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   Evaluation of Performance and Life Cycle Cost of Asphalt (8/18 Specifications)

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13. Abstract

The Louisiana Department of Transportation and Development (DOTD) revised its asphalt pavement specifications based upon research conducted at the Louisiana Transportation Research Center (LTRC). These changes introduced performance-based specifications in the form of the semi-circular bending (SCB) and the loaded wheel tracking (LWT) tests. Additionally, there were revisions made to the volumetric and compaction criteria during the pavement design process. The intent of this research was to analyze and compare the performance of asphalt pavements constructed using specifications from the 2006 specifications to pavements built with the 2016 specifications. The project evaluated the density, volumetric, and performance data for various pavement sections. The research found that the new mixtures passed the performance-based criteria as well as the volumetric criteria, and the new specifications enhanced field rutting and cracking performance and have the potential to increase pavement service life by one to three years.

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Each research project will have an advisory committee appointed by the LTRC Director. The Project Review Committee is responsible for assisting the LTRC Administrator or Manager in the development of acceptable research problem statements, requests for proposals, review of research proposals, oversight of approved research projects, and implementation of findings.

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

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Louisiana Transportation Research Center

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Abstract

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Implementation Statement

The revised asphalt specifications have already been implemented into the standard specifications. This research sought to evaluate the performance of the new mixtures as well as perform a life-cycle cost analysis.

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Introduction

In the past, roadways constructed with hot mix asphalt (HMA) for the state of Louisiana have relied on control of the volumetric properties of voids filled with asphalt (VFA), air void content (AV), voids in the mineral aggregate (VMA), and density to ensure pavement performance. Sole reliance upon these volumetric properties for quality, as well as increased traffic volume, has led to roadways failing prematurely at an increased frequency. In an effort to improve the performance and value of its asphalt roadways, the Louisiana Department of Transportation and Development (DOTD) has implemented changes to its asphalt pavement specifications based on research conducted at the Louisiana Transportation Research Center (LTRC). These changes include the introduction of performance-based specifications (PBS), which required the use of loaded wheel tracking (LWT) and semi-circular bending (SCB) tests for rutting and cracking characterization, respectively, as well as a revision to the volumetric and compaction criteria during the design process.

With the implementation of the new specification in the 2016 *DOTD Standard Specifications for Roads and Bridges* (SSRB) and revisions made in special provision 8/18, this study was conducted to measure and evaluate the performance and life-cycle costs for the asphalt pavements. Additionally, a balanced evaluation of the effects of the specification changes on various mixtures was conducted to ensure that the changes made to the specifications result in overall improvements.

Literature Review

Throughout the years, state transportation departments (DOTs) have relied on various types of construction specifications to ensure quality construction practices and materials [1]. Many of the earlier specification types had downsides. For instance, method specifications, which began in the 1940s, provide a "cookbook" with "recipes" for the contractor to follow. These specifications are not linked to product quality or long-term performance. Additionally, they do not allow contractors to utilize economical or innovative construction methods. In an attempt to improve upon method specifications, the 1958 AASHTO Road Test helped lay the groundwork for end-result specifications. These specifications require the contractor to take full responsibility for producing and placing the product and for quality control (QC) sampling, testing, and inspection. The problem with these specifications is that they often do not clearly define QC, and the acceptance target values are often based on subjective experience rather than historical data. Quality assurance (QA) specifications, which began in the 1960s, require contractor QC and agency acceptance activities throughout production and placement of a product. Additionally, final acceptance of the product is usually based on a statistical sampling of the measured quality level for key characteristics [2]. Often, when QA specifications are developed for asphalt pavements, they attempt to control the volumetric properties such as aggregate gradation, air void content, and asphalt content. The disadvantage of this method is that there is a lack of correlation between the volumetric properties and the long-term performance of the asphalt pavement [1]. In the late 1980s, construction specifications evolved into performance-related specifications. These specifications correlate quantified quality characteristics and life-cycle cost (LCC) relationships to product performance. Furthermore, these specifications act as a link between construction quality and long-term performance. Currently, the development and implementation of performance-based specifications remains on the horizon for some state DOTs. The Transportation Research Circular Number E-C037 (April 2002) formally defines performance-based specifications as: *"Quality Assurance Specifications that describe the desired levels of fundamental engineering properties (e.g., resilient modulus, creep properties, and fatigue) that are predictors of performance and appear in primary prediction relationships (i.e., models that can be used to predict stress, distress, or performance from combinations of predictors that represent traffic, environment, supporting materials, and structural conditions)* [3]."

State DOTs have increasingly turned to performance-related or performance-based specifications because they focus on roadway performance.

In 2014, LTRC conducted research to evaluate the effects that modifying specifications to address the need for balanced mix designs (i.e., mechanistic laboratory evaluation to complement volumetric criteria) would have on the laboratory performance of asphalt mixtures. In this project, mixtures were produced in accordance with proposed specifications to achieve a balance with respect to rutting and fatigue cracking. Additionally, eleven plant-produced mixtures were collected from six field projects using the proposed balanced specification criteria. Results from LWT and SCB testing for mixtures produced under the proposed specifications were compared with mixtures produced under the previous specification criteria. The results of the research found that, with respect to rut resistance, the mixtures produced under the proposed specifications exhibited improved or similar performance to mixtures produced under the previous specification. The research also found that 50% of the mixtures designed according to the proposed specifications met or exceeded the cracking criteria as determined by the SCB test [4].

Mohammad et al. (2014) found that "the concept of performance-oriented specification is promising since it takes more direct performance measures as the quality goal of the pavement construction. However, applications of the concept to actual projects require the use of complicated prediction models for material properties and pavement performance." [1] Additionally, this research found that loaded-wheel tracking (LWT) and semi-circular bend (SCB) tests are practical and promising tools for evaluating the rutting and cracking performance, respectively, of compacted asphalt mixtures. This research also helped establish the criteria for rutting and cracking that were adopted in the 2016 version of the Louisiana DOTD *Standard Specifications for Roads and Bridges*.

In 2016, NCHRP Synthesis 492 reported many findings on the use of performance specifications for asphalt mixtures. A survey of DOTs and local public agencies (LPAs) in the U.S. and Canada found that many had either implemented performance-based specifications already or were conducting research to address performance testing. The survey also found that 80% of DOTs require performance testing and moisture damage evaluation, whereas 27% of DOTs use performance specifications for mixture acceptance. Additionally, the report found that the most frequent reasons for the use of performance specifications for asphalt mixtures are to achieve longer pavement service life in terms of fatigue cracking and other distresses, and to quantify the quality and encourage better construction of flexible pavements. The synthesis also found that the most common performance testing tools were the loaded-wheel tracking (LWT) test, asphalt pavement analyzer (APA), and the modified Lottman test for rutting resistance and moisture damage characterization [5].

Objective and Scope of Study

The objective of this research was to analyze and compare the performance of asphalt pavements constructed using specifications from the 2006 SSRB to pavements built under the 2016 SSRB and its accompanying special provision 8/18.

This study evaluated the density, volumetric, and performance data for various pavement sections. A life-cycle cost analysis was also performed to determine if the specification changes had increased the service life of asphalt pavements in Louisiana. To sufficiently analyze the various aspects of the project, several different resources were employed. The volumetric data for asphalt pavements that utilized the 2006 specification for construction was obtained from DOTD laboratory engineers throughout the state. The online pavement management system known as LaPave was used to gather volumetric data for the roadways constructed per the 2016 specification and special provision 8/18. The long-term performance and life-cycle costs of the pavement sections were determined by using the pavement mechanistic empirical design (i.e., Pavement ME) software to ascertain the effects of the current specifications on field performance compared to the previous specifications. Additionally, asphalt samples were collected from various contractors to conduct volumetric and performance testing in a laboratory setting.

Methodology

The following tasks were conducted to achieve the objective of the research project:

- Task 1 – Conduct literature review
- Task 2 – Develop experimental program
- Task 3 – Data and asphalt sample collection
- Task 4 – Laboratory testing
- Task 5 – Perform data analyses
- Task 6 – Perform Life-Cycle Cost Analysis
- Task 7 – Prepare draft final report

Test Factorial

When this project started, there were still projects being constructed with the 2006 asphalt specifications. It was determined that all projects after November 14, 2018, would be utilizing the 2016 asphalt specifications. Fourteen projects were identified as candidates for analysis. The information for the mixtures used in these projects is shown in Table 1, and the project locations are shown in Figure 1. The mix IDs shown in the table are consistent throughout the report. The job-mix formulas (JMFs) for each project were compiled, as were the plant report, the roadway report, the pay report, and the project design proposal. The asphalt samples were obtained at the asphalt plant on the day they were produced before being brought back to LTRC for testing. Volumetric testing was conducted to determine the air void content (AV), voids in mineral aggregate (VMA), and voids filled with asphalt (VFA). Additionally, the asphalt content was found using the ignition method in accordance with AASTHO T 308, as well as the mixture gradation. Finally, samples were prepared and subjected to the laboratory performance testing summarized in Table 2.

Table 1. Asphalt mixture information

Project Location	Project No.	Type of Construction	Mix ID[1]	Design Level	Binder Grade	NMAS (in.)
LA 16	H.010124	Roundabout and Asphalt Roadway	124B	1	70-22	3/4
LA 16	H.010124	Roundabout and Asphalt Roadway	124W	1	70-22	1/2
US 190	H.013262	Patch, Mill and Overlay	262B	1	70-22	3/4
LA 26	H.009615	Patch, Mill and Overlay	615B	1	76-22	3/4
LA 26	H.009615	Patch, Mill and Overlay	615W	1F	70-22	1/2
LA 3235	H.010688	Asphalt Concrete and Overlay	688B	1	70-22	3/4
LA 3235	H.010688	Asphalt Concrete and Overlay	688W	1F	70-22	1/2
LA 63	H.013739	Mill and Overlay	739B	1	70-22	3/4
LA 63	H.013739	Mill and Overlay	739W	1	70-22	1/2
I-12	H.011152	Patch, Mill, Asphalt Concrete	152B	2	76-22	3/4
US 61	H.013209	Patch, Mill and Overlay	209W	2F	76-22	1/2
US 61	H.000320	Mill and Overlay	320W	2F	76-22	1/2
US 167	H.010353	Patch, Mill, Widening	353W	2F	76-22	1/2
I-10	H.010601	Micro-Milling, Asphalt Concrete	601B	2	76-22	1

B: Binder course, W: Wearing course; NMAS: Nominal maximum aggregate size.

Figure 1. Approximate project locations

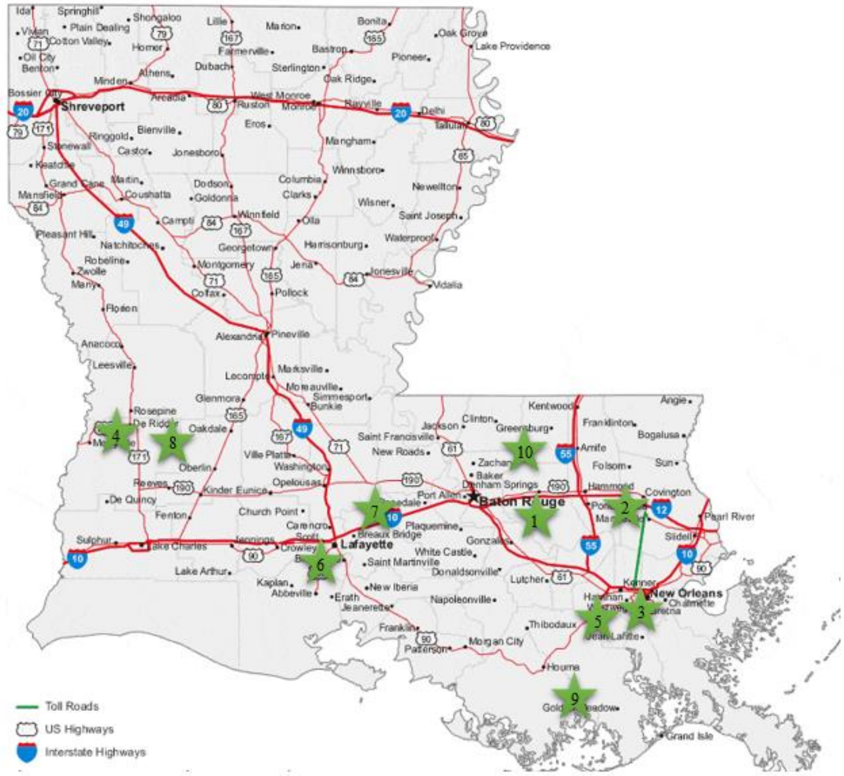


Table 2. Laboratory performance test parameters and protocols

Test Method	Performance Indicator	Test Temperature (C)	Test Procedure
SCB	J_c (kJ/m^2)	25º	DOTD TR 330
LWT	Rut Depth (mm)	50º	AASHTO T 324
|E*|	Dynamic Modulus	-4.4º to 54º	AASHTO T 342

2016 Asphalt Specification

The new specification can be seen in Table 3; it differs from the 2006 asphalt specification in several ways. First, the number of N_{design} gyrations has been reduced from 75 to 55 for level 1 mixtures and from 100 to 65 for level 2 mixtures. Additionally, the required maximum gyrations (N_{max}) have been reduced from 115 to 90 for level 1 mixtures and from 160 to 105 for level 2 mixtures. These changes mean that the mix design needs to meet its density target at a much lower gyration count. There was also a reduction of the $N_{initial}$ gyrations from 8 to 7 for level 2 asphalt mixtures. Furthermore, the maximum quantity of reclaimed asphalt pavement (RAP) allowed in the asphalt mixtures was increased from 15% to 20% for wearing course, 20% to 25% for binder course, and 30% to 35% for base course mixtures. The minimum voids in mineral aggregate (VMA) value at N_{design} was increased from 13% to 13.5%. Finally, mixture performance testing was introduced into the 2016 asphalt specifications. The new specification recommended the use of the loaded wheel tracking (LWT) device for rutting resistance characterization, with a specified maximum laboratory-measured rut depth for level 1 and 2 mixtures. In addition to rutting performance, the new specification specifies criteria for resistance to cracking with the semi-circular bending test (SCB). The LWT and SCB criteria are shown in Table 3.

Table 3. Asphalt concrete general criteria

Nominal Max., Size Agg.	0.5 inch (12.5 mm)			0.75 inch (19 mm)			1.0 inch (25 mm)				1.5 inch (37.5 mm)	SMA
Type of Mix	Incidental Paving[1]	Wearing Course		Wearing Course	Binder Course		Binder Course		Base Course	ATB[7]	Base Course	Wearing
Level[2]	A	1	2	2	1	2	1	2	1	1	1	2
Coarse Agg. Angularity, % Crushed, (Double Faced), Min. %	55	75	95	95	75	95	75	95	75	75	75	98
Fine Agg. Angularity, Min. %	40	40	44	44	40	44	40	44	40	40	40	45
Flat and Elongated Particles (5:1), Max. %	10											5[9]
Sand Equivalent, Min. %	40	40	45	45	40	45	40	45	40	40	40	NA
Natural Sand - Max. %	---	15		15			15			25	25	0
Asphalt Binder		Table 502-2, (3% minimum for Asphalt Treated base (ATB), 6% min for SMA)										
RAP, Max. % of Mix[3]	25	20	20	20	25	25	25	25	35	35	35	0
	Compacted Mix Volumetrics											
VMA @ N_{design}, Min. %	13.5	13.5	13.5	12.5	12.5	12.5	11.5	11.5	11.5	n/a	10.5	16.0
Air Voids @ N_{design}, %[4]		(2.5-4.5); (no limit for ATB)										
VFA @ N_{design}, %[5]		(69-80); no limit for ATB; no maximum for SMA										
$N_{initial}$ 90% max.[6] (Gyrations)	7	7	7	7	7	7	7	7	7	n/a	7	7
N_{design} 96.5±1 % (Gyrations)	55	55	65	65	55	65	55	65	55	30	55	65
N_{max} 98 % max. (Gyrations)	90	90	105	105	90	105	90	105	90	n/a	90	65
LWT, max. rut-design, mm @ # passes, @ 50°C	10 @ 10,000	10 @ 20,000	6 @ 20,000	6 @ 20,000	10 @ 20,000	6 @ 20,000	10 @ 20,000	6 @ 20,000	12 @ 20,000	10 @10,000	12 @ 20,000	6 @ 20,000
Dust/Effective Asphalt Ratio, %	0.6 – 1.6											
SCB, min, Jc, KJ/m² @ 25°C	---	0.5	0.6	0.6	0.5	0.6	0.5	0.6	---	---	---	0.6
Design Lift Thickness, inch[8]	≤2.0	1.5–2.0		1.5–2.0	2.0–3.0		2.5–4.0		≥2.5	≥3.0	≥4.0	1.5-2.0

[1]May be used for minor mix uses (except patching and widening), airports, and other incidental items approved by the project engineer. (May be used as a standard roadway mix for local governments.)

[2]Mixtures designated at Level 1F and 2F shall meet the requirements of Level 1 and 2, respectively. Additionally, Level 1F and 2F shall meet the friction rating requirements in Table 502-3 for travel lane wearing courses.

[3]RAP is not be allowed for airports or stome-matrix asphalt (SMA).

[4]Air voids mix design target is a 3.5%.

[5]Mix design minimum VFA is 72.0%, Mix design minimum VFA for PG76-22rm is 75%, and 71% for 25-mm NMS mixtures.

[6]For Level 1 mixtures, $N_{initial}$ shall be 91.0% max. For Level A mixes, $N_{initial}$ shall be 92.0% max.

[7]Asphalt Treated Base (ATB) may be used for patching of base material, for shoulder <3500 ADT and maintenance widening; when used achieve average density of 90% of G_{mm} as measured per minor mix table.

[8]Absolute minimum of lift thickness across width equal to 1/2 inch lower than minimum lift thickness.

[9]Also must meet a maximum of 25% at a 3:1 ratio.

Experimental Evaluation

Replicate specimens were prepared for testing. For the semi-circular bend (SCB) test, four specimens at each notch depth were evaluated. For the Hamburg loaded wheel tracking (LWT) test, four specimens were tested. For the dynamic modulus test, three specimens were tested at four different temperatures. A brief description of each of the test methods is presented in the following sections:

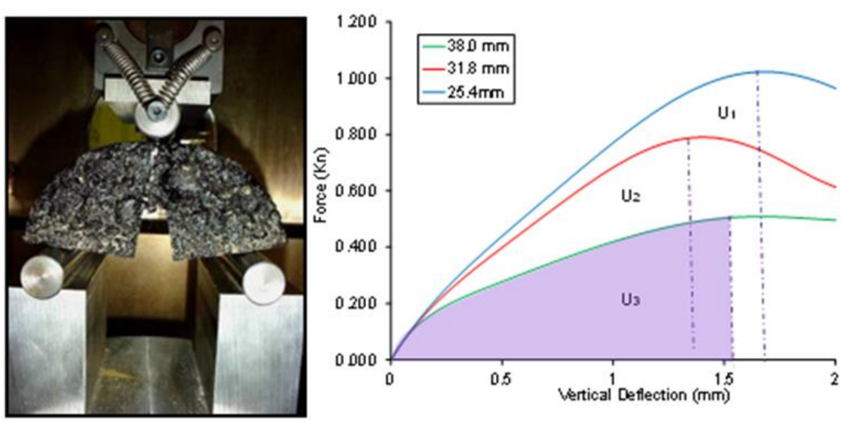
Semi-Circular Bend Test

The semi-circular bend test characterizes the fracture resistance of HMA mixtures based on fracture mechanics principles and the critical strain energy release rate, also called the critical value of J-integral, or J_c. Figure 2 presents the three-point bend load configuration and typical test result outputs from the SCB test. To determine the critical value of J-integral (J_c), semi-circular specimens with at least two different notch depths need to be tested for each mixture. In this study, three notch depths of 25.4 mm, 31.8 mm, and 38.0 mm were selected, with a test temperature of 25°C. The semi-circular specimen is loaded monotonically until fracture failure occurs under a constant cross-head deformation rate of 0.5 mm/min in a three-point bending load configuration. The load and deformation are continuously recorded, and J_c is determined using the following equation:

$$Jc = -\left(\frac{1}{b}\right)\left(\frac{dU}{da}\right) \quad (1)$$

Where b = sample thickness, mm; a = the notch depth, mm; and U = the strain energy to failure, kN-mm.

Figure 2. Semi-circular bending test



Hamburg Loaded Wheel Test (LWT)

The rutting performance of the mix was assessed using the LWT device, manufactured by Troxler Inc. of Durham, North Carolina. This test was conducted in accordance with AASHTO T 324, "Standard Method of Test for Hamburg Wheel-Track Testing of Compacted Hot Mix Asphalt (HMA)." This test is considered a torture test that produces damage by rolling a 703-N (158-lb.) steel wheel across the surface of a specimen that is submerged in 50°C water for 20,000 passes at 56 passes a minute. The current Louisiana specifications allow for maximum LWT rut depths of 10 and 6 mm for level 1 and 2 mixtures, respectively, at 20,000 passes.

Dynamic Modulus (|E*|) Test

The dynamic modulus (|E*|) test was used for performance prediction and to evaluate the stiffness of asphaltic mixtures; see Figure 3. The test was conducted at four temperatures: 4.4, 21, 37.8, and 54°C (40, 70, 100, and 130°F), at loading frequencies of 0.1, 0.5, 1.0, 5, 10, and 25 Hz at each temperature, according to AASHTO T 342, "Standard Method of Test for Determining Dynamic Modulus of Hot-Mix Asphalt (HMA)". Each specimen was tested for each of the 24 combinations of temperatures and frequencies of loading, starting with the lowest temperature and proceeding to the highest. Testing at a given temperature began with the highest frequency of loading and proceeded to the lowest. Each test specimen was prepared using test specimens cored from 150-mm (6-in.) gyratory compacted mixtures with diameters ranging from 100 to 104 mm (3.94 to 4.1 in.) ±1.0 mm (0.04 in.) standard deviation. The specimens were then short-term aged for four hours at a temperature of 135°C and brought to testing temperature according to the guidelines prior to the start of the test.

Figure 3. Dynamic modulus test systems

(a) FHWA SPT Tester

(b) LTRC UTM-25

(c) Sample Setup for LTRC |E*| test

The |E*| device can test one specimen at a time using a hardened steel disk to apply the desired load while an electronic measuring system records the stress and strain data. The specimen was placed in an environmental chamber, and a contact load (P_{min}) equal to 5% of the specified dynamic load was applied. Sinusoidal (haversine) loading ($P_{dynamic}$) was applied to the specimen in a cyclic manner, ensuring the axial strains produced by the dynamic loads were kept between 50 and 150 microstrains. Table 4 shows the typical dynamic stress levels for the various testing temperatures. The recorded stress and strain data were used to compute dynamic modulus and phase angle values at different temperatures and frequencies. Further, dynamic modulus master curves were generated to characterize the performance of the asphalt mixtures over a wide range of frequencies and temperatures.

Table 4. Dynamic stress levels

Temperature, °C (°F)	Range, kPa	Range, psi
4.4 (40)	700-1400	100-200
21 (70)	350-700	50-100
37.8 (100)	140-350	20-50
54 (130)	35-70	5-10

Table 5. Number of cycles for testing sequence

Frequency, Hz	Number of Cycles
25	200
10	200
5	100
1	20
0.5	15
0.1	15

Life-Cycle Cost Analysis

An analysis was performed to compare asphalt mixtures produced with the new specifications (hereafter referred to as BMD mixtures) to mixtures produced using the previous specifications (hereafter referred to as PreBMD mixtures). The Pavement ME design software was used for the analysis. The software is the newest pavement design software, which builds upon the AASHTO mechanistic-empirical pavement design guide. It calculates pavement responses (i.e., stresses, strains, and deflections) based on traffic, climate, and material parameters to predict the progression of key pavement distresses and smoothness loss over time for asphalt pavements. For the purposes of this analysis, asphalt pavement sections were designed using the typical sections from the construction projects used for the research; see Table 6. The dynamic modulus values, determined in the laboratory for BMD mixtures, were used to characterize the mechanical properties of the asphalt layers. If dynamic modulus data for the wearing course and binder course were available, then the entire pavement section would be designed with the available data. For pavement sections without available dynamic modulus data for the binder or wearing course, the historic dynamic moduli data obtained from mixtures designed with prior specifications were used.

Next, the pavement sections designed with BMD mixtures were analyzed in the AASHTO ME software. After the analysis was complete for the BMD mixtures, the dynamic modulus for the wearing or binder course, depending on which one had current data, was changed to the historic dynamic moduli data obtained from PreBMD mixtures. Similar to the BMD mixtures, the pavement sections with asphalt layers comprising the PreBMD mixtures were analyzed in the Pavement ME software. The analysis period for the pavement sections ranged from 20 to 30 years. After the analyses, distress data were collected from pavement sections with BMD mixtures and compared with those of pavement sections constructed with the PreBMD mixtures. From Table 6, pavement sections considered in this study were categorized into flexible and composite pavement structures. Performance data considered in the flexible pavement sections included international roughness index (IRI), total rut depth, bottom-up fatigue cracking, and top-down fatigue cracking. For composite pavement sections, four types of distresses were evaluated: IRI, total rut depth, transverse cracking (new + reflective), and top-down fatigue cracking. The distress data obtained from each mixture design approach, BMD and PreBMD, were analyzed to ascertain the effect of each design approach on the service years (i.e., the time required for any of the distresses to reach the specified threshold for maintenance activity).

Table 6. Properties of Pavement Sections

Project Location	Pavement Structure Type	Mix ID	Design Level	Pavement Layer Type/Thickness (in.)	ADT
LA 16	Flexible	124W & 124B	1	WC/2 BC/6 LTS/12	7650
US 190		262B		WC/1.5 BC/2 Ex. AC/7 CTB/8	9100
LA 26		615W & 615B		WC/1.5 BC/2 Ex. AC/6 CTB/8	5200
LA 3235		688W & 688B		WC/2 BC/4 Ex. AC/8 LTS/8	16296
LA 63		739W & 739B		WC/1.5 BC/2 Ex. AC/4.25 CTB/10 LTS/6	2300
I-12		152B	2	OGFC/1 WC/2 C/5 Ex. AC/6 CTB/12 LTS/12	70700
US 61	Composite	209W		WC/2 Ex. AC/3 PCC/10.5	30511
US 61		320W		WC/2 Ex. AC/10.2 PCC/8.5	27185
US 167	Flexible	353W		WC/2 Ex. AC/11 CTB/6	37297
I-10		601B		OGFC/1 WC/2 BC/10 CSB/4 CTB/8 LTS/12	52240

WC: Wearing course; BC: Binder course; LTS: Lime-treated subbase; Ex. AC: Existing asphalt concrete layer; CTB: Cement-treated base; PCC: Portland cement concrete; OGFC: Open-graded friction course; CS: Crushed-stone base; ADT: Average daily traffic

Table 7 shows the pavement distress type considered for each pavement section and their respective threshold values. For flexible pavement sections, a total rut depth and fatigue cracking (top-down or bottom-up) values greater than 0.5 in. and 25%, respectively, will trigger an overlay treatment.

Table 7. Distress types and performance thresholds

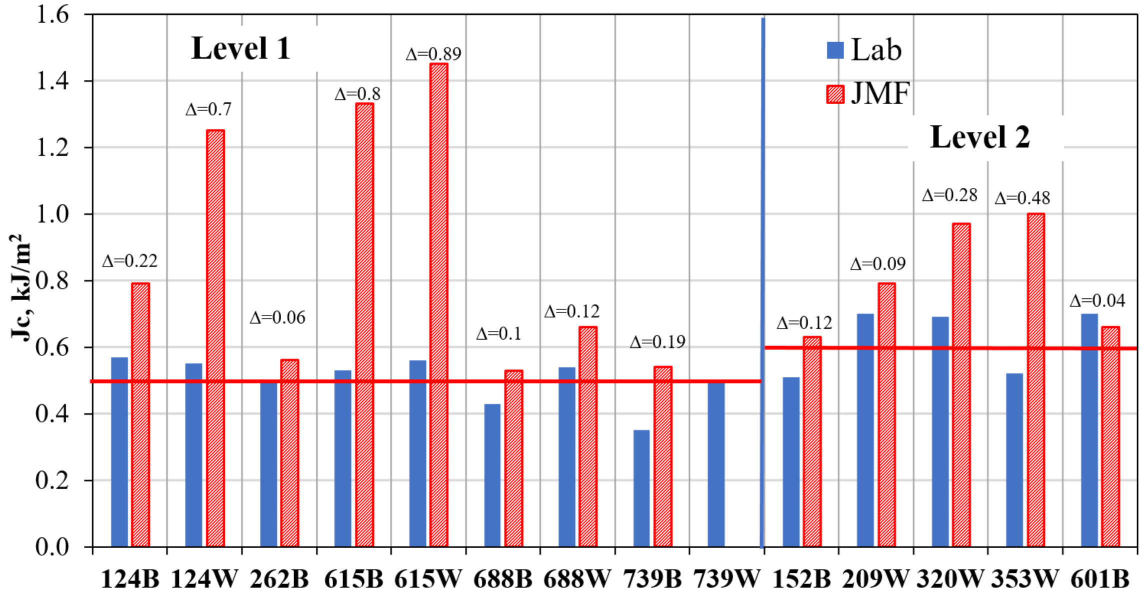
Pavement Section Type	Distress Type	Specified Pavement ME Threshold
Flexible Pavement	Terminal IRI (in/mile)	172
	Total rut depth (in.)	0.5
	Bottom-up fatigue cracking (%)	25
	Top-down fatigue cracking (%)	25
Composite Pavement	Terminal IRI (in/mile)	172
	Total rut depth-AC Only (in.)	0.25
	Transverse cracking: new + reflective (ft/mile)	2500
	Top-down fatigue cracking (%)	25

Discussion of Results

Semi-Circular Bend Test

Figure 4 presents the SCB J_c values of the asphalt mixtures evaluated in the study. The semi-circular bending test determined the cracking resistance of the mixtures, as mentioned earlier. The current Louisiana specification requires minimum SCB J_c values of 0.5 and 0.6 kJ/m^2 for levels 1 and 2 mixtures, respectively. The SCB J_c values from the laboratory-compacted samples were compared to values reported on the job mix formulas (JMF) for each mixture, and the absolute value of the difference in SCB J_c values (Δ) was reported in Figure 4. All the JMF samples showed SCB J_c values greater than the recommended minimum values; see Figure 4. Ten out of the fourteen laboratory-measured samples showed SCB J_c values that met the minimum recommended criteria. Laboratory-compacted samples 688B, 739B, 152B, and 353W exhibited SCB J_c values that did not meet the minimum recommended criteria. Among the level mixtures evaluated, sample 124B showed the highest SCB J_c value of 0.57 kJ/m^2, indicating a better resistance to cracking compared to the other level 1 mixtures. For the level 2 mixtures, sample 601B showed the highest resistance to cracking with an SCB J_c value of 0.7 kJ/m^2. The delta (Δ) for the mixture set ranged from 0.04 for mixture 601B to 0.89 for mixture 615W. It is noted that all SCB J_c values reported on the JMF forms were higher than those measured in the laboratory, with sample 601B being the only exception.

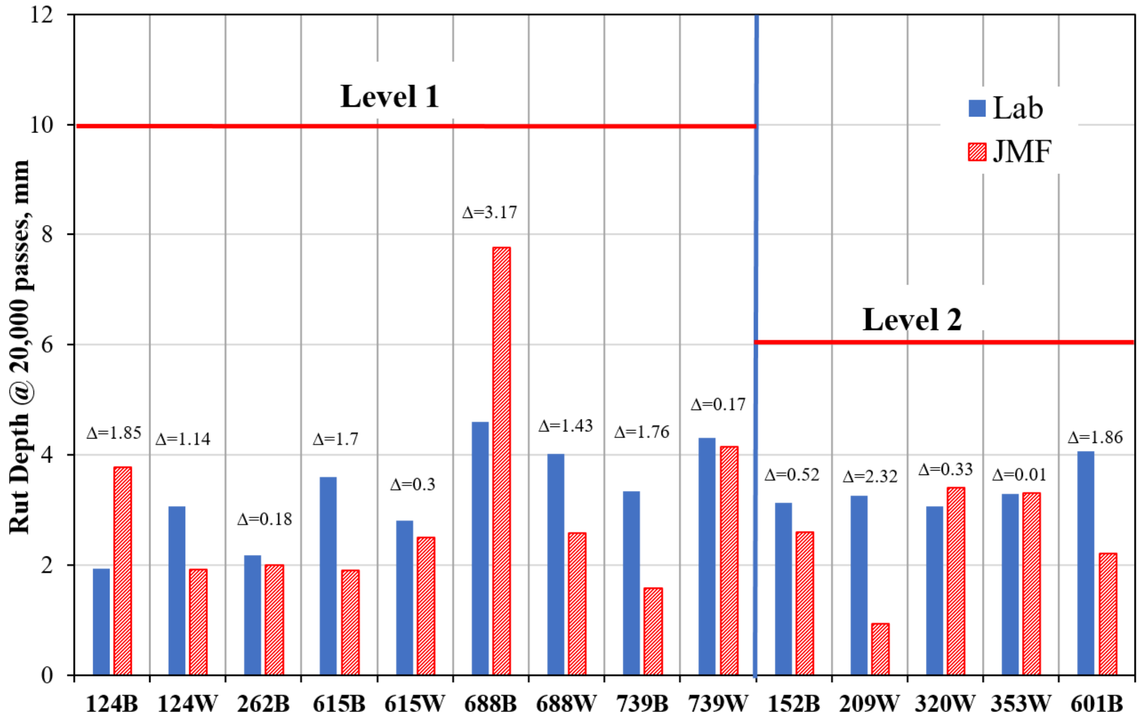
Figure 4. SCB test results



Hamburg Loaded Wheel Test

Rutting is a significant concern for asphalt roadways in Louisiana; therefore, the mixtures were subjected to the LWT test to characterize their behavior in response to cyclic rolling loads. Figure 5 presents the LWT data generated for this report. As stated earlier, the specifications for level 1 asphalt roadways call for a maximum rut depth of 10 mm at 20,000 passes, and level 2 asphalt roadways require a maximum rut depth of 6 mm at 20,000 passes. The level 1 mixtures are shown on the left, and the level 2 mixtures are shown on the right. The results from the laboratory-compacted test samples were compared to the rut depth reported on the job mix formula for each mixture and the absolute value of the difference between the two values (Δ) reported in Figure 5. All the mixtures evaluated exhibited LWT rut values (i.e., laboratory measured and JMF values) lower than the Louisiana DOTD recommended maximum values. Among the laboratory-tested level 1 mixtures, mixture 615W showed the highest resistance to rutting, with an LWT rut depth of 2.8 mm at 20,000 passes. For the Level 2 mixtures, sample 320W exhibited the highest resistance to rutting, with an LWT rut depth of 3.07 mm at 20,000 passes. The deltas (Δ) for the mixture set ranged from 0.01 for mixture 353W to 3.17 for mixture 688W.

Figure 5. LWT test results



Dynamic Modulus (|E*|)

The dynamic modulus for each mixture was determined in accordance with AASHTO T 342. The test determines the stiffness of the mixture under repeated axial-cyclic loads. Figure 6 illustrates the dynamic modulus (|E*|) master curves for level 1 binder and wearing mixtures made utilizing the current mix design approach (BMD) and their PreBMD counterparts. The variation of |E*| with frequency for level 1 wearing course (WC) mixtures built using BMD and PreBMD mixtures was inconsistent. For example, 124W and 615W WC mixtures designed using the current specifications showed higher |E*| values than their corresponding mixtures designed using the previous approach, whereas 739W mixtures designed with the previous approach showed higher |E*| values than their current counterparts for the frequency range considered. For the 688W mixture, however, the present mixture design approach produced a mixture with |E*| values higher than those of the previous approach for frequency levels greater than 10^{-3}Hz and vice versa for frequency levels lower than 10^{-3}Hz. It is noted that asphalt mixtures with higher |E*| values in the low reduced frequency range of 10^{-5} to 10^{-3} Hz are considered to exhibit better rutting performance than those with lower |E*| values within the specified frequency range [1].

Figure 6b shows that the 262B level 1 BC mixture designed using the previous method had higher |E*| values compared to its counterpart designed with the current approach. For the remaining level 1 BC mixtures (124B, 615B, 688B, and 739B), mixtures designed using the old specifications had higher |E*| values at higher frequencies than mixtures designed using the new specifications, and the opposite was true for mixtures designed using the new specifications at lower frequencies.

Figure 6. Dynamic modulus master curves for level 1 (a) wearing course and (b) binder course mixtures

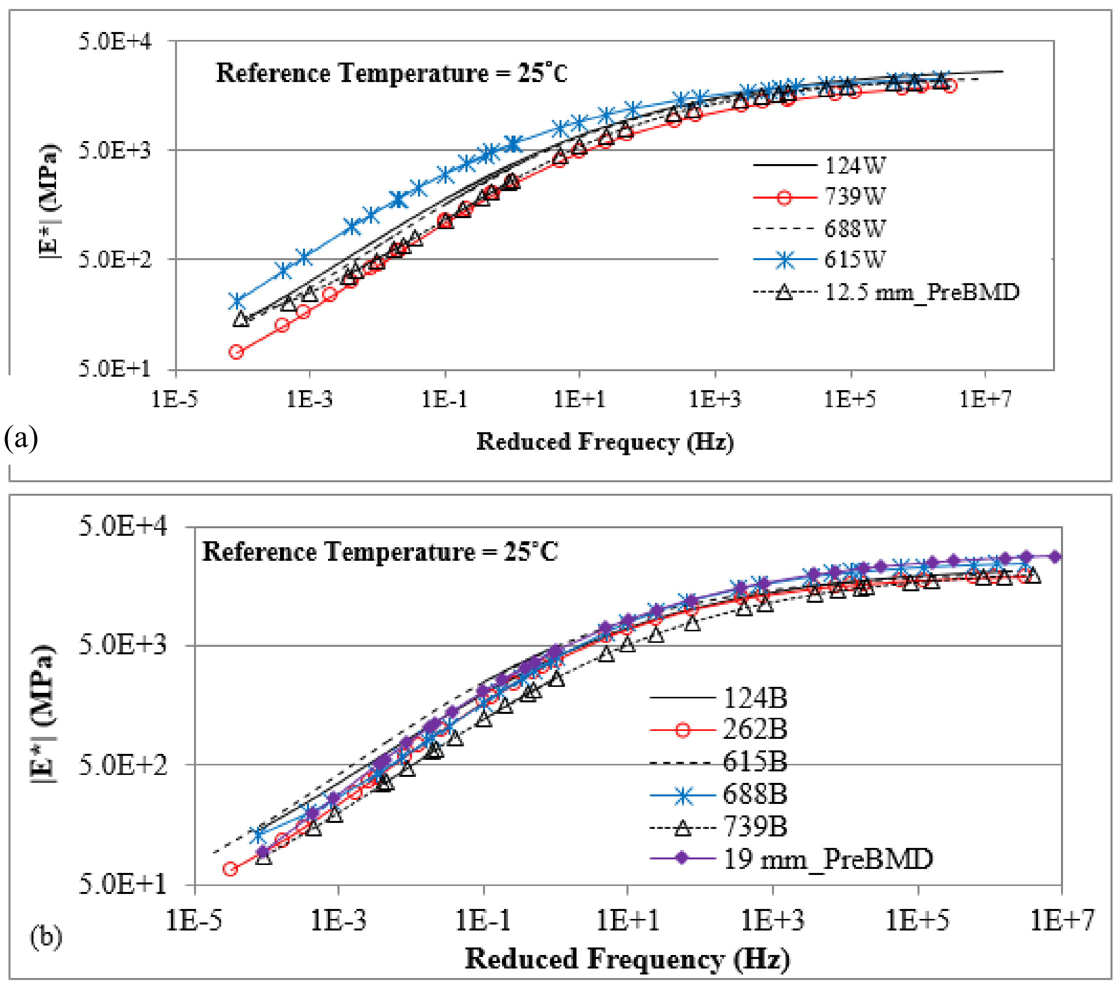
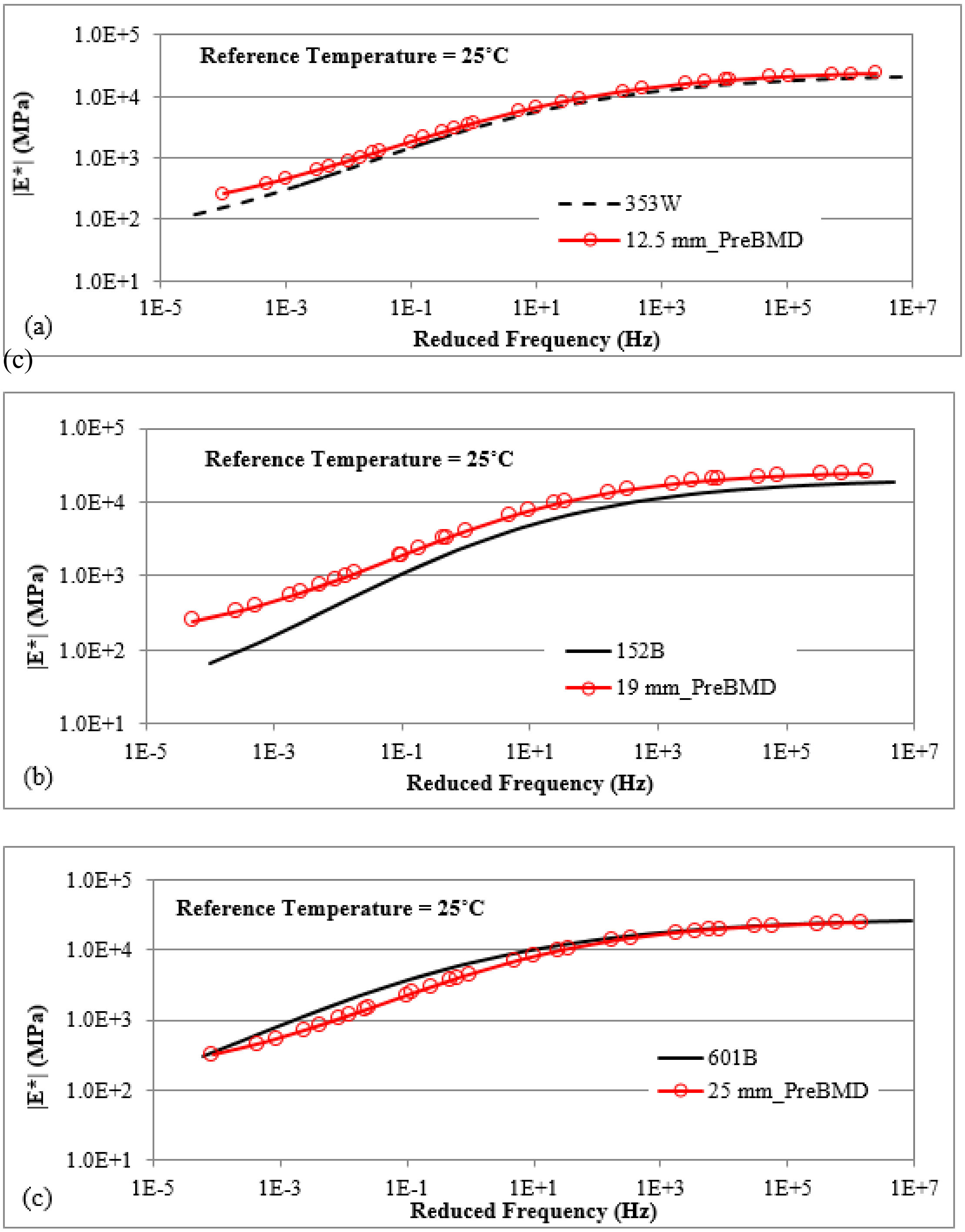


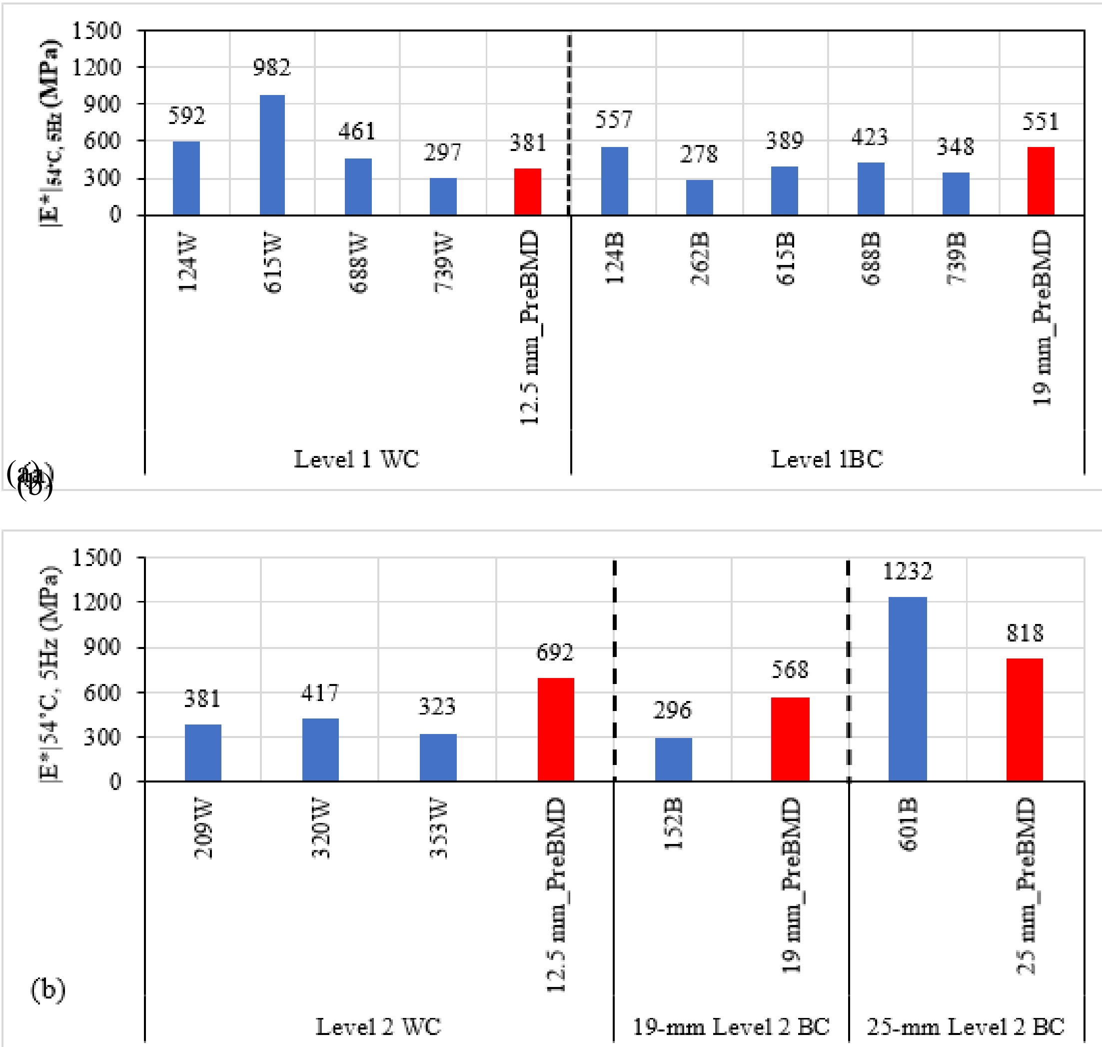
Figure 7 presents the dynamic modulus master curves for the level 2 WC and BC mixtures. For the level 2 WC (i.e., 353W) and 19-mm BC (152B) mixtures, the previous mix design specifications produced mixtures with higher stiffness values than those of mixtures designed with the current approach. However, the 25-mm level 2 BC mixture (i.e., 152B) produced using the current mix design specification resulted in higher |E*| values than those of the corresponding mixture designed using the previous mix design specification.

Figure 7. Dynamic modulus master curves for level 2 (a) wearing, (b) 19-mm binder course, and (c) 25-mm binder course mixtures



The dynamic modulus values were further analyzed to determine $|E^*|_{54℃, 5Hz}$ parameter of mixtures designed using the current mix design specification compared with their corresponding mixtures designed using the previous specification. The $|E^*|_{54°C,\ 5Hz}$ has been shown to be a good indicator of rutting performance. Higher $|E^*|_{54°C,\ 5Hz}$ values indicate higher rutting performance, and vice versa for lower $|E^*|_{54°C,\ 5Hz}$ values. Figure 8 shows the $|E^*|_{54°C,\ 5Hz}$ values for the mixtures considered in the study. For level 1 wearing course mixtures, all mixtures designed using the current mix design specification showed higher $|E^*|_{54°C,\ 5Hz}$ values than their corresponding mixtures (i.e., 12.5 mm-PreBMD) designed using previous mix design approach, except the 739W mixture. The 739W mixture showed lower $|E^*|_{54°C,\ 5Hz}$ values for mixtures designed using the current approach as compared to those designed with the previous approach. All level 1 BC mixtures exhibited lower $|E^*|_{54°C,\ 5Hz}$ values for mixtures designed using the current approach compared to those designed with the previous approach, except the 124B mixture, which showed a higher $|E^*|_{54°C,\ 5Hz}$ value for the current approach. The level 2 WC and 19-mm BC course mixtures designed using the previous approach showed higher $|E^*|_{54°C,\ 5Hz}$ values than their corresponding mixtures designed using the current approach. However, the level 2 25-mm BC course designed with the current specification exhibited higher $|E^*|_{54°C,\ 5Hz}$ values compared to the corresponding mixture designed using the previous mix design specification.

Figure 8. $|E^*|_{54^\circ C, 5Hz}$ for (a) level 1 and (b) level 2 wearing and binder course mixtures

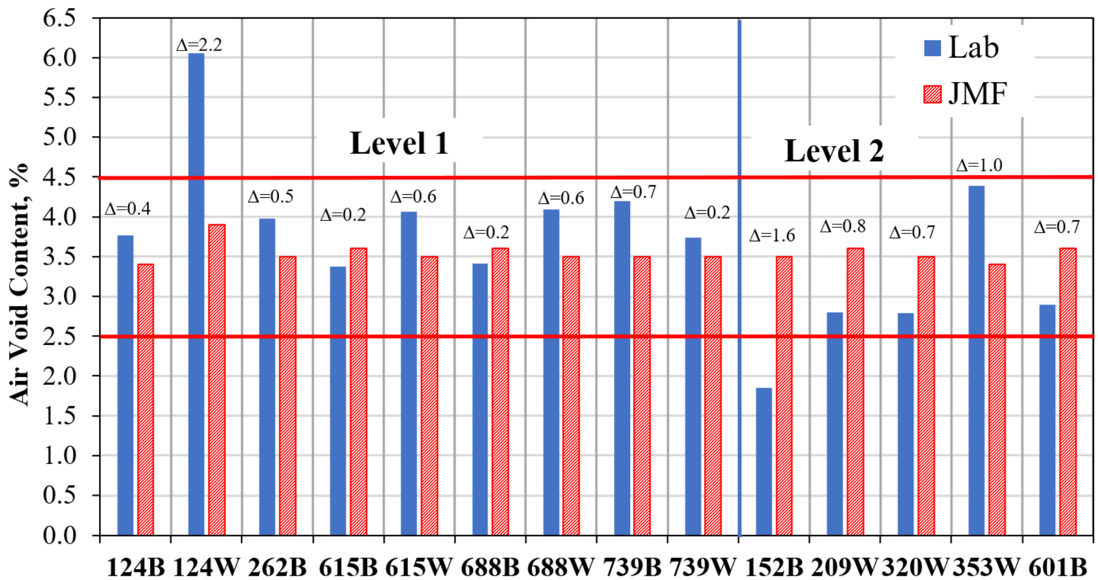


Volumetrics

Air Void Content

Figure 9 presents the air void content (AV) values reported in the job mix formula and those measured in the laboratory. The specifications call for the air void content at N_{design} to be between 2.5-4.5%. The results from the laboratory-compacted specimens were compared to those of the JMF, and the difference (Δ) reported was as shown in Figure 9. The air void content values reported in JMF were within Louisiana DOTD-specified limits of 2.5 to 4.5% N_{design}. However, mixture 124W exhibited a laboratory-measured AV value greater than the specified limits. The deltas (Δ) for the mixture set ranged from 0.2 to 2.2.

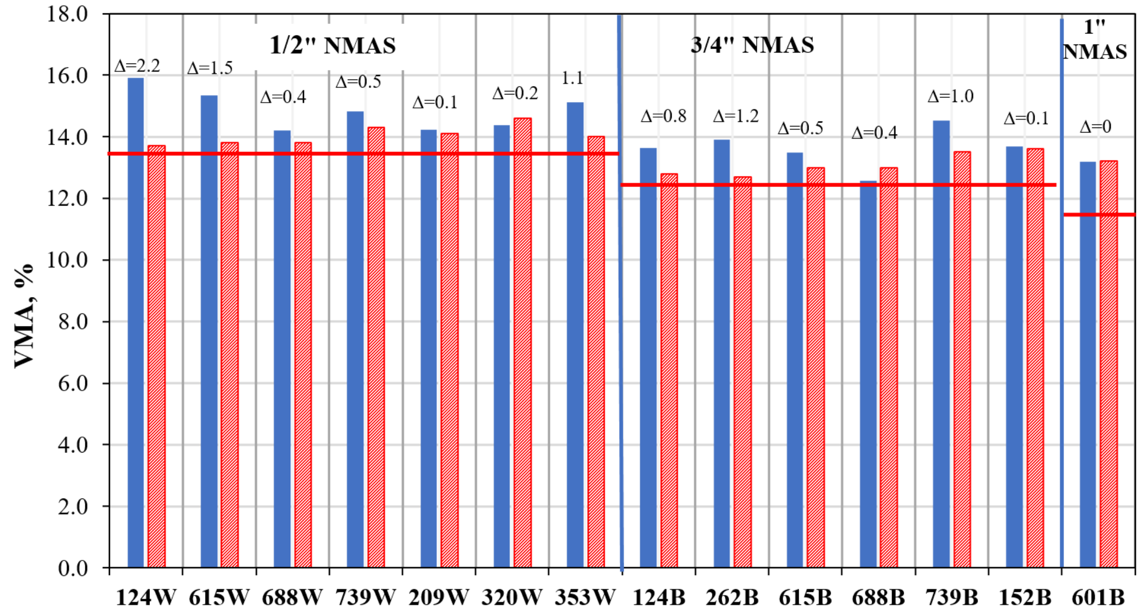
Figure 9. Air void content values



Voids in the Mineral Aggregate

Figure 10 presents the VMA values reported in the job mix formula and those measured in the laboratory. The current Louisiana specification require minimum VMA at N_{design} of 13.5% for ½-in. nominal maximum aggregate size (NMAS) mixtures, 12.5% for ¾-in. NMAS mixtures, and 11.5% for 1-in. NMAS mixtures. The results from the laboratory-compacted specimens were compared to those of JMF for each mixture and the difference in values (Δ) reported in Figure 10. All mixtures showed VMA values greater than the minimum recommended value. The deltas (Δ) for the mixture set ranged from 0 for mixture 601B to 2.2 for mixture 124W.

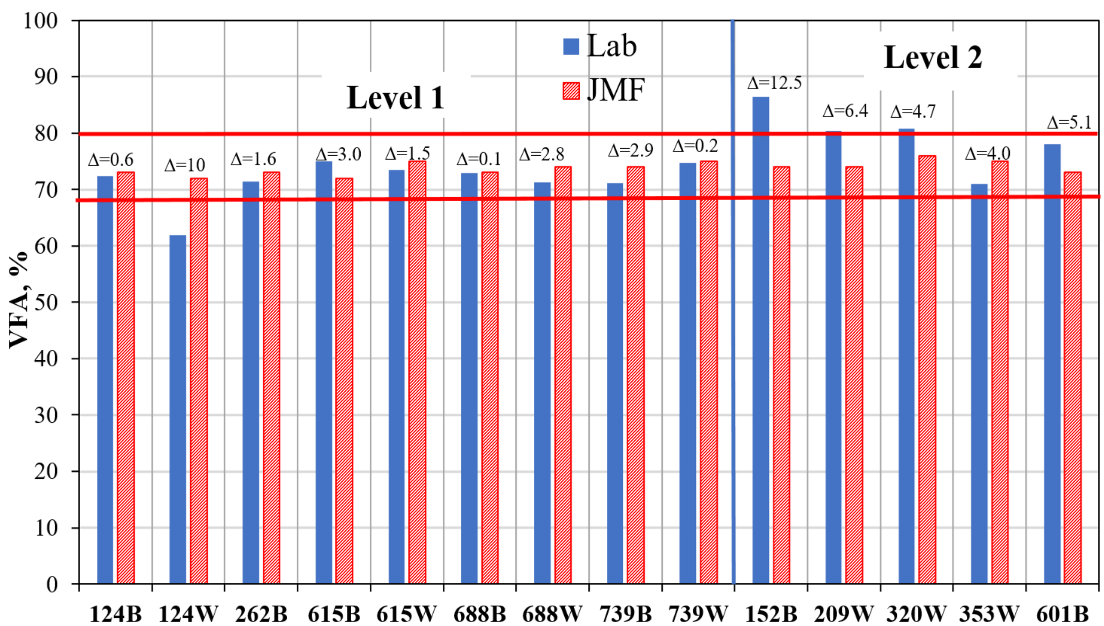
Figure 10. VMA results



Voids filled with asphalt

Figure 11 presents the VFA values reported in the JMF and those measured in the laboratory. The current Louisiana specification recommends VFA values ranging from 69–80% at N_{design}. The difference in values between laboratory-measured VFA and those reported on the JMF (i.e., Δ) is reported in Figure 11. All specimens exhibited VFA values within the specified limits, except mixtures 124W, 152B, and 320W. Mixture 124W showed laboratory-measured VFA values lower than the specified limits, whereas mixtures 152B and 320W exhibited laboratory-measured VFA values greater than the recommended maximum value. The deltas for the mixture set ranged from 0.1 for mixture 688B to 12.5 for mixture 152B.

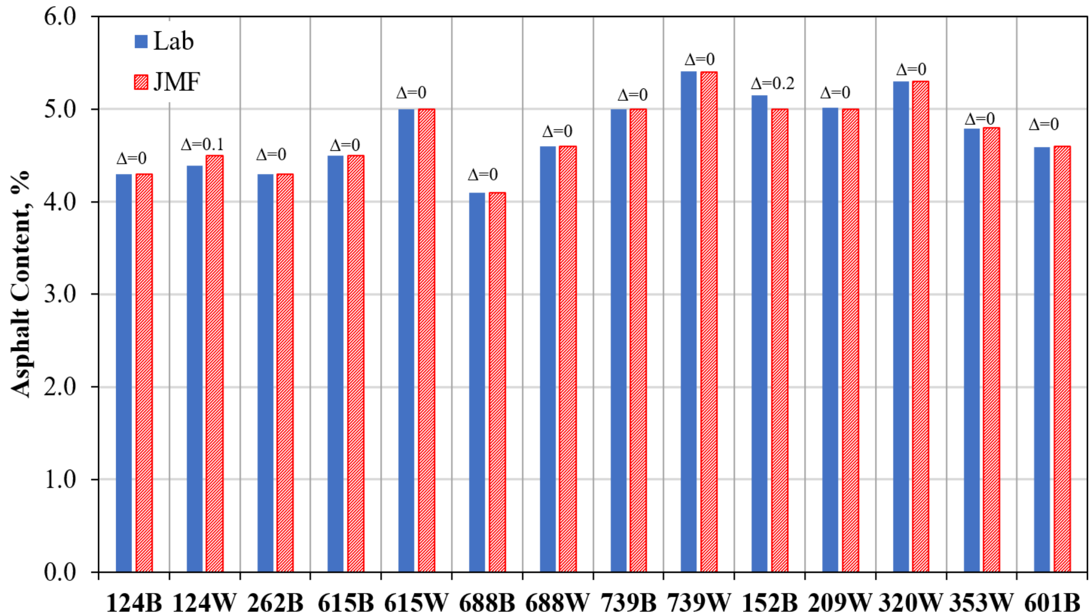
Figure 11. VFA results



Asphalt Content

Figure 12 presents the asphalt content values reported in the JMF and those measured in the laboratory using the ignition method. Furthermore, Figure 12 shows the difference between the laboratory-measured asphalt content values and those reported on the JMF (i.e., Δ). All mixtures evaluated showed no difference between asphalt content values reported in the JMF and those measured in the laboratory (i.e., Δ=0), except mixtures 124 W and 152 B. Mixtures 124W and 152B exhibited delta values (Δ) of 0.1 and 0.2, respectively.

Figure 12. Asphalt content results



Life-Cycle Cost Analysis

The life-cycle cost analysis was performed with the AASHTO Pavement ME design software. Distress data recorded on pavement sections designed with BMD mixtures were compared with those recorded on pavement sections designed with PreBMD mixtures. Further pavement performance curves obtained from the Pavement ME software were analyzed to determine the service lives of BMD sections as compared to PreBMD sections. The service life of each pavement section was noted as the shortest time required for any of the distresses to reach a specified threshold; see Table 7. Additionally, the AASHTO Pavement ME design software was used as an indication of service life. The number of years projected will vary from actual field service life. However, the relative change in service life can still indicate whether BMD is providing benefit.

Figures 13 and 14 show how the service lives of pavement sections designed with mixtures 615BW and 124BW were determined for the BMD and PreBMD design approaches. For the 124BW mixtures, both BMD and PreBMD mixtures failed under bottom-up fatigue cracking, with service lives of 12.6 and 10.8 years, respectively; see Figure 13. The 124BW mixtures designed using the BMD approach failed under bottom-up fatigue cracking, with a service life of 14 years, whereas those designed using the PreBMD approach failed under rutting, with a service life of 11 years; see Figures 14 a and 14b. The lower rutting resistance values exhibited by the PreBMD 124BW mixtures as compared to their BMD counterparts are consistent with the lower $|E^*|_{54°C, 5Hz}$ values reported for the PreBMD 124BW mixtures in Figure 8a. Lower $|E^*|_{54°C, 5Hz}$ values indicate poor rutting performance [1]. The difference in service life between BMD and PreBMD sections was computed for each route to ascertain whether the adoption of the current mix design approach has resulted in enhanced service life for asphalt pavement sections in Louisiana. Pavement sections with better performance and extended service lives are assumed to have a lower life-cycle cost, as the amount of money used to operate and maintain such pavement sections is usually lower. Potential savings associated with longer service life include reduced maintenance costs, delays in re-construction or rehabilitation, improved traffic flow and safety, and reduced environmental impacts [6].

Figure 13. Pavement ME performance curves for 615BW

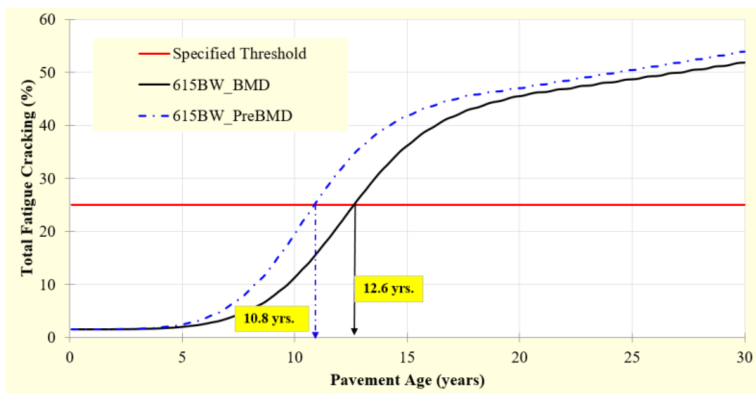
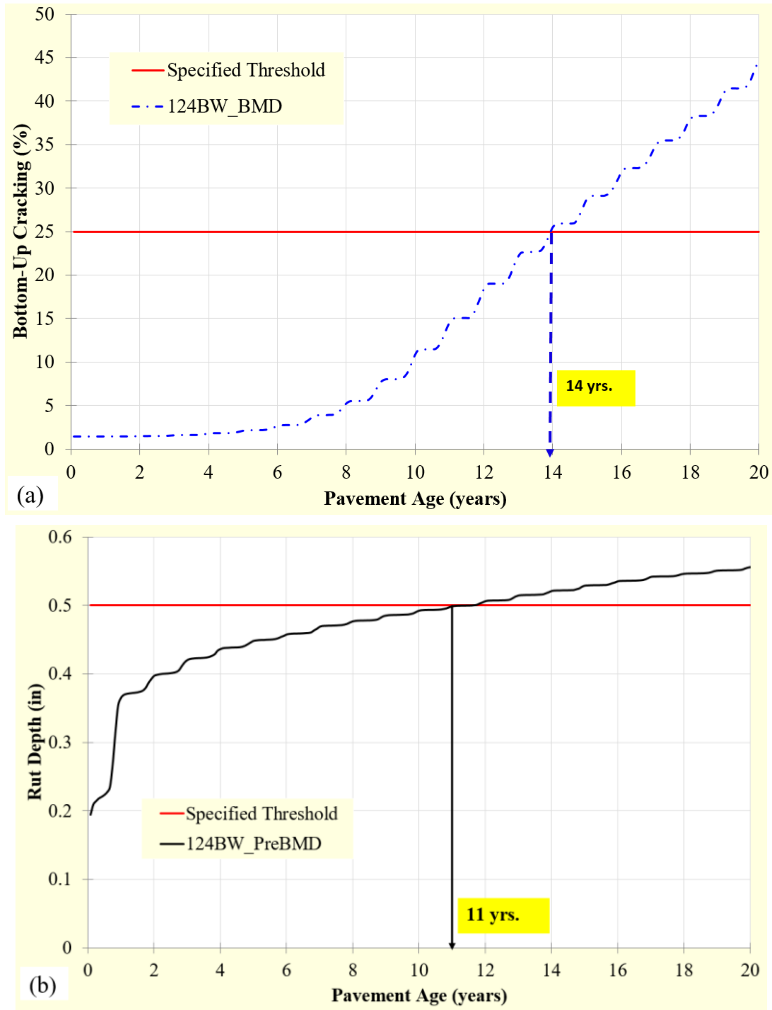


Figure 14. Pavement ME performance curves for 124BW



Tables 8 and 9 present the pavement distress data for the flexible and composite pavement sections evaluated in the studies. For each pavement section, the service life was determined from the performance curves from the two design approaches, which were recorded in Tables 8 and 9. Further, the service life values, a measure of the difference between the service of BMD pavement sections and their PreBMD counterparts, were also recorded. Positive enhanced service life values indicate that the adoption of the BMD mix design approach has resulted in improved service life for asphalt pavements. For the flexible pavement sections, the use of the BMD mixtures resulted in improved service life values ranging from 0.1 to 3 years; see Table 8. For mixtures 152B and 353W, the adoption of the BMD approach did change the service life of the pavement sections as compared to the previous mix design approach. Generally, the BMD and PreBMD mixtures considered in the study failed under the bottom-up fatigue cracking phenomenon. The service lives of the BMD and PreBMD flexible pavement sections ranged from 7.8 to 16.8 years.

For the composite pavement sections, the BMD mix design approach did affect the service of the pavement sections compared to the PreBMD approach; see Table 9. It is noted that two composite pavement sections failed under transverse and reflective cracking phenomena. The service lives of the BMD and PreBMD composite pavement sections ranged from 8.3 to 16.3 years.

Table 8. Pavement ME distress data for flexible pavements

Mix ID	Specification Type	Total Rut depth (in.)	Bottom-up fatigue cracking (%)	Top-down fatigue cracking (%)	Cause of Deterioration	Service Life (years)	Enhanced Service Life (years)	Percent Increase in Service Life (%)
		Specified Threshold						
		0.50	25.00	25.00				
124BW	BMD	0.50	44.65	12.68	Bottom-up fatigue Cracking	14.0	3.0	27.3
	PreBMD	0.56	43.93	11.60	Rutting	11.0		
262B	BMD	0.59	56.79	7.53	Rutting	13.1	0.3	2.3
	PreBMD	0.50	63.78	12.45	Bottom-up fatigue Cracking	12.8		
615BW	BMD	0.52	51.88	14.51	Bottom-up fatigue Cracking	12.6	1.8	16.7
	PreBMD	0.50	53.90	4.69	Bottom-up fatigue Cracking	10.8		
688BW	BMD	0.31	46.70	4.69	Bottom-up fatigue Cracking	16.8	1.0	6.3
	PreBMD	0.31	47.17	4.69	Bottom-up fatigue Cracking	15.8		
739BW	BMD	0.51	44.29	4.69	Bottom-up fatigue Cracking	10.8	3.0	38.5
	PreBMD	0.43	42.89	4.69	Bottom-up fatigue Cracking	7.8		
152B	BMD	0.28	46.23	77.22	Bottom-up fatigue Cracking	16.2	0.0	0.0
	PreBMD	0.26	45.34	77.22	Bottom-up fatigue Cracking	16.2		
353W	BMD	0.21	40.37	11.21	Bottom-up fatigue Cracking	16.3	0.0	0.0
	PreBMD	0.20	40.09	14.04	Bottom-up fatigue Cracking	16.3		
601B	BMD	0.21	40.14	15.47	Bottom-up fatigue Cracking	11.8	0.1	0.9
	PreBMD	0.22	39.97	13.98	Bottom-up fatigue Cracking	11.7		

Table 9. Pavement ME distress data for composite pavements

Mix ID	Specification Type	IRI (in./mile)	Total Rut depth (in.)	Transverse + Reflective cracking (ft./mile)	Top-down fatigue cracking (%)	Cause of Deterioration	Service Life (years)	Enhanced Service Life (years)	Percent Increase in Service Life (%)
		Specified Threshold							
		172.00	0.50	2500.00	25.00				
209W	BMD	135.90	0.10	4336.31	7.06	Transverse + reflective cracking	8.3	0.0	0.0
	PreBMD	139.20	0.08	4336.31	14.89	Transverse + reflective cracking	8.3		
320W	BMD	131.00	0.04	4154.86	4.69	Transverse + reflective cracking	16.3	0.0	0.0
	PreBMD	136.00	0.04	4154.46	14.57	Transverse + reflective cracking	16.3		

Conclusions

The objective of this research was to analyze and compare the performance of asphalt pavement sections constructed using recommendations from the 2006 Louisiana SSRB to those built under the 2016 Louisiana SSRB and its accompanying special provision 8/18. The study evaluated the density, volumetric, and laboratory-measured rutting and cracking data for various pavement sections. Further, Pavement Me-generated performance data were collected and analyzed to ascertain the effects of the specification changes on performance. Additionally, the research sought to determine if the specification changes had resulted in increased value. Based on the results presented, the following conclusions were drawn:

- Most of the mixtures exhibited SCB J_c values that met the Louisiana DOTD recommended minimum values for levels 1 and 2 mixtures. However, noticeable differences were observed between laboratory-measured values and those reported on the JMF.
- All the mixtures evaluated exhibited LWT rut depth values that met the Louisiana DOTD recommended maximum thresholds for level 1 and 2 mixtures.
- Most of the mixtures showed volumetric properties that met the Louisiana DOTD recommended mixture volumetric criteria, with minimal differences in laboratory-measured values and those reported on the JMF.
- The Pavement ME analysis showed that adoption of the BMD approach has the potential to improve field rutting and cracking performance.
- The BMD approach resulted in improved service life values ranging from 0.1 to 3 years. The improvement in service life with respect to the preBMD service life ranged from 0.9 to 38.5%.
- The Pavement ME analysis showed the average service life improvement for all sections evaluated is 9.2%, which can substantially influence the maintenance and operation costs of asphalt pavements in Louisiana.

Recommendations

Based on the outcome of this study, the authors do not recommend any changes to the performance-based specifications. Furthermore, it is recommended that the pavement sections be continuously monitored to validate the results of the Pavement ME analysis.

Acronyms, Abbreviations, and Symbols

Term	Description
AASHTO	American Association of State Highway and Transportation Officials
APA	Asphalt pavement analyzer
ATB	Asphalt Treated Base
AV	Air Void Content
cm	centimeter(s)
DOT	Department of Transportation
DOTD	Department of Transportation and Development
FHWA	Federal Highway Administration
ft.	foot (feet)
HMA	Hot-mix asphalt
in.	inch(es)
IRI	International roughness index
JMF	Job mix formula
LADOTD	Louisiana Department of Transportation and Development
LPA	Local public agencies
LTRC	Louisiana Transportation Research Center
lb.	pound(s)
LWT	Loaded Wheel Test
m	meter(s)
mm	millimeter(s)
NCHRP	National Cooperative Highway Research Program
NMAS	Nominal maximum aggregate size
PBS	Performance-based specifications
PMS	Pavement management system
QA	Quality assurance
QC	Quality control
RAP	Reclaimed asphalt pavement
SCB	Semi-Circular Bend Test

Term	**Description**
SMA	Stone-matrix asphalt
SSRB	Stand Specifications for Roads and Bridges
TSR	Tensile-strength ration
VFA	Voids filled with asphalt
VMA	Voids in the mineral aggregate

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