Asphalt production, paving and compaction techniques

Improving Asphalt Pavement Density: Design and Construction

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Abstract

In-place density of asphalt pavements is one of the most important factors influencing performance. Typically, specified in-place density of an asphalt pavement is achieved through a combination of proper mix design, production, placement, compaction, and quality control of the mixture. The objective of this study was to evaluate the effect of increasing the initial in-place density of asphalt pavements on durability as measured by field in-place density and laboratory high and intermediate temperature properties. Two different approaches of increasing field density were adopted. The first approach included the addition of a chemical type of Warm Mix Asphalt (WMA) additive at a dosage rate of 0.6% by the mixture weight. The second approach included a 0.2% increase to the design optimum asphalt binder content (Plus AC). Field project was constructed with 50.8 mm wearing course (WC) mixtures on a new binder course layer. In this field project, three 1,200 m test sections were evaluated. A control section with conventional hot-mix asphalt (HMA) mixture; a chemical type of WMA additive section; and Plus AC section. Cores from each test section were secured for measurements of density (air voids) as well as high and intermediate temperature properties using Hamburg Loaded Wheel Tracking (LWT) test and Semi-Circular Bending (SCB) test, respectively. Test sections with the two methodologies (i.e., WMA and Plus AC) of improving field compaction and in-situ densities adopted in this project were successful in achieving an increased field density by 1.0% – 2.3% of theoretical maximum specific gravity as compared to conventional section. Further, increased in densities (lower air voids) of the WMA and Plus AC WC mixtures resulted in an improvement in high and intermediate temperature properties as compared to conventional mixtures. Keywords: In-place density, Durability, WMA additive, LWT, SCB

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1. INTRODUCTION

The design and construction of durable asphalt pavements extend the service life of road infrastructure and provides safer means for the transportation of goods and services. Resilient, and durable road networks are needed for the successful implementation technologies for mobility (i.e., intelligent transportations systems, autonomous vehicles, etc.). Durable road networks minimize the cost that State and Highway Agencies (SHAs) incur in maintaining defective roads. The US government requires approximately $35B annually to maintain the conditions on highways and bridges to satisfactory levels through the year 2040 [1]. It estimated that the average annual savings of $5.25B could be made if 5 to 25% improvement in pavement performance is achieved on US roads [2]. The savings made from constructing durable roads can be invested in other sectors of the economy.

Bonaquist [3] identified construction practices, and mix design as essential factors influencing the durability of asphalt pavements. Good construction practices that have been utilized to improve pavement durability include minimizing temperature segregation in asphalt mixture mat during construction [4, 5]; selecting in-place compaction (field density) requirements to minimize permeability [2, 3]; curtailing segregation of asphalt materials during construction [3]; adequate and proper application of tack coat materials [6]; and proper construction of longitudinal joints to improve densities [7]. The degree of compaction (i.e., in-place density) of an asphalt layer is the most critical factor affecting the performance and durability [3, 8]. It has been established that lower in-place densities have the following adverse effects on asphalt pavements [9]: increased oxidative aging of bitumen film; increased permeability; reduced strength; decreased resistance to moisture damage; reduced mixture stiffness; decreased resistance to rutting, and decreased resistance to fatigue cracking. During pavement construction, asphalt layers are placed at densities within the range of 80 to 85 percent of Gmm, prior to roller compaction. Most state highway agencies usually specify an average in-place density of 92 to 93 percent of Gmm for a compacted asphalt pavement [3]. For dense-graded asphalts with air voids above 7 percent, a 1 percent increase in-place density can result in a 10% improvement in pavement service life [10]. According to Tran et al. [11], the 10 percent improvement in service life associated with the increased in-place density can translate into an average of 8.8 percent cost savings through the life cycle of the pavement.

Recent advancements in pavement construction technology have resulted in the utilization of various techniques to improve the in-place density of asphalt pavements in order to improve durability. The approaches usually adopted to improve the in-place density of asphalt pavements make the mixtures easier to compact without compromising on rutting performance [12]. New techniques such as Warm Mix Asphalt (WMA) [13, 14]; intelligent compaction [15]; and the use on infrared imaging to minimize temperature segregation [4, 5] have been used successfully by other researchers to improve field in-place densities. It has been reported that WMA technologies can be used as compaction aids for highly modified stiff asphalt materials [13]. Despite the adoption of these approaches for improving the in-place density of asphalt pavements, state and highway agencies (SHAs) have found it difficult to achieve in-place density targets above the conventional 92 to 93% theoretical maximum specific gravity (Gmm) range [2,11]. It is anticipated that these increased in-place density approaches can be effectively used by SHAs to enhance field in-place density targets in order to improve mixture durability and extend the service life of asphalt pavements.

2. OBJECTIVE AND SCOPE OF RESEARCH

The objectives of this research include the following: (1) identifying efficient techniques for improving asphalt durability utilizing increase in-place density methods; and (2) evaluating the effect of the increased in-place techniques considered on pavement performance and durability.

Two different approaches of increasing field density were considered: (1) addition of a chemical type of Warm Mix Asphalt (WMA) additive at a dosage rate of 0.6% by the mixture weight; and (2) 0.2% increase in the design optimum bitumen content (Plus AC). Field project was constructed with 50.8 mm wearing course (WC) mixtures on an existing binder course layer. Three 1,200 m test sections were evaluated. A control section with conventional hot-mix asphalt (HMA) mixture; a WMA section; and Plus AC section. A styrene butadiene styrene (SBS) polymer-modified PG 76-22 bitumen was used for the three mixtures. Cores from each test section were collected for density (air voids) measurements as well as high and intermediate temperature properties using Hamburg Loaded Wheel Tracking (LWT) test and Semi-Circular Bending (SCB) test, respectively.

3. Methodology

3.1. Materials

Asphalt component materials utilized in this project are listed in Table 1. Aggregates selected for the asphalt included coarse sandstone, coarse limestone, fine limestone, river sand, and 19.1% Recycled Asphalt Pavement (RAP) materials. The design aggregate gradation utilized for this study is reported elsewhere [16]. The mixture for each test section was prepared using a styrene-butadiene-styrene (SBS) polymer-modified bitumen meeting Louisiana specifications for PG 76-22M [17].

Table 1. Asphalt component materials

Component Type	Quantity (%)
Coarse Sandstone	30
#78 Coarse Limestone	13
#8 Coarse Limestone	14.5
#11 Fine Limestone (Washed)	11.3
Fine River Pump Sand	12.1
RAP	19.1

RAP: Recycled asphalt pavement

3.2. Asphalt Mixture Design

Three 12.5 mm Superpave asphalt mixtures were considered. A Level 2 mixture was designed according to AASHTO R 35, "Standard Practice for Superpave Volumetric Design for Hot Mix Asphalt (HMA) [18]," AASHTO M 323, "Standard Specification for Superpave Volumetric Mix Design [19]," and Section 502 of the 2016 Louisiana Standard Specifications for Roads and Bridges [17]. Table 2 presents the design properties of the mixtures evaluated.

Table 2. Mixture design properties

Mixtures	Control Mixture	WMA Mixture	Plus AC Mixture
%Design BC	5.0	5.1	5.2
Gmm	2.448	2.441	2.441
VMA	14.6	15.0	15.1
VFA	76	77	77
%AV	3.5	3.5	3.5
Dust Ratio	1.02	1.00	0.98
P_{be} (%)	4.9	5.0	5.1

VMA: Voids in the mineral aggregate; BC: Bitumen content; VFA: Voids filled with asphalt; Gmm: Theoretical maximum specific gravity; %AV: Design air void content; P_{be}: Effective bitumen content; Plus AC Asphalt: Mixture contained 0.2% more bitumen content than the control mix

3.3. Construction of Pavement Test Sections

The three test sections (i.e., Control, WMA and Plus AC) were constructed on a new binder course layer. Prior to placing the test sections, the surface of the new binder course layer was cleaned using a power broom. SS-1 anionic emulsion bitumen was sprayed on the binder course surface utilizing a spray truck and at a residual application rate of 0.045 g/sy, according to section 501.08.1 of the 2016 Louisiana Standard Specifications for Roads and Bridges [17]. A Caterpillar paver (model: CAT AP1055) was used to place the asphalt mixture in each test section. A full-size material transfer vehicle (MTV), Caterpillar E2850, was used for the pavement construction. For each pavement section, the surface temperature of the un-compacted mat behind the paver was monitored and was found to range from 240°F to 275°F. Compaction of the asphalt layers was achieved using two different models of steel rollers (i.e., CAT CB 534D and CAT CB 434D). CAT CB 534D and CAT CB 434D were used as breakdown and finish roller, respectively. Along 30 to 45m span of asphalt mat, the breakdown roller applied an average of 8 passes with vibration. After five to ten minutes of breakdown compaction, the finish roller applied an average of 8 passes to the asphalt mat without vibration. Figure 1 presents the paving train in action during the night paving activities.

Figure 1: Paving train in action at night

3.4. Field In-Place Density Measurements

Random locations were selected along the center of each of the three 1,200-m-long test sections for the evaluation of field in-place densities. Field cores were secured from each test section and the densities measured according to AASHTOT166, "Standard Method of Test for Bulk Specific Gravity (Gmb) of Compacted Hot Mix Asphalt (HMA) Using Saturated Surface-Dry Specimens." [20].

3.5. Asphalt Mixture Performance Tests

3.5.1. Rutting and Moisture Susceptibility

The Hamburg Loaded Wheel Tracking (LWT) test was conducted following AASHTO T 324, "Standard Method of Test for Hamburg Wheel-Track Testing of Compacted Hot Mix Asphalt (HMA)" [21], for the evaluation of the rutting and moisture susceptibility of the mixtures. The Hamburg test is a torture test. During testing, the Hamburg loaded wheel tracking device produces damage by rolling a steel wheel across the surface of Superpave gyratory compacted specimens (150mm diameter by 60mm thick) that are submerged in water at 50°C for a maximum of 20,000 passes. In this study, the average rut depth at 20,000 passes was used in the analysis.

3.5.2. Intermediate Temperature Cracking Resistance

The SCB test was performed per ASTM D 8044, "Standard Test Method for Evaluation of Asphalt Mixture Cracking Resistance using the Semi-Circular Bend Test (SCB) at Intermediate Temperatures" [22]. This test was performed to characterize the fracture resistance of asphalt mixtures regarding the critical strain energy release rate or the critical J-integral (Jc). To determine Jc, specimens with two notch depths (i.e., 25.4 and 38 mm) were considered. Four replicate specimens were tested for each notch depth at 25 °C. The SCB specimens were loaded monotonically at a constant crosshead displacement of 0.5mm/min until fracture failure. The load and deformation data were recorded continuously for the determination of Jc as illustrated in Equation 1

$$\boldsymbol{J_c = \left(\frac{1}{b}\right)\frac{dU}{dA}} \qquad \textbf{(1)}$$

Where
Jc = critical strain energy release rate (kJ/m^2),
b = sample thickness (m),
a = notch depth (m), and
U = strain energy to failure (kJ)
Higher Jc value is an indication of higher cracking resistance at intermediate-temperatures and vice versa. The fracture resistance of field cores secured from test section were determined and analyzed.

3.6. Statistical Analyses

Statistical analyses of the test results were carried out with the Statistical Analysis System (SAS) software [23]. A multiple comparison procedure, Tukey test, was carried out with a 95% confidence level. The multiple comparison procedure ranked the mean test results and placed them in groups designated A, B, C, D, A/B, and so on. The letter A is used to rank the group with the most desired values, such as high Jc or low LWT rut depths, followed by the other letter grades in the appropriate order. A double-letter designation, such as A/B, indicates that the mean performance (i.e., Jc or HWT rut depth) of the given group is not significantly different from that of either Group A or Group B.

4. RESULTS AND DISCUSSIONS

4.1. Field In-Place Density Results

Figure 2 presents the average densities (expressed as a percent Gmm) of field cores from the three test sections. The two increased in-place density approaches (i.e., WMA, and Plus AC) adopted in this study resulted in a marginal increase in densities (i.e., lower air voids) of the WMA and Plus AC test sections as compared to the Control one. It is noted that the density of the control test section was relatively high (i.e., 95.6% Gmm) as compared to the conventional 92 to 93% Gmm typically recommended by state and highway agencies [2, 11]. Therefore, the two methodologies were not expected to further increase densities of the WMA and the Plus AC test sections significantly.

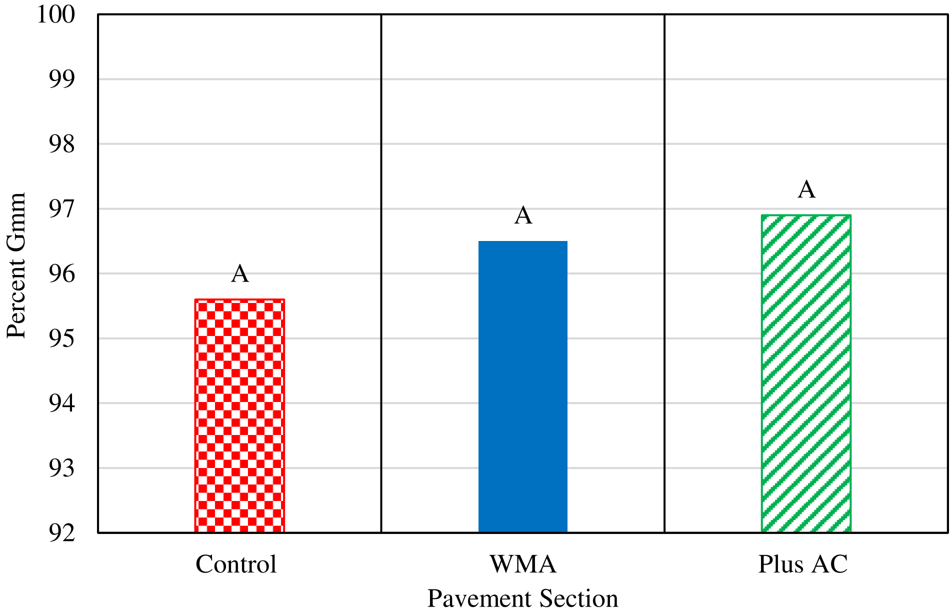

Figure 2: Average in-place densities of test sections

4.2. Rutting and Moisture Susceptibility

Figure 3 shows the HWT test results for the Control, WMA, and Plus AC test sections evaluated. The average coefficient of variation (COV) of the rut depths at 20000 passes was 10%. The increased in- place densities associated with the WMA and Plus AC technologies resulted in significantly better rutting performance in WMA and the Plus AC test sections as compared to the Control test section. This observation suggests that the two increased in-place density methodologies (i.e., WMA, and Plus AC) were effective in improving rutting performance and hence the durability of asphalt pavements.

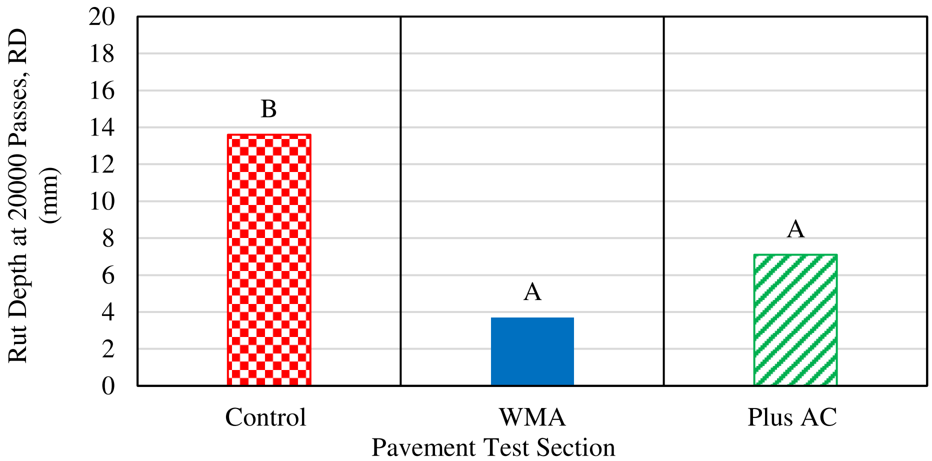

Figure 3: HWT test results, 50°C wet

Figure 4 presents the SCB Jc of the three pavement test sections evaluated. The average COV of the Jc values was 17%. The improvement in in-place density observed in the WMA mixtures, Figure 2, resulted in a significant increase in the SCB Jc of the WMA test section as compared to the Control test section. However, the improvement in density associated with the Plus AC increased in-place density technique resulted in a minimal increase in the SCB Jc of the Plus AC test section as compared to the control one. This observation indicates that the two increasing in-place density methodologies identified in this study are effective means of improving the intermediate-temperature cracking resistance and durability of asphalt pavements.

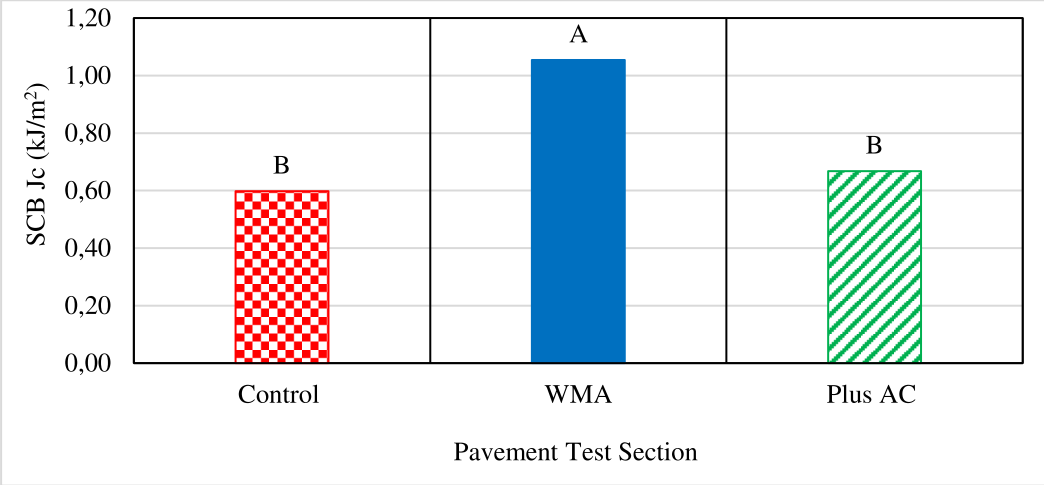

Figure 4: SCB test results, 25°C

5. SUMMARY AND CONCLUSIONS

This study evaluated two approaches for improving in-place density of asphalt pavements: (1) addition of a chemical type of Warm Mix Asphalt (WMA) additive at a dosage rate of 0.6% by the mixture weight; (2) 0.2% increase in design optimum bitumen content (Plus AC). Field project was constructed with 50.8 mm wearing course (WC) mixtures on a new binder course layer. Three 1,200 m test sections were evaluated. A control section with conventional hot-mix asphalt (HMA) mixture; a WMA section; and Plus AC section. A styrene butadiene styrene (SBS) polymer-modified PG 76-22 bitumen was used for the three mixtures. Cores from each test section were collected for density (air voids) measurements, Hamburg Loaded Wheel Tracking (LWT) test and Semi-Circular Bending (SCB) test. The two increased in-place techniques (i.e. WMA, and Plus AC) selected were effective in increasing field in-place densities and subsequently improving the high- and intermediate-temperature cracking performance of the field cores. The improvements in densities, high-, and intermediate temperature performance associated these increased in-place density approaches has the potential to improve durability. Specific observations include:

- Two increased in-place density approaches (i.e., WMA, and Plus AC) resulted in a marginal increase in densities (i.e., lower air voids) of the WMA and Plus AC test sections as compared to the control one, which already had a high density.
- Increased in- place densities associated with the WMA and Plus AC technologies resulted in significant improvement in rutting performance of WMA and Plus AC test sections as compared to the Control one.
- Improvement in in-place density observed in the WMA mixtures resulted in a significant increase in the SCB Jc of WMA test section as compared to the Control one.

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