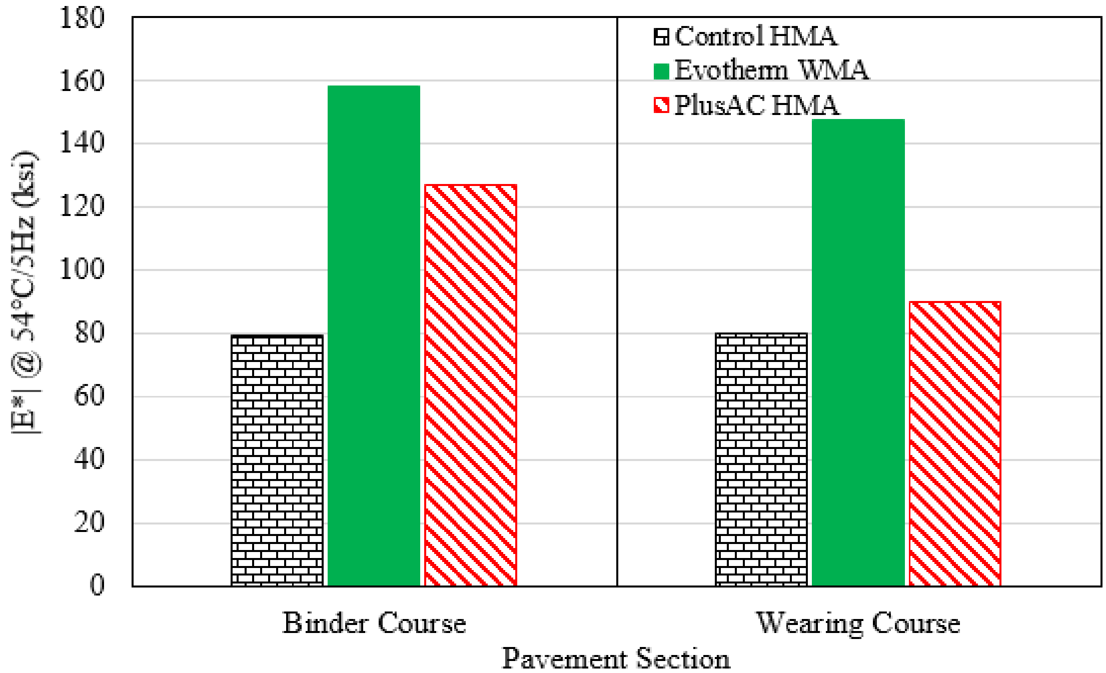


Figure 14 shows the mean $|E^*|_{54°C,\ 5Hz}$ for the test sections evaluated. The $|E^*|_{54°C,\ 5Hz}$ parameter has been found to be a good indicator of mixture rutting performance [20]. Higher |E*|54°C, 5Hz values indicate higher rutting performance. $|E^*|_{54°C,\ 5Hz}$ values were extrapolated from the dynamic modulus master curves. For the BC test sections, the Evotherm WMA and the Plus AC HMA increased in-place density methodologies were effective in increasing the $|E^*|_{54°C,\ 5Hz}$ values of the Evotherm WMA and the Plus AC HMA test sections as compared to the Control HMA section. Further, the two increased in-place density techniques caused the $|E^*|_{54°C,\ 5Hz}$ values of the Evotherm WMA and the Plus AC HMA WC test sections to increase relative to the control HMA WC section.

Figure 14. |E*|$_{54°C,5Hz}$ for asphalt mixtures



Summary and Conclusions

This demonstration project evaluated the effects of increasing the initial in-place density of asphalt pavements on their potential field performance, which is part of FHWA demonstration project on Enhanced Durability through Increased In-Place Pavement Density. In order to achieve the objectives of this project, two different approaches of increasing the field density were adopted. The two approaches adopted in this study for increasing in-place density were (1) addition of Evotherm WMA additive at a dosage rate of 0.6% by the weight of mix, and (2) addition of 0.2% asphalt binder (Plus AC) to the design optimum asphalt binder content. Three test sections, each consisting of 4,000-ft. long overlay sections of Control HMA, Evotherm WMA, and Plus AC HMA of binder and wearing course mixtures were constructed. Density measurements were determined in the laboratory from field cores taken at each test section. Along with field cores, multiple in-situ density measurements were taken using non-destructive density gauges, such as PaveTracker (a non-nuclear type field density gauge) and a Pavement Quality Indicator (PQI, a non-nuclear type field density gauge). The high- and intermediate-temperature properties of field cores were evaluated using the Loaded Wheel Tracking and Semi-Circular Bending tests, respectively. Further, indirect tensile dynamic modulus (IDT |E*|) test was conducted for full viscoelastic characterization of the asphalt mixtures. In general, the two approaches considered in this study were successful in increasing field density, and improving high- and intermediate-temperature properties of field cores. Specific observations include:

- For the binder course test sections, Evotherm WMA and Plus AC HMA sections had a significant increase in in-place densities (i.e., lower air voids) as compared to the control HMA section. However, the improvement in the in-place densities of the wearing course sections was not as significant. This is because the control HMA mixture had a low air void (i.e., 4.4% air void content) and further densifications were not expected.
- The increased density techniques (Evotherm WMA and Plus AC HMA) resulted in increased in-place density in the Evotherm WMA and the Plus AC HMA test sections of as measured by PaveTracker and the PQI gauges, as compared to the control section.
- Evotherm WMA and Plus AC BC and WC test sections achieved much higher field densities (i.e., lower air voids) than the FHWA proposed density requirements (i.e., an average of 1.5% increased in-place density) for this project.

- Two increasing in-place density approaches considered in this study were effective in improving rutting performance as measured by LWT test. Evotherm WMA and Plus AC HMA wearing course mixtures had significantly lower LWT rut depths as compared to the control section.
- Two increasing in-place density approaches considered in this study were effective in improving intermediate temperature cracking performance as measured by SCB test. The Evotherm WMA technology resulted in a significant increase in the SCB J_c parameter.
- For the BC test sections, Evotherm WMA and Plus AC HMA sections showed increased stiffness (i.e., higher |E*|) at the low reduced frequency range (i.e., 10-5 Hz to 10-3 Hz) and higher |E*|54°C, 5Hz values as compared to the control section. Similar trend was observed for the wearing course test sections.

Recommendations

This demonstration project evaluated the effects of increasing the initial in-place density of asphalt pavements on their potential field performance. Two different approaches of increasing the field density were adopted. The first approach was a chemical warm-mix additive technology. Evotherm additive at the dosage rate of 0.6% by the weight of mix was added to both binder and wearing course mixtures during mixing. The second approach attempted in this project was adding slightly more asphalt cement (i.e., 0.2%) to the design optimum asphalt content. The performance of these two mixtures were evaluated together with a conventional mixture referred to as Control HMA. Three test sections each consisting of 4,000-ft. long overlay section of Control HMA, Evotherm WMA, and Plus AC HMA binder and wearing courses were constructed.

The two methodologies (i.e., WMA and increased AC content) of improving field compaction and in-situ densities adopted in this demonstration project were successful in achieving the proposed increased field density of 93.5% of the theoretical maximum specific gravity (Gmm). Generally, the improvement in mixture density resulted in an improvement in the high and intermediate temperature performance of the mixtures as measured by the LWT and the SCB J_c. Further, the improvement in the mixture density resulted in increased mixture stiffness as measured by the IDT $|E^*|$ values within the temperature range considered. It is recommended that DOTD adopts these two technologies in order to improve in-place field density of asphalt pavements in Louisiana. Furthermore, it is recommended that long-term pavement performance monitoring of the control and test sections is performed in the future to determine the ultimate benefits of the increased in-place density of asphalt pavements.

Acronyms, Abbreviations, and Symbols

Term	Description
AASHTO	American Association of State Highway and Transportation Officials
AC	Asphalt Content
ASTM	American Society for Testing and Materials
BBR	Bending Beam Rheometer
BC	Binder Course
°C	degree Celsius
cm	centimeter
DOTD	Department of Transportation and Development
°F	degree Fahrenheit
FHWA	Federal Highway Administration
ft.	foot (feet)
Gmm	theoretical maximum specific gravity
HMA	hot mix asphalt
Hz	Hertz
IDT|E*|	Indirect Tensile Dynamic Modulus
in.	inch(es)
J_c	Critical Strain Energy Release Rate
JMF	job mix formula
kJ	kilojoule
kPa	kilopascal
ksi	Kilopund force per square inch
lb.	pound
LTRC	Louisiana Transportation Research Center
LWT	Loaded-Wheel Tracking
m	meter(s)
MTV	Material Transfer Vehicle
mm	millimeter
mm/min.	millimeter per minute

Term	Description
N	Newton
NCAT	National Center for Asphalt Technology
NCHRP	National Cooperative Highway Research Program
NMAS	Nominal Maximum Aggregate Size
Pa	Pascal
PAV	Pressure Aging Vessel
PG	Performance Grade
PQI	Pavement Quality Indicator
RAP	reclaimed asphalt pavement
RTFO	Rolling Thin-Film Oven
SCB	semi-circular bend
TSR	tensile strength ratio
WC	Wearing Course

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Appendix

A: Special Provision

Louisiana DOTD Non-Standard (NS) ASPHALTIC CONCRETE Enhanced Durability
(State Project No. H.009549)

NS ASPHALTIC CONCRETE – Enhanced Durability (State Project No. H.009549) (08/17):

DESCRIPTION. This work consists of mixing, placing, and compacting Asphaltic Concrete mixtures, which has been modified to increase to the current density requirements by 1.5% (min.). The mixture will be evaluated as a 4,000 ft. test section(min.). Options to increase density include use of WMA technologies/processes, temperature control, compaction aids, increase asphalt content, increase compaction effort, or any other method approved by LTRC Asphalt Research Group. The work shall be in accordance with the plans, the 2016 Louisiana Standard Specifications for Roads and Bridges as amended by supplemental specifications, this special provision, and as directed.

MATERIALS. Comply with section 502 of the standard specifications, except as modified herein.

GENERAL REQUIREMENTS. Construct Asphaltic Concrete mixtures, which have been modified to increase to the current density requirements by 1.5% (min.). The mixture will be evaluated as a 4,000 ft. test section(min.). Options to increase density include use of WMA technologies/processes, temperature control, compaction aids, increase asphalt content, increase compaction effort, or any other method approved by LTRC Asphalt Research Group. The Asphaltic Concrete mixture will be placed on the mainline roadway. The contractor shall meet the Asphaltic Concrete Mixtures (2016 Louisiana Standard Specifications for Roads and Bridges) for Job Mix Formula (JMF) submittals and approvals. The contractor shall meet all acceptance and testing requirements, and will be subject to the pay penalties and incentives as for standard Asphalt Concrete Mixtures conforming to section 502.

The Louisiana Transportation Research Center will monitor these test sections for performance. Contact information is as follows:

Dr. Louay N. Mohammad, Ph.D., P.E. (WY)
Professor, Department of Civil and Environmental Engineering, Louisiana State University
Director, Engineering Materials Research Characterization Facility, LTRC
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In addition to the required quality control/quality acceptance, the contractor shall perform Tensile Strength Ratio (TSR) testing of the produced mixtures at the plant in accordance with DOTD TR 322 (Lottman). In addition, Loaded Wheel Tracking (LWT) Tests in accordance with AASHTO T324 "Hamburg Wheel-Track Testing of Compacted Hot Mix Asphalt (HMA)" and Semi Circular Bend (SCB) test according to ASTM D8044: Standard Test Method for Evaluation of Asphalt Mixture Cracking Resistance using the Semi-Circular Bend Test (SCB) at Intermediate Temperatures." A detailed report of all test results shall be furnished to the LTRC Asphalt Research Group.

The contractor shall also furnish the LTRC Asphalt Research Group with six randomly sampled Superpave Gyratory samples, meeting the requirements for the semi-circular bend test for each asphaltic concrete mixture used for this project.

The contractor shall record and report the temperature just behind the paver approximately every 500 feet. Measurements shall be taken at the centerline of the roadway and at each of the wheel paths. A periodic temperature of the mixture in the truck while dumping into the MTV shall also be collected. All temperatures shall be recorded and reported to the LTRC Asphalt Research Group. Any nuclear readings obtained shall also be reported to the LTRC Asphalt Research Group. The rolling pattern established shall also be reported along with the data used to determine the rolling pattern.

Non-standard items NS-DEV-50204 shall be an Asphaltic Concrete – High Density, modified with a chemical additive to produce a higher density mixture. Each of these chemical additives shall be added to the asphalt binder prior to mixing. These additives shall be introduced to the binder in accordance with the manufacturer's recommendation. Submit a new JMF for each of these mixtures listing the additive type and amount along with the proposed mix temperature.

Only chemical additives (compaction aid/warm mix additive) listed on the DOTD approved products list shall be allowed for this item.

Non-standard item NS-DEV-50205 shall be an Asphaltic Concrete – High Density, modified with any of the foaming processes listed in the 2016 Louisiana Standard Specifications for Roads and Bridges.

Non-standard item NS-DEV-50206 shall be an Asphaltic Concrete – High Density, modified with increased asphalt cement content to achieve density. High density asphalt concrete achieved through increased asphalt content and compaction effort shall conform to the Job Mix Formula requirements found in section 502 of the 2016 Louisiana Standard Specifications for Roads and Bridges.

Measurement: Asphaltic Concrete will be measured by the ton in accordance with section 502.14.

Payment: Payment will be made at the contract unit price per ton in accordance with section 502.15.

Payment will be made under:

Item No.	Pay Item	Pay Unit
NS-DEV-50204	Superpave Asphaltic Concrete – High Density (Chem)	Ton
NS-DEV-50205	Superpave Asphaltic Concrete – High Density (Foam)	Ton
NS-DEV-50206	Superpave Asphaltic Concrete – High Density (+AC)	Ton

B: Job Mix Formula

Job Mix Formula for Binder Course Mixtures

Louisiana Department of Transportation and Development
JMF SUPERPAVE ASPHALTIC CONCRETE MIXTURES

Metric/English	E	Plant Code	PS00000880-Coastal Bridge Company #1204 - Port Allen
Project No.	H009540	SMM ID	0
Specs	2016	Plant Type	3-dryer drum
ESAL	0	Prod.Rate	380
Adj. Factor	1.00	ADT/lane	21300
Project Name	US190	Project Cont.	COASTAL PA
Mix Type	Binder Course	Mix Use	ML - Binder
Mix Temp	300	Nom.Agg.Size	0.75 in.
Des.Level	2	Seq No	236
AC Corr Factor	0.06	Project Engr	K. WASCOM
Mix Type	Binder Course	Mix Use	ML - Binder

Aggregate

Material	Source Code	Aggr. Type	Aggr. %	Bulk Sp Gr, Gsb	Abs.	FAA	Sand Eq	Flat& Elong	CAA	Fr. Rate	%Ret #8
Cr. Aggr	APS00007480	1003M00120-67'S	26.7	2.673	0.5			0.9	100	I	95
Cr. Aggr	APS00007480	1003M00120-78'S	18.8	2.679	0.6			0.9	100	I	98
Cr. Aggr	APS00007480	1003M00120-8'S	8.1	2.664	0.8			1	100	I	96
RAP Aggr	PS00000880	1003M01000-SCR RAP	23.8	2.576							52
Fine Aggr	APS00007480	1003M00110-W11'S	12.2	2.670	0.7	47				I	22
Fine Aggr	APS00002200	1003M00110-P. SAND	11.4	2.635	0.5	44	96				0
Composite			GSB	2.645	0.57	48	96	0.9	100		

Asphalt Cement and Additives

Material	Source Code	Material Name	% of Mix
Asphalt Cement	PS00000880	1003M00260-PG82-22RM	3.7
Alternate Asphalt			
Alternate Asphalt			
Rap Asphalt			1.2
Anti Strip	PS00011060	1003M00220-Anti-Strip	0.8

DESIGN DATA / VALIDATION DATA

Parameter	Submittal	Average	Std. Dev	PWL	JMF Limits (per valid.avg)		
Gmm	2.464			–		–	
%Gmm,Nini	88.7			–			90
%Gmm,Nmax	97.4			–		–	98
VMA	14.8			–	12.5	–	
VFA	76			–	69	–	80
% Voids	3.5			–	2.5	–	4.5
% Design AC	4.9						
Comp Temp	300			–		–	
% DF Crushed	99				95	–	
1 1/2 (37.5mm)	100			–		–	
1 in (25mm)	100			–		–	
3/4 (19mm)	97			–		–	
1/2in (12.5mm)	86			–		–	
3/8in (9.5mm)	72			–		–	
No. 4 (4.75mm)	42			–		–	
No. 8(2.36mm)	32			–		–	
No.16(1.18mm)	23			–		–	
No.30(600um)	18			–		–	
No.50(300um)	10			–		–	
No100(150um)	8			–		–	
No. 200(75um)	4.1			–		–	
% AC Extracted	4.9			–		–	
Dust/Pbeff	0.85			–	0.6	–	1.6
Gse	2.684						
Pba	0.14					± 0.0	
Pbe	4.8						

Loaded Wheel Test

Design: No. Passes 20000; Rut 0.64

Validation: No. Passes 0; Rut

SCB Jc: 0.81

Submitted for Contractor By:
Date Submitted 11/03/17

Technician

Proposal Approved Y=Yes N=No Y

By: HV
Date: 11-13-2017

Signature

Validation Approved Y=Yes N=No

By:
Date:

Number of Validation Attempts

LWT = PASS
Each PWL Parameter ≥ 71
Avg. within JMF spec. limits

Approved By

Date First Used

Remarks: MIX AS PER FHWA AND LTRC FOR TEST SECTION FOR INCREASE IN PLACE DENSITY STUDY

LaPave 502 v17.05.18

11/13/2017

Job Mix Formula for Wearing Course Mixtures

Louisiana Department of Transportation and Development
JMF SUPERPAVE ASPHALTIC CONCRETE MIXTURES

Metric/English: E
Project No.: H009549
Specs: 2016
ESAL: 0
Adj. Factor: 1.00
Project Name: US190
Plant Code: PS00000880-Coastal Bridge Company #1204 - Port Allen
Plant Type: 3-dryer drum
Prod.Rate: 350
ADT/lane: 21300
Project Cont.: COASTAL PA
Mix Type: Wearing Course
Mix Type: Wearing Course
Mix Temp: 300
Nom.Agg.Size: 0.5 in.
Mix Use: ML - Wearing
SMM ID: 0
Des.Level: 2F
Seq No: ~~305~~ 2359
AC Corr Factor: 0.09
Project Engr: K. WASCOM
Mix Use: ML - Wearing

Aggregate

Material	Source Code	Aggr. Type	Aggr. %	Bulk Sp.Gr. Gsb	Abs.	FAA	Sand Eq	Flat& Elong	CAA	Fr. Rate	%Ret #8
Cr. Aggr	APS00006370	1003M00120-SANDSTONE	30.0	2.608	1.4			1.1	100	I	88
Cr. Aggr	APS00007480	1003M00120-78'S	13.0	2.679	0.6			0.9	100	II	98
Cr. Aggr	APS00007480	1003M00120-8'S	14.5	2.664	0.6			1	100	II	96
RAP Aggr	PS00000880	1003M01000-SCR RAP	19.1	2.575							52
Fine Aggr	APS00007480	1003M00110-W11'S	11.3	2.670	0.7	47				II	22
Fine Aggr	APS00002200	1003M00110-P. SAND	12.1	2.636	0.5	44	96				0
Composite			GSB	2.629	0.80	45	96	1.0	100		

Asphalt Cement and Additives

Material	Source Code	Material Name	% of Mix
Asphalt Cement	PS00000880	1002M00260-PG82-22RM	4.2
Alternate Asphalt			
Alternate Asphalt			
Rap Asphalt			0.9
Anti Strip	APS00011068	1002M00230-Anti-Strip	0.6

Loaded Wheel Test

Design: No. Passes 20000; Rut 2.24
Validation: No. Passes 0; Rut
SCB Jc: 0.67

DESIGN DATA		VALIDATION DATA			JMF Limits (per valid avg)		
Parameter	Submittal	Average	Std. Dev	PWL			
Gmm	2.441			–		–	
%Gmm,Nini	88.3			–			90
%Gmm,Nmax	97.8			–		–	98
VMA	15.0			–	13.5	–	
VFA	77			–	69	–	80
% Voids	3.6			–	2.5	–	4.5
% Design AC	5.1						
Comp Temp	300			–		–	
% OF Crushed	99				95	–	
1 1/2 (37.5mm)	100			–		–	
1 in (25mm)	100			–		–	
3/4 (19mm)	100			–		–	
1/2in (12.5mm)	93			–		–	
3/8in (9.5mm)	80			–		–	
No. 4 (4.75mm)	45			–		–	
No. 8(2.36mm)	35			–		–	
No.16(1.18mm)	27			–		–	
No.30(600um)	22			–		–	
No.50(300um)	12			–		–	
No100(150um)	7			–		–	
No. 200(75um)	5.0			–		–	
% AC Extracted	5.1			–		–	
Dust/Pbeff	1.00			–	0.6	–	1.6
Gse	2.658						
Pba	0.09				± 0.0		
Pbe	5.0						

Submitted for Contractor By:
Date Submitted: 11/04/17

Technician

Proposal Approved Y=Yes N=No: Y
By: MV
Date: 11-14-2017
Signature

Validation Approved Y=Yes N=No
By:
Date:

Number of Validation Attempts
LWT = PASS (y/n)
Each PWL Parameter ≥ 71
Avg. within JMF spec. limits

Approved By

Date First Used

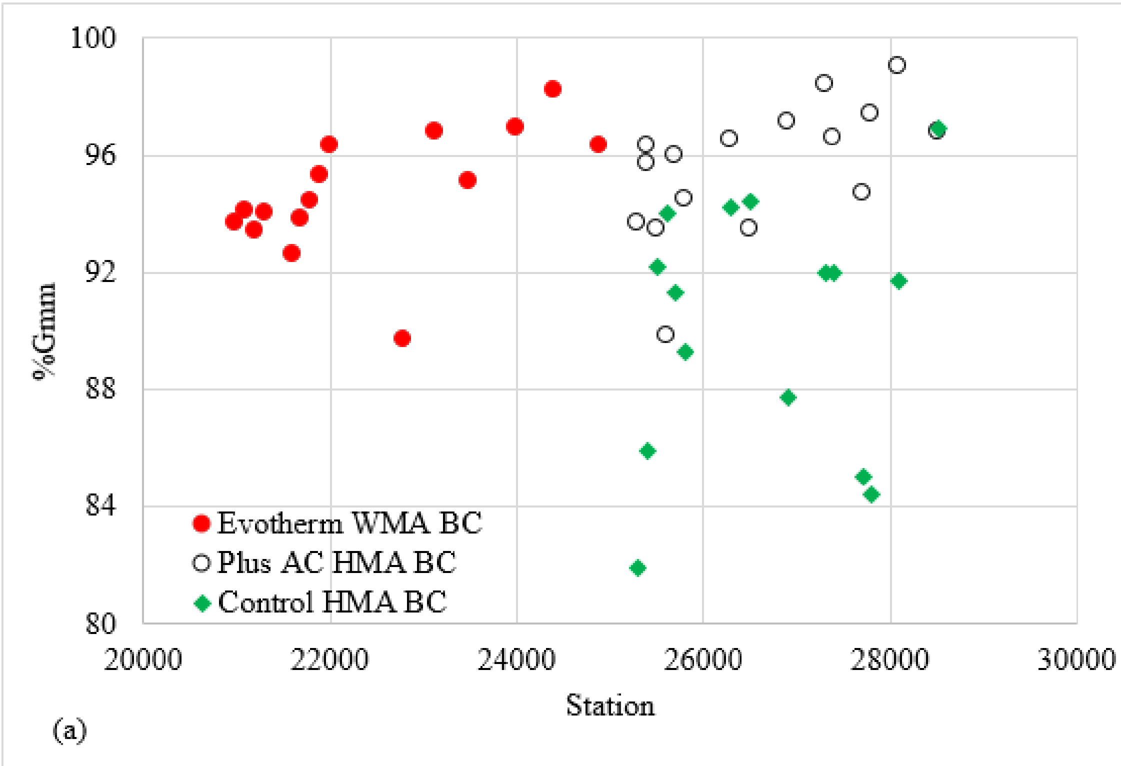
Remarks:

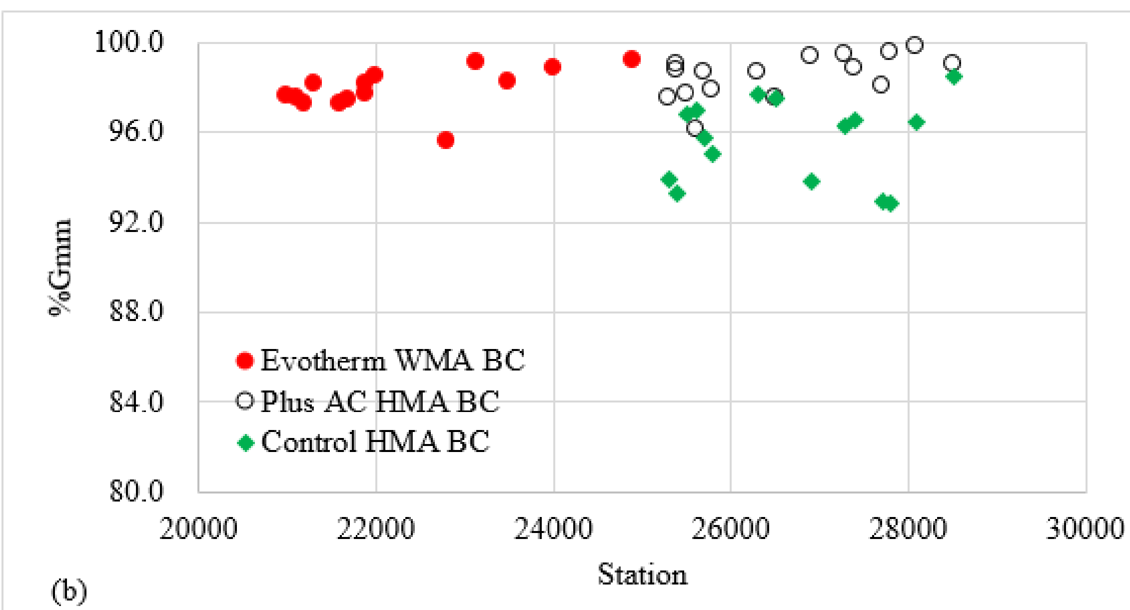
LaPave 502 v17.05.18

11/13/2017

C: Field In-Situ Density Test

Figure C.1. Field in-situ density test results: (a) PaveTracker, and (b) PQI





D: Indirect Tensile Dynamic Modulus Results

Table D. 1. Dynamic modulus (|E*|), Poisson's ratio and phase angle data for Control HMA BC

|E*|(ksi)	CoV	ν	CoV	Ø, H (°)	CoV	Ø, V(°)	CoV
3,129	2%	0.21	14%	2	33%	5	6%
2,997	4%	0.22	12%	3	12%	4	23%
2,769	4%	0.22	13%	5	8%	5	6%
2,700	4%	0.22	13%	5	2%	5	7%
2,491	4%	0.24	13%	7	2%	6	5%
1,861	12%	0.29	21%	10	4%	9	4%
1,725	11%	0.31	11%	14	8%	12	6%
1,396	15%	0.33	20%	18	5%	17	2%
1,198	12%	0.32	16%	19	4%	19	1%
902	10%	0.34	13%	24	3%	24	5%
626	11%	0.32	16%	25	3%	24	5%
501	7%	0.35	14%	27	4%	27	3%
304	19%	0.35	19%	33	2%	33	7%
236	15%	0.39	21%	34	3%	34	5%
144	11%	0.38	25%	36	2%	34	4%

ν: Poisson's ratio; CoV: Coefficient of variation; $Ø_{,H}$: Phase angle for the horizontal deformations; $Ø_{,V}$: Phase angle for the vertical deformations.

Table D. 2. Dynamic modulus (|E*|), Poisson's ratio and phase angle data for Control HMA WC

|E*|(ksi)	CoV	ν	CoV	Ø, H (°)	CoV	Ø, V(°)	CoV
3,405	3%	0.16	18%	1	17%	2	34%
3,098	12%	0.17	11%	3	16%	3	25%
2,923	9%	0.17	11%	6	29%	5	14%
2,851	10%	0.18	12%	6	17%	5	14%
2,611	12%	0.18	9%	7	23%	6	9%
1,809	7%	0.21	5%	11	10%	10	6%
1,663	7%	0.22	6%	14	3%	13	3%
1,280	6%	0.23	8%	17	10%	17	3%
1,136	8%	0.24	10%	21	9%	20	1%
815	9%	0.26	14%	26	5%	26	4%
559	3%	0.26	11%	26	1%	27	2%
459	5%	0.27	11%	30	2%	29	1%
255	10%	0.28	22%	35	1%	35	2%
182	5%	0.26	12%	35	1%	36	1%
101	8%	0.28	13%	35	3%	34	3%

ν: Poisson's ratio; CoV: Coefficient of variation; $Ø_{,H}$: Phase angle for the horizontal deformations; $Ø_{,V}$: Phase angle for the vertical deformations.

Table D. 3. Dynamic modulus (|E*|), Poisson's ratio and phase angle data for Evotherm WMA BC

E*(ksi)	CoV	ν	CoV	Ø, H (°)	CoV	Ø, V(°)	CoV
3,431	1%	0.16	5%	2	33%	1	31%
3,363	2%	0.17	9%	3	26%	3	16%
3,123	4%	0.17	10%	5	24%	6	15%
3,037	4%	0.18	7%	7	25%	6	13%
2,759	5%	0.18	12%	7	13%	7	13%
2,013	7%	0.24	1%	11	7%	10	15%
1,862	8%	0.26	3%	14	9%	13	8%
1,415	8%	0.27	8%	20	5%	19	7%
1,241	9%	0.28	5%	21	7%	22	7%
891	10%	0.30	9%	26	7%	25	7%
632	14%	0.36	5%	28	10%	24	5%
513	14%	0.37	0%	30	9%	26	2%
320	8%	0.38	0%	34	6%	33	5%
267	2%	0.40	2%	35	4%	32	3%
169	11%	0.40	1%	35	2%	32	1%

ν: Poisson's ratio; CoV: Coefficient of variation; $Ø,_{H}$: Phase angle for the horizontal deformations; $Ø,_{V}$: Phase angle for the vertical deformations.

Table D. 4. Dynamic modulus (|E*|), Poisson's ratio and phase angle data for Evotherm WMA WC

|E*|(ksi)	CoV	ν	CoV	Ø, H (°)	CoV	Ø, V(°)	CoV
3,603	2%	0.21	11%	3	37%	1	10%
3,591	1%	0.23	18%	3	10%	4	21%
3,350	1%	0.23	19%	5	33%	5	11%
3,212	1%	0.23	16%	6	8%	6	9%
2,913	1%	0.24	16%	8	5%	7	10%
1,996	3%	0.26	5%	12	2%	10	8%
1,818	4%	0.26	2%	15	2%	13	8%
1,418	8%	0.31	7%	22	4%	19	8%
1,212	7%	0.29	4%	22	5%	21	5%
863	10%	0.33	12%	27	2%	25	6%
576	14%	0.31	26%	28	1%	27	8%
452	14%	0.31	24%	31	3%	30	4%
247	17%	0.33	28%	36	2%	35	4%
194	16%	0.34	26%	36	2%	36	4%
104	16%	0.34	26%	36	2%	36	1%

ν: Poisson's ratio; CoV: Coefficient of variation; $Ø,_{H}$: Phase angle for the horizontal deformations; $Ø,_{V}$: Phase angle for the vertical deformations.

Table D. 5. Dynamic modulus (|E*|), Poisson's ratio and phase angle data for Plus AC HMA BC

E*(ksi)	CoV	ν	CoV	Ø, H (°)	CoV	Ø, V(°)	CoV
3,574	6%	0.23	18%	1	36%	2	20%
3,446	10%	0.24	22%	4	2%	3	19%
3,275	10%	0.25	22%	5	7%	5	21%
3,180	11%	0.25	23%	6	8%	5	9%
2,901	10%	0.26	19%	8	11%	6	10%
2,115	2%	0.26	8%	10	6%	9	7%
1,971	0%	0.27	5%	13	5%	11	6%
1,549	1%	0.29	4%	18	0%	17	2%
1,374	2%	0.29	4%	19	4%	19	4%
986	2%	0.32	9%	25	4%	23	3%
720	5%	0.33	12%	27	2%	25	4%
592	2%	0.37	8%	29	1%	28	5%
331	2%	0.38	7%	35	2%	33	2%
291	10%	0.40	7%	34	3%	34	3%
197	3%	0.44	8%	35	5%	34	7%

ν: Poisson's ratio; CoV: Coefficient of variation; $Ø,_{H}$: Phase angle for the horizontal deformations; $Ø,_{V}$: Phase angle for the vertical deformations.

Table D. 6. Dynamic modulus (|E*|), Poisson's ratio and phase angle data for Plus AC HMA WC

|E*|(ksi)	CoV	ν	CoV	Ø, H (°)	CoV	Ø, V(°)	CoV
3,411	5%	0.17	7%	2	21%	2	26%
3,231	5%	0.18	9%	4	4%	3	5%
3,039	5%	0.19	13%	6	18%	4	21%
2,933	6%	0.19	16%	7	12%	5	6%
2,665	6%	0.19	16%	8	2%	6	8%
2,124	9%	0.24	20%	9	13%	8	14%
1,969	10%	0.24	16%	12	10%	11	9%
1,532	11%	0.25	17%	17	6%	17	6%
1,354	12%	0.27	15%	19	12%	19	8%
980	13%	0.30	20%	24	3%	23	5%
631	11%	0.34	18%	26	5%	26	4%
507	12%	0.35	18%	28	5%	29	4%
283	16%	0.36	30%	35	6%	34	4%
242	25%	0.37	34%	35	6%	35	3%
156	21%	0.38	40%	35	7%	35	3%

ν: Poisson's ratio; CoV: Coefficient of variation; $Ø,_{H}$: Phase angle for the horizontal deformations; $Ø,_{V}$: Phase angle for the vertical deformations.

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