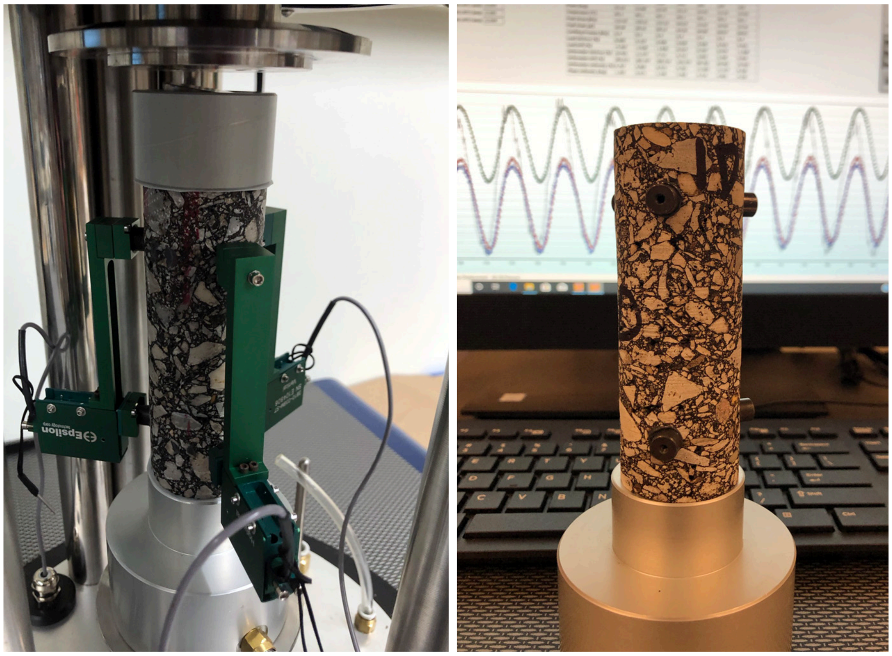
JOINT TRANSPORTATION RESEARCH PROGRAM
INDIANA DEPARTMENT OF TRANSPORTATION
AND PURDUE UNIVERSITY

Demonstration Project for Asphalt Performance Engineered Mixture Design Testing



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16. Abstract

The asphalt industry is moving towards performance-based methods for asphalt mixture design. The Federal Highway Administration (FHWA) is supportive of state departments of transportations (DOT) adopting index and predictive performance tests, especially those making use of the Asphalt Mixture Performance Tester (AMPT). The FHWA is therefore encouraging state DOTs to gain experience with the requirements of the procedures and analysis tools for Balanced Mixture Design (BMD). The main objective of this study is to evaluate fatigue cracking on three INDOT mainline pavement projects that have asphalt mixtures designed by the Superpave 5 mixture design, and to better understand the fundamental engineering testing capabilities of the AMPT. A total of four Superpave 5 asphalt mixtures were collected and tested from the three projects. The viscoelastic characteristics and fatigue behavior of plant-mixed, laboratory compacted (PMLC), laboratory-mixed, laboratory compacted (LMLC), and plant-mixed, field compacted (PMFC) specimens were assessed according to the AASHTO TP-132 and AASHTO TP-133 test methods. Two AMPT machines (IPC Controls and PaveTest) were used to conduct the dynamic modulus tests, while all fatigue tests were performed using a PaveTest AMPT. The raw data were analyzed using the FlexMAT software.

The dynamic modulus and cyclic fatigue test results indicate that AMPT testing can be used to effectively evaluate INDOT asphalt mixtures during the mixture design and production phases. However, to do so, detailed planning and effective training are needed to help ensure the successful completion of AMPT testing.

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EXECUTIVE SUMMARY

Introduction

The complicated nature of asphalt mixtures makes it difficult to predict the performance of asphalt pavements over their service lives; and several visions of performance-based mixture design have been developed over the past decades. The Federal Highway Administration (FHWA) intends to unify these performance-focused methods under a single vision called Performance Engineered Mixture Design (PEMD), which can be used to predict the performance of asphalt mixtures.

The FHWA is supportive of state departments of transportations (DOTs) adopting index and predictive performance tests, especially those making use of the Asphalt Mixture Performance Tester (AMPT). Under the Accelerated Implementation and Deployment of Pavement Technologies Program, the FHWA provided state DOTs the opportunity to evaluate and better understand the AMPT and its testing capabilities. The FHWA is therefore encouraging state DOTs to gain experience with the requirements of the procedures and analysis tools for PEMD.

The main objective of this study is to evaluate the fatigue cracking of three INDOT mainline pavement projects and to better understand the fundamental engineering testing capabilities of the AMPT.

Findings

The results of dynamic modulus and cyclic fatigue tests indicate that AMPT testing can be used to effectively evaluate INDOT asphalt mixtures during the mixture design and production phases. However, detailed planning and effective training are needed to help ensure the successful completion of AMPT testing. The study yielded the following findings.

- The FlexMat software is not entirely user friendly and was initially designed to handle output from only one manufacturer's equipment type. A more robust software program will need to be more fully developed before widespread use can occur.
- Great care must be taken in small core (38 mm) specimen preparation, especially when the small cores are taken from thin surface mixture field cores. Extra precaution must be taken to obtain the best possible quality without any visible damage. Additionally, the cutting saw needs to be inspected regularly to ensure the blade cuts a completely flat surface. A poor core/cut can cause an uneven tensile load distribution during cyclic fatigue testing, which results in unacceptable test results (e.g., end failure).
- AASHTO TP-133 test method sample preparation and test setup can influence the final test results. This influence is even more evident for asphalt mixtures with higher dynamic moduli and lower phase angles. These more brittle mixtures do not behave well at the currently recommended AASHTO TP-133 test temperature. A higher test temperature and lower strain level for testing such mixtures might provide more acceptable results.
- The AASHTO TP-133 methods provides guidance on determining the target on-specimen strain levels. Although, helpful in estimating the initial strain levels, it appears these suggested values are too high for INDOT's asphalt mixtures. A lower on-specimen strain level should be selected for the first cyclic fatigue test of each mixture.
- The AMPT was specifically developed for evaluating performance of asphalt mixtures. Although it is not complicated to work with the AMPT, there are a myriad of details that must be looked after. AMPT technicians should be thoroughly trained, the testing organized, and technical resources provided to ensure successful test completion.
- Dynamic modulus testing can differentiate between asphalt mixture characteristics, such as relaxation capability and stiffness. Lower relaxation and higher stiffness can mean a mixture is more susceptible to cracking.
- All four asphalt mixtures tested in this project indicate adequate cracking resistance according to the currently suggested FHWA guidelines for standard traffic.

Implementation

While many challenges were experienced during the execution of this research, not the least being a worldwide pandemic that closed the testing laboratories, the results demonstrate that both AMPT testing and performance engineered asphalt mixture designs can be implemented in Indiana. Successful implementation would require additional testing and training and upgrades to the FlexMat software.

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1. INTRODUCTION

The asphalt industry is moving towards the performance-related methods of design for asphalt mixtures. Several visions of mixture design based on performance have been developed over the past decades. The Federal Highway Administration (FHWA) intends to unify these performance focused methods under a single vision called Balanced Mixture Design (BMD). BMD is a performance-based program that aims to incorporate the long-term performance of asphalt mixtures in the design stage along with the volumetric properties (Hajj et al., 2019).

Several testing methods and parameters have been developed over the past decades to assess the performance of asphalt mixtures. The complicated nature of asphalt mixtures makes it difficult to predict the performance of asphalt pavements over their service lives.

The Federal Highway Administration (FHWA) is supportive of state departments of transportation (DOT) adopting index and predictive performance tests, especially those making use of the Asphalt Mixture Performance Tester (AMPT). Under the *Accelerated Implementation and Deployment of Pavement Technologies Program*, the FHWA provided state DOTs the opportunity to evaluate and better understand the AMPT and its testing capabilities. The FHWA is therefore encouraging state DOTs to gain experience with the requirements of the procedures and analysis tools for BMD.

The Indiana Department of Transportation (INDOT) has recently adopted the Superpave 5 method as its primary method of mixture design. The Superpave 5 mixture design selects optimum binder content based on 5% air voids content. Such mixtures are also expected to achieve 5% air voids (95% G_{mm} density) when compacted in the field (Hekmatfar et al., 2015).

The main objective of this study is to evaluate fatigue cracking on three INDOT mainline pavement projects that have asphalt mixtures designed by Superpave 5, and better understand the fundamental engineering testing capabilities of Asphalt Mixture Performance Tester (AMPT).

2. PROJECT OVERVIEW

The research team worked with INDOT to identify the three INDOT projects for the research project. All four asphalt mixtures for the research were designed and produced by Milestone Contractors, LLP, who agreed to be a partner in the research project, according to standard INDOT Superpave 5 specifications. The three contracts from which samples were collected were the following.

- Contract R-38757, U.S. Highway 421, north of Delphi, IN
  - ○ Surface mixture, 9.5-mm nominal maximum size, PG 64-22
  - ○ Intermediate mixture, 12.5-mm nominal maximum size, PG 64-22
- Contact RS-39328, U.S. Highway 231, south of Lafayette, IN
  - ○ Surface mixture, 9.5-mm nominal maximum size, PG 70-22
- Contract R-42140, State Route 135, south of Indianapolis, IN
  - ○ Surface mixture, 9.5-mm nominal maximum size, PG 70-22

2.1 U.S. Highway 421, Contract R-38757

The U.S. 421 project was located west of Delphi, IN and the hot mix plant was located on the eastern edge of West Lafayette, IN. A typical cross section for the project is shown in Figure 2.1. Highway U.S. 421 is a two-lane highway with 1-foot shoulders. Design traffic is as follows.

- Average annual daily traffic (2020)—5,317 vehicles per day.
- Percent heavy trucks (2020)—9.8% AADT.

The INDOT project documents included a geotechnical investigation report with core information. One of the geotechnical investigation cores was located near where intermediate layer cores were taken for this project. The existing pavement consisted of the following.

- 7 inches of hot mix asphalt.
- Undetermined thickness compacted aggregate base.

At the location where cores for this project were taken for the surface layer, the pavement consisted of the following:

- 13.5 inches of hot mix asphalt, and
- undetermined thickness of compacted aggregate base.

The existing asphalt pavement is underlain by a non-plastic sandy loam soils with and average moisture content of 15%. The construction project called for milling and placing two lifts of new hot mix.

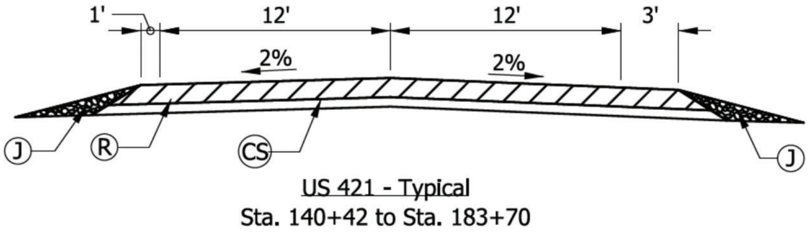


Figure 2.1 Typical cross section for most of U.S. 421 projects west of Delphi, IN.

- Mill 1.5 inches of existing surface.
- Place 2.0 inches of 12.5-mm intermediate.
- Place 1.5 inches of 9.5-mm surface.

Traffic was carried on the milled surface prior to placement of the new intermediate course. Figure 2.2 shows the milled surface near the west end of the project, where there is a turning lane. In this photo, the sample location for the intermediate mixture is located about where the road begins to curve in the distance. Paving at the sample location is typical of most of the project, where the travel lane and a narrow shoulder are paved at the same time.

The haul route between the hot mix plant and the project is shown in Figure 2.3, while Figure 2.4 shows a view of the hot mix plant layout. The plant is a drum mix plant with an embedded burner as shown in Figure 2.5. Construction was done using the following equipment as shown in Figure 2.6.

Figure 2.2 U.S. 421 project west of Delphi, IN—typical milled surface used for driving surface.

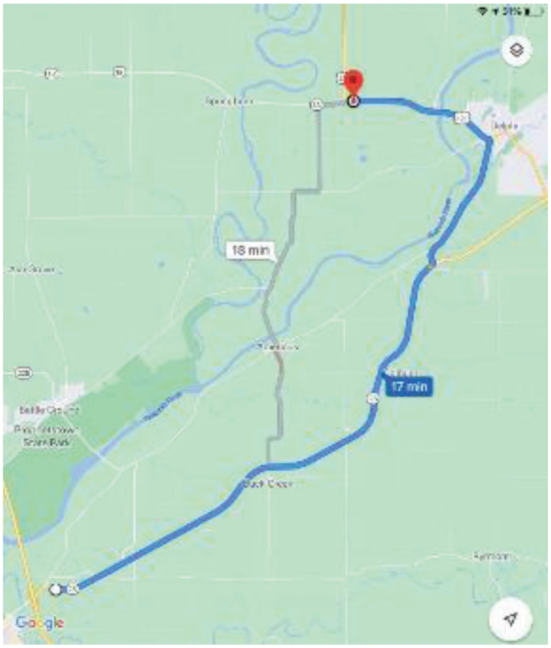


Figure 2.3 Haul route from hot mix plant in West Lafayette to a project west of Delphi, IN (Google, n.d.c).

- End dump trucks
- Material transfer vehicle
  - Weiler E2850 with 25 tons capacity
- Paver
  - Caterpillar 1000F paver
- Rollers
  - Two Caterpillar CB13 vibratory rollers

The following samples were gathered.

- Plant mix
  - For the 12.5-mm intermediate mixture, the sample was obtained from a truck as shown in Figure 2.7.
  - For the 9.5-mm surface mixture, the sample was taken as follows.
    - A partial load was placed into a truck.
    - The mix was dumped on the ground.
    - The front-end loader flattened the pile to approximately 1-foot thick.
    - The sample was taken by shovel at various places around the pile.
    - A series of photos in Figure 2.8 shows the process.
- Cores
  - Road cores were taken from locations such that the cores correspond to the truck samples taken before trucks left the mixing plant.
  - Photos of where the cores were taken are shown in Figures 2.9 and 2.10.
- Raw materials
  - Aggregates and reclaimed asphalt pavement were obtained from the working face of the stockpiles at the same time that the plant mixture was being sampled.

Mix design information related to Delphi surface mixture are shown in Table 2.1 and Figures 2.11 and 2.12, and the mix design information and gradation related to Delphi intermediate mixture are shown in Table 2.2 and Figures 2.13 and 2.14.

2.2 U.S. Highway 231, Contract RS-39328

This project was located south of Crawfordsville, IN and the hot mix plant was located near Veedersburg, IN. The cross-section from the contract plans is shown in Figure 2.15. Highway U.S. 231 is a two-lane highway with 1-foot shoulders. Design traffic is as follows.

- Average annual daily traffic (2020)—6,190 vehicles per day.
- Percent heavy trucks (2020)—17.2% AADT.

The highway is an existing composite pavement with hot mix asphalt overlaying cement concrete pavement. The construction project called for milling to remove the surface layer and replacing it with a new hot mix surface layer.

Figure 2.4 Satellite view of hot mix asphalt plant near West Lafayette, IN (Google, n.d.f).

Figure 2.5 Hot mix plant used for asphalt mixture on U.S. 421. Clockwise from top left, embedded burner drum mixer, silos with drum mixer and drag slat, aggregate cold feed bins, and RAP cold feed bins.

Figure 2.6 Construction equipment used on U.S. 421 project west of Delphi, IN.

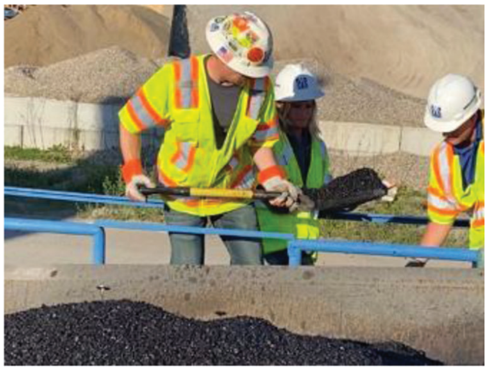


Figure 2.7 Plant-mix sample for the 12.5-mm intermediate mixture that was taken from a truck box at the sampling stand of the hot mix plant.

- Mill existing mainline and shoulder 1.5 inches and overlay with 165 lb/yd2 of QC/QA HMA-3, 70, surface 9.5 mm.

The geotechnical investigation report included 24 cores that indicated the average layer thicknesses in the existing pavement as the following.

- 10.9 inches hot mix asphalt.
- 8.0 inches concrete pavement.
- 11.0 inches compacted aggregate base.

The pavement is underlain by cohesive soils with the following.

- Liquid limit ranging from 22 to 65 with an average of 51.

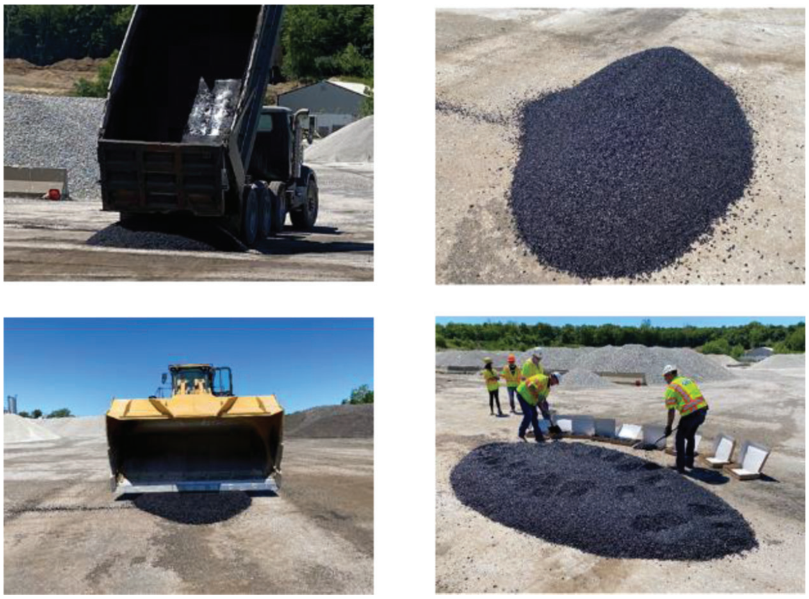


Figure 2.8 Process used to obtain plant-mix sample for the 9.5-mm surface mixture. Mixture was dumped from the silo into a truck, placed on the ground, flattened with a loader, and shoveled from random locations into boxes.

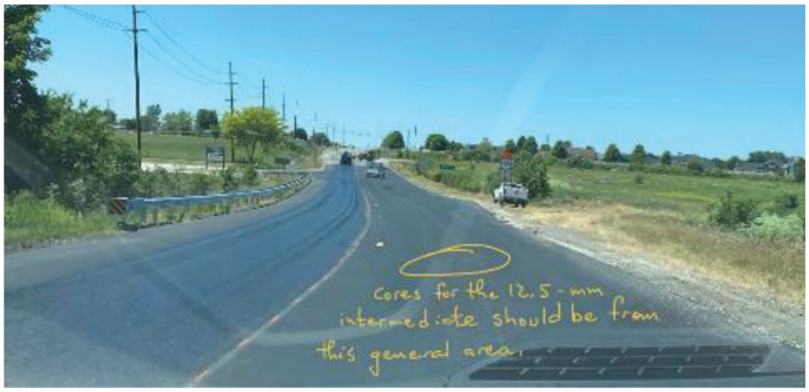


Figure 2.9 Cores for the 12.5-mm intermediate mixture taken at approximately Station 188+00, near the west end of the project in the westbound lane.

Figure 2.10 Cores for the 9.5-mm surface mixture taken at approximately Station 160+00, near the center of the project in the eastbound lane.

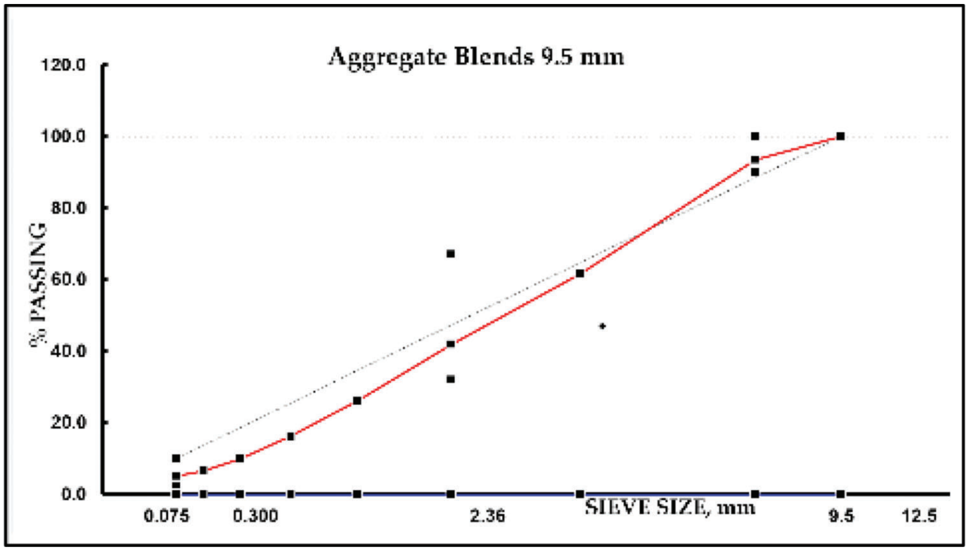


Figure 2.11 Gradation of surface mixture used on U.S. 421 project R-38757.

TABLE 2.1
Gradation of Surface Mixture Used on U.S. 421 Project R-38757

Mixture Course		**Surface**	
Mixture Designation		**9.5 mm**	
Maximum Particle Size		**12.5 mm**	
Percent Passing	**Spec**	**DMF Mass**	**JMF Mass**
% Pass 37.5 mm	–	–	–
% Pass 25.0 mm	–	–	–
% Pass 19.0 mm	–	–	–
% Pass 12.5 mm	100	100.0	–
% Pass 9.5 mm	90.0–100.0	93.5	–
% Pass 4.75 mm	<90.0	61.6	–
% Pass 2.36 mm	32.0–67.0	41.9	–
% Pass 1.18 mm	–	26.2	–
% Pass 600 µm	–	16.2	–
% Pass 300 µm		9.8	
% Pass 150 µm		6.5	
% Pass 75 µm	2.0–10.0	5.0	

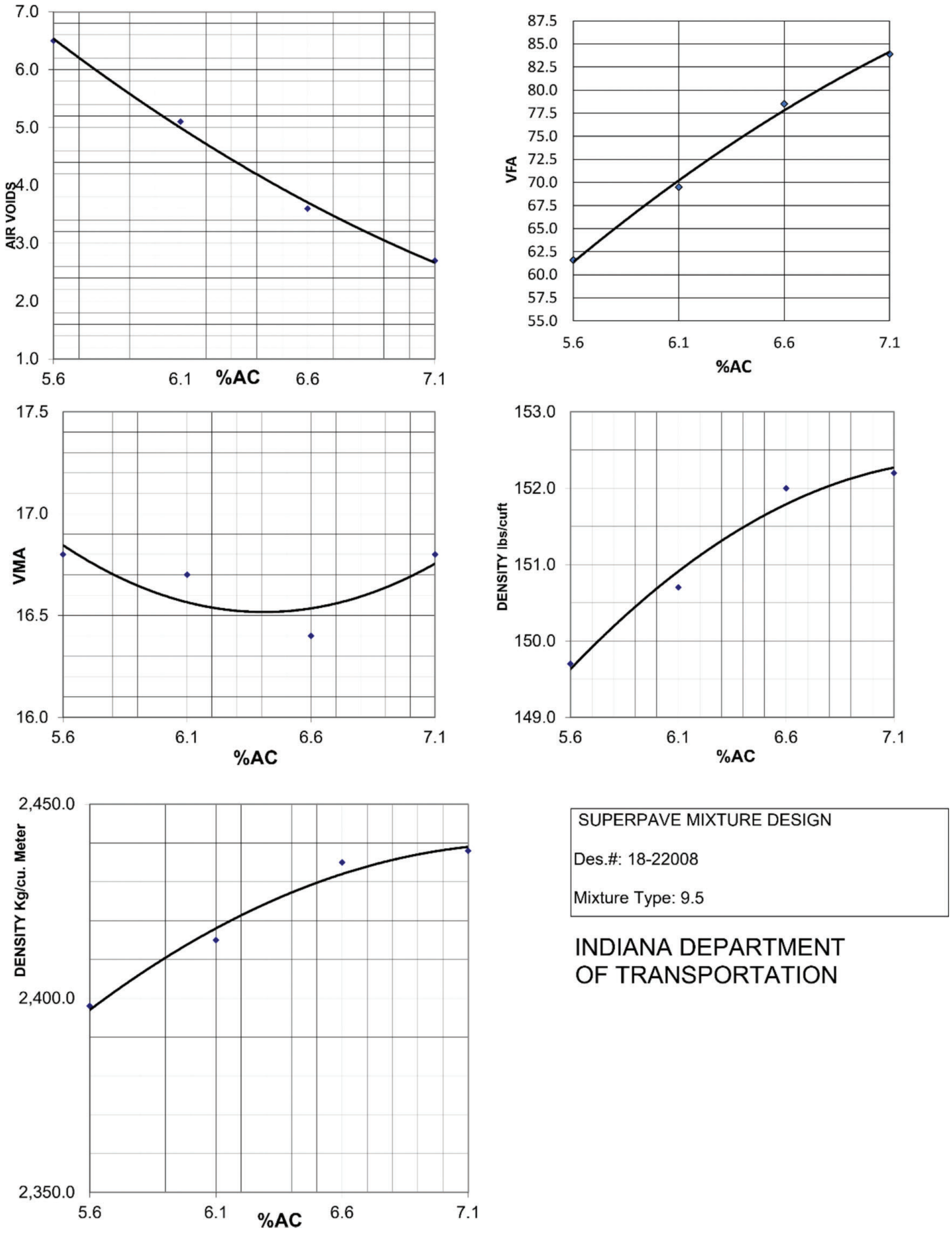


Figure 2.12 Mixture volumetric properties of surface mixture used on U.S. 421 project R-38757.

- Plasticity index ranging from 9 to 46 with an average of 19.
- Average moisture of 21.5%.

The haul route between the plant and the project is shown in Figure 2.16. The end of the haul route is shown at the approximate location where the mixture was placed. Figure 2.17 shows a street view of the approximate location. Photos of the road and construction process are not available. As shown in the photo, the shoulder in this area is narrow. One lane and

TABLE 2.2
Gradation of Intermediate Mixture Used on U.S. 421 Project R-38757

Mixture Course		**Inter/Surf**	
Mixture Designation		**12.5 mm**	
Maximum Particle Size		**19.0 mm**	
Percent Passing	**Spec**	**DMF Mass**	**JMF Mass**
% Pass 37.5 mm			
% Pass 25.0 mm			
% Pass 19.0 mm	100	100	
% Pass 12.5 mm	90.0–100.0	91.5	
% Pass 9.5 mm	<90.0	81.1	
% Pass 4.75 mm		55.3	
% Pass 2.36 mm	28.0–58.0	40.1	
% Pass 1.18 mm		24.4	
% Pass 600 µm		15.3	
% Pass 300 µm		10.0	
% Pass 150 µm		6.6	
% Pass 75 µm	2.0–10.0	5.4	

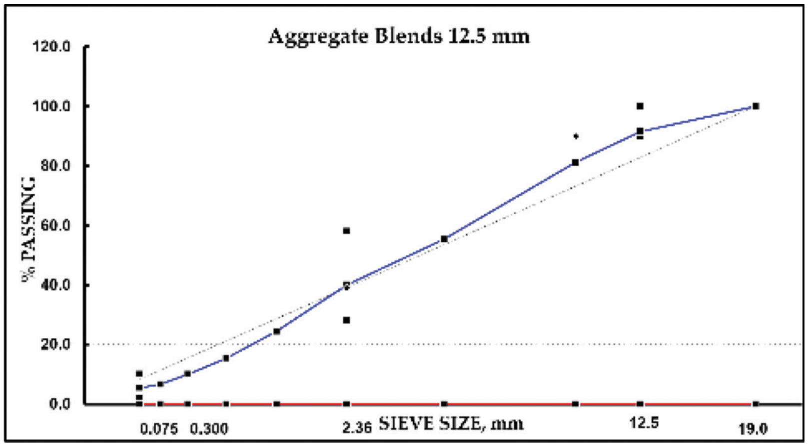


Figure 2.13 Gradation of intermediate mixture used on U.S. 421 project R-38757.

the adjacent shoulder were paved at the same time, on top of a milled surface. Figure 2.18 shows a view of the hot mix plant layout. The plant is a drum mix plant with an embedded burner as shown in Figure 2.19.

The following three samples were gathered from this project.

1. Plant mix
    a. The sample was taken as follows.
        i. A partial load was placed into a truck.
        ii. The mix was dumped on the ground.
        iii. The front-end loader flattened the pile to approximately 1-foot thick.
        iv. The sample was taken by shovel at various places around the pile.
        v. A series of photos in Figure 2.20 shows the process.
2. Cores
    a. Cores were taken from the road grouped in one location.
3. Raw materials
    a. Aggregates and reclaimed asphalt pavement were obtained from the working face of the stockpiles while the plant mixture was being sampled. The typical sampling operation is shown in Figure 2.21.

Mix design information, gradation, and volumetric properties related to U.S. 231 project surface mixture are shown in Table 2.3 and Figures 2.22 and 2.23.

2.3 State Route 135, Contract R-42140

This project was a mill and repave rehabilitation contract on SR 135 located in the south part of Indianapolis, IN. SR 135 is a four-lane highway with various turning lanes and shoulder widths that vary from two feet to 10 feet. It is predominantly a commuter route into the city and carries a low percentage of truck traffic. Design traffic is as follows.

- Average annual daily traffic (2020)—35,769 vehicles per day.
- Percent heavy trucks (2020)—1.4% AADT.

The project has two general pavement thicknesses. From the geotechnical investigation report that

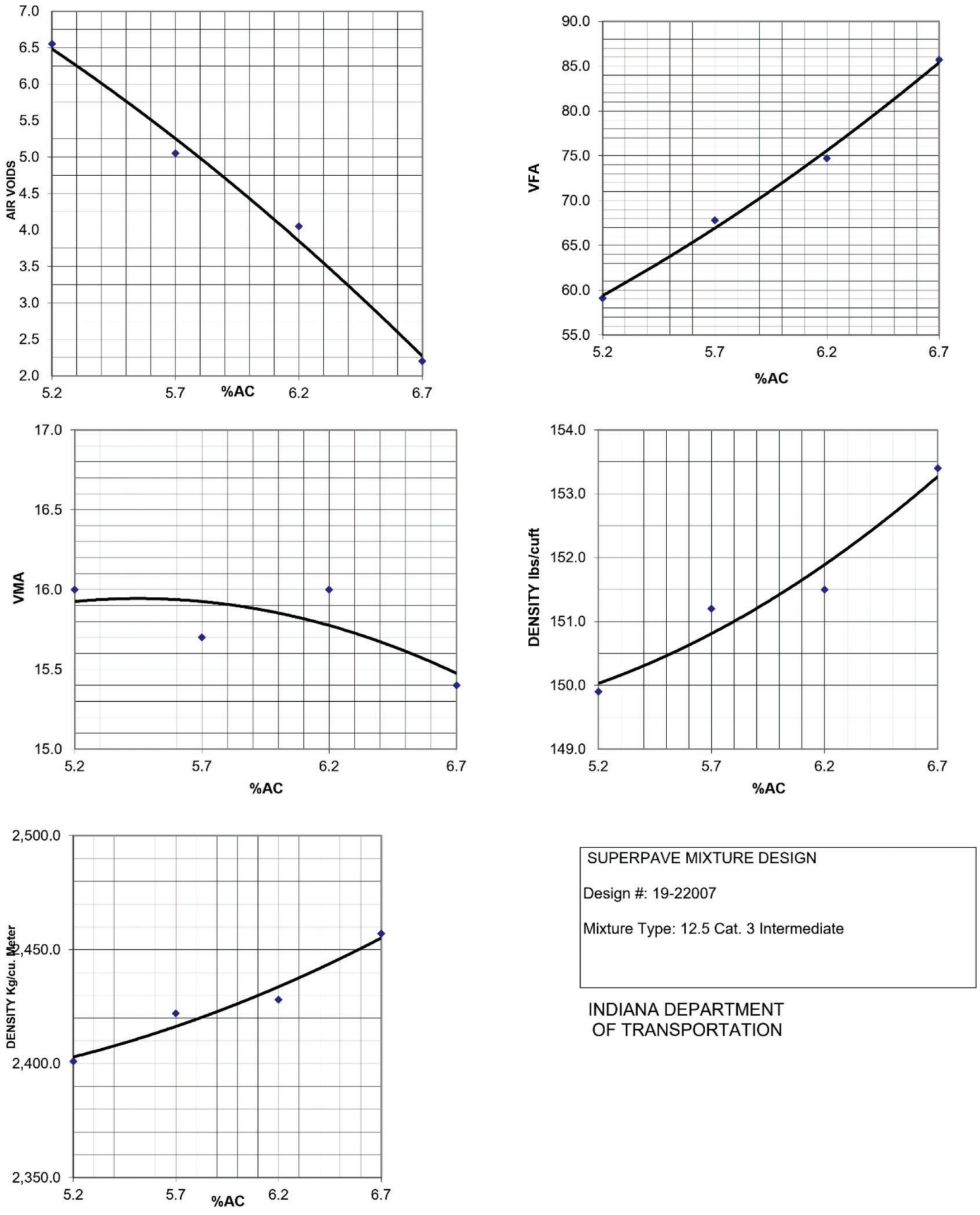


Figure 2.14 Mixture volumetric properties of intermediate mixture used on U.S. 421 project R-38757.

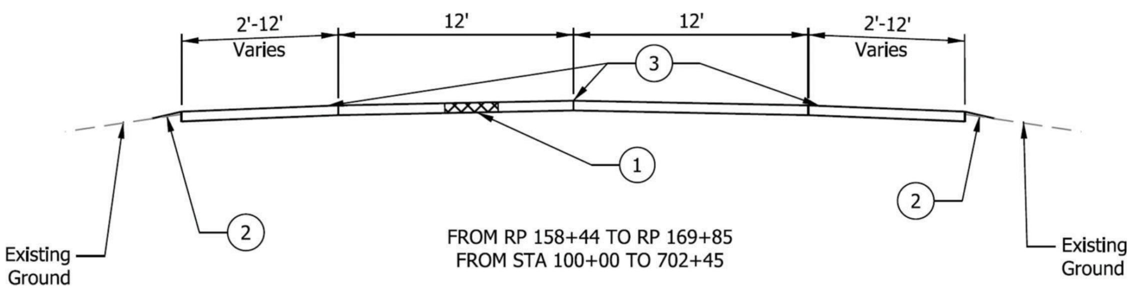


Figure 2.15 Typical cross section for most of the U.S. 231 project south of Crawfordsville, IN.

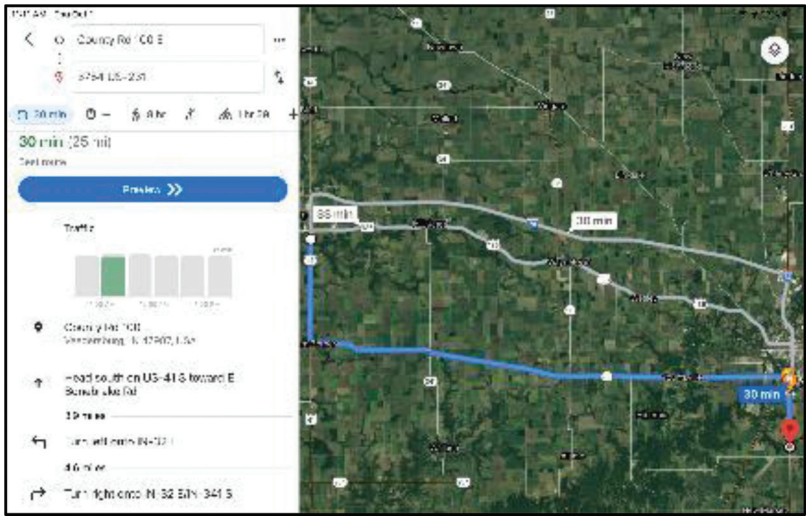


Figure 2.16 Haul route from hot mix plant near Veedersburg, IN to project south of Crawfordsville, IN (Google, n.d.a).

Figure 2.17 Typical cross section for most of the U.S. 231 project south of Crawfordsville, IN (Google, n.d.h).

included 25 cores in the main lanes, the average thickness of layers in the existing pavement were as follows.

- Composite pavement section
  - ○ 3.5 inches hot mix asphalt.
  - ○ 9.5 inches concrete pavement.
  - ○ 3.0 inches aggregate base.
- Full depth pavement section.
  - ○ 17.3 inches hot mix asphalt.

At the location where the sampled hot mix was placed, the pavement cross section is the composite pavement section. The pavement is underlain by cohesive soils with the following.

- Liquid limit average of 33.
- Plastic limit average of 16.
- Plasticity index is an average of 17.
- Average subgrade moisture content is 13.5%.

The construction project called for milling 1.5 inches to remove the surface layer and replacing it with 1.5 inches of new hot mix asphalt as shown in Figure 2.24.

Figure 2.18 Satellite view of hot mix asphalt plant near Veedersburg, IN (Google, n.d.g).

Mill existing mainline and shoulder 1.5 inches and overlay with 165 lb./yd2 of QC/QA HMA-3, 70, Surface 9.5 mm on existing pavement.

The hot mix plant is located on the south side of Indianapolis, a few miles west of the project. The haul route between the plant and the project is shown in Figure 2.25. Photos are not available of the construction operation on the road. Figure 2.26 shows a photo of the project in the general location where the experimental mixture was placed. Figure 2.27 shows a view of the hot mix plant layout. The plant is a large manufacturing facility as shown in Figure 2.28. It is a drum mix plant with an embedded burner.

The project was a night paving project and hence the loose mix sample was taken at night. The following samples were gathered.

- Plant mix
  - ○ The sample was taken as follows.
    - ▪ A partial load was placed into a truck.
    - ▪ The mix was dumped on the ground.

Figure 2.19 Hot mix plant used for asphalt mixture on U.S. 231. Clockwise from top left, embedded burner drum mixer, silos with drum mixer and drag slat, aggregate cold feed bins, and RAP cold feed bins.

Figure 2.20 Process used to obtain plant-mix sample for the 9.5-mm surface mixture. Mixture was dumped from the silo into a truck, placed on the ground, flattened with a loader, and shoveled from random locations into boxes.

    - The front-end loader flattened the pile to approximately 1-foot thick.
    - The sample was taken by shovel at various places around the pile.
    - A series of photos in Figure 2.29 shows the process.
  - Cores
    - Cores were taken from the road grouped in one location.
  - Raw materials
    - Aggregates and reclaimed asphalt pavement were obtained from the working face of the stockpiles while the plant mixture was being sampled.

Mixture design information, gradation, and volumetric properties related to the SR 135 project surface mixture are shown in Table 2.4 and Figures 2.30 and 2.31.

Figure 2.21 Process used to sample aggregates.

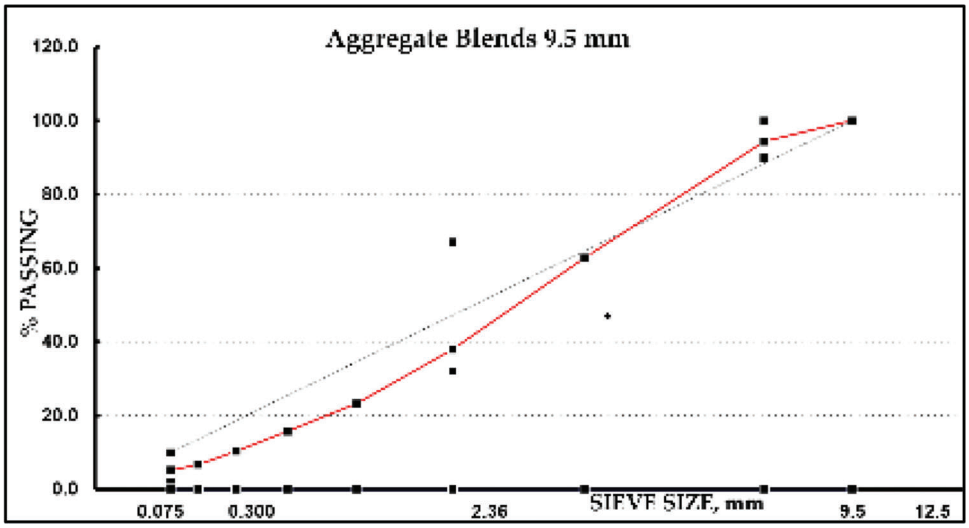
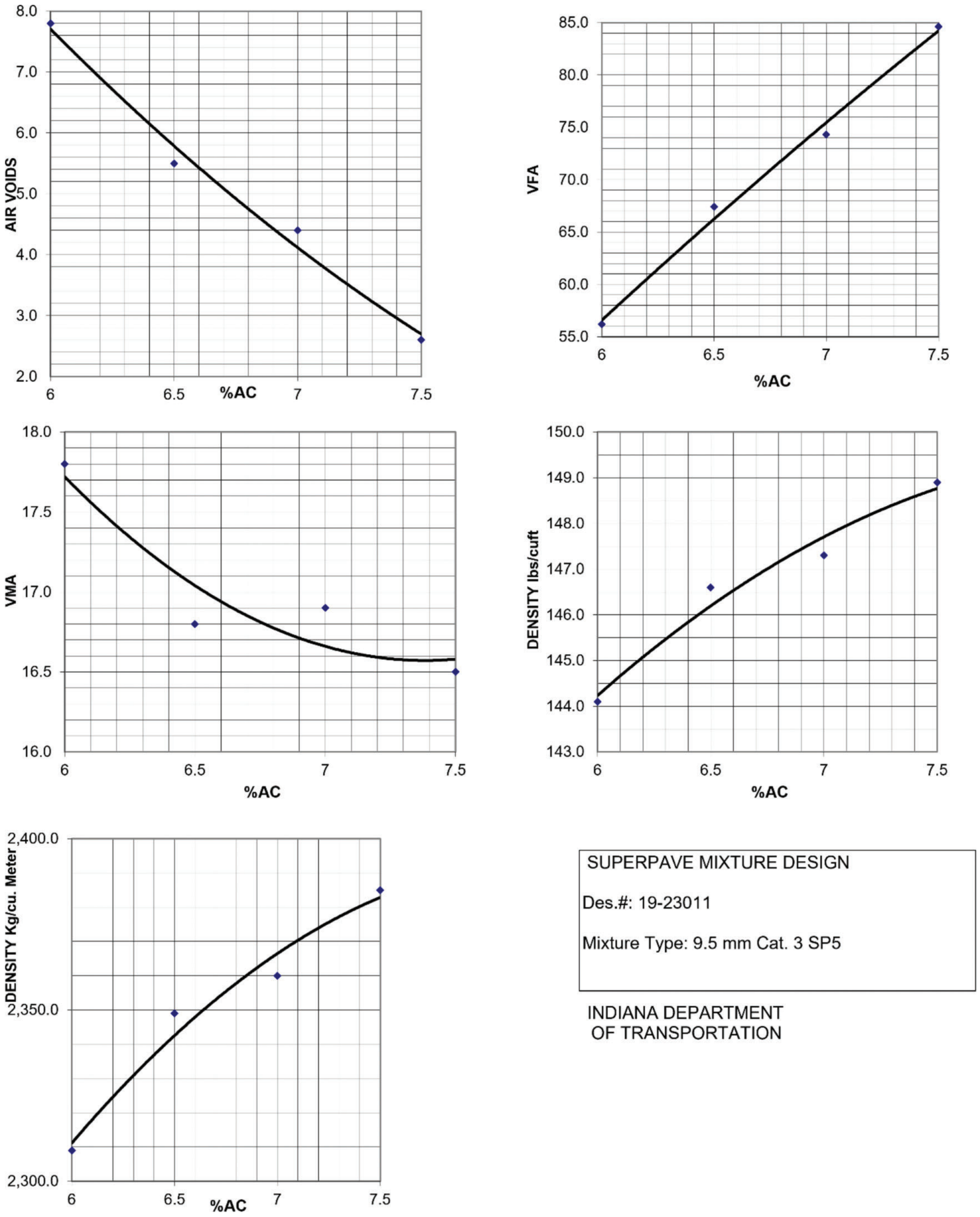


Figure 2.22 Gradation of surface mixture used on U.S. 231, project RS-39328.

TABLE 2.3
Gradation of Surface Mixture Used on U.S. 231 Project RS-39328

PG Grade, Design TSR		**64–22**	
Mixture Course		**Surface**	
Mixture Designation		**9.5 mm**	
Maximum Particle Size		**12.5 mm**	
Percent Passing	**Spec**	**DMF Mass**	**JMF Mass**
% Pass 37.5 mm			
% Pass 25.0 mm			
% Pass 19.0 mm			
% Pass 12.5 mm	100	100	
% Pass 9.5 mm	90.0–100.0	94.3	
% Pass 4.75 mm	<90.0	62.9	
% Pass 2.36 mm	32.0–67.0	38.0	
% Pass 1.18 mm		23.3	
% Pass 600 µm		15.8	
% Pass 300 µm		10.4	
% Pass 150 µm		6.7	
% Pass 75 µm	2.0–10.0	5.2	



SUPERPAVE MIXTURE DESIGN

Des.#: 19-23011

Mixture Type: 9.5 mm Cat. 3 SP5

INDIANA DEPARTMENT
OF TRANSPORTATION

Figure 2.23 Mixture volumetric properties of surface mixture used on U.S. 231 project RS-39328.

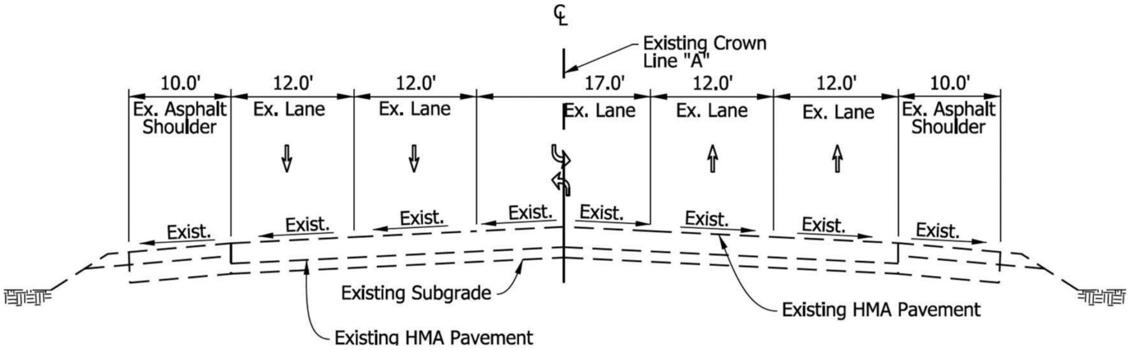


Figure 2.24 Typical cross section for location on SR 135 where sampled mixture was placed on the south side of Indianapolis, IN.

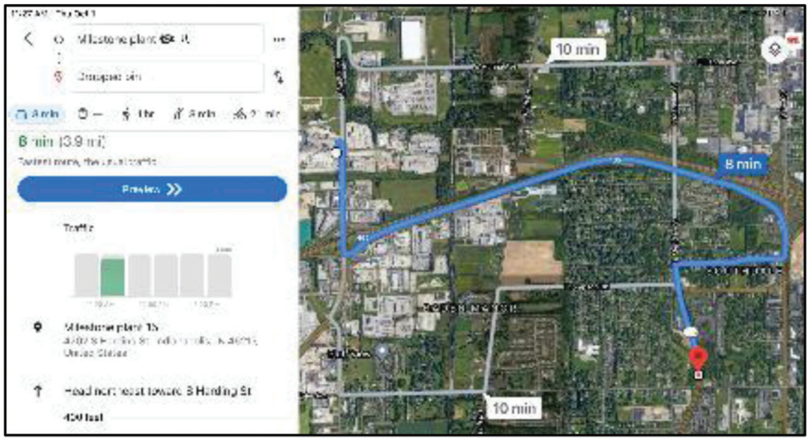


Figure 2.25 Haul route from hot mix plant in Indianapolis to project on south side of Indianapolis, IN (Google, n.d.b).

Figure 2.26 Approximate location on SR 135 where the research mixture was placed (Google, n.d.d).

Figure 2.27 Satellite view of hot mix asphalt plant on the south side of Indianapolis, IN (Google, n.d.e).

Figure 2.28 Hot mix plant used for asphalt mixture on SR 135. Clockwise from top left, embedded burner drum mixer, silos with drum mixer and drag slat, aggregate cold feed bins, and RAP cold feed bins.

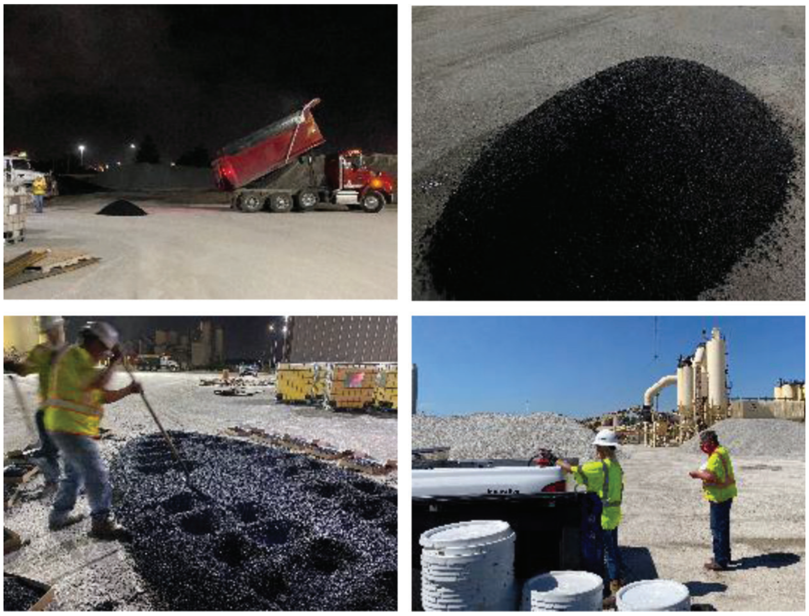


Figure 2.29 Process used to obtain plant-mix sample for the 9.5-mm surface mixture. Mixture was dumped from the silo into a truck, placed on the ground, flattened with a loader, and shoveled from random locations into boxes.

TABLE 2.4
Gradation of Surface Mixture Used on SR 135 Project R-342140

Mixture Course		**Inter/Surf**	
Mixture Designation		**9.5 mm**	
Maximum Particle Size		**12.5 mm**	
Percent Passing	**Spec**	**DMF Mass**	**JMF Mass**
% Pass 37.5 mm			
% Pass 25.0 mm			
% Pass 19.0 mm			
% Pass 12.5 mm	100	100.0	
% Pass 9.5 mm	90.0–100.0	93.5	
% Pass 4.75 mm	<90.0	60.4	
% Pass 2.36 mm	32.0–67.0	39.4	
% Pass 1.18 mm		25.4	
% Pass 600 μm		16.7	
% Pass 300 μm		10.5	
% Pass 150 μm		7.3	
% Pass 75 μm	2.0–10.0	6.0	

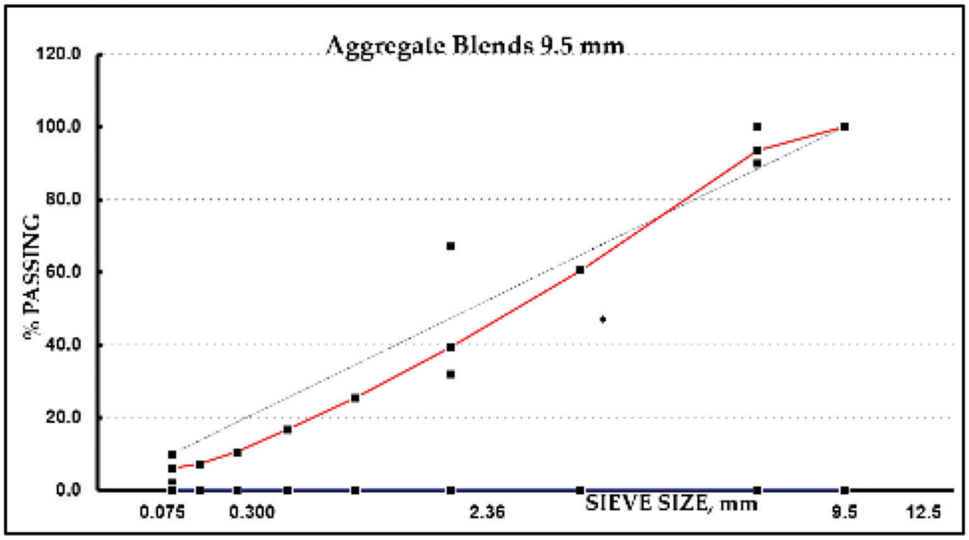


Figure 2.30 Gradation of surface mixture used on SR 135 project R-342140.

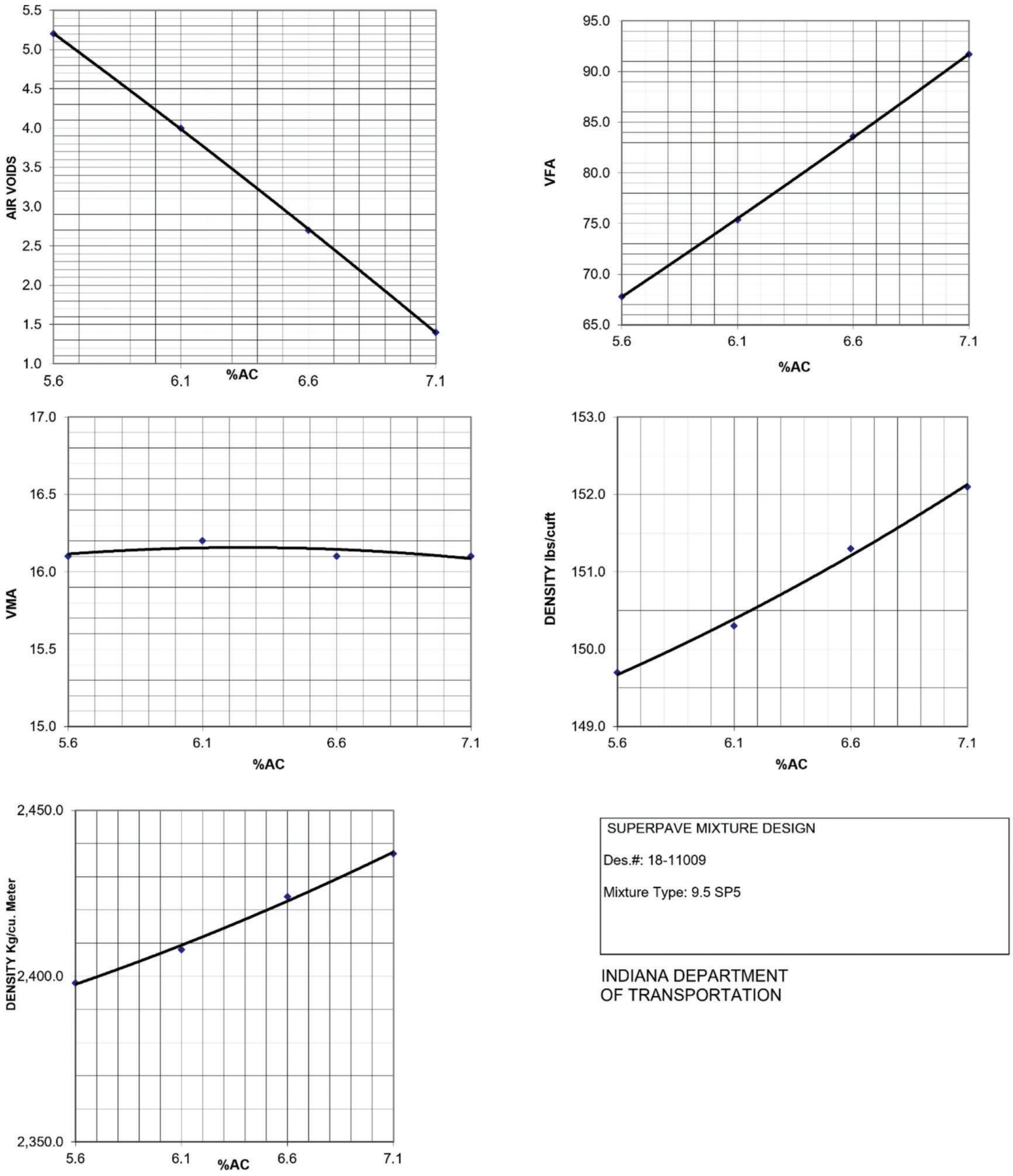


Figure 2.31 Volumetric properties of surface mixture used on SR 135 project R-342140.

3. SAMPLE PREPARATION

The asphalt materials were collected as raw materials, loose mixtures, and field core samples. Aggregates were taken from the aggregate stockpiles at the contractor's plants. Loose asphalt mixtures were collected in boxes either from truck samples or from a partial load of asphalt mixture dumped on the ground at the asphalt plants. Once all the materials were returned to the laboratory, test specimens for each mixture type (PMLC, LMLC, and PMFC) were prepared for laboratory testing.

3.1 Fabrication

3.1.1 Laboratory Mixed, Laboratory Compacted (LMLC)

In order to fabricate the specimens, the raw materials were heated in an oven for approximately 2 hours at the design mixing temperature (315°F–320°F). Figure 3.1a shows aggregates ready for placement in the oven. Once proper temperature was achieved, the aggregates, RAP, and asphalt binder were proportioned and mixed for 5 minutes using a laboratory asphalt mixer (Figure 3.2b). After mixing, the loose specimens were conditioned in an oven for 4 hours ± 5 minutes at a temperature of 275 ± 5°F (135 ± 3°C), in accordance with AASHTO R-30 *"Standard Practice for Mixture Conditioning of Hot Mix Asphalt (HMA)"* for short term aging.

Following short term aging, the oven temperature was raised to the design compaction temperature (300°F–320°F) and the loose specimens were held at this temperature for 2 hours before compaction. This time can vary slightly for each specimen, depending on number of specimens being compacted in a day. Laboratory compaction of asphalt specimens was accomplished using the Superpave Gyratory Compactor (SGC) in accordance with AASHTO T-312, *Preparing and Determining the Density of Hot-Mix Asphalt Specimens by Means of Superpave Gyratory Compactor*, using the necessary gyrations to achieve 5% ± 0.5 air voids content.

3.1.2 Plant Mixed, Laboratory Compacted (PMLC)

PMLC specimens were fabricated using the loose mixture samples produced in the hot mix asphalt plant and were obtained as either plate samples from the pavement mat, or directly from plant. Figure 3.2 shows boxes of loose asphalt materials in the laboratory.

As the plant mixed materials were already short term aged by the field production process, only 2 hours of reheating at 300°F–320°F was applied before specimen compaction. The reheated materials were compacted using the SGC, according to AASHTO T-312, to obtain 5% ± 0.5 air void content.

3.1.2.1 Plant mixed—field compacted (PMFC). The PMFC specimens were cut by Milestone, typically the same day as pavement construction (see Figure 3.3). The field core samples were taken from pavement surface layers. Manufacturing test specimens from the 9.5-mm mixture field cores was challenging. Laydown thickness of 9.5-mm mixtures was planned to be 1.5 inches, which is the same as the required test specimen diameter. As a result, coring test specimens from the field cores was challenging, to say the least.

3.2 Preparation of Test Specimens

The specific gravity (G_{mb}) of the specimens were measured according to AASHTO T-166, *Standard Method of Test for Bulk Specific Gravity (G_{mb}) for*

Figure 3.2 Boxes of loose asphalt mixtures.

Figure 3.1 LMLC samples preparation: (a) aggregate pans, (b) mixer, and (c) SGC specimen.

Figure 3.3 Field core samples.

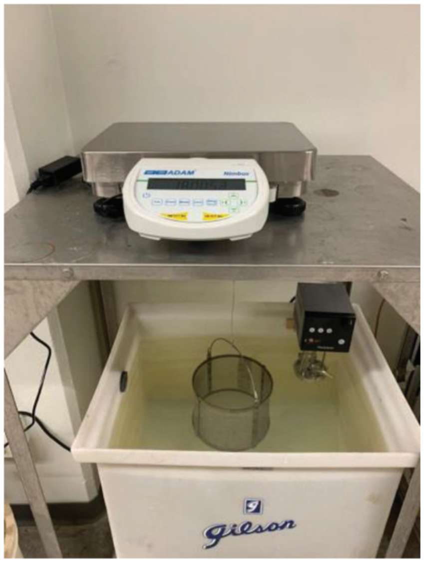


Figure 3.4 Water bath and scale for G_{mb} measurements.

Compacted Asphalt Mixtures Using Saturated-Dry Specimens. The air voids content measurements were performed on SGC-compacted/field cored samples, as well as on the specimens after coring and trimming to ensure that the air voids contents of the test specimens were within the target range (Figure 3.4).

Following AASHTO PP-99 (2019), *Preparation of Small Cylindrical Performance Test Specimens Using the SGC and Field Cores,* the SGC-compacted specimens and the field cored samples were cored and the resulting cores trimmed to provide test specimens. Figure 3.5a shows the coring jig and the saw used. Four small specimens with a 38-mm (1.50 in.) diameter and a 110-mm (4.33 in.) height were cored from each SGC specimen, as shown in Figure 3.5b. Also, one or two small specimens were obtained from each field core sample. As mentioned earlier, cutting a 38-mm (1.50-in.) diameter test specimen from a thin 9.5-mm surface mixture core is a challenge.

To minimize the impact on test specimen preparation the road cores were not trimmed (cut off from the layers below) so that the core barrel kerf could cut into the lower layer ensuring that all of the 9.5-mm mixture thickness could be used in the test specimen. At the top of the core a disk of sacrificial mixture was clamped to allow for the core barrel kerf. Ensuring that the edge of the core barrel was cutting in mixture ensured that the core barrel did not drift and right-angled cylinders could be obtained for the test specimen.

When field cores have a thickness of less than 38 mm (1.50 in.), it is impossible to get a suitable test specimen from the core. In such cases, for this project, the inside edge of the core barrel was positioned at the surface of the core and a thin arc of material from the underlying layer was incorporated into the test specimen. At most

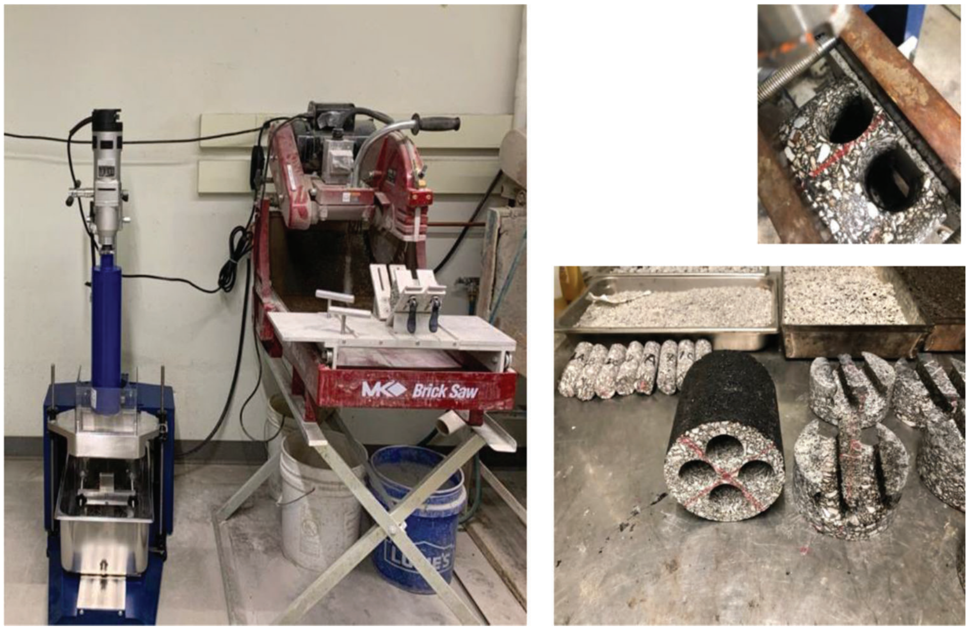


Figure 3.5 (a) Coring jig and brick saw and (b) coring of SGC and field cored samples.

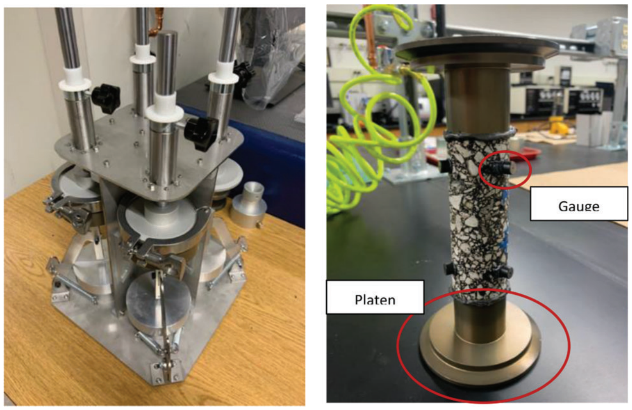


Figure 3.6 Gluing jig for gauge points and platens attachment.

the test specimen contained about 5 mm (0.2 in.) thick arc of underlying, which represents about 8% of the test specimen cross-sectional area. While a small area, this could influence the test results on such specimens.

After the samples were cored and trimmed, their G_{mb} was measured again. The specimens were then screened, to select which would become test specimens. For PMLC specimen, those with 5% ± 0.5 air voids contents were selected for testing. For PMFC (field core) specimens, the air voids were documented but specimens were not discarded if they were outside of the range, as there were a limited number of field cores.

A gluing jig (Figure 3.6) was used to attach the gauge points and platens to the test specimens. Six gauge-points were glued using epoxy and the LVDTs mounted on them. In addition, the gluing jig is used for gluing platens using epoxy, in order to conduct the cyclic fatigue testing method.

4. TESTING METHODS AND PARAMETERS

4.1 Dynamic Modulus (AASHTO TP-132)

The dynamic modulus test method was used to determine the viscoelastic properties of asphalt mixtures, following *AASHTO TP-132 Standard Method of Test for Determining the Dynamic Modulus for Asphalt Mixtures Using Small Specimens in the Asphalt Mixture Performance Tester (AMPT)*. Testing was performed on at least three replicates from each mixture using the Asphalt Mixture Performance Tester (AMPT). During dynamic modulus testing, a sinusoidal compression load is applied on unconfined specimens at different temperatures and frequencies. Dynamic modulus and phase angle data were used to develop the master curves using the FlexMAT program, according to the time-temperature superposition principle. In addition, the black space diagram were used to plot mixture stiffness (E*) and relaxation capability (δ) in one plot. The dynamic modulus (AASHTO TP-132) for the U.S. 421 project mixtures were conducted at Purdue, while the dynamic modulus of the U.S. 231 and SR 135 mixtures were performed by HRG.

4.2 Cyclic Fatigue (AASHTO TP-133)

To characterize fatigue cracking properties, the cyclic fatigue test was conducted in accordance with *AASHTO TP-133 Standard Method of Test for Determining the Damage Characteristic Curve and Failure Criterion Using Small Specimens in the Asphalt Mixture Performance Tester (AMPT) Cyclic Fatigue Test*. The concept of the S-VECD model can be utilized to evaluate the fatigue potential of asphalt mixtures using data from the AMPT. The fatigue data were analyzed using the FlexMAT program.

- The timing of sample preparation and testing for each mixture can be determined as follows.
- Short-term conditioning (only for LMLC specimens): 4 hours.
- Specimen fabrication: 2–3 hours.
- G_{mb} measurement (SGC samples): 1 hour (conducted the day after fabrication).
- Coring and trimming: 2–3 hour.
- G_{mb} measurement (cored specimens): 1 hour (conducted the day after coring).
- Gluing (after drying the specimens).
    - Gauge points: less than an hour.
    - Platens (AASHTO TP 133 only): less than one hour but needs to be done at least 24 hours before testing.
- Test
    - AASHTO TP 132: 2–3 days for three temperatures.
    - AASHTO TP 133: 1–2 days.

The total time for fabrication, sample preparation, and tests is determined about 8–10 days. This approximate time was specified for one mixture, however, to save time, the process can be performed for three mixtures simultaneously.

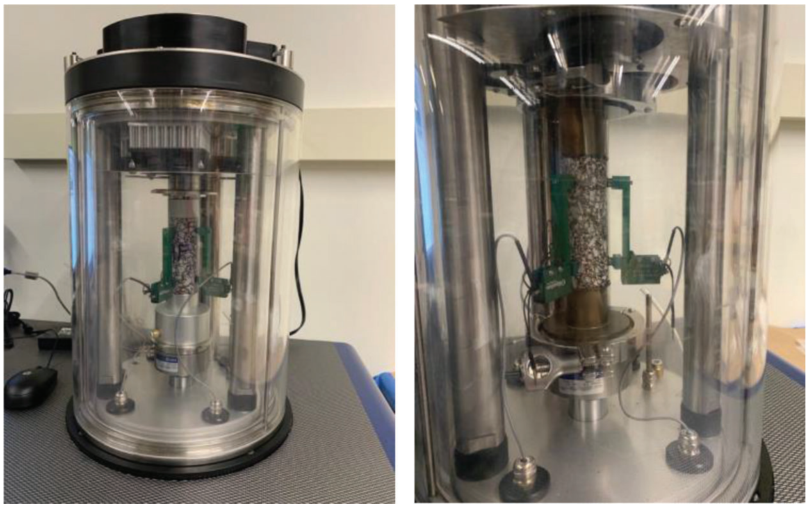


Figure 4.1 Dynamic modulus and cyclic fatigue test setups.

5. RESULTS AND DISCUSSIONS

5.1 Dynamic Modulus

Figure 5.1 shows the dynamic modulus master curves for four mixtures at the 20°C reference temperature. Two U.S. 421 mixtures were fabricated and tested at Purdue University, while the U.S. 231 and SR 135 mixtures were fabricated and tested at the HRG laboratory. Although the mixture fabrication procedures, including the conditioning times were the same in the two laboratories, the dynamic modulus trends are slightly different. For both U.S. 421 mixtures, LMLC mixtures show a higher dynamic modulus, followed by the PMLC mixtures; the field cored samples have the lowest stiffness. However, for U.S. 231 and SR 135, PMLC mixtures show a greater stiffness.

Figure 5.2 shows the phase angle master curves for the various mixtures. Phase angle is an indicator of a mixture's relaxation capability. A mixture with lower phase angle is expected to have less ductility and be more prone to cracking. Generally, phase angle is lower at higher frequencies and lower temperatures, where the elastic behavior of mixtures is dominant. The phase angle values increase with the increasing temperature (decreasing frequency) to reach to a peak value, and then decreases.

The relaxation capability of the 9.5-mm and 12.5-mm U.S. 421 mixtures are similar, with the lowest relaxation capability for LMLC mixtures, and highest values for PMFC mixtures. However, the phase angles of PMLC mixtures are very low for U.S. 231 and SR 135 mixtures, so that they do not reach the peak phase angle in the shown frequency range. Lower relaxation and higher stiffness can make these mixtures more susceptible to cracking.

To capture the dynamic modulus and phase angle in one plot, without the effect of frequency, black space diagrams are presented in Figure 5.3. at an identical dynamic modulus value, black space diagram can determine which mixtures have lower relaxation (Rahbar-Rastegar et al., 2018). For the U.S. 421 mixtures, more brittleness and lower relaxation capability is observed in LMLC mixtures as the inflection point moves to the left side. The U.S. 231 and SR 135 LMLC mixtures are more ductile than the PMLC and PMFC mixture specimens.

5.2 Cyclic Fatigue

The raw data of the fatigue characteristics of the asphalt mixtures were analyzed using FlexMAT to determine the fatigue behavior of mixtures. Figure 5.4 show the damage characteristics curves (DCC) for different mixtures. These curves indicate a reduction in mixture integrity as damage is increasing in mixture specimens during testing.

Wang and Kim (2018) showed a linear relationship exists between the summation of (1-C) values and the number of cycles to failure (N_f) and defined the slope of this line as the D^R criterion. The D^R parameter is defined as the average reduction in pseudo stiffness during the test, up to failure, as shown in Equation 5.1 (Wang et al., 2018).

$$D^R = \frac{\int_0^{N_f} (1 - C) dN}{N_f} \qquad \text{(Eq. 5.1)}$$

Figure 5.5 shows the D^R criterion for the mixtures tested in this project. Error bars on the plot indicate one standard deviation interval of the three or four replicates. The variability of test results is low, varying between 0.012 and 0.065. Other than careful planning and execution of specimen preparation and testing, Purdue took no additional steps to insure low testing variability. The trend for the two U.S. 421 mixtures and the SR 135 mixture is similar, indicating similar fatigue behavior for LMLC, PMLC, and PMFC mixtures. A slightly higher D^R was observed for SR 135 PMFC mixture than PLLC and LMLC mixtures. The U.S. 231 mixture does not follow this trend; the U.S. 231 LMLC mixture shows a higher D^R value, for no apparent reason the research team can determine.

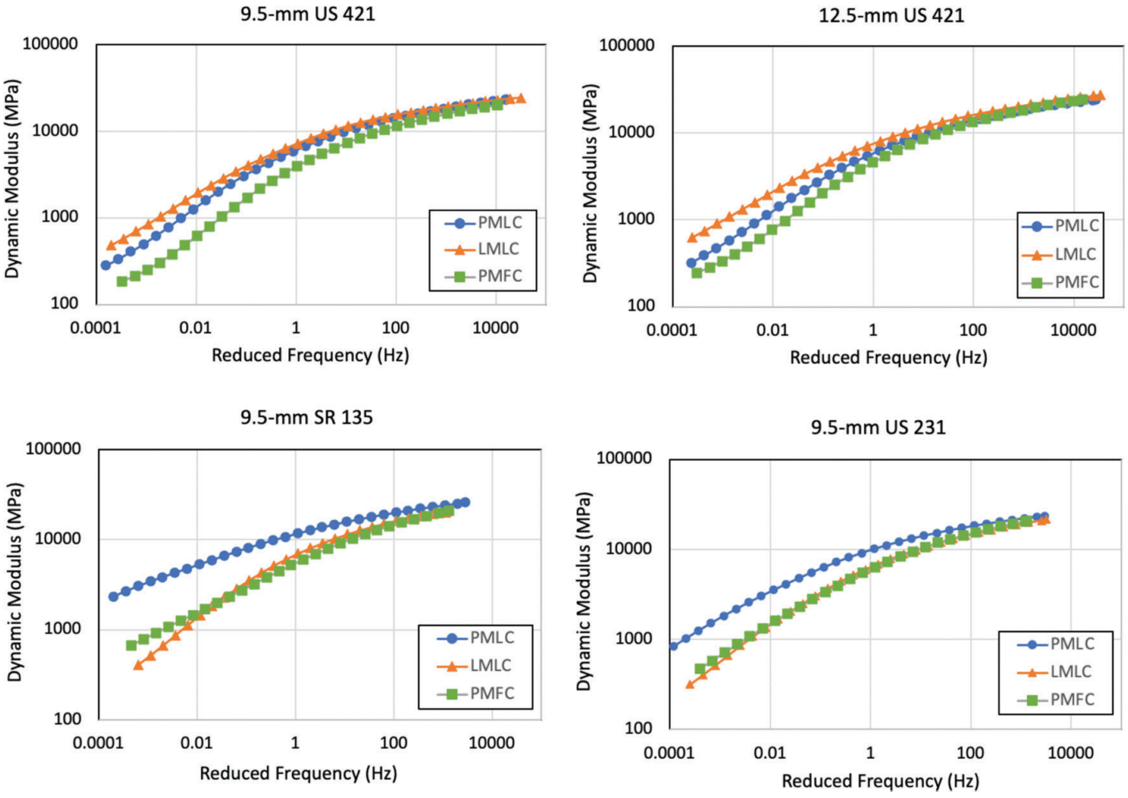


Figure 5.1 Dynamic modulus master curves (reference temperature: 20°C).

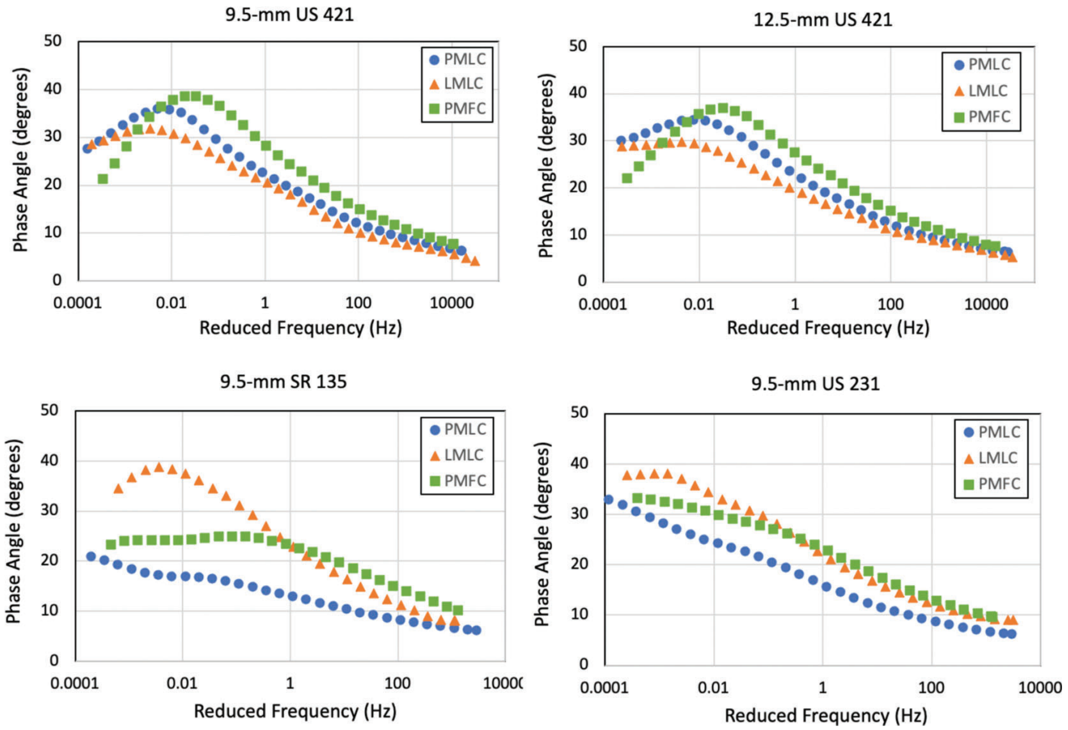


Figure 5.2 Phase angle master curves (reference temperature: 20°C).

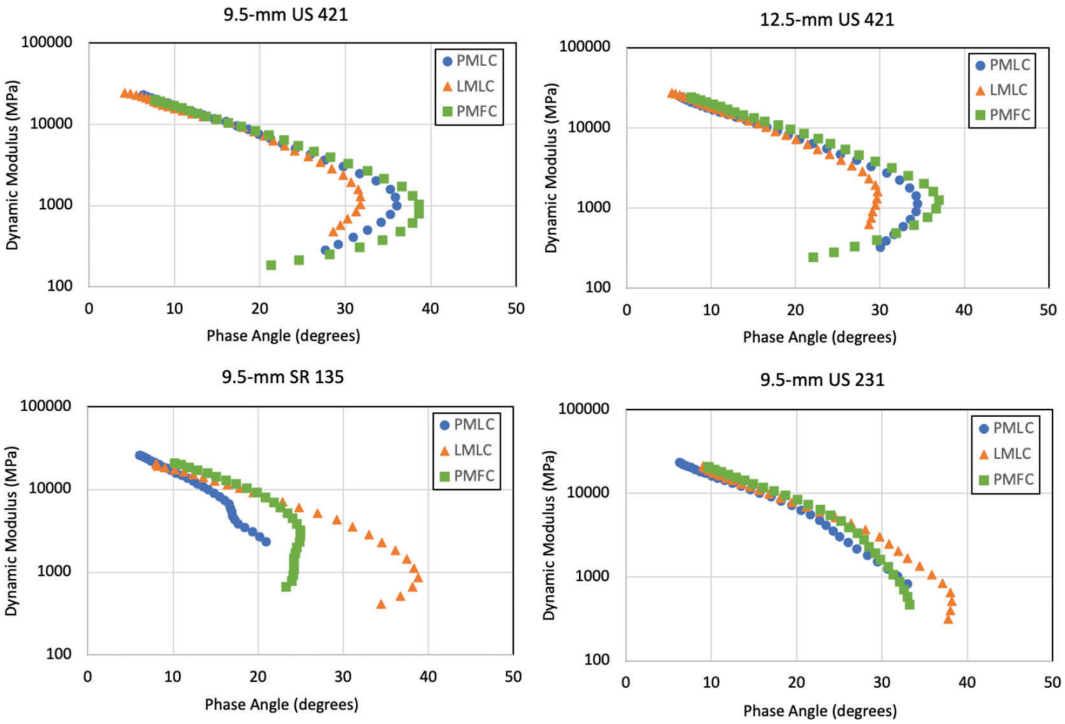


Figure 5.3 Black space diagrams (reference temperature: 20°C).

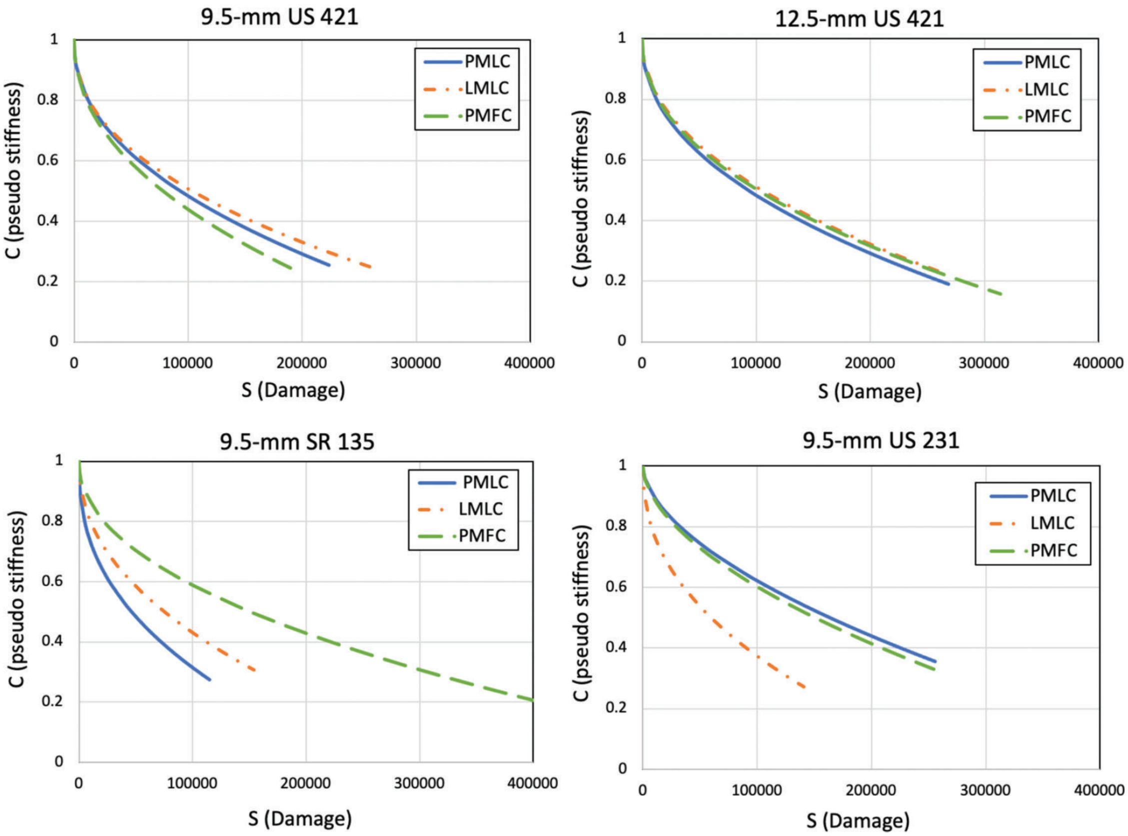


Figure 5.4 Damage characteristics curves for different mixtures.

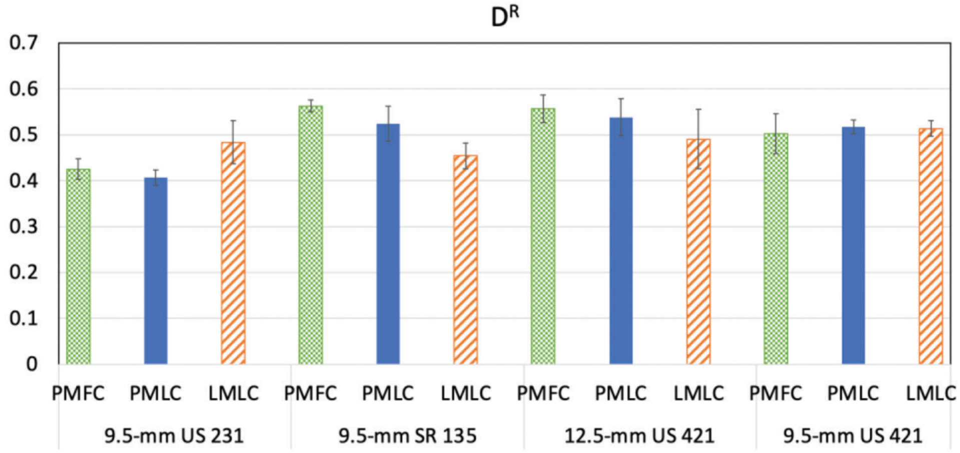


Figure 5.5 DR fatigue failure criterion.

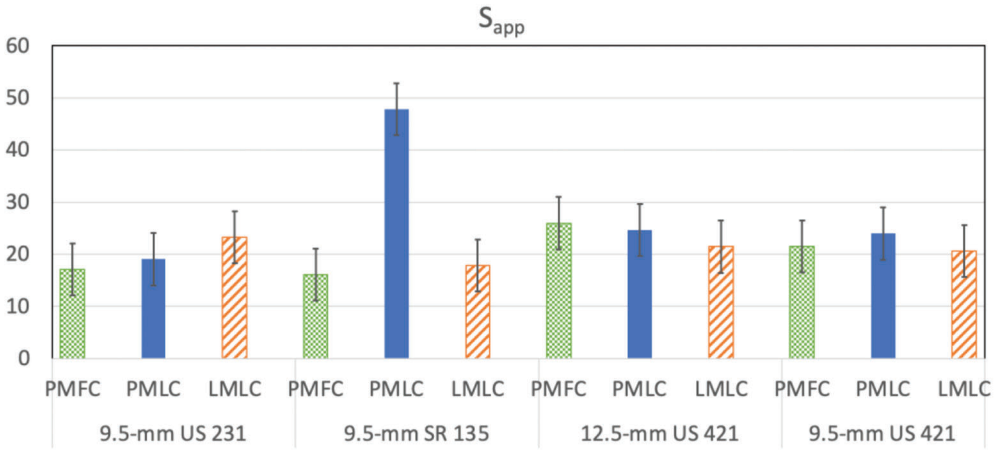


Figure 5.6 S_{app} values for different mixtures.

5.3 Fatigue Index Parameter (S_{app})

S_{app} is a relatively new parameter, based on the S-VECD approach, used to characterize the fatigue behavior of asphalt mixtures. This parameter considers the effects of toughness and stiffness on fatigue performance (Equation 5.2). In Equation 5.2, a_T is time-temperature shift factor, |E*| is dynamic modulus at the target temperature and a frequency of 10 Hz, and C_{11} and C_{12} are the coefficients obtained from C-S curve (Etheridge et al., 2019). Generally, a higher S_{app} is an indicator of better fatigue cracking resistant.

$$S_{app} = \frac{1}{1{,}000} \frac{\left(\frac{a_T^{\frac{C_{12}}{\alpha+1}}}{C_{11}} D^R \right)^{1/C_{12}}}{|E*|^{\alpha/4}} \qquad \text{(Eq. 5.2)}$$

The FHWA has suggested that S_{app} can be used as a fatigue cracking parameter for (BMD) and recommends minimum values of 8, 24, 30, and 36 for standard, heavy, very heavy, and extremely heavy traffic, respectively. These values were developed using a wide range of data from various states (Etheridge et al., 2019; FHWA, 2019). All three projects in this research had standard traffic (ESAL less than 10 million), and as shown in Figure 5.6, all the S_{app} values meet the required threshold of 8, indicating acceptable fatigue cracking performance. Surprisingly, the SR 135 PMLC mixture with the lowest C-S curve shows the higher S_{app} value among the mixtures. No obvious reasons can be found for this result. There appear to be no testing irregularities, nor an abnormal aging issue.

6. QUALITY CONTROL AND QUALITY ACCEPTANCE TEST RESULTS

6.1 Development of INDOT Acceptance Specifications

INDOT uses only one performance test as part of the design process, *AASHTO T 283, Resistance to Moisture Induced Damage*. For the mixture acceptance no performance tests are used. Currently, INDOT is evaluating rutting tests such as the Hamburg Wheel Track tester and cracking tests such as the I-FIT or IDEAL-CT for possible adoption. Test selection or an implementation timetable for any performance test has not been established.

In the mid-1990s, with the advent of Superpave mixture design method, INDOT changed mixture acceptance criteria from gradation to volumetric properties. At the same time, compaction acceptance on the road, which had been based on percent of laboratory molded density (Marshall density), was changed to percent of maximum theoretical density (%G_{mm}).

Historically the main performance concern of asphalt mixtures prior to adoption of Superpave was cracking. Compaction specifications for Marshall mixtures allowed more than ten percent air voids in the roadway and cracking issues were related to accelerated asphalt binder aging. The move to Superpave mixtures and adoption of %G_{mm} for compaction acceptance resulted in lower in-place air voids, typically, 8% or lower.

By the 2010s the department perceived a gradual decrease in design asphalt binder content. The average asphalt binder content of mixture designs approved by the INDOT is shown by year in Figure 6.1. The two most used mixtures in Indiana are the 9.5- and 19.0-mm mixtures. From 2005 to 2009 the average content for these two mixtures had decreased about 0.2%.

Indiana is not the only state to have concerns about asphalt binder content being too low or decreasing. An NCHRP study done in 2019 indicated that most DOTs (43 of 49 respondents) felt asphalt binder content was low (Tran et al., 2019). In the asphalt community numerous “remedies” have been suggested to increase asphalt content.

The NCHRP study investigates the most common perceptions and shows some are either ineffective or based upon faulty reasoning. Examples of such remedies include the following.

- *High design gyrations produce low asphalt binder content mixtures.* This premise is incorrect. The concept of decreasing design gyrations to increase asphalt binder content is not valid.
- *Reduce design air voids by targeting a lower design air void content or by adding additional asphalt binder to reduce air voids.* This approach will work providing VMA is met during design and production using AASHTO M323 criteria.
- *Deduct value used for aged asphalt binder in RAP.* Cracking has been attributed to the use of RAP when low asphalt binder content is caused by lack of control on other mixture properties.
- *Require fine-graded asphalt mixes.* Mistaken impression that fine-graded mixtures have a higher asphalt binder content than a coarse-graded mixture and so specifying fine-graded mixtures will automatically increase asphalt binder contents.
- *Specify film thickness.* Incorrect perception that thicker asphalt films are more durable rather than the amount of asphalt binder in the mixture. Caused industry to design mixtures with low dust content to meet the film thickness requirement while still having a low asphalt binder contents.

When the Superpave mixture design method was implemented, INDOT chose to adopt AASHTO M323 into their specifications without the many changes used by other DOTs. As part of the implementation they focused on mixture design criteria, mixture adjustment allowances during production and mixture acceptance criteria.

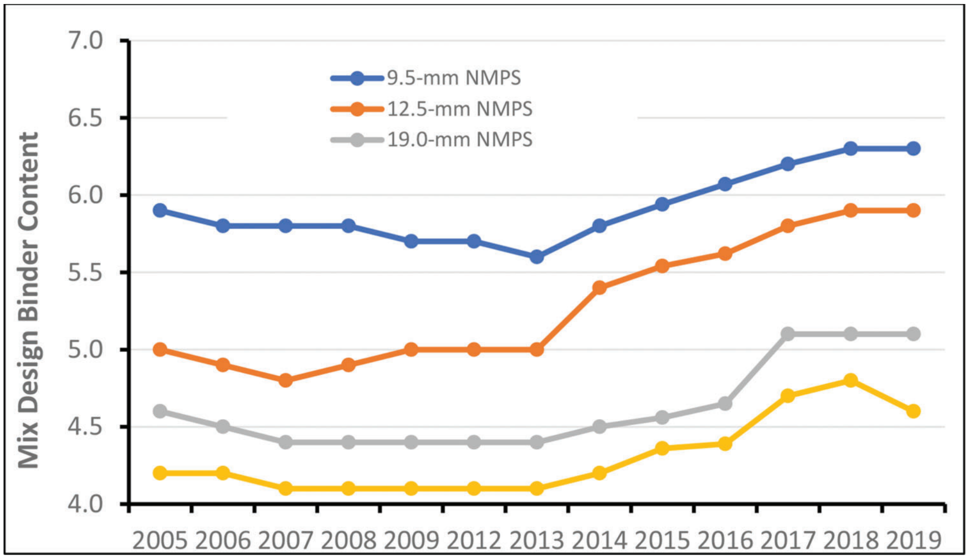


Figure 6.1 Average asphalt binder content of all mix designs.

Ensuring the design asphalt binder content is correct and that the asphalt binder content of plant-produced asphalt mixture is also correct requires control of air voids and VMA. VMA calculations must use accurate values for aggregate bulk specific gravity (G_{sb}). Air voids are an acceptance parameter used by most highway agencies. VMA, on the other hand, is usually given less consideration or is ignored.

During INDOT acceptance specification development in the early 2000s discussion focused on the determination of G_{sb} values. Initially, RAP aggregates were assigned a G_{se} value calculated from the RAP's maximum specific gravity.

As the percentage of RAP increased during the late 1990s and early 2000s the substitution of G_{se} for G_{sb} caused an increasing over-estimation of G_{sb} for the VMA calculation. The G_{se} specific gravity inflates G_{sb}, increases the calculated VMA and thereby allows a decreased design asphalt binder content. As RAP content increased from 15% to more than 30%, this error became more significant.

In response, a specification change was implemented. In 2011 INDOT required the use of G_{sb} measured on extracted aggregate for RAP aggregates. But following implementation of this change, the average asphalt content for 9.5-mm mixtures continued to decrease. In 2013 discussion focused on G_{sb} values being used in mixture designs.

For new aggregates in the design the DOT required values from the Department's aggregate catalogue to be used. To ensure catalogue values were current the Department increased testing frequency. The changes in determining G_{sb} for both RAP aggregates and new aggregates led to a better estimate of VMA and a higher asphalt binder content. In 2014 asphalt binder content increased by 0.1% to 0.4% for the different mixtures as shown in Figure 6.1.

These changes increased the design asphalt binder content but concerns still existed about reductions allowed during field production. At that time pay factors were applied to asphalt binder content, VMA and air voids in the ratio of 30%, 10% and 30%. The remaining 30% of the pay factor was applied to compaction measured by core density.

VMA is an intermediary to asphalt binder content, that is, if air voids are fixed, asphalt binder content increases as VMA increases. During mixture production, air voids and VMA vary. For example, if one lot of 9.5-mm mixture has a VMA of 15.3% and air voids of 4.7%, the effective asphalt volume, V_{be}, is 10.6%. Full pay is received for this lot because VMA is above the minimum of 15.0% and the air voids are within the specification range. If another lot has a VMA of 14.9% and air voids of 3.6%, then the V_{be} is 11.3%, greater than the first lot, but in penalty because VMA is less than 15.0%.

An analysis of pay factors showed that sometimes the VMA pay factor remained consistently in penalty, suggesting it was intentionally allowed to be low to reduce asphalt binder content within limits of the specification. Savings from reduced asphalt binder content exceeded payment reduction from the low VMA pay factor. INDOT realized that V_{be} was the most important parameter and decided the specification should reflect that importance.

In 2017 INDOT discontinued the use of asphalt binder content as a pay factor. Then, in 2019 INDOT also discontinued the use of VMA as a pay factor. These two factors were replaced with effective asphalt binder volume, V_{be}. Effective asphalt binder volume is calculated by subtracting air voids from VMA. The new pay factors became air voids, V_{be} and compaction in the ratio of 30%, 35%, and 35%. As shown in Figure 6.1, this change to the specifications did not impact design asphalt binder content. However, as shown in Figure 6.2, it caused an increase in mixtures as produced. In 2018 mixtures produced under the VMA specification had average air voids 0.18% above the target, whereas in 2019 mixtures produced under a V_{be} specification the air voids are 0.2% below the target.

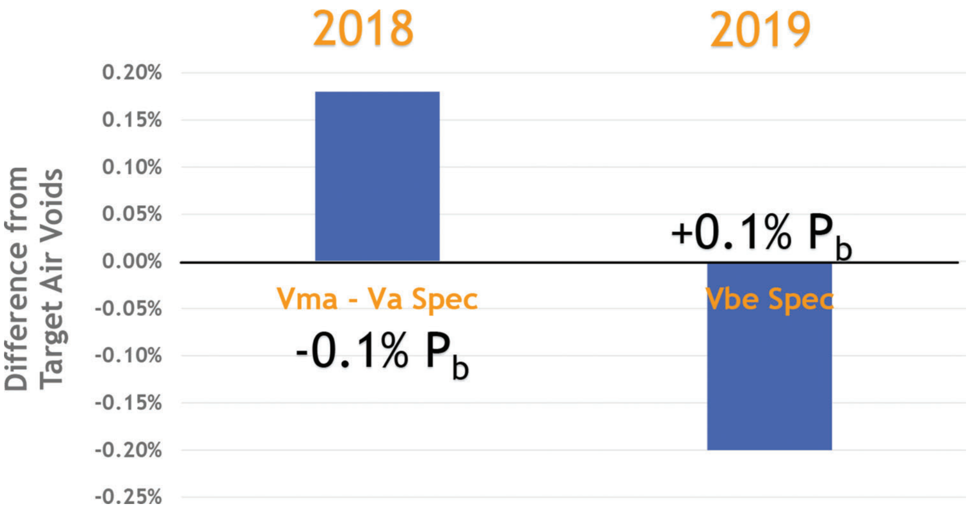


Figure 6.2 Air void result of all mixtures produced in 2018 with a VMA.

This difference translates to an increased asphalt content of 0.2% in the mixtures as produced.

Indirectly VMA is still part of the specification and so determination of accurate G_{sb} values remains important to ensuring adequate asphalt content. As part of the specification change for 2019, INDOT discontinued use of catalogue values for new aggregates and G_{sb} for RAP aggregates. Instead, mixture designers were free to determine the G_{sb} of the combined aggregate blend. Then, during acceptance a mixture sample is extracted, the aggregate is split into coarse and fine, and the bulk specific gravity is determined for each. One aggregate specific gravity sample is taken from each lot (there are five sublots per lot).

A moving average of three G_{sb} tests is used to calculate VMA in the acceptance process. This has direct impact on V_{be}. If the value of VMA is lower using the moving average G_{sb}, then the V_{be} will be lower. For the acceptance testing, INDOT will use the design G_{sb} if the moving average remains within +/-0.020 of the design G_{sb}. If the moving average changes more than 0.020, then all subsequent samples are evaluated with the new value.

From 2018 to 2019 a second, unrelated, change occurred. INDOT began the implementation of Superpave 5. Superpave 5 had been researched at Purdue University in the early 2010s and the first trial project was built in 2013. In 2018 a five-year forensic review was done and INDOT decided to begin implementation. In 2019 some trial projects were let with Superpave 5 specifications and for other contracts a change could be requested from a standard Superpave mixture to Superpave 5. More than half of the asphalt mixture produced in 2019 was converted to Superpave 5.

The discussion regarding use of V_{be} for acceptance of mixtures applies equally to Superpave 5-designed mixtures as to standard Superpave-designed mixtures. In Superpave 5 mixtures, the design air voids are 5.0%, 1% higher than standard Superpave mixtures, and the VMA criteria are also 1% higher. As a result, V_{be} in Superpave 5 mixtures is the same as in Superpave mixtures.

6.2 Quality Control and Quality Acceptance for Research Mixtures

All four mixtures in this project were obtained from materials being supplied for INDOT. Hence the mixture design specifications and the mixture acceptance specifications are specific to INDOT. Mixture acceptance is based on air voids, effective volume of asphalt binder and in-situ compaction in the proportion of 30%, 35% and 35%, respectively.

Quality Control (QC) and Quality Acceptance (QA) data for the mixtures is shown in Tables 6.1, 6.2, 6.3, and 6.4. Each table contains test results for the lot from which the research mixture was sampled. Generally, each lot contains five sublots. However, if the contract contains more than one lot of material, but insufficient for a second lot, then these sublots are added to the previous lot. Such is the case for the 9.5-mm surface mixture on U.S. Highway 421 (Table 6.2). Sublot size is 1,000 tons for base and intermediate mixtures, 600 tons for surface mixtures.

QA and QC samples are obtained by plate sampling behind the paver. A typical example of sampling is shown in Figures 6.3 and 6.4. These photos show the sampling of the 12.5-mm intermediate mixture from U.S. Highway 421.

Cores are taken from two locations in each sublot, each location determined by random x-y numbers. Two cores are taken: one for the contractor, the other for the agency. Generally, cores are taken the same day (after sufficient cooling) or on the next day. The contractor tests their samples shortly after the plates are taken. The QA samples are sent to the INDOT laboratory where the material is reheated and tested.

INDOT's acceptance specification is a statistical specification based on calculation of percent within limits. Quality limits used for calculation of percent

TABLE 6.1
Quality Control and Quality Acceptance of 12.5-mm Intermediate Mixture, U.S. 421, Project R-38757

	Quality Control Data				
Sublot	1-1	1-2	1-3	1-4	1-5
Binder Content, %	5.87	5.41	5.83	5.71	5.83
VMA, %	16.00	15.70	15.60	16.30	16.10
Air Voids, %	4.40	5.20	4.40	5.20	5.00
Effective Asphalt Binder Volume, %	11.60	10.50	11.20	11.10	11.10
Compaction, % Max. Theoretical	95.82	94.98	96.36	94.26	—
	Quality Acceptance Data				
Sublot	1-1	1-2	1-3	1-4	1-5
Binder Content, %	5.83	5.53	5.52	5.44	5.53
VMA, %	15.81	15.84	15.61	16.48	16.57
Air Voids, %	3.94	4.66	4.36	5.69	5.52
Effective Asphalt Binder Volume, %	11.87	11.18	11.24	10.79	11.05
Compaction, % Max. Theoretical	96.20	94.91	96.72	94.49	—

TABLE 6.2
Quality Control and Quality Acceptance of 9.5-mm Surface Mixture, U.S. 421, Project R-38757

	Quality Control Data					
Sublot	1-1	1-2	1-3	1-4	1-5	1-6
Binder Content, %	6.24	6.03	5.87	6.23	6.02	6.01
VMA, %	17.60	17.40	16.40	17.00	17.70	17.50
Air Voids, %	5.20	5.30	4.20	4.60	5.70	5.70
Effective Asphalt Binder Volume, %	12.40	12.10	12.20	12.40	12.00	11.80
Compaction, % Max. Theoretical	96.46	95.72	94.45	96.52	93.04	94.06
	Quality Acceptance Data					
Sublot	1-1	1-2	1-3	1-4	1-5	1-6
Binder Content, %	6.03	6.05	5.95	5.98	5.75	6.04
VMA, %	17.88	17.83	16.61	17.48	17.89	17.92
Air Voids, %	5.79	5.54	4.49	5.31	6.42	5.79
Effective Asphalt Binder Volume, %	12.09	12.29	12.11	12.17	11.47	12.13
Compaction, % Max. Theoretical	97.20	96.23	94.89	96.38	92.91	94.73

Figure 6.3 Layout of sample plates ahead of paver on U.S. 421.

Figure 6.4 Transferring mixture from sample plate to sample box on U.S. 421.

within limits are shown in Table 6.5. PWL calculations use the sample mean and standard deviation with the quality limits to calculate a Q-value. Statistical tables indicate the percent of results calculated to be above the lower limit and below the upper limit. Using the two values a PWL within the two limits is determined.

As noted in Table 6.5, the quality limits for effective asphalt binder volume are dependent on the mixture *nominal* maximum size. Also note, as shown in Table 6.5, that compaction has only a lower quality limit. There is no upper limit. Table 6.6 shows the PWL calculated for each of the acceptance properties, the pay factor for that property and the combined pay factor.

TABLE 6.3
Quality Control and Quality Acceptance of 9.5-mm Surface Mixture, U.S. 231, Project R-39328

	Quality Control Data				
Sublot	2-1	2-2	2-3	2-4	2-5
Binder Content, %	7.09	7.23	6.72	7.31	6.78
VMA, %	16.10	17.00	17.20	17.30	16.60
Air Voids, %	3.60	4.80	5.50	4.50	4.90
Effective Asphalt Binder Volume, %	12.50	12.20	11.70	12.80	11.70
Compaction, % Max. Theoretical	94.24	95.74	93.95	94.00	94.69
	Quality Acceptance Data				
Sublot	2-1	2-2	2-3	2-4	2-5
Binder Content, %	6.69	6.76	6.65	6.81	6.64
VMA, %	17.49	17.37	17.45	16.94	16.66
Air Voids, %	5.56	5.78	6.06	4.81	5.36
Effective Asphalt Binder Volume, %	11.93	11.59	11.39	12.13	11.30
Compaction, % Max. Theoretical	94.28	96.23	93.66	94.26	95.60

TABLE 6.4
Quality Control and Quality Acceptance of 9.5-mm Surface Mixture, SR 135, Project R-42140

	Quality Control Data				
Sublot	2-1	2-2	2-3	2-4	2-5
Binder Content, %	5.60	6.08	6.13	5.89	5.88
VMA, %	18.30	16.90	16.80	17.00	16.60
Air Voids, %	6.20	4.40	4.20	4.40	4.40
Effective Asphalt Binder Volume, %	12.10	12.50	12.60	12.60	12.20
Compaction, % Max. Theoretical	95.28	94.79	94.51	95.64	95.10
	Quality Acceptance Data				
Sublot	2-1	2-2	2-3	2-4	2-5
Binder Content, %	5.70	6.23	6.57	6.13	6.11
VMA, %	17.83	16.73	17.10	17.88	16.83
Air Voids, %	6.08	4.31	4.20	5.51	4.71
Effective Asphalt Binder Volume, %	11.75	12.42	12.90	12.37	12.12
Compaction, % Max. Theoretical	94.70	94.53	94.40	95.33	94.24

TABLE 6.5
Quality Limits for Percent Within Limits Acceptance Specification

	Lower Quality Limit	Upper Quality Limit
Air Voids	3.60	6.40
Effective Asphalt Volume	—	—
12.5-mm Mixture	10.0	12.5
9.5-mm Mixture	11.0	13.5
Compaction	93.0	—

TABLE 6.6
Percent Within Limits and Pay Factors for Mixtures in the Study

	Air Voids		Effective Asphalt Volume		Compaction		Combined
	PWL	Pay Factor	PWL	Pay Factor	PWL	Pay Factor	Pay Factor
R-38757 12.5-mm Mixture	99	1.05	100	1.05	100	1.05	1.05
R-38757 9.5-mm Mixture	100	1.05	100	1.05	96	1.03	1.04
RS-39328 9.5-mm Mixture	98	1.04	100	1.05	99	1.05	1.05
R-42140 9.5-mm Mixture	99	1.045	100	1.05	100	1.05	1.05

7. CONSIDERATIONS AND RECOMMENDATIONS

7.1 Challenges

7.1.1 COVID-19 Pandemic

The project's timeline was seriously affected by the pandemic. Laboratory testing cannot be performed remotely, and Purdue University closed all Purdue laboratories in mid-March 2020. The Pankow Materials Laboratory received approval to restart laboratory operations at the end of June 2020, finally ending nearly three months of laboratory lockdown. Even when the Pankow Laboratory restarted operations, testing progress was slow, due to strict laboratory regulations requiring social distancing (no more than one person in a specific laboratory area).

7.1.2 Asphalt Mixture Performance Tester (AMPT) Technical Issues

A major challenge during the study relates to the AMPT machines. The project plan called for asphalt mixture testing to be performed at both the Purdue University Pankow Laboratory and the Heritage Research Group (HRG) Laboratory. Purdue has a PaveTest AMPT, while the HRG AMPT is an IPC Controls Group machines.

At project initiation, the HRG AMPT had been out-of-service for several years and the previous operator had left the company, leaving an inexperienced operator to arrange AMPT servicing and perform testing. Before project testing could begin, the HRG AMPT needed servicing and calibration Initially there was some confusion about which company would (could) service the machine, and when a service visit was finally scheduled, it ended up being the very week that HRG had a complete operational shutdown (mid-March), due to COVID. In July, the Heritage Group management finally allowed someone outside the company to visit, and the service technician drove to Indianapolis (flights were considered unsafe) to complete the servicing and calibration.

Getting the machine running and calibrated was challenge enough, but running tests was confusing, sometimes frustrating, and often time consuming. Initial dynamic modulus testing was completed, and the resulting test files compared with example files from the North Central Superpave Center (NCSC). Several issues were noted. It was thought that perhaps the HRG AMPT test software was out-of-date. Trying to confirm the test software was up to date was frustrating (2007 shepherding files), but it was finally confirmed that the test software was current.

When the fatigue test was attempted, the data seemed reasonable, but the HRG AMPT testing ran very slowly, and after a day a *memory full* error was received. After investigation, it was determined that the HRG AMPT was an early model with a serial port that could not handle the necessary data transfer rate; a new card with a USB port (several thousand dollars) was required. The new card was manufactured in Italy, which at the time was still being impacted by COVID. A delay of approximately two months (mid-October to mid-December) was experienced waiting on the new data card. Once the card arrived, installation was easily completed.

Beginning in January 2021, new template files were received, and fatigue tests were attempted. An error message was received, *platen bolts are loose*, but they were not. After further troubleshooting, it was determined that the HRG AMPT was a “earlier machine” and was not capable of performing in tension-compression mode. To do so, the machine would need different actuator seal. A price estimate was received for changing the seal ($23,300), and the decision was made by HRG to not spend additional funds on the old AMPT. After 6 months and $15,000 the machine was mothballed. Quotes were received and a new machine was ordered in February 2021; it was installed in April 2021. Due to cyclic fatigue issues with the HRG AMPT, the Purdue AMPT was used to complete all cyclic fatigue testing for the project.

With all the AMPT issues faced by HRG, it should be noted that the Purdue AMPT machine was out of service two different times during the project. This AMPT was brand new and experienced issues with temperature control and the motor controller. These issues resulted in project delays.

7.1.2.1 FlexMAT software. During this study, an Excel-based software package (FlexMAT version 1.1.2) was available to analyze the dynamic modulus and cyclic fatigue data. This version of the FlexMAT software was designed and developed based on the output of IPC Controls Group produced AMPT machines. All the fatigue tests in this project were conducted using a PaveTest AMPT, which has a different file output than does the IPC AMPT. This resulted in the AMPT cyclic fatigue data files being reformatted, by hand, before being used in FlexMAT to complete the data analyses. The research team worked with both manufacturer and software development team to figure out how to convert the machine fatigue output to a generic format required for FlexMAT. Updates to the software have been produced since the data in this project were acquired, but as of April 2022 the software is still being updated.

7.2 Best Identified Practices

7.2.1 Core Specimen Quality

As mentioned in the previous section, great care must be taken in small core sample preparation, especially when the small cores are taken from thin surface mixture field cores. Extra precaution must be taken to obtain the best possible quality without any visible damage. Additionally, the cutting saw needs to be inspected regularly, to ensure the blade cuts a completely flat surface. A poor core/cut can cause an uneven tensile load distribution during cyclic fatigue testing, which can result in unacceptable test results (e.g., end failure).

7.2.2 Brittle Mixtures

Generally, the AASHTO TP-133 test method is a very sensitive test. Sample preparation and test setup can influence the final test results. During the project, it was observed that the test is even more challenging for asphalt mixtures with higher dynamic modulus and lower phase angle. Higher stiffness and lower relaxation capabilities make mixtures more brittle and therefore more prone to cracking. The probability of fracture, or end failure (crack at the very top or bottom of sample) increases in these mixtures. Such mixtures do not behave well at the currently recommended AASHTO TP-133 test temperature (the average of high and low temperature minus 3), as the asphalt binder has somewhat stiffened during mixture production and is therefore different than the original virgin binder grade. A higher test temperature and lower strain level for testing such mixtures might help to obtain more acceptable results.

7.2.3 Strain Level Determination

Table X1.1 in AASHTO TP-133 is used to determine the target on-specimen strain levels using the initial dynamic modulus results. Although, this table can be helpful in estimating the initial strain levels, it was observed that the suggested values are too high for INDOT's asphalt mixtures. The research team suggests a lower on-specimen strain level be selected for the first cyclic fatigue test of each mixture.

7.2.4 Training

The AMPT was specifically developed for evaluating performance of asphalt mixtures. Although, it is not complicated to work with the AMPT, there are a myriad of details that must be looked after. The research team strongly recommends that thorough training for AMPT users be organized and technical resources provided.

7.2.5 Asphalt Mixture Test Results

As indicated in the Table 6.6 data, INDOT considers the four asphalt mixtures to have been well constructed; the contractor received a bonus of 5% for three of the mixtures and a 4% bonus for the fourth. The mixtures having exceeded minimum construction requirements and assuming INDOT's QA specifications are designed to help insure asphalt mixture performance, it can be concluded the four mixtures used in this project can be expected to perform well throughout their roadway lives. Additionally, all four mixtures meet the FHWA recommended minimum S_{app} value of 8. Thus, the AMPT test results seem to agree with QA results from the field.

This project is the first time that INDOT has used the AMPT to collect data from field mixtures, so no prior data is available on which to base firm conclusions. However, it does appear that good asphalt mixture can be expected. INDOT will monitor the mixtures over their lives in order to collect additional data. AMPT testing on additional projects would also be helpful in that it will allow INDOT to begin to build a database to guide further implementation of BMD.

8. SUMMARY

The objective of this study was to evaluate the cracking behavior of asphalt mixtures from three mainline paving projects in Indiana in order to better understand the fundamental engineering testing capabilities of the AMPT. A total of four Superpave 5 asphalt mixtures were collected from the three projects and tested in this study. The viscoelastic characteristics and fatigue behavior of PMLC, LMLC, and PMFC specimens were assessed according to the AASHTO TP-132 and AASHTO TP-133 test methods. Two AMPT machines (IPC Control and PaveTest) were used to conduct the dynamic modulus tests, while all fatigue tests were performed using a PaveTest AMPT. The raw data were analyzed using the FlexMAT software.

The results of dynamic modulus and cyclic fatigue tests indicate that AMPT testing can be used to effectively evaluate INDOT asphalt mixtures during the mixture design and production phases. However, to do so, detailed planning and effective training are needed, to help ensure the successful completion of AMPT testing. Regular training needs to be scheduled for contractors to ensure they are familiar with the AMPT and comfortable operating the machine. Considering the sensitivity of cracking evaluation results to specimen preparation, AMPT users need to be trained on how to properly prepare, core, and trim asphalt mixture specimens with great consistency.

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On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1—evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,600 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at http://docs.lib.purdue.edu/jtrp.

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