FEBRUARY 7, 2018

REINFORCED ASPHALT CONCRETE

IAPA ASPHALT RESEARCH

ZACH CREECH
SOUTHERN ILLINOIS UNIVERSITY AT EDWARDSVILLE
School of Engineering

CONTENTS

INTRODUCTION

The intent of the following research is to test different methods of reinforcing for asphalt concrete using Illinois Low ESAL Mix Design Criteria. Of the types of reinforcement used two types were chosen. The first is a commercially available fiber reinforcement Forta-Fi® provided by FORTA Cooperation with the aid of Josh Hammaker. The second reinforcement was No. 3 black annealed steel concrete tie wire cut into 3” lengths. The asphalt was mixed using SIUE Civil Engineering Departments’ Asphalt Lab procedures along with the mixing procedures provided by FORTA Corp. The samples were then sent to ET Simmons to be evaluated using a Hamburg Wheel Test with the aid of Joe Lenzini. The results of the tests are shown in the data sheets provided below.

PROCEDURE

Please see Addendums A through F for procedures and equipment used in the experiment.

SUMMARY OF MIX SPECIFICATIONS

- Percent of Asphalt Binder in Mix: 5.6% - PG64-22
- Bulk Specific Gravity of Aggregates: 2.627
- Average Effective Specific Gravity of Aggregates: 2.622
- Theoretical Maximum Specific Gravity Adjusted: 2.410
- Gyrations: $N_{Initial} = 5$;$N_{Design} = 30$;$N_{Maximum} = 42$
- Bulk Specific Gravity:

	$G_{mb\ Initial}$	$G_{mb\ Design}$	$G_{mb\ Maximum}$
Control	2.132	2.299	2.329
Fiber Reinforcement	2.203	2.363	2.390
Steel Reinforcement	2.144	2.315	2.349

- Percentage of Maximum Specific Gravity:

	$G_{mm\ Initial}$	$G_{mm\ Design}$	$G_{mm\ Maximum}$
Control	88.45%	95.38%	96.64%
Fiber Reinforcement	91.39%	98.03%	99.16%
Steel Reinforcement	88.97%	96.05%	97.46%

- Percentage of Air Voids:

	$V_{a\ Initial}$	$V_{a\ Design}$	$V_{a\ Maximum}$
Control	11.52%	4.62%	3.36%
Fiber Reinforcement	8.61%	1.97%	0.85%
Steel Reinforcement	11.03%	3.95%	2.54%

- Percentage of Voids Filled with Asphalt:

	$VFA_{Initial}$	VFA_{Design}	$VFA_{Maximum}$
Control	50.59%	73.39%	79.35%
Fiber Reinforcement	58.68%	86.95%	94.01%
Steel Reinforcement	51.89%	76.47%	83.67%

- Percentage of Voids in Mineral Aggregate:

	$VMA_{Initial}$	VMA_{Design}	$VMA_{Maximum}$
Control	23.38%	17.38%	16.29%
Fiber Reinforcement	20.83%	15.08%	14.11%
Steel Reinforcement	22.93%	16.80%	15.58%

- Percentage of Voids in Total Mix:

	$VTM_{Initial}$	VTM_{Design}	$VTM_{Maximum}$
Control	11.55%	4.62%	3.36%
Fiber Reinforcement	8.61%	1.97%	0.85%
Steel Reinforcement	11.03%	3.95%	2.54%

SUMMARY OF RESULTS

Mix Design Check:

Parameter	Specification	Control Sample	Fiber Sample	Steel Sample
Design Air Voids	4.0% Target	4.62%	1.97%	3.95%
Voids in Mineral Aggregate	15% Minimum	17.38%	15.08%	16.80%
Voids in Total Mix	2.0% to 8.0%	4.62%	1.97%	3.95%
Voids Filled with Asphalt	65% to 78%	73.39%	86.95%	76.47%
Dust to Binder Ratio	1.0 maximum	1.07	1.07	1.07
Percentage of G_{mm} at Initial Gyrations	89% Maximum	88.45%	91.39%	88.97%
Percentage of G_{mm} at Design Gyrations	98% Maximum	95.38%	98.03%	96.05%
Meets Standards?		No	No	No

Hamburg Wheel Test Results:

Sample	Failure Depth	Failure Cycles	Cycles Specified	Pass?
Control	15.0 mm	15,500	20,000	No
Fiber	15.0 mm	12,800	20,000	No
Steel	12.4 mm	20,000	20,000	Yes

APPENDIX-A DATA TABLES

Table A.1 IDOT IL-9.5 Low ESAL Aggregate Gradation Control Points

Sieve		Percent Passing	
Designation	Size (mm)	Minimum	Maximum
1/2”	12.5	--	100
3/8”	9.50	95	100
No. 4	4.75	52	80
No. 8	2.36	38	65
No. 30	0.600	< 50% of the percentage passing the No. 4	
No. 200	0.075	4.0	8.0
Asphalt Binder %	--	4.0	8.0
Dust/Binder Ratio	--	--	1.0 at design A.C. %

Table A.2 SIUE CE Department Laboratory Aggregate Gradation

Sieve					
Designation	Size (mm)	CA-16	FA-01	MF	Combined
1/2”	12.5	100	100	100	100
3/8”	9.50	98	100	100	98.66
No. 4	4.75	39	98	100	58.55
No. 8	2.36	6	92.3	100	34.79
No. 16	1.18	4	82.9	100	30.72
No. 30	0.60	3	51.8	100	21.03
No. 50	0.30	3	11.7	100	9.40
No. 100	0.20	3	1.4	98	6.34
No. 200	0.75	3	1	93	6.04
Specific Gravity		2.61	2.66	2.67	2.63

Table A.3 Batch Specifications from SIUE Aggregate Stock Piles

Aggregate Proportion Percentage by Mass of Total Aggregates		
CA-16	FA-01	MF
67	29	4

Table A.4 Design Specifications for IL-9.5L

Parameter	Target Value
Gyrations Required for Initial Density	5
Gyrations Required for Design Density	30
Gyrations Required for Maximum Density	42
Design Air Voids	4.0% target at N_{design}
Voids in Mineral Aggregate	15% minimum at N_{design}
Percent Voids in Total Mix	2.0% minimum – 8.0% maximum at N_{design}
Voids Filled with Asphalt	65-78% at N_{design}
Dust/AC Ratio	1.0 maximum
Maximum Percentage of G_{mm} at $N_{Initial}$	89%
Maximum Percentage of G_{mm} at N_{Design}	98%

APPENDIX-B GRAPHS

Figure B.1 Superpave 0.45 Power Chart

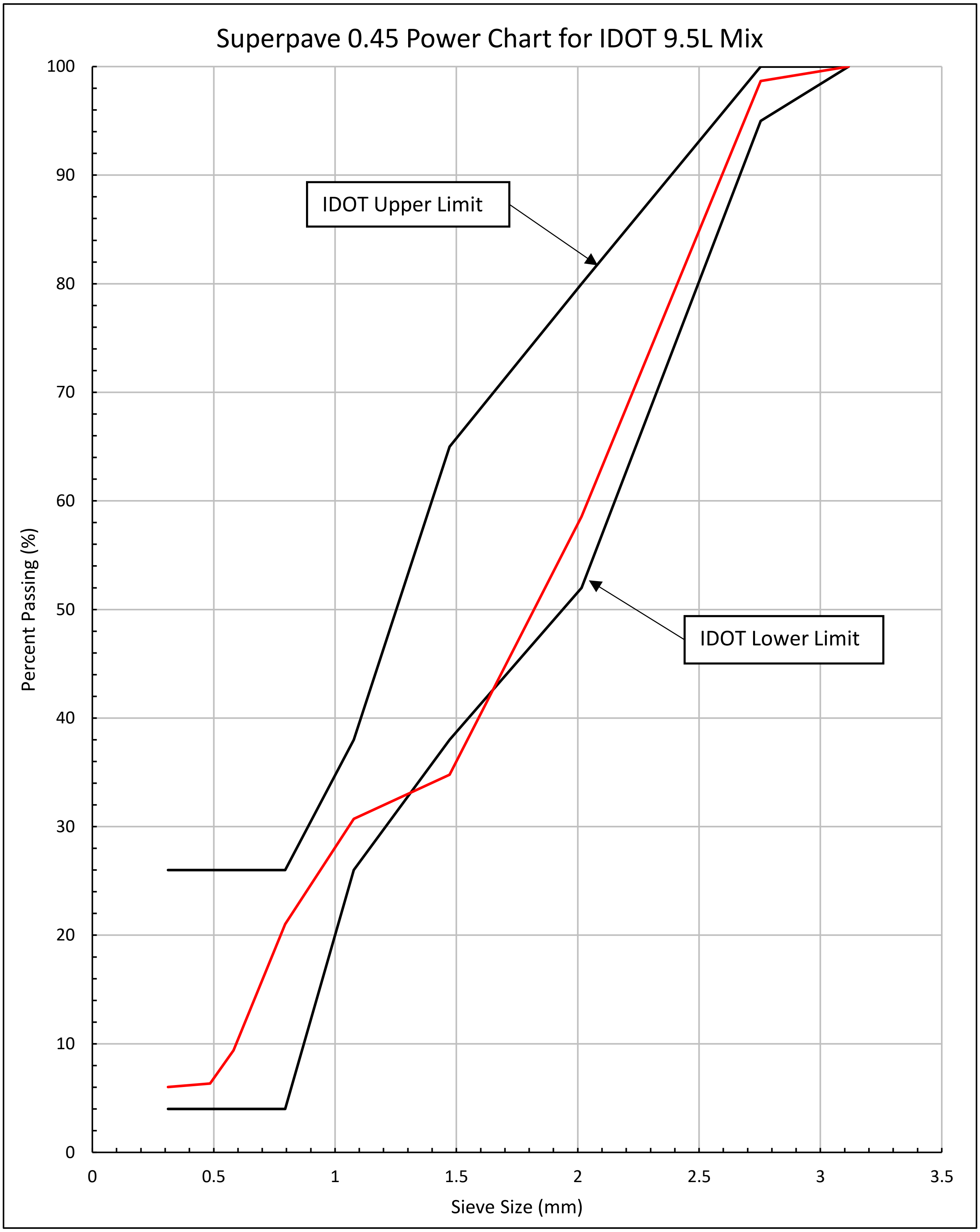
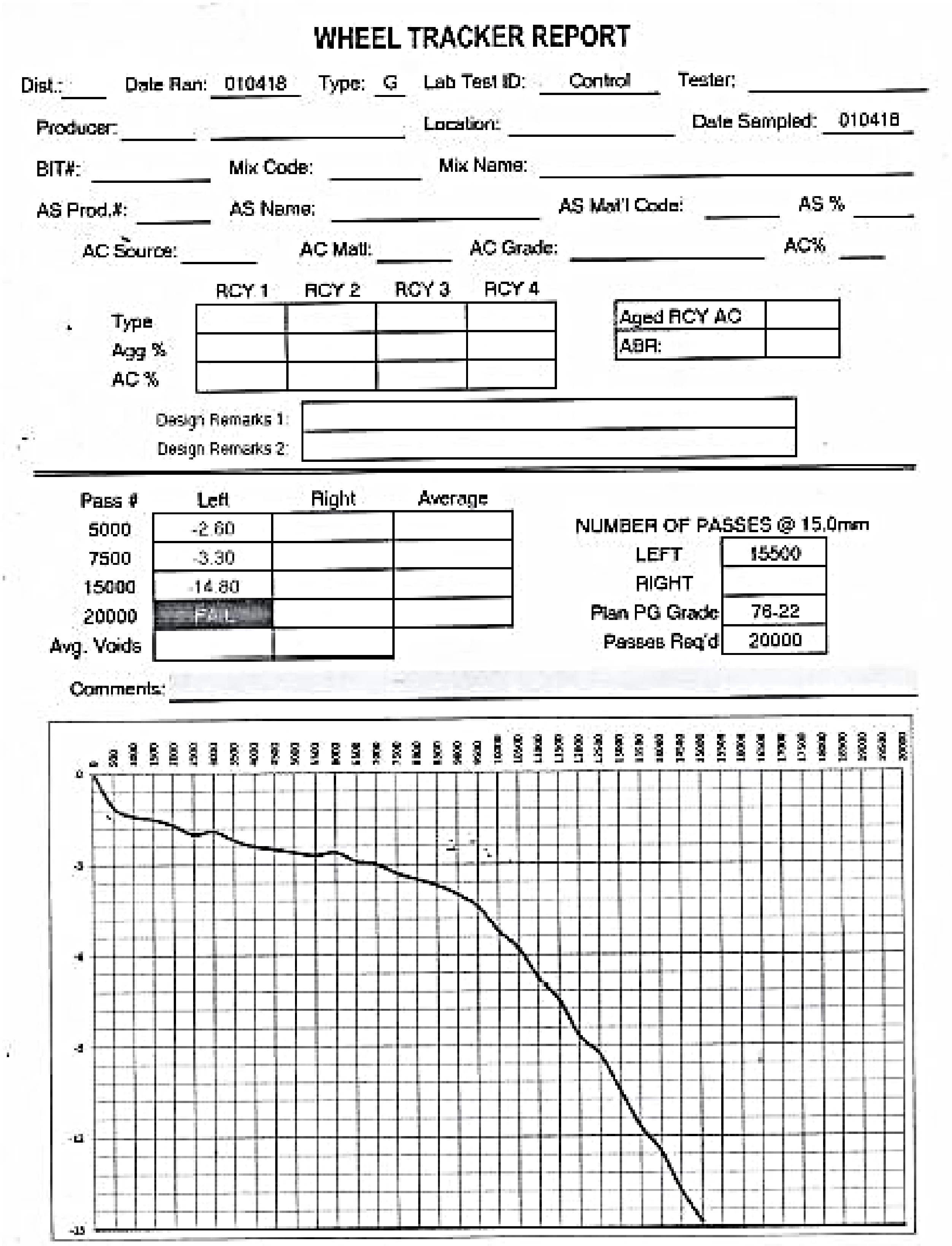


Figure B.2 Hamburg Wheel Test Result – Control



WHEEL TRACKER REPORT

Dist.: Date Ran: 010418 Type: G Lab Test ID: Control Tester:

Producer: Location: Date Sampled: 010418

BIT#: Mix Code: Mix Name:

AS Prod.#: AS Name: AS Mat'l Code: AS %

AC Source: AC Matl: AC Grade: AC%

	RCY 1	RCY 2	RCY 3	RCY 4
Type				
Agg %				
AC %				

Aged RCY AC	
ABR:	

Design Remarks 1:
Design Remarks 2:

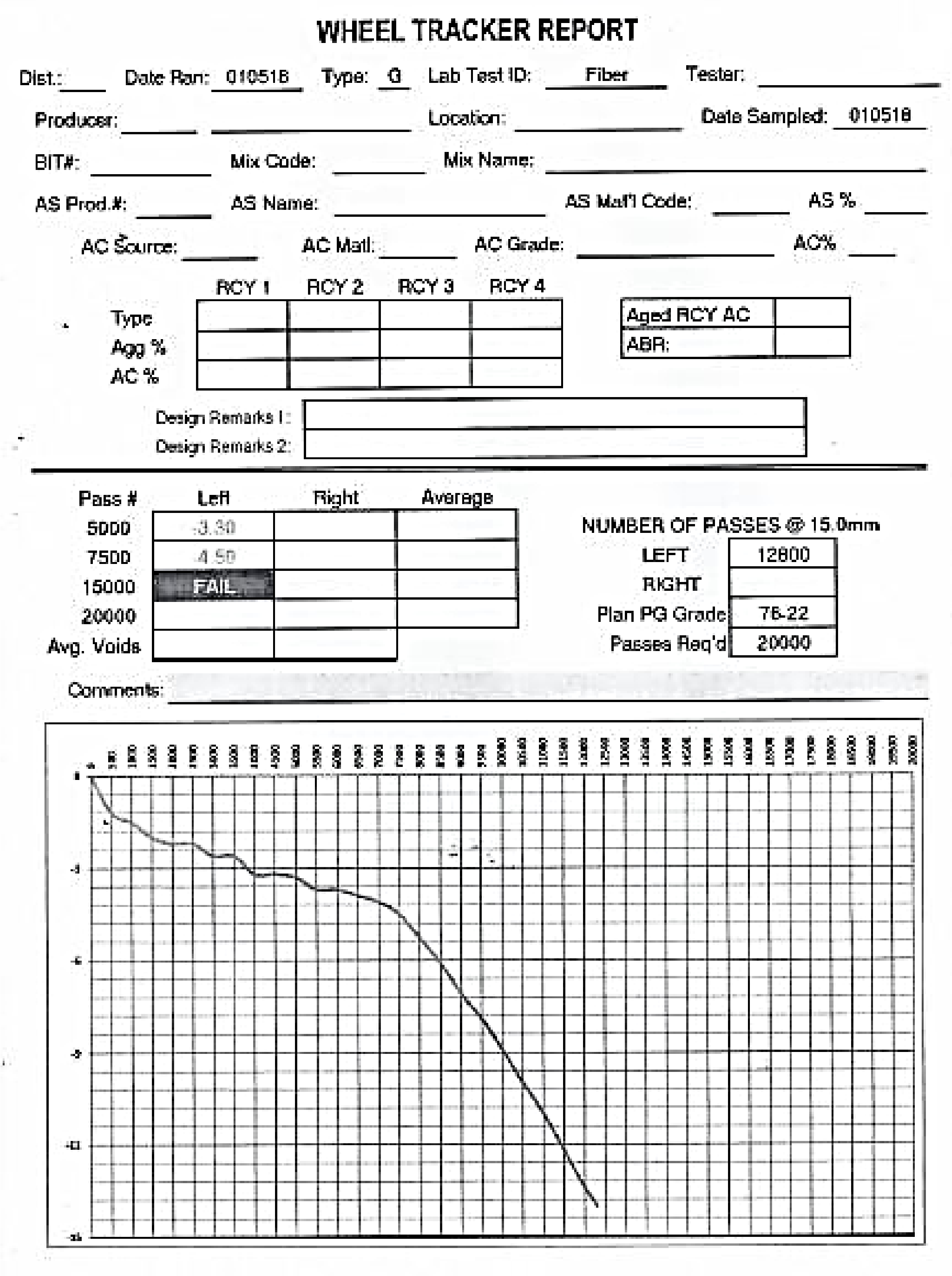
Pass #	Left	Right	Average
5000	-2.60		
7500	-3.30		
15000	-14.80		
20000	FAIL		
Avg. Voids			

NUMBER OF PASSES @ 15.0mm

LEFT	15500
RIGHT	
Plan PG Grade	76-22
Passes Req'd	20000

Comments:

Figure B.3 Hamburg Wheel Test Results – Fiber Reinforcing



WHEEL TRACKER REPORT

Dist.: ____ Date Ran: 010518 Type: G Lab Test ID: Fiber Tester: ____

Producer: ____ Location: ____ Date Sampled: 010518

BIT#: ____ Mix Code: ____ Mix Name: ____

AS Prod.#: ____ AS Name: ____ AS Mat'l Code: ____ AS % ____

AC Source: ____ AC Matl: ____ AC Grade: ____ AC% ____

	RCY 1	RCY 2	RCY 3	RCY 4
Type				
Agg %				
AC %				

Aged RCY AC	
ABR:	

Design Remarks 1:

Design Remarks 2:

Pass #	Left	Right	Average
5000	3.30		
7500	4.50		
15000	FAIL		
20000			
Avg. Voids			

NUMBER OF PASSES @ 15.0mm

LEFT	12800
RIGHT	
Plan PG Grade	76-22
Passes Req'd	20000

Comments: [redacted]

Figure B.4 Hamburg Wheel Test Results – Steel Reinforcing

WHEEL TRACKER REPORT

Dist.: Date Ran: 010818 Type: G Lab Test ID: Steel Tester:

Producer: Location: Date Sampled:

BIT#: Mix Code: Mix Name:

AS Prod.#: AS Name: AS Mat'l Code: AS %

AC Source: AC Mat'l: 10131 AC Grade: PG 76-22 MOD AC%

	RCY 1	RCY 2	RCY 3	RCY 4
Type				
Agg %				
AC %				

Aged RCY AC	
ABR:	

Design Remarks 1:

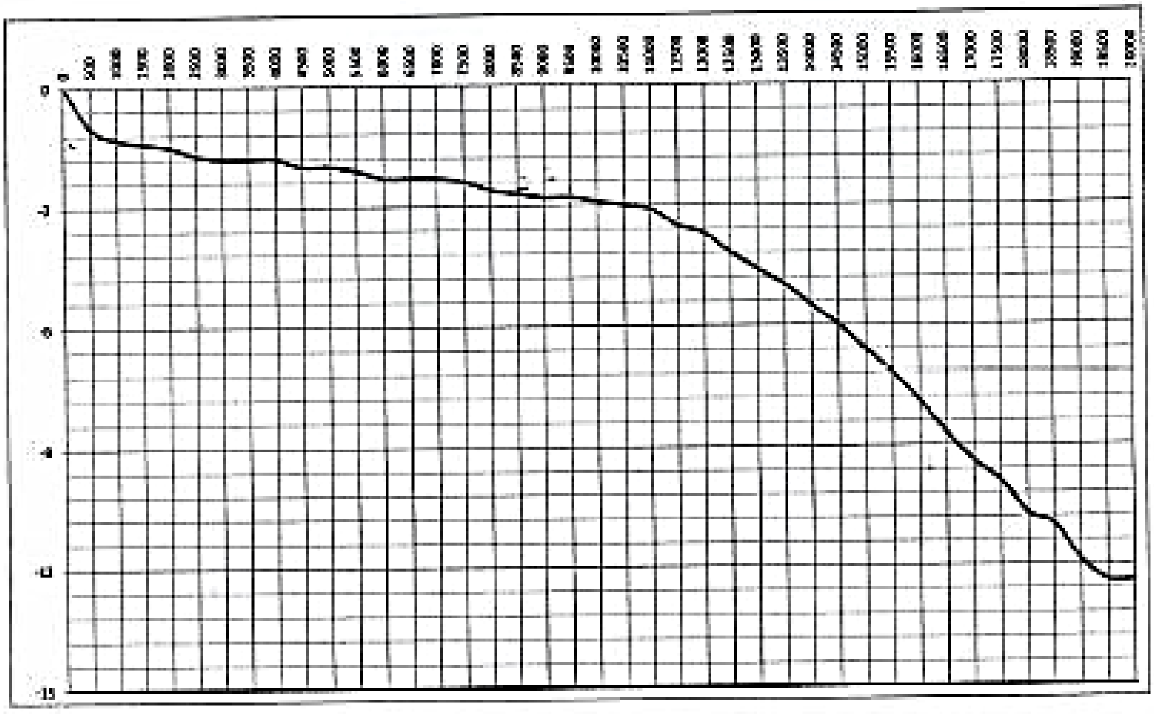
Design Remarks 2:

Pass #	Left	Right	Average
5000	-2.00		
7500	-2.40		
15000	-6.60		
20000	-12.40		
Avg. Voids			

NUMBER OF PASSES @ 15.0mm

LEFT	
RIGHT	
Plan PG Grade	76-22
Passes Req'd	20000

Comments:



ANALYSIS

From the data above, one can deduce many issues with the experiment. First, the specified mix did not meet IDOT's aggregate gradation limits and the mixes did not meet the IL 9.5L Low ESAL mix specification. Secondly, the control sample and fiber reinforced sample failed the Hamburg Wheel Tracker Test. If the mix design was made to the specification, then the samples would have more than likely passed the specified test. Lastly, the fiber reinforcement should have shown improvement to the standard mix, however, this was shown to be inaccurate. The following describes reasons for failure:

- Inaccurate Aggregate Measurements
- Temperature fluctuation during mixing and aging
- Improper Aggregate Type Ratios
- Pre-Dispersion and Mixing of Fiber/Reinforcement
- Fiber/Reinforcement Alignment
- Inconsistent Weight Measurements
- Unequal Aging times

The attached addendums G and H provided by Josh Hammaker shows additional studies conducted by State Government Agencies. Looking at this data it can be said that the polymer fiber reinforcement can greatly impact mix strength and longevity over time. However, it cannot be compared to IL 9.5L or the steel reinforcing tested in this experiment.

The fiber reinforcement provided by FORTA Corp. was quoted at $10 per bag which is enough reinforcement for 1 ton of asphalt. This could potentially provide a viable solution for increasing the life cycle of a project while maintaining an economic solution when comparing regular asphalt, reinforced asphalt, and concrete.

REFERENCES

- SIUE Civil Engineering Department Student Lab Manual
- AASHTO M 323
- AASHTO T 324
- TXDOT FM2222 Testing Results 2014
- Federal Highway Administration Testing Results for PennDOT
- Laboratory Mixing Procedures for FORTA-FI

CE 330L Student Lab Manual
Superpave^{TM} Mix Design (IL-9.5L)
PART A
Pre-Laboratory Preparation

Introduction

This manual outlines the steps necessary to design, prepare and evaluate a hot mix asphalt (HMA) specimen using the Superpave^{TM} (Superior Performing Asphalt Pavements) mix design method and criteria. Superpave^{TM} has been recently adopted by many state highway departments, replacing the Marshall and the Hveem methods for asphalt mix design.

This manual includes the following parts.

A. Project parameters, aggregate blending, asphalt binder selection, and material properties.
B. Preparation of the hot mix specimen.
C. Validation of the final mix results.
D. Appendix with supporting data and lab worksheets.

Related topics of asphalt binder properties and selection, equipment calibration and performance testing are not part of this document. Students wishing to learn more about the total Superpave^{TM} process can contact the instructor for a list of additional resources.

Design Criteria

Superpave mix design requires many aggregate and asphalt cement (IDOT refers to this as bituminous) properties to be evaluated and selected to meet a particular set of standards. In Illinois, as in most states, certain characteristics of the final mix design have been adopted and must be used for certain projects. To reduce detail work that is beyond the scope of CE330L, many of the properties have already been selected. The following procedures are based on the selected properties. The specifications given in Table 1 are presented to highlight the primary design target values necessary for approval of the mix under IDOT's criteria (modified AASHTO M 323) for the **IL-9.5L)** mix designation only. For other mixes, refer to appropriate sources for the target values.

Table 1. Design Specification for IL-9.5L

Parameter	Target Value
Required Initial Density, $N_{initial}$	5
Required Design Density, N_{design}	30
Required Maximum Density, N_{max}	42
Design Air Voids (Va)	4.0%, target at N_{design}
Voids in Mineral Aggregate (VMA)	15%, minimum at N_{design}
Percent (%) Voids in Total Mix (VTM)	2.0%, minimum to 8.0%, maximum at N_{design}
Voids Filled with Asphalt (VFA)	65-78% at N_{design}
Dust/AC ratio (D/B)	1.0 maximum
Maximum percentage of G_{mm} @ $N_{initial}$	89%
Maximum percentage of G_{mm} @ N_{max}	98%

(Note: G_{mm} is the theoretical maximum specific gravity of the mix.)

Safety Considerations

This lab experiment involves working with hot aggregates and hot liquid asphalt at temperatures of up to about 350 °F. The asphalt ignition oven will be operating at about 1100 °F. Also, there is risk that some of the materials could stain your clothing, so plan to wear appropriate clothing.

In addition to the standard lab safety requirements, you are required to bring and wear the following safety items:

- safety glasses
- long pants
- shoes that completely cover your feet

In addition to the items above, you will be provided with heat-resistant gloves, Kevlar sleeves, a lab coat and face shield as needed for certain operations in the lab.

Procedures

A key step in the procedure for designing a Superpave mix is to select appropriate amounts of standard aggregate gradations to achieve a well-graded, dense mix. Though you have already tested the aggregates in a previous experiment, we will use standardized results in the actual mixing procedures to reduce variations in the final mix since each group will share their HMA mix design results with the other groups.

Testing was performed to find the gradation characteristics of the materials stockpiled for this lab. Table A1 shows the gradations required for the IL-9.5L mix. Table A2 shows the results of the sieve and specific gravity tests for the four standard aggregate gradations stockpiled for this lab. Table A3 shows the standardized aggregate proportions for the Superpave HMA mix design to be used in the experiment.

Step 1

Refer to Table A3 which shows the percentage of each aggregate gradation to be used to make a 7,000-gram batch, which includes the mass of the asphalt. Compute the mass of each aggregate per this table. Note that the standard mix design procedure for the CA-16 material is to presort and place into individual buckets to separate the larger particle sizes (3/8" inch through #30). This is done to reduce the effects of particle size segregation on the final mix design. Using this method, the mass of each particle size gradation to be used from the CA-16 stock is given in the table. However, if reasonable precautions have been taken to prevent particle size segregation, the CA-16 does not need to be presorted. Your instructor will let you know which method to use for this lab. ***Complete the table by computing the total mass of each aggregate required for the asphalt content assigned to your group***. The total should add to 7,000 grams.

Step 2

Superpave uses the 0.45 power chart for plotting the mix gradation (Figure A1). **Using the results of your group's sieve tests**, plot the total batch percentages for each sieve size of the combined aggregates on the 0.45 power chart. Verify that the batch gradation is within the control points. For the purpose of this experiment, mention any deviations in your report.

NOTE: In actual practice the aggregate used for the trial batch must be within the gradation parameters of the 0.45 power chart in order to proceed. If it doesn't meet the parameters, then the mix designer must adjust material percentages, recalculate the batch percentages, and plot the resulting new batch gradation.

Step 3

Having successfully obtained the trial batch gradation percentages, make a batch of asphalt mix. For specific instructions on how to make the asphalt mix refer to Part B of this manual.

Superpave Asphalt Mix Design - Part B

Laboratory Procedures for the Preparation of HMA Test Specimens

Materials

The following materials will be used in the specimen production.

- Performance Graded Asphalt Binder
- Course Aggregate
- Fine Aggregate
- Mineral Filler (is needed for the mix)

Equipment

The following equipment will be utilized in the specimen production.

- Ovens, thermostatically controlled
- Mechanical Mixer, 10 qt.
- Flat bottom metal pans
- Metal Scoop, spatula, and spoons
- WD-40 or other light lubricating fluid
- Pouring pot, for heating and dispensing liquid asphalt binder
- Thermometers to measure 250-350°F
- Balances, 8 kg capacity
- Heat resistant gloves, Kevlar sleeves
- Yellow lumber crayon, for specimen identification marking
- Paper disks, 6 inches, for gyratory compaction
- Gyratory Compactor with computer (for compacting and recording specimen data)

Definitions

Although students should be familiar with the basic terminology of the asphalt mix design process from lecture, the following definitions are provided for ease of reference as these are used throughout the manual.

- **Asphalt Binder**: the asphalt cement used to mix and bind the aggregate and mineral filler.
- **Course Aggregate**: rock particles generally larger than the #4 sieve.
- **Fine Aggregate**: sand, silt, and clay particles generally smaller than the #4 sieve but larger than the #200 sieve.
- **Mineral Filler**: dust size particles used to fill small voids in the hot mix asphalt specimen.
- **Gyratory Compactor**: a piece of equipment used to compact the asphalt mix design specimen at a specified pressure, angle of tilt, and revolution cycles.
- **N_{design}, Design Gyrations**: the number of gyrations for the particular mix design specimen. Corresponds to the compaction at the end of the pavements design life. This is where the optimum asphalt content is determined corresponding to the specified air voids.
- **N_{init}**: the number of gyrations at which the specific gravity must not exceed 89 percent of Gmm. Corresponds to the expected compaction at the time of the pavement's construction.

- **N_{max}**: the number of gyrations at which the specific gravity must not exceed 98 percent of Gmm. Corresponds to the maximum recommended density.

Warning: The asphalt mix design specimen procedure involves the use of heavy aggregates and hot asphalt liquid. Students should follow all lab safety procedures to avoid injury.

Procedures

The following steps outline the basic procedures in the HMA specimen production. These basic steps are taken from Asphalt Institute. (1996). "Superpave Mix Design: Superpave Series No. 2 (SP-2)." U.S.A. Some adjustments were made to help fit the sequence to our allotted lab schedule.

Materials

Step 1

Complete the pre-lab exercise described in Part A to determine the batch weights of course and fine aggregate, mineral filler and asphalt to be used for the HMA specimen production. Carefully weigh out the required aggregate sizes and place in separate containers. Put the aggregate in the oven and heat for 1 hour at 165+/-3^{o}C (329+/-5^{o}F).

Step 2

After preheating, remove the materials from the oven as you need them. Avoid allowing anything to cool before mixing.

Combining and Mixing

Step 3

Place the CA-16 aggregate into the mechanical mixing bowl. Do NOT add the FA-01 materials yet.

Form a "bowl" shape in the FA-01. Dispense the required amount of asphalt into this aggregate bowl.

Add the FA-01 and asphalt to the aggregate already in the mixing bowl. Mount the mixing bowl on the mixer. Turn the mixer on (low speed setting of 1) and mix until most of the asphalt is distributed. Turn the mixer off. Add the remaining aggregate filler fines, if any. Turn the mixer on and mix the batch until all the aggregate is fully coated with the asphalt binder. Periodically turn the mixer off and lightly scrape the material sticking to the sides of the bowl or upper portion of the mixing wisp. Turn the mixer off.

Step 4

Remove all the specimen materials from the mixer and place mixture onto two shallow metal pans. Spread mixture to an even thickness and place in the oven for 1 hour at 165^{o}C. This time in the oven is done to simulate short-term aging that occurs during the actual HMA production and transportation phases prior to compaction.

Compaction

In this sequence, you will make a compacted HMA specimen. The gyratory compactor will monitor the compaction pressure, sample height and number of gyrations. This data will be displayed during the compaction phase and saved to a file on the computer. The computer program will stop the gyratory compactor at the specified endpoint, which for our lab will be after N_{max} gyrations of 42.

Step 5

While the mixture is aging in the oven, prepare the gyratory compactor for use. Connect the computer to the gyratory compactor via the COM1 serial port. Prepare the computer software that operates and collects the data from the compactor. For this operation, verify the compaction pressure of 600 kpa, compaction mold inclination angle of 1.25^o, and enter the $\mathbf{N_{max} = 42}$ into the software at the appropriate location on the screen. Place the compaction mold and mold bottom in the oven for 60 minutes at the 165^oC temperature.

Step 6

Remove the mixture and the compaction mold from the oven at the same time. Spray a thin layer of a light lubricant (eg. WD-40) to coat the inside of the mold. Next, place a paper filter disk on the bottom plate of the mold.

Using a scoop or spatula, measure approximately 4,500 grams of the specimen mixture into a preheated bowl.

IMPORTANT: Record on the datasheet the **actual** mass of HMA to be placed in the mold.

Then dump the mix into the mold in one smooth operation.

Finally, gently level the top of the HMA specimen and place another paper filter disk on top of the specimen mixture in the mold. Do NOT tamp the loose HMA.

Step 7

Place the mold with the specimen into the gyratory compactor and click the Start button on the gyratory compactor program screen. During the compaction process, the computer will monitor the specimen height, the compaction pressure, tilt angle and number of gyrations. The program will stop the test once reaching the designated $\mathbf{N_{max}}$ gyrations. Be sure the compaction angle stays within 0.10° of the 1.25° target angle. If it varies, stop the compactor temporarily by lifting the guard door. This will stop the rotation so you can insert the handle to adjust the tilt angle. Then remove the handle, close the door and allow the compaction process to continue.

Step 8

Once the compaction is complete, remove the mold from the center hold. Center the mold over the top of the extraction piston on the compactor base. Press the extraction button on the compactor and extrude the specimen from the mold. Let the specimen cool enough so that it does not crumble or distort when carefully handled. Use a small fan to speed the cooling process. Remove the paper disks and, using a lumber crayon or chalk, mark the top of the specimen with your lab group number for future identification.

Proceed to Part C for Validation test procedures.

Superpave Asphalt Mix Design - Part C

Validation Procedures and Report Requirements for the Prepared HMA Test Specimens

Introduction

The final step in the Superpave mix design method is to determine if the trial batch meets the specifications. Follow the steps in the section below to determine Va, VMA, and VFA. These are the last criteria that the mix design must meet. Having met these remaining criteria, you will have successfully completed a proper Superpave mix design.

Procedures

Volumetrics

In order to determine if the trial batch meets the ***Design Criteria***, the mix needs to be tested to determine whether the target values have been met for the particular gradation chosen. The following procedures highlight the final process of the mix design. The results will determine whether the mix meets the specified design criteria.

- HMA Maximum Theoretical Density, $\mathbf{G_{mm}}$

  Refer to AASHTO T 209 (our masses used are equivalent to the masses in T 209)

- HMA Bulk Specific Gravity, $\mathbf{G_{mb}}$

  Refer to AASHTO T 166 Method A(our masses are equivalent to the masses in T 166)

  NOTE: Soak specimen in water @ 25 +/- 1ºC for **10 +/- 1** minutes before reading the immersed mass.

- Combined Bulk Specific Gravity of Aggregate Blend, $\mathbf{G_{sb}}$

  When the total aggregate trial blend consists of aggregates with different specific gravities, which is usually the case, then the Bulk Specific Gravity for the blend must be calculated using:

$$G_{sb} = \frac{P_1 + P_2 + \ldots\ldots + P_n}{\frac{P_1}{G_1} + \frac{P_2}{G_2} + \ldots. + \frac{P_n}{G_n}}$$

Where, $\mathbf{G_{sb}}$ = bulk specific gravity of total aggregate blend

$\mathbf{P_1, P_2, P_n}$ = individual percentages by mass of aggregate

$\mathbf{G_1, G_2, G_n}$ = individual specific gravities of aggregate

- Aggregate Percentage by Mass, $\mathbf{P_s}$

  Total percentage by mass of the batch by the total mass of the aggregate.

Calculations

Using the above values, substitute into the following equations to determine **VMA, Va** and **VFA.**

Property

VMA $= 100 - (G_{mb} * P_s)/G_{sb}$

Va $= 100 * (G_{mm} - G_{mb})/G_{mm}$

VFA $= 100 * (VMA - Va)/VMA$

Report Requirements

After completing the lab work, you must submit a report summarizing what you learned. The data collected by your group as well as others should be included in the report. The report should be in R-4 format. R-4 report format is shown in the Report Requirements section on the CE330L web site.

In the appendix, include the following:

- Data (raw data from your group's work, end results, i.e. G_{mm}, G_{mb} from the other groups' results.)
- Sample calculations for aggregate gradation, specific gravity and mix volumetrics. Use the Superpave Volumetrics Worksheet as a guide.
- Plot each aggregate gradation on its own semilog gradation chart.
- Plotted 0.45 power chart (use Figure App-1) for the combined aggregate gradation.
- Plot the following curves in separate charts *aligned vertically on one page* showing Asphalt Content (AC) percentage on the x-axis vs. the volumetric values listed below. Draw and label the projection lines you use to find the following coordinates:
    1. Percent Air Voids (AV). Draw line from Air Voids axis to find the optimum AC at the specified air voids ratio.
    2. Percent Voids in Mineral Aggregate (VMA). Draw a line representing the required VMA minimum and indicate the point on the VFA curve corresponding to optimum AC.
    3. Percent Voids Filled with Asphalt (VFA). Draw lines representing the minimum and maximum limits of VFA and indicate the point on the VFA curve corresponding to optimum AC.

Appendix

Table A1. IDOT IL-9.5L Low ESAL Aggregate Gradation Control Points

(Ref. Art. 1030.04, IDOT Standard Specifications for Road and Bridge Construction Adopted January 1, 2012)

Sieve Designation	Size mm	Percent Passing Min	Max
1/2"	12.5	--	100
3/8"	9.50	95	100
No. 4	4.75	52	80
No. 8	2.36	38	65
No. 30	0.600		<50% of the percentage passing the #4
No. 200	0.075	4.0	8.0
Asphalt Binder %		4.0	8.0
Ratio Dust/Asphalt Binder			1.0 at design AC%

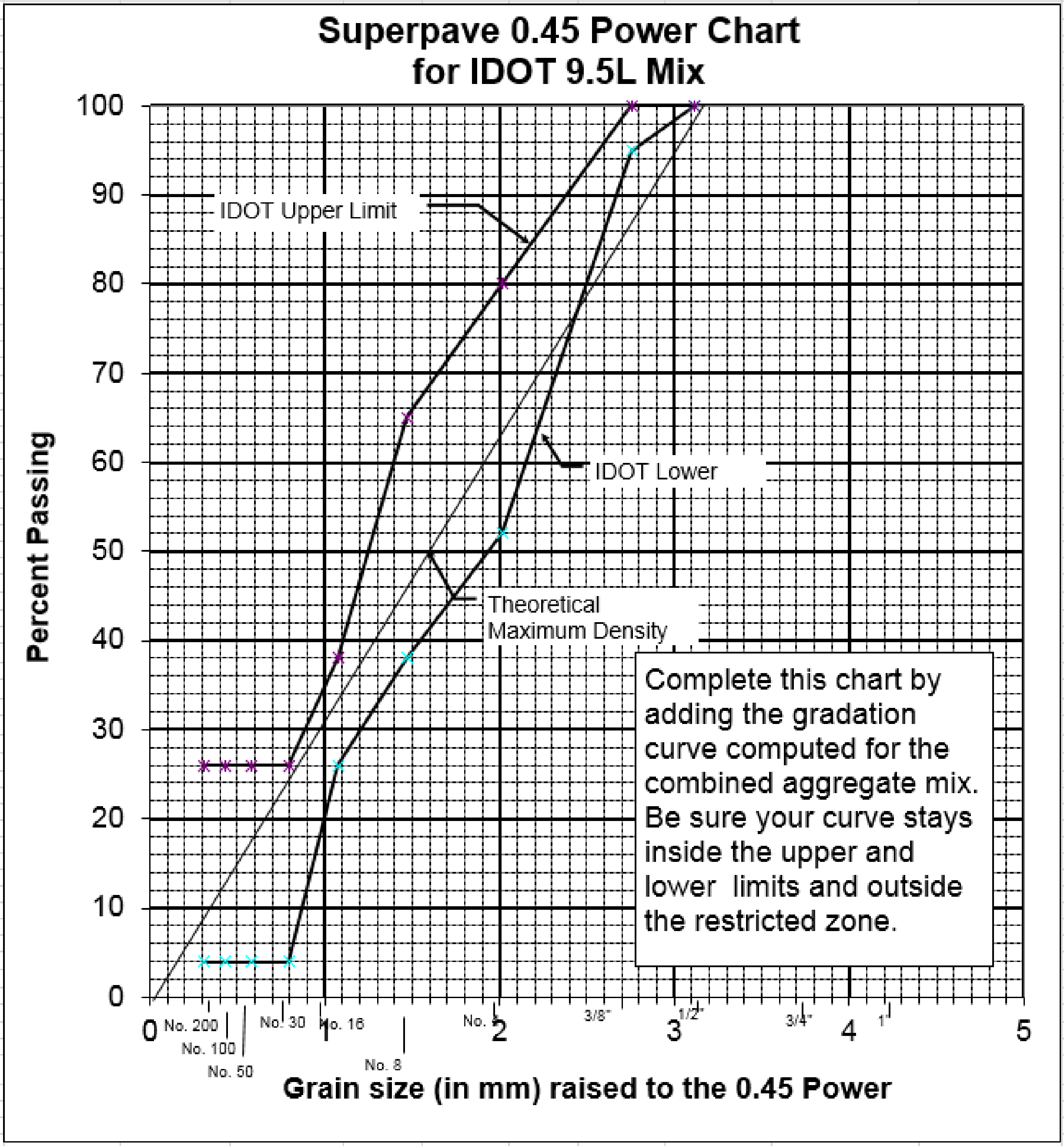
Table A2. CE Dept. Laboratory Aggregate Gradations

Sieves Designation	Size mm	CA-16	FA-01	MF
1/2"	12.5	100.0	100.0	100.0
3/8"	9.50	98	100.0	100.0
No. 4	4.75	39	98	100.0
No. 8	2.36	6	92.3	100.0
No. 16	1.18	4	82.9	100.0
No. 30	0.60	3	51.8	100.0
No. 50	0.30	3	11.7	100.0
No. 100	0.20	3	1.4	98.0
No. 200	0.075	3	1.0	93.0
Specific Gravity		2.61	2.66	2.67

Table A3. Batch Requirements from Aggregate Stockpiles

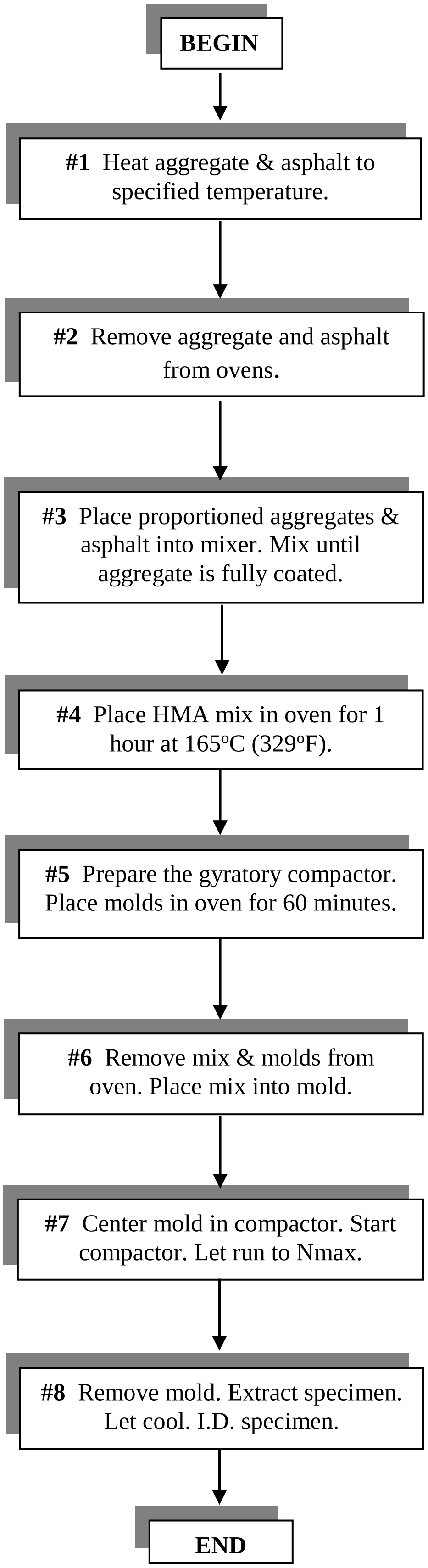
Batch Requirements - Aggregate Proportion Percentage by mass of total aggregates		
CA-16	**FA-01**	**MF**
67	**29**	**4**

Figure A2 – Superpave 0.45 Power Chart



Complete this chart by adding the gradation curve computed for the combined aggregate mix. Be sure your curve stays inside the upper and lower limits and outside the restricted zone.

Figure A2. HMA Specimen Production Flowchart



SUPERPAVE VOLUMETRICS LAB WORKSHEET

Name: ________________________ Group: __

Enter the sample mass, SGC gyrations and corresponding sample heights

$W_m := \blacksquare \ \mathrm{g}$ Mass of compacted sample "puck"

$N_{init} := \blacksquare$ $h_{init} := \blacksquare \cdot \mathrm{mm}$

$N_{des} := \blacksquare$ $h_{des} := \blacksquare \cdot \mathrm{mm}$ $d := 150 \cdot \mathrm{mm}$ Mold diameter

$N_{max} := \blacksquare$ $h_{max} := \blacksquare \cdot \mathrm{mm}$ NOTE The subscripts refer to the three main gyration levels as follows: *init* => initial, *des* => design, *max* => maximum

Specify Asphalt Cement Content (as a percentage of the <u>total HMA mass</u>),P_b

$P_b := \blacksquare \ \%$ $P_b =$

Specify Specific Gravity of Asphalt, G_b

$G_b := \blacksquare$ $G_b =$

Calculate Aggregate Percentage by Mass, P_s

$$P_s := 100 \cdot \frac{100}{100 + P_b} \ \%$$

$P_s = \ \%$

Calculate Combined Bulk Specific Gravity of Aggregate Blend, G_{sb}

$P_1 := \blacksquare$ $G_1 := \blacksquare$

$P_2 := \blacksquare$ $G_2 := \blacksquare$

$P_3 := \blacksquare$ $G_3 := \blacksquare$

$P_4 := \blacksquare$ $G_4 := \blacksquare$

$$G_{sb} := \frac{P_1 + P_2 + P_3 + P_4}{\frac{P_1}{G_1} + \frac{P_2}{G_2} + \frac{P_3}{G_3} + \frac{P_4}{G_4}}$$

$G_{sb} =$

Calculate Theoretical Maximum Specific Gravity of HMA Mix for this group's mix, G_{mm}

Mass of HMA added to Pycnometer, A

$A := \blacksquare \cdot \mathrm{g}$

Mass of HMA and Pycnometer filled with Water, E

$E := \blacksquare \cdot \mathrm{g}$

Mass of Pycnometer filled with Water at the same temperature as for E

$D := \blacksquare \cdot \mathrm{g}$

$$G_{mm} := \frac{A}{A + D - E}$$

$G_{mm} =$

Calculate Effective Specific Gravity of Aggregate for this Group's mix, G_{se_i}

$$G_{se\_i} := \frac{100 - P_b}{\frac{100}{G_{mm}} - \frac{P_b}{G_b}}$$

i = your group number

$G_{se\_i} =$

Calculate Average Effective Specific Gravity of Aggregate for all Groups' mixes, G_{se_avg}

$$G_{se\_avg} := \frac{\Sigma G_{se\_i}}{N_{mixes}}$$

N_{mixes} = the number of mixes from which the individual $G_{se\text{-}i}$ values come from

$G_{se\_avg} =$

Calculate Adjusted Theoretical Maximum Specific Gravity of HMA Mix for this group's mix based on the average G_{se_avg}, G_{mm_adj}

$$G_{mm\_adj} := \frac{100}{\frac{P_s}{G_{se\_avg}} + \frac{P_b}{G_b}}$$

Calculate Bulk Specific Gravity of Compacted HMA Mix, G_{mb} @ $N_{max} =$

Mass of HMA puck in water, C

$C := \blacksquare \cdot g$

Mass of saturated-surface-dry HMA puck in air, B

$B := \blacksquare \cdot g$

Mass of dried HMA puck in air, F

$F := \blacksquare\ g$

$$G_{mb} := \frac{F}{B - C}$$

$G_{mb} =$

Calculate compacted sample volume

$$V_{m\_init} := \frac{\pi \cdot d^2 \cdot h_{init}}{4} \cdot 0.001 \cdot \frac{cm^3}{mm^3}$$

$V_{m\_init} =$

$$V_{m\_des} := \frac{\pi \cdot d^2 \cdot h_{des}}{4} \cdot 0.001 \cdot \frac{cm^3}{mm^3}$$

$V_{m\_des} =$

$$V_{m\_max} := \frac{\pi \cdot d^2 \cdot h_{max}}{4} \cdot 0.001 \cdot \frac{cm^3}{mm^3}$$

$V_{m\_max} =$

Calculate bulk specific gravity

$$G_{mb\_max\_est} := \frac{\frac{W_m}{V_{m\_max}}}{1 \cdot \frac{g}{cm^3}} \qquad G_{mb\_des\_est} := \frac{\frac{W_m}{V_{m\_des}}}{1 \cdot \frac{g}{cm^3}} \qquad G_{mb\_init\_est} := \frac{\frac{W_m}{V_{m\_init}}}{1 \cdot \frac{g}{cm^3}}$$

$G_{mb\_max\_est} =$

Calculate correction factor

$$C := \frac{G_{mb}}{G_{mb\_max\_est}}$$

C =

Calculate relative compaction

$G_{mb\_init} := C \cdot G_{mb\_init\_est}$ $G_{mb\_init} =$ @ $N_{init} =$

$G_{mb\_des} := C \cdot G_{mb\_des\_est}$ $G_{mb\_des} =$ @ $N_{des} =$

$G_{mb\_max} := C \cdot G_{mb\_max\_est}$ $G_{mb\_max} =$ @ $N_{max} =$

Calculate corrected G_{mb}

$\%G_{mm\_init} := 100 \cdot \frac{G_{mb\_init}}{G_{mm\_adj}}$ % $V_{a\_init} := 100 - \%G_{mm\_init}$

$\%G_{mm\_des} := 100 \cdot \frac{G_{mb\_des}}{G_{mm\_adj}}$ % $V_{a\_des} := 100 - \%G_{mm\_des}$

$\%G_{mm\_max} := 100 \cdot \frac{G_{mb\_max}}{G_{mm\_adj}}$ % $V_{a\_max} := 100 - \%G_{mm\_max}$

Calculate Voids in Mineral Aggregate in Compacted Mix, VMA

$VMA_{init} := 100 - \frac{G_{mb\_init} \cdot P_s}{G_{sb}}$ % $VMA_{init} =$ %

$VMA_{des} := 100 - \frac{G_{mb\_des} \cdot P_s}{G_{sb}}$ % $VMA_{des} =$ %

$VMA_{max} := 100 - \frac{G_{mb\_max} \cdot P_s}{G_{sb}}$ % $VMA_{max} =$ %

Calculate Percentage of Air Voids in Compacted Mix, V_a

$V_{a\_init} := 100 \cdot \frac{\left(G_{mm\_adj} - G_{mb\_init}\right)}{G_{mm\_adj}}$ % $V_{a\_init} =$ %

$V_{a\_des} := 100 \cdot \frac{\left(G_{mm\_adj} - G_{mb\_des}\right)}{G_{mm\_adj}}$ % $V_{a\_des} =$ %

$V_{a\_max} := 100 \cdot \frac{\left(G_{mm\_adj} - G_{mb\_max}\right)}{G_{mm\_adj}}$ % $V_{a\_max} =$ %

Calculate Percentage of Voids Filled with Asphalt in Compacted Mix, VFA

$VFA_{init} := 100 \cdot \frac{VMA_{init} - V_{a\_init}}{VMA_{init}}$ % $VFA_{init} =$ %

$VFA_{des} := 100 \cdot \frac{VMA_{des} - V_{a\_des}}{VMA_{des}}$ % $VFA_{des} =$ %

$VFA_{max} := 100 \cdot \frac{VMA_{max} - V_{a\_max}}{VMA_{max}}$ % $VFA_{max} =$ %

SUMMARY

% Asphalt in mix	$P_b =$ %
Bulk Sp. Grav of Aggregate	$G_{sb} =$
Average Effective Sp. Grav of Aggregate	$G_{se\_avg} =$
Theoretical Max. Sp. Grav., adjusted based on all mixes	$G_{mm\_adj} =$

Gyrations	$N_{init} =$	$N_{des} =$	$N_{max} =$
Bulk Sp. Gravity	$G_{mb\_init} =$	$G_{mb\_des} =$	$G_{mb\_max} =$
% of Max Sp. Gravity	$\%G_{mm\_init} =$ %	$\%G_{mm\_des} =$ %	$\%G_{mm\_max} =$ %
% Air Voids	$V_{a\_init} =$ %	$V_{a\_des} =$ %	$V_{a\_max} =$ %
% Voids Filled with Asphalt	$VFA_{init} =$ %	$VFA_{des} =$ %	$VFA_{max} =$ %
% Voids in Mineral Aggregate	$VMA_{init} =$ %	$VMA_{des} =$ %	$VMA_{max} =$ %

FORTA-FI®

Laboratory Sample Mixing for FORTA-FI

Calculation of Fiber Dosage

The fiber dosage rate is calculated based on weight of the asphalt mix sample to be prepared in the laboratory. The typical fiber dosage rate is 0.05%. The amount of each type of fiber to be used shall be coordinated with FORTA Corporation. FORTA-FI consists of different types of fibers designed to provide optimum mix performance. FORTA will prepare two sample bags of fiber for laboratory blending: Bag #1 and Bag #2.

Batching Aggregates and Mix Preparation (bucket mixer)

1. Divide Bag #1 into two equal portions (by mass).
2. Calculate the amount of each aggregate size and the amount of asphalt cement required to make one gyratory sample using the mix design gradation.
3. Weigh and batch the aggregates in a single container.
4. Evenly divide (by mass) the batched aggregates into three suitable size metal containers for heating.
5. Keep the metal containers with the batched aggregates in the oven until thoroughly heated to 6 - 8°C higher than the mixing temperature (to compensate for heat lost while adding fibers). Preferably heat overnight but a minimum of 6 hours unless local laboratory practice suggests less time is sufficient.
6. Prior to mixing, heat asphalt cement in an oven at the mixing temperature and wait until the asphalt cement reaches the mixing temperature.
7. Heat all mixing tools (bucket, blade, metal scoop, metal spoon and spatula) to the mixing temperature.
8. Once the asphalt cement reaches the mixing temperature, transfer the aggregates and Bag #1 fibers to the mixing bucket according to the following steps (The entire process of adding aggregate and fiber in the 3-layer system should be accomplished within 3 – 4 minutes).
    a. Add the first container of aggregate (1/3rd of total aggregate by mass) to the mixing bucket.
    b. Evenly sprinkle the first half of Bag #1 fibers onto the first layer of aggregate.
    c. Slowly add (circular motion) the second container of aggregate (1/3rd of total aggregate by mass) to the mixing bucket so that the fibers do not become airborne.
    d. Sprinkle the remaining half of Bag #1 fibers (by mass) onto the second layer of aggregate.
    e. Slowly add (circular motion) the third container of aggregate (1/3rd of total aggregate by mass) to the mixing bucket so that the fibers do not become airborne.
    f. Create a crater in the middle of the aggregates without stirring the aggregate and fiber mixture.
9. If the addition of fibers and aggregate to the mixing bucket exceeds four minutes in duration, take appropriate steps to ensure the aggregate is at the appropriate mixing temperature.
10. Place the bucket on the weighing scale.
11. Carefully pour the correct amount of heated asphalt cement into the blend. Pouring the asphalt binder into the bucket should not take longer than 20 seconds.
12. Take the container of pre-weighed Bag #2 fiber and sprinkle it directly into the binder.
13. Place the mixing bucket into the mixing machine and run it for a minimum of 1.5 minutes. If at the end of the 1.5 minutes the aggregate and asphalt have not fully blended, continue mixing until all aggregates are completely coated with asphalt cement.
14. Once mixing is completed, transfer the hot asphalt mixture to an aging pan and scrape the side of the bucket and the blade using a heated spatula. Add the material scraped from the bucket and blade and any material

stuck to the spatula back into the aging pan.

15. Remove the metal scoop from the oven and stir the aging material thoroughly.
16. Continue stirring the material during the aging process according to AASHTO R30 and again prior to compaction.
17. Follow regular procedures for compacting asphalt mixtures being careful to use heated utensils at every step to prevent loss of mixture and fibers.

Refer to Figure 2 for a pictorial summary of the aforementioned steps to properly mix FORTA-FI fibers into asphalt concrete specimens in a laboratory setting.

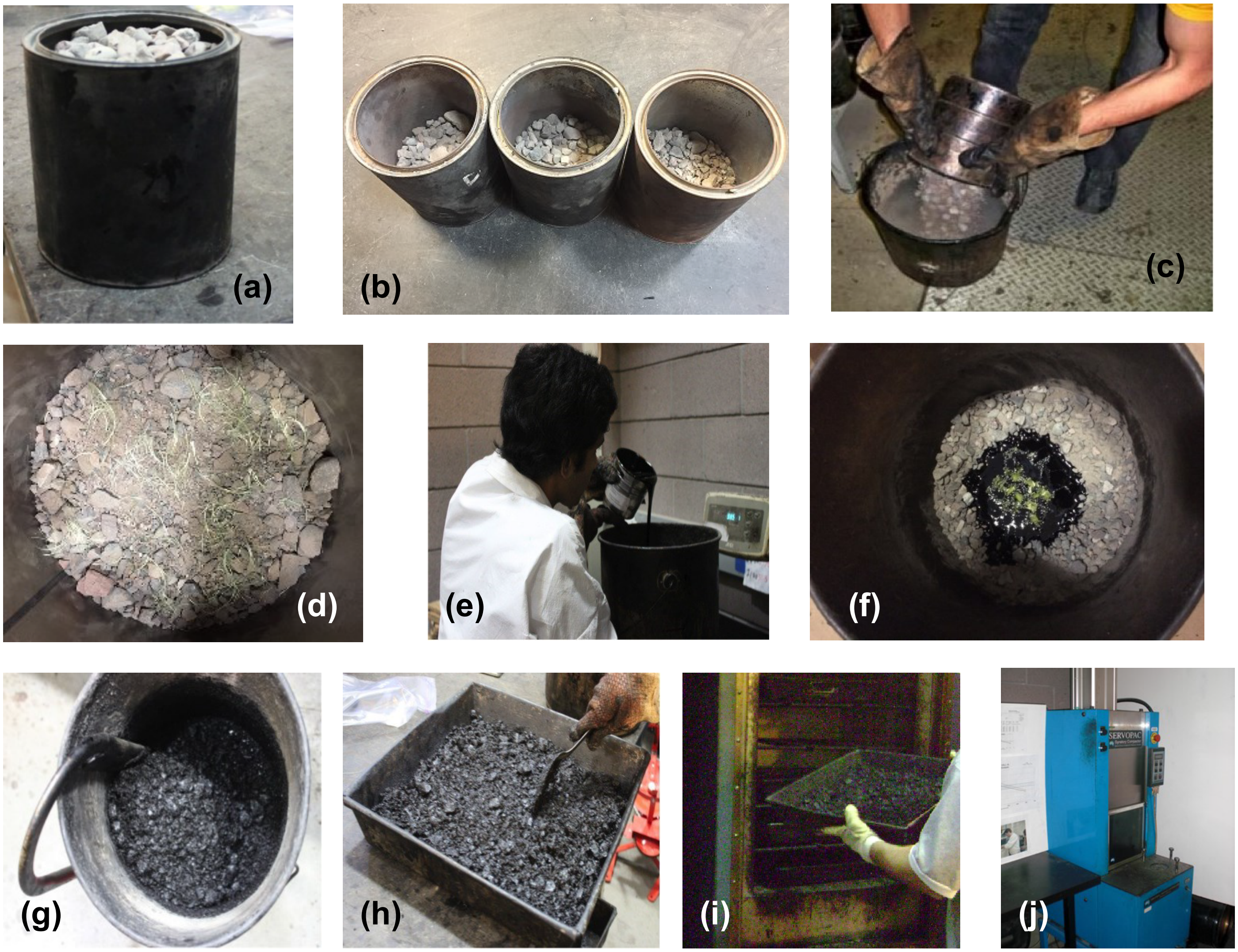


Figure 2. Laboratory mixing of FORTA-FI, fiber-reinforced asphalt concrete mixture: a) batched aggregates, b) batched aggregate divided into thirds (by mass), c) pouring 1/3 of aggregate into the mixing bucket, d) evenly spreading ½ of Bag #1 fibers to top of first 1/3 layer of aggregate (repeat for the 2nd 1/3 of aggregate and second ½ of Bag #1), e) weighing asphalt binder, f) Bag #2 fiber added directly into the binder, g) mixing of asphalt fiber-aggregate blend, h) transferred hot asphalt mixture for aging process, i) aging of fiber reinforced asphalt mixture, and j) compaction of fiber reinforced asphalt mixture.

PaveTex Engineering & Testing, Inc.
3989 HWY 290 East
Dripping Springs, Texas, 78620
PH 512-858 2993 Fax 512-858 2921

Client: TxDOT- Austin
Attn: Lisa Lukefahr

Report No: 17358
Date: 10/6/14

Report of: Overlay Test
Test Method: Tex-248-F

Sample ID: Trial Batch
Sampled By: Client
Sample Location: Truck at Plant
Producer: Industrial Asphalt- Buda Centex
Material Description: PFC-F with Cellulose Fiber + PG 76-22

Lab No: 143363
Production/ Sampled Date: 10/1/14
Project No: NP
Received Date: 10/2/14
Test Performed By: Phillip New, CET

Results:

Sample No.	Starting Load	Final Load	% Decline in Load	# Cycles to Failure
Average	352.2	39.5	88.9	839

Report Reviewed by:

PaveTex Engineering and Testing, Inc.
Firm Registration No. F-961

PaveTex Engineering & Testing, Inc.
3989 HWY 290 East
Dripping Springs, Texas, 78620
PH 512-858 2993 Fax 512-858 2921

Client: TxDOT- Austin
Attn: Lisa Lukefahr

Report No: 17360
Date: 10/7/14

Report of: Overlay Test
Test Method: Tex-248-F

Sample ID: Trial Batch
Sampled By: Client
Sample Location: Truck at Plant
Producer: Industrial Asphalt- Buda Centex
Material Description: PFC-F with Fortified Fiber + PG 76-22

Lab No: 143364
Production/ Sampled Date: 10/1/14
Project No: NP
Received Date: 10/2/14
Test Performed By: Phillip New, CET

Results:

Sample No.	Starting Load	Final Load	% Decline in Load	# Cycles to Failure
Average	367.4	49.5	86.5	1000

Report Reviewed by:

PaveTex Engineering and Testing, Inc.
Firm Registration No. F-961

PaveTex Engineering & Testing, Inc.
3989 HWY 290 East
Dripping Springs, Texas, 78620
PH 512-858 2993 Fax 512-858 2921

Client: TxDOT-Austin
Attn: Lisa Lukefahr
Report No: 17395
Date: 10/13/14

Report of: Hamburg Wheel-Tracking Test
Test Method: Tex-242-F

Sample ID: Lot 1-2
Sampled By: Client
Sample Location: N/A
Producer: Industrial Asphalt
Material Description: PFC-F + Cellulose Fiber
Lab No: 143457
Production/ Sampled Date: NP
Project No: 2100-01-058 RM 2222
Received Date: 10/10/14
Test Performed By: Phillip New, CET

Results:

Temperature:	**50ºC**
No. of Passes:	**Rut Depth (mm):**
5,000	11.4
6,900	12.5
10,000	NA
15,000	NA

Report Reviewed by:

PaveTex Engineering and Testing, Inc.
Firm Registration No. F-961

PaveTex Engineering & Testing, Inc.
3989 HWY 290 East
Dripping Springs, Texas, 78620
PH 512-858 2993 Fax 512-858 2921

Client: TxDOT-Austin
Attn: Lisa Lukefahr

Report No: 17396
Date: 10/13/14

Report of: Hamburg Wheel-Tracking Test
Test Method: Tex-242-F

Sample ID: Lot 2-2
Sampled By: Client
Sample Location: N/A
Producer: Industrial Asphalt
Material Description: PFC-F + Forta Fiber

Lab No: 143458
Production/ Sampled Date: NP
Project No: 2100-01-058 RM 2222
Received Date: 10/10/14
Test Performed By: Phillip New, CET

Results:

Temperature:	**50ºC**
No. of Passes:	**Rut Depth (mm):**
5,000	9.4
10,000	11.5
14,150	12.5
15,000	NA

Report Reviewed by:

PaveTex Engineering and Testing, Inc.
Firm Registration No. F-961

Federal Highway Administration
Office of Asset Management, Pavement, and Construction

MOBILE ASPHALT TESTING TRAILER

Long Life Asphalt Pavements for the 21st Century

Superpave Performance Testing
of
Fiber Reinforced WMA Overlay Mixture
for the
Pennsylvania Department of Transportation (PennDOT)

July 2015

U.S. Department
of Transportation
Federal Highway Administration

Federal Highway Administration
Office of Asset Management,
Pavements, and Construction
1200 New Jersey Ave., SE
Washington, DC 20590

Long Life Asphalt Pavements for the 21st Century

Asphalt Technology Guidance Program

Prepared by the Program Manager

Matthew Corrigan, P.E.

Supported by the Mobile Asphalt Testing Trailer Staff

Chuck Paugh
Habtamu Zelelew, Ph.D.
Amir Golalipour, Ph.D.
Satish Belagutti
Jeevan RamakrishnaReddy

The success of this project is made possible through the close partnership of the transportation community. The FHWA Office Asset Management, Pavement, and Construction wishes to express sincere thanks to the, Pennsylvania Department of Transportation (PennDOT), HRI Inc., and FHWA Pennsylvania Division Office. The provided communication and cooperation contributed to this project's success.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

MOBILE ASPHALT TESTING TRAILER

The Mobile Asphalt Testing Trailer (MATT) is one of the tools available to the Federal Highway Administration (FHWA) Office of Asset Management, Pavement, and Construction in assisting the advancement of the technology for long life pavements. It is an AASHTO accredited laboratory. During the last few decades, the MATT (shown in Figure 1) has been providing technical assistance to State Department of Transportations (DOTs), highway agencies, and industry for the implementation of the Superpave system developed by the Strategic Highway Research Program (SHRP). It addresses National pavement issues by interacting with transportation partners, such as FHWA Division Offices and Resource Center, Expert Task Groups (ETG), and Technical Working Groups (TWG). In addition, it provides technical support to national research initiatives that involve Hot-mix Asphalt (HMA), Warm-mix Asphalt (WMA), Reclaimed Asphalt Pavement (RAP), and Reclaimed Asphalt Shingles (RAS). The MATT also introduced the concept of field management for asphalt mixtures by employing volumetric-based quality control procedures. Today, the MATT program focuses on adopting new asphalt technologies, addressing national issues related to the implementation of innovative testing equipment, and completing the development and validation of performance related design and construction specifications. It also assists State DOTs in evaluating the new Mechanistic-Empirical Pavement Design procedures released as AASHTOWare Pavement ME Design as well as working towards field validation and calibration of the performance models used in this design guide.

Figure 1. (a) Photo of the outside of the FHWA Mobile Asphalt Testing Trailer looking back from the front passenger side corner of the tractor; (b) Photo of the inside of the FHWA Mobile Asphalt Testing Trailer looking from the front to back showing asphalt testing equipment

PROJECT DESCRIPTION

In August 2013, the Pennsylvania Department of Transportation (PennDOT) in cooperation with HRI Inc. invited the FHWA MATT to assist in sample preparation and performance testing of asphalt mixtures. This opportunity was particularly beneficial for the FHWA in that it allowed on-site evaluation of plant produced WMA mixtures containing a mixture reinforcing fiber using locally available aggregate materials. The reinforcing fiber, called FORTA-FI®, consists of a "proprietary blend containing aramid and polyolefin fibers, and other materials." The mixtures were placed on State Route 220 near Jersey Shore, PA in a "thin lift" overlay application.

Two WMA mixtures were produced using a fine-graded 9.5 mm Superpave mix design compacted to 75 design gyrations (Ndesign = 75). These include:

- a Plant Mix Lab Compacted (PMLC) control mixture without fiber; identified as ***PMLC (WMA)***, and a
- Plant Mix Lab Compacted (PMLC) mixture with fiber; identified as ***PMLC (WMA) Fiber.***

These mixtures were produced using a PG 76-22 binder (with a 0.25 % anti-strip) supplied by Suite-Kote asphalt. A water foaming process (1.5 to 3 % by weight of binder) was used to produce the WMA mixtures. During production, the fiber was added to the mixtures at the rate of 1 lb/ton. Four aggregate stockpiles were used to produce these mixtures. The plant produced asphalt mixtures were used in the surface layer (thin-lift overlay) of the pavement structure. The asphalt mixtures were produced using a batch plant with a production rate of 250 tons/hr. The plant was also equipped with six cold feed bins for aggregates, two bins for the recycled materials, three binder storage tanks, and a baghouse dust collection system.

A work plan was developed that involved testing of aggregates and plant produced asphalt mixtures. The aggregate shape properties were evaluated using the Aggregate Imaging Measurement System (AIMS) and the Superpave method. The specific gravity and water absorption properties of the aggregates were also measured. The asphalt mixture evaluation included volumetric and performance testing. The Asphalt Mixture Performance Tester (AMPT) was utilized to perform the dynamic modulus (|E*|), cyclic fatigue (S-

VECD), and Flow Number (F_n) tests to characterize the stiffness, fatigue cracking, and permanent deformation properties of the asphalt mixtures, respectively. Additionally, the Hamburg wheel-track test was conducted to evaluate both rutting and moisture susceptibility of the asphalt mixtures.

AGGREGATE TESTING

Characterization of Aggregate Shape Properties

Aggregates constitute a major part of the asphalt mixture and transmit the vehicle wheel loads through contact, friction, and interlocking. The shape and physical properties of aggregates relate to the performance of asphalt pavements. The shape, angularity, and surface texture of aggregates influence the engineering properties of highway construction materials such as asphalt concrete, Portland cement concrete, and unbound aggregate layers. Recent advances in digital imaging applications to characterize shape properties of aggregates have led to the development of objective measurements of shape indices. Through the FHWA, Highways for Life technology partnership program, the Pine Instrument Company developed the second generation, Aggregate Image Measurement System (AIMS2) technology to characterize aggregate shape characteristics. The AIMS2 technology (hereafter called AIMS) utilizes a variable magnification microscope-camera system and different lighting configurations to capture aggregate images for analysis (Figure 2). The AIMS provides direct measurement of aggregate shape, angularity, and texture. For coarse aggregates, the shape properties include gradient angularity, sphericity, texture, and flat and elongated. For fine aggregates, the shape properties include gradient angularity and 2D Form.

Figure 2. Photo of the exterior of the Pine Instrument's Aggregate Image Measurement System (AIMS) Model AFA2A equipment

The AASHTO TP 81[1] provisional test method defines aggregate shape properties captured through AIMS as:

- ***Gradient angularity*** - applies to both fine and coarse aggregate sizes and relates to the sharpness of the corners of two-dimensional (2D) images of aggregate particles. The gradient angularity quantifies changes along a particle boundary with higher gradient values indicating a more angular shape. Gradient angularity has a relative scale of 0 to 10,000 with a perfect circle having a small but non-zero value.
- ***Texture or Micro-Texture*** - applies to coarse aggregate sizes only describing the relative smoothness or roughness of surface features less than 0.5 mm in size which are too small to affect the overall shape. Texture has a relative scale of 0 to 1,000 with a smooth polished surface approaching a value of 0.
- ***Sphericity*** - applies to coarse aggregate sizes only and describes the overall three-dimensional (3D) shape of a particle. Sphericity has a relative scale of 0 to 1. A sphericity value of one indicates a particle has equal dimensions (cubical).
- ***2D Form*** - applies to fine aggregate sizes only and is used to quantify the relative form from 2D images of aggregate particles. 2D Form has a relative scale of 0 to 20. A perfect circle has a 2D Form value of zero.
- ***Flat <u>and</u> Elongated*** - those particles having a ratio of longest dimension to shortest dimension greater than a specified value.

---

[1] AASHTO TP 81-12 *"Standard Method of Test for Determining Aggregate Shape Properties by Means of Digital Image Analysis"*

- ***Flat or Elongated*** - those particles having a ratio of intermediate dimension to shortest dimension or longest dimension to intermediate dimension greater than a specified value. The reference scale for the comparison of the aggregate shape properties is shown in Table 1. It includes four sub-categories (i.e., low, medium, high, and extreme) for each of the AIMS shape indices. The approximate aggregate mass and the number of particles in each sieve size needed for AIMS testing is shown in Table 2.

Table 1. AIMS reference scale[2]

Shape Index	Range				Aggregate Size
	Low	Medium	High	Extreme	
Angularity	2100	3975	5400	10000	Fine and coarse
Texture	200	500	750	1000	Coarse
Sphericity (3D Form)	0.5	0.6	0.8	1.0	Coarse
2D Form	6.5	8.0	10.75	20	Fine

Table 2. Required aggregate mass and counts[3]

Sieve Size	Approximate Mass	Minimum Number of Particles
1 in (25 mm)	5 kg	50
3/4 in (19 mm)	2 kg	50
1/2 in (12.5 mm)	2 kg	50
3/8 in (9.5 mm)	2 kg	50
No. 4 (4.75 mm)	2 kg	50
No. 8 (2.36 mm)	200 g	150
No. 16 (1.18 mm)	200 g	150
No. 30 (0.600 mm)	200 g	150
No. 50 (0.300 mm)	200 g	150
No. 100 (0.150 mm)	200 g	150
No. 200 (0.075 mm)	200 g	150

---

[2] Pine Instrument

[3] AASHTO TP 81-12 *"Standard Method of Test for Determining Aggregate Shape Properties by Means of Digital Image Analysis"*

Aggregates Tested

Four aggregate stockpiles were used to produce the project mixtures. Table 3 presents the gradations of aggregate stockpile blends. These properties were measured using washed oven-dried aggregates.

Table 3. Aggregate stockpile blend properties

Sieve Size	PMLC (WMA)	PMLC (WMA) Fiber
	Percent Passing (%)	
1 in (25 mm)	100	100
3/4 in (19 mm)	100	100
1/2 in (12.5 mm)	100	100
3/8 in (9.5 mm)	100	100
No. 4 (4.75 mm)	84.2	87.4
No. 8 (2.36 mm)	49.9	55.8
No. 16 (1.18 mm)	32.8	36.2
No. 30 (0.600 mm)	23.6	25.7
No. 50 (0.300 mm)	15.7	17.2
No. 100 (0.150 mm)	8.3	9.3
No. 200 (0.075 mm)	4.9	5.4

AIMS Test Results

The AIMS test included aggregate sizes passing the 9.5 mm sieve and retained on the 0.075 mm sieve. Testing was conducted using the individual aggregate stockpiles and the stockpile blends. The summary of the overall average AIMS shape properties are presented in Table 4 and Figure 3. A higher angularity index (i.e., angular or sub-angular) indicates a higher aggregate angularity and yields aggregate interlocking which may improve rutting resistance. Moreover, asphalt mixtures with higher surface texture aggregates (i.e., high roughness) may provide improved friction and skid resistance. The aggregate blends in AIMS testing resulted in medium angularity, medium texture, medium 2D form, and high sphericity. Details of the AIMS test results including the distribution of aggregate particles for each stockpile blend are presented in Appendix A.

AASHTO M 323[4] defines an aggregate particle to be flat and elongated (F&E) if the longest particle dimension (i.e., length) divided by smallest particle dimension (i.e., thickness) exceeds five. In addition, the percentage of particles for this ratio is limited to a maximum of 10 %. This criterion is based on the Job Mix Formula (JMF) blend and not for individual stockpile aggregates. However, if a stockpile contains more than 10 %, the stockpile's usage in the total blend may be limited. Figure 4 shows the comparison of AIMS F&E 5:1 and 3:1 ratios. It is shown in this figure that the aggregate stockpiles and blends measured a 5:1 ratio within 10 %.

---

[4] AASHTO M 323-13 *"Standard Specification for Superpave Volumetric Mix Design"*

Table 4. Summary of AIMS test results

Source	Aggregate Type	Fine Angularity		Coarse Angularity		Fine & Coarse Angularity		Texture		Sphericity (3D Form)		2D Form	
		Value	Range	Value	Range	Value	Range	Value	Range	Value	Range	Value	Range
Blend	PMLC (WMA)	2126.6	Medium	2676.6	Medium	2136.1	Medium	434.1	Medium	0.61	High	7.1	Medium
	PMLC (WMA) Fiber	2099.4	Medium	2621.3	Medium	2106.0	Medium	383.7	Medium	0.62	High	7.1	Medium

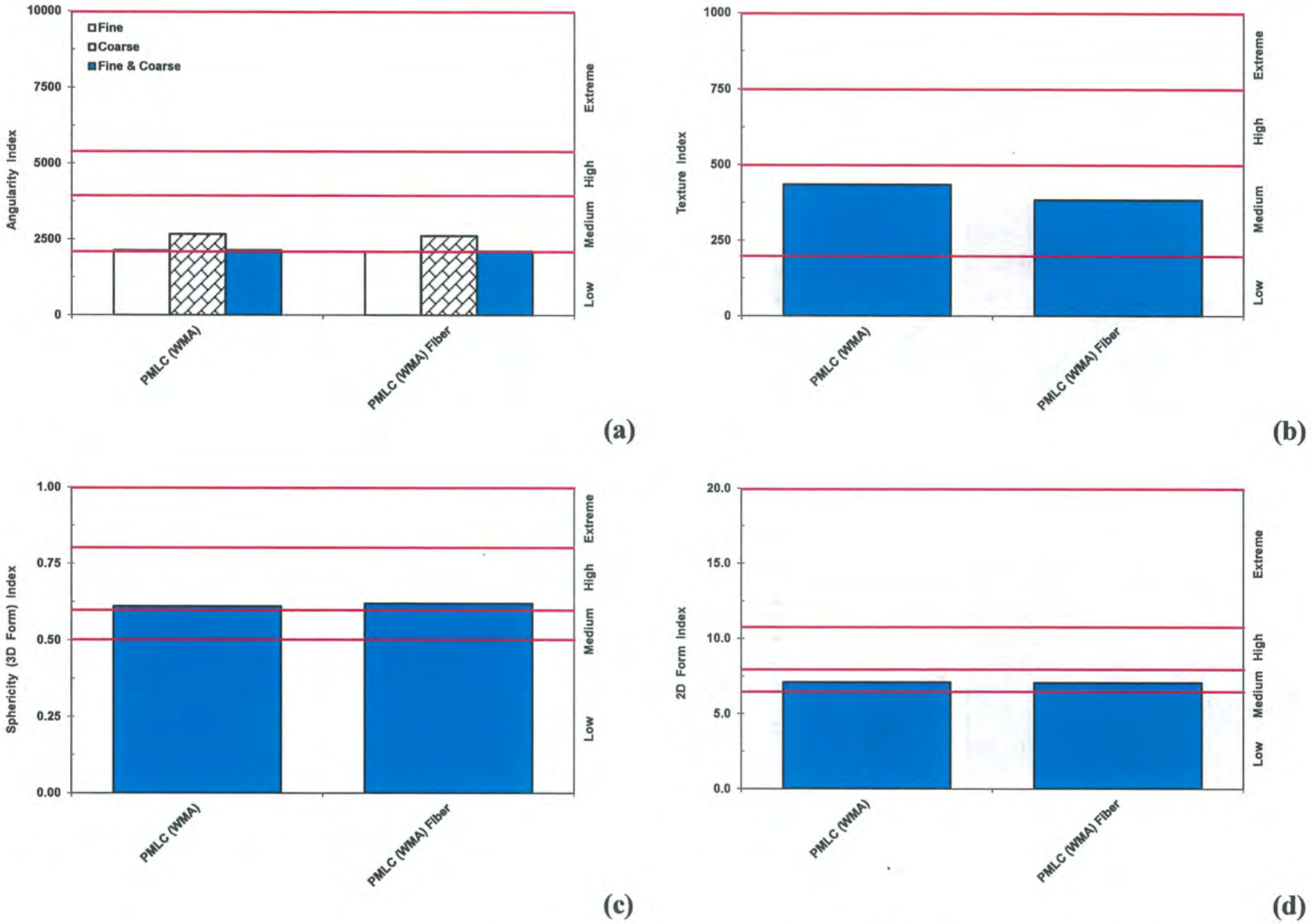


Figure 3. AIMS test results; (a) Angularity, (b) Texture, (c) Sphericity (3D Form), and (d) 2D Form

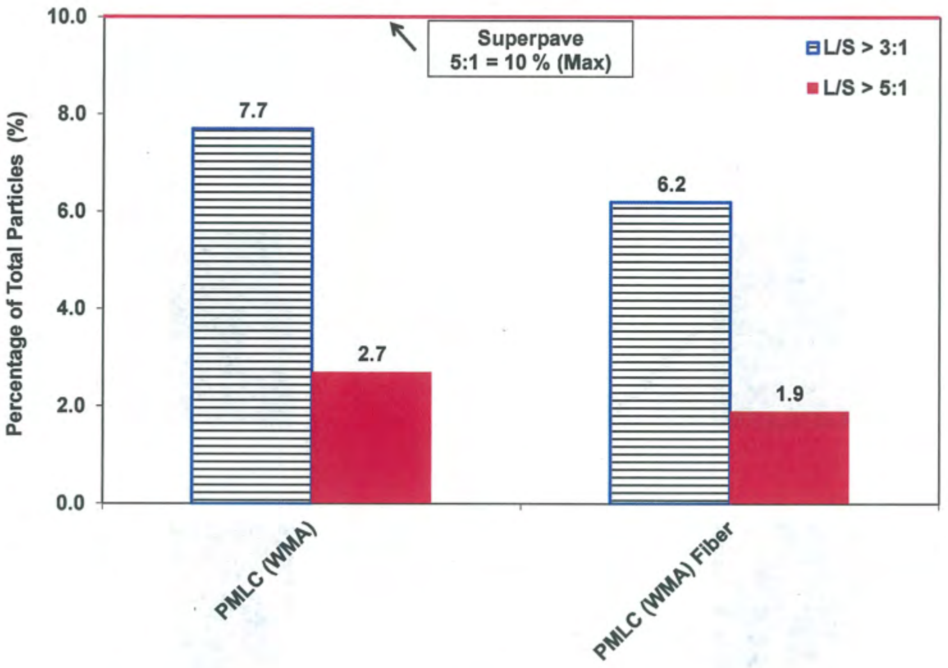


Figure 4. AIMS aggregate flat and elongation percentages

VOLUMETRIC TESTING OF PLANT PRODUCED MIXTURES

Asphalt mixtures were sampled from haul trucks. The control PMLC WMA (without fiber) mixture were reheated during specimen fabrication. The technicians collected asphalt mix samples from the plant during September 5 to 9, 2013 when the production schedule allowed. Two WMA samples (one with fiber and one without fiber) were collected for volumetric and performance testing. Table 5 shows the asphalt mixture sampling schedule.

Comparable aggregate gradations between the JMF and the plant produced mixtures were obtained (Figure 5). The percent passing on individual sieves is also presented in Figure 6. The upper and lower control limits (UCL and LCL) are MATT established control limits originally determined as part of FHWA Demonstration Project No. 74 *Field Management of Asphalt Mixtures* and subsequently refined with additional MATT project data. The comparison of the volumetric properties of the asphalt mixtures is shown in Figure 7. Overall, the plant produced mixtures resulted in satisfactory binder content, air voids, and VMA when compared to the JMF target values. The aggregate specific gravity can be used to assess the validity of VMA calculations in the mix (Figure 7). The condition (i.e., $G_{se} \geq G_{sb}$) is satisfied and therefore the G_{sb} used to calculate VMA was representative of the aggregate stockpiles. Detailed volumetric test results are presented in Appendix B.

Table 5. Asphalt mixture sampling and testing plan

Mix ID	Production Sample Temperature (°C)	Sampling Date	Test Performed	
			Volumetric	Performance
PMLC (WMA)	-	September 5, 2013	Yes	Yes
PMLC (WMA) Fiber	155	September 7, 2013	Yes	Yes

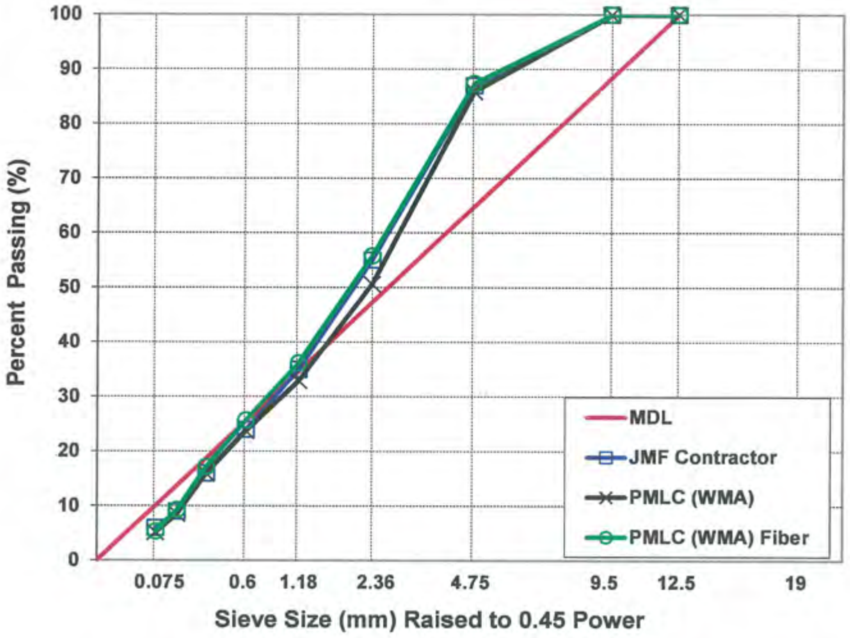


Figure 5. Aggregate gradation for Plant produced mixtures.

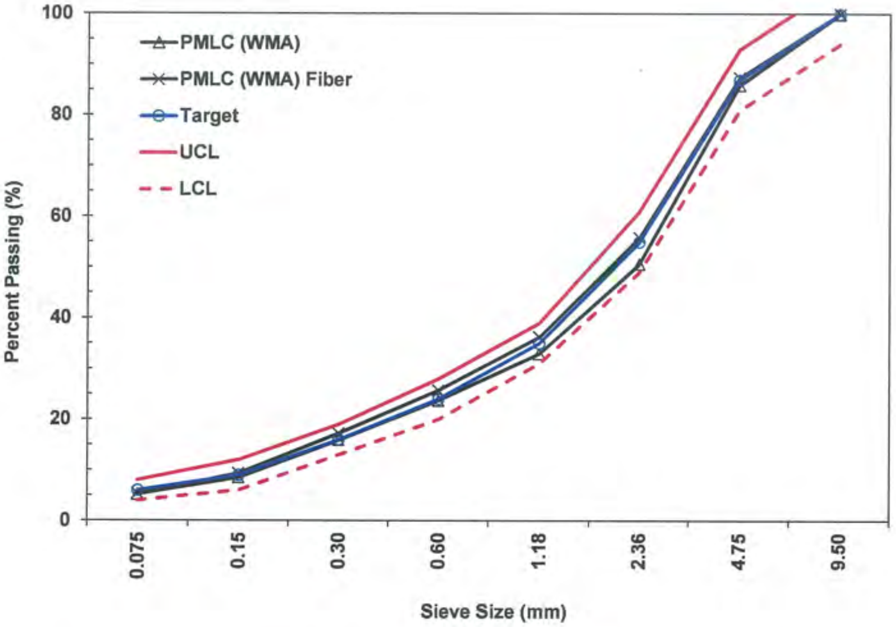


Figure 6. Aggregate gradation for the individual sieves for Plant produced mixtures.[5]

---

[5] Upper Control Limit (UCL)
Lower Control Limit (LCL)

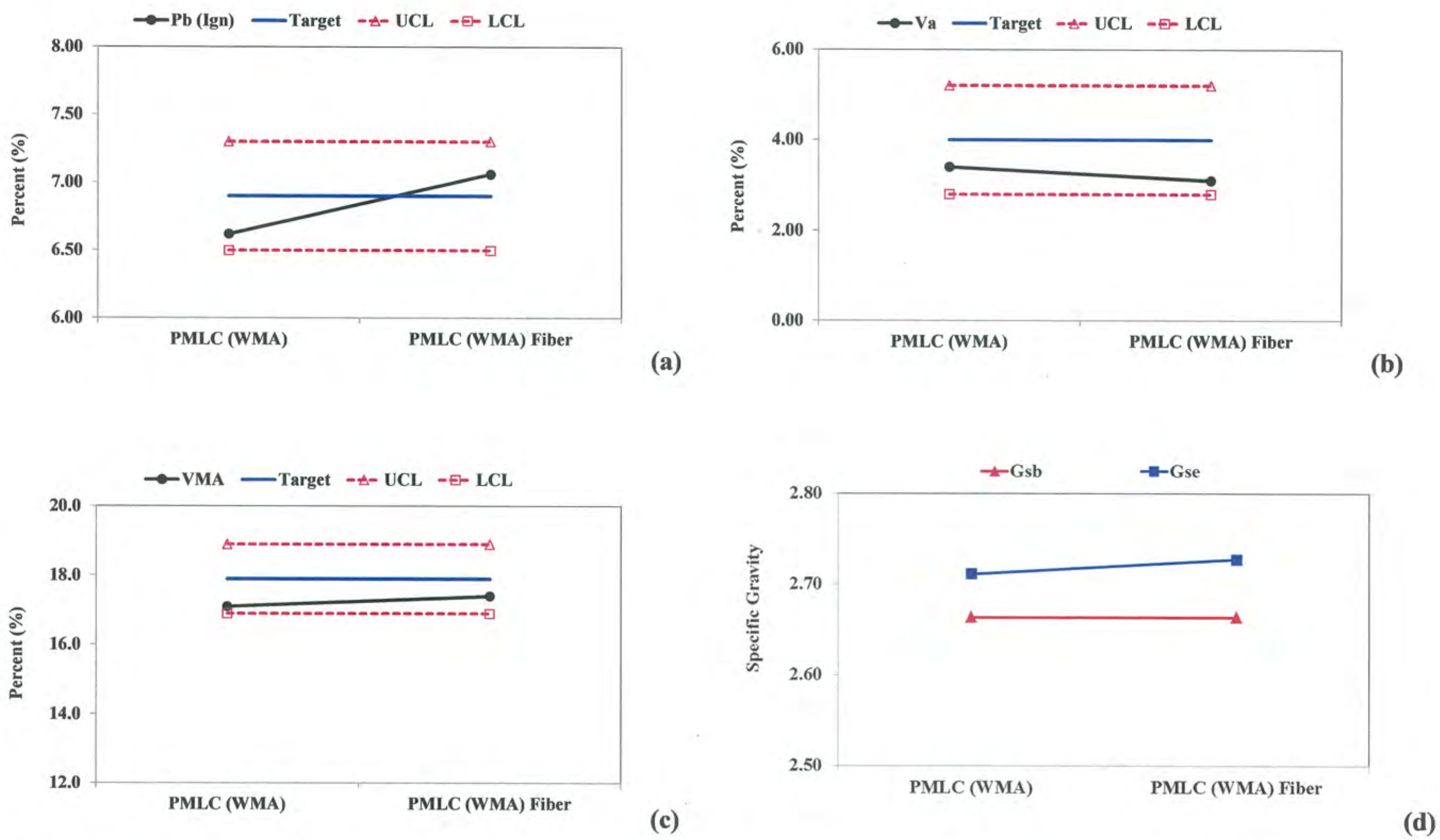


Figure 7. Plant produced mixture volumetric[6]; (a) Asphalt content percent (P_b), (b) Percent air voids in compacted mixture (V_a), (c) Voids in mineral aggregate (VMA), and (d) Specific gravity

---

[6] Upper Control Limit (UCL)
Lower Control Limit (LCL)

ASPHALT MIXTURE DESIGN

The mixtures were fine-graded 9.5 mm Superpave mix designs compacted with a Superpave gyratory to 75 design gyrations (Ndesign = 75). These include:

- a Plant Mix Lab Compacted (PMLC) control mixture without fiber; identified as ***PMLC (WMA)***, and a
- Plant Mix Lab Compacted (PMLC) mixture with fiber; identified as ***PMLC (WMA) Fiber***.

These two mixtures were produced using a PG 76-22 binder (with a 0.25 % anti-strip) supplied by Suite-Kote asphalt. A water foaming process (1.5 to 3 % by weight of binder) was used in the production of the WMA mixtures. During production, the fiber was added to the mixtures at the rate of 1 lb/ton. Four aggregate stockpiles were used to produce these mixtures. The plant produced asphalt mixtures were used in the surface layer (thin-lift overlay) on top of an existing pavement structure. The mix design volumetric properties are presented in Table 6 while the comparison of aggregate gradations is shown in Figure 5. Mixture design report details are shown in Appendix C.

Table 6. Mix design volumetric; Job Mix Formula and Plant Mixed Lab Compacted samples

Parameters	**Contractor JMF**	**Production**	
		PMLC (WMA)	**PMLC (WMA) Fiber**
Binder PG	PG 76-22	PG 76-22	PG 76-22
Compaction Temp. (°C)	155	155	155
P_b (%)	6.90	6.62	7.06
V_a (%)	4.0	3.4	3.1
VMA (%)	17.9	17.1	17.4
VFA (%)	78.0	80.1	82.1
F/P_{be}	1.00	0.84	0.80
P_b: binder content; V_a: air voids; VMA: voids in mineral aggregates; VFA: voids filled with asphalt; and F/P_{be}: dust to effective binder ratio			

FIBER REINFORCEMENT

When the produced asphalt does not meet the requirements, modification of the asphalt with additives has served as one of the cost-effective engineering solutions. Consequently, many researchers and designers, in order to create a failure-free pavement, have been motivated to specify modified asphalt binders and mixtures. Many materials have been used to reinforce asphalt materials and fibers are among the more significant ones[7]. Although fiber modification has shown to improve the performance of asphalt mixtures against permanent deformation and fatigue cracking, however understanding the reinforcing mechanism as well as ways of optimizing fiber properties, e.g. fiber diameter, length, surface texture are playing critical roles to ensure a desirable outcome[8].

FORTA-FI® fiber consisting of a "proprietary blend containing aramid and polyolefin fibers, and other materials" was used as reinforcement for a WMA mixture on this project. This fiber product is marketed to improve the rutting and cracking resistance of asphalt mixtures. Figure 8 shows the structure of the fiber that was used with the WMA mix.

Figure 8. FORTA-FI® fibers for WMA mixture application

---

[7] Kaloush, K. E., Zeiada, W., Biligiri, K., Rodezno, M. C., and Reed J.; "Evaluation of Fiber-Reinforced Asphalt Mixtures Using Advanced Material Characterization Tests ", Journal of Testing and Evaluation 38, no. 4 (2010).

[8] Abtahi, S. M., Sheikhzadeh, M., and Hejazi S. M.; "Fiber-reinforced asphalt concrete – A review " Journal of Construction and Building Materials , Vol. (24), pp. 871-877, 2010.

ASPHALT MIXTURE PERFORMANCE TESTER

The Asphalt Mixture Performance Tester (AMPT) was used to investigate the performance of asphalt mixtures included in this project (Figure 9). The AMPT simulates changing field conditions such as traffic loading, rate of loading, temperature, and confinement that the pavement will experience during its design life. The AMPT equipment is capable of conducting several performance tests such as dynamic modulus ($|E^*|$), flow number (F_n), and fatigue.

The final AMPT test specimen dimensions and air voids are vital to obtain valid performance test specimens suitable for testing. The specimen tolerances documented in AASHTO PP 60[9] provisional standard practice were enforced for specimen diameter, height, end flatness, and perpendicularity of the $|E^*|$ and F_n test specimens. The specimen tolerances documented in AASHTO TP 107[10] provisional test method were followed for specimen diameter; height, end flatness, and perpendicularity (see Table 8). The asphalt mixtures for performance testing were compacted to 8.5 % air voids in the gyratory compactor in order to achieve the 7.0 ± 0.5 % target air void content of the final AMPT test specimen. The AMPT test specimens were cored from the center 100 mm of the 150 mm diameter SGC specimen. The sample ends were trimmed from a height of more than 180 mm down to 150 mm for $|E^*|$ and F_n test specimens. The AMPT cyclic fatigue specimen heights are trimmed down to 130 mm. Water was used during coring and sawing to avoid heat buildup damaging the test specimens.

---

[9] AASHTO PP 60-13 *"Preparation of Cylindrical Performance Test Specimens Using the Superpave Gyratory Compactor (SGC)"*

[10] AASHTO TP 107 "Determining the Damage Characteristic Curve of Asphalt Mixtures from Direct Tension Cyclic Fatigue Tests"

Figure 9. Photo of exterior of the IPC Global's Asphalt Mixture Performance Tester

Table 7. Test specimen fabrication criteria

Parameter	AASHTO Specification	
	PP 60-13 for $\lvert E^*\rvert$ and F_n	TP 107-14 for Cyclic Fatigue
Average Diameter (mm)	98 to 104	100 to 104
Standard Deviation of Diameter (mm)	≤ 0.5	≤ 0.5
Height (mm)	147.5 to 152.5	127.5 to 132.5
End Flatness (mm)	≤ 0.5	≤ 0.5
End Perpendicularity (mm)	≤ 1.0	≤ 1.0

DYNAMIC MODULUS, |E*| TEST

Dynamic modulus of a viscoelastic material (i.e. asphalt mixture) is the absolute value of the complex modulus calculated by dividing the peak-to-peak stress by the peak-to-peak strain. In linear viscoelastic theory, the absolute value of the complex modulus |E*|, by definition, is the dynamic (complex) modulus. The dynamic modulus of an asphalt mixture test is a materials response measured under sinusoidal loading conditions and is typically designated as E*. In general, the term dynamic modulus is used to denote any type of modulus that has been determined under non-static load conditions. The dynamic modulus test is a stress-controlled test where a sinusoidal axial compressive load is applied to the AMPT specimen and the resulting applied stress and recoverable axial strain response are measured. It is calculated by dividing the maximum peak-to-peak stress by the recoverable peak-to-peak strain. The time lag in degrees between the applied stress and resulting strain defines phase angle (ϕ). A typical dynamic modulus test result consisting of stress-strain response is shown in Figure 10.

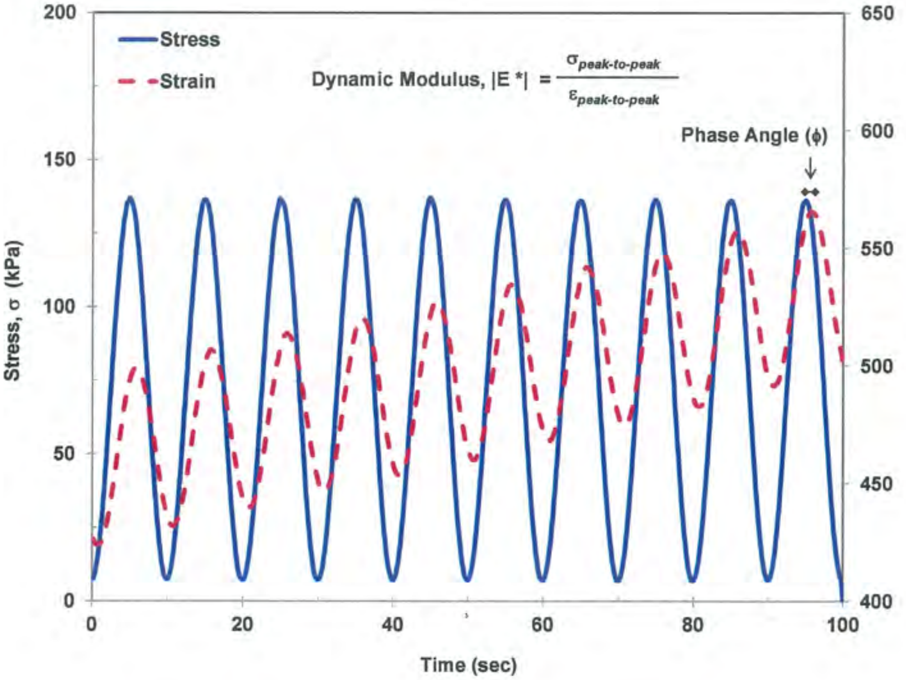


Figure 10. Illustration of stress-strain response in dynamic modulus test

Temperature and load frequency influence the dynamic modulus response of asphalt mixtures. The AASHTOWare Pavement ME Design guide recommends dynamic modulus testing performed using five test temperatures (-10, 4.4, 21.1, 37.8, and 54.4 °C) and six frequencies (0.1, 0.5, 1, 5, 10, and 25 Hz). Due to equipment cost considerations, the AMPT test equipment was not developed to achieve and control a test temperature of -10 °C. Therefore, the dynamic modulus tests can be performed using the remaining four test temperatures (i.e., 4.4, 21.1, 37.8, and 54.4 °C) and the -10 °C data is determined through calculation of the dynamic modulus master curve.

Since the dynamic modulus test is non-destructive at low temperatures, the same set of four replicates of the asphalt mixtures were tested at the three lower temperatures (i.e., 4.4, 21.1, and 37.8 °C) while another set of four replicates were fabricated and tested at the high temperature (i.e., 54.4 °C) (Table 9). Following the AASHTO TP 79[11] test method, the unconfined dynamic modulus tests were performed from the lowest temperature to the highest temperature and from the highest frequency to the lowest frequency.

Table 8. Dynamic modulus test matrix

Mix ID	**Temperature (°C)**			
	4.4	**21.1**	**37.8**	**54.4**
PMLC (WMA)	4 Replicates			4 Replicates
PMLC (WMA) Fiber	4 Replicates			4 Replicates

---

[11] AASHTO TP 79-13 *"Determining the Dynamic Modulus and Flow Number for HMA Using the Asphalt Mixture Performance Tester (AMPT)"*

Evaluation of Dynamic Modulus Test Data

The Data Quality Statistic (DQS) shown in Table 9 were verified at each loading frequency and test temperature during the dynamic modulus test. These statistics were used to assess the quality or acceptability of the measured $|E^*|$ data. If one or more of the DQS exceed the limit, the measured $|E^*|$ values will be rejected and another specimen would be tested. In this project, the reported $|E^*|$ values for each test temperature and frequency comply with the criteria.

In addition, the black space diagram was used to investigate the viscoelastic properties of asphalt mixtures. This diagram can be used to evaluate potential inconsistencies in the data trends and help identify errors in the dataset. It is represented using the measured $|E^*|$ and phase angle in semi-log space. Figure 11 shows the black space diagrams of the asphalt mixtures (by test temperature and mix type). Comparatively, the asphalt mixtures exhibited similar viscoelastic rheological properties. The asphalt mixtures resulted in higher stiffness (lower phase angle) at low temperature and vice-versa demonstrating viscoelastic solid materials. The dynamic modulus test results are summarized in Appendix D.

Table 9. AMPT Dynamic Modulus Data Quality Statistics Requirements documented in AASHTO standard TP79[12]

Data Quality Statistic	Limit
Deformation drift	In the direction of applied load
Peak-to-peak strain	75 to 125 microstrain (Unconfined)
	85 to 115 microstrain (Confined)
Load standard error	10 %
Deformation standard error	10 %
Deformation uniformity	30 %
Phase uniformity	3°

---

[12] AASHTO TP 79-13 *"Determining the Dynamic Modulus and Flow Number for HMA Using the Asphalt Mixture Performance Tester (AMPT)"*

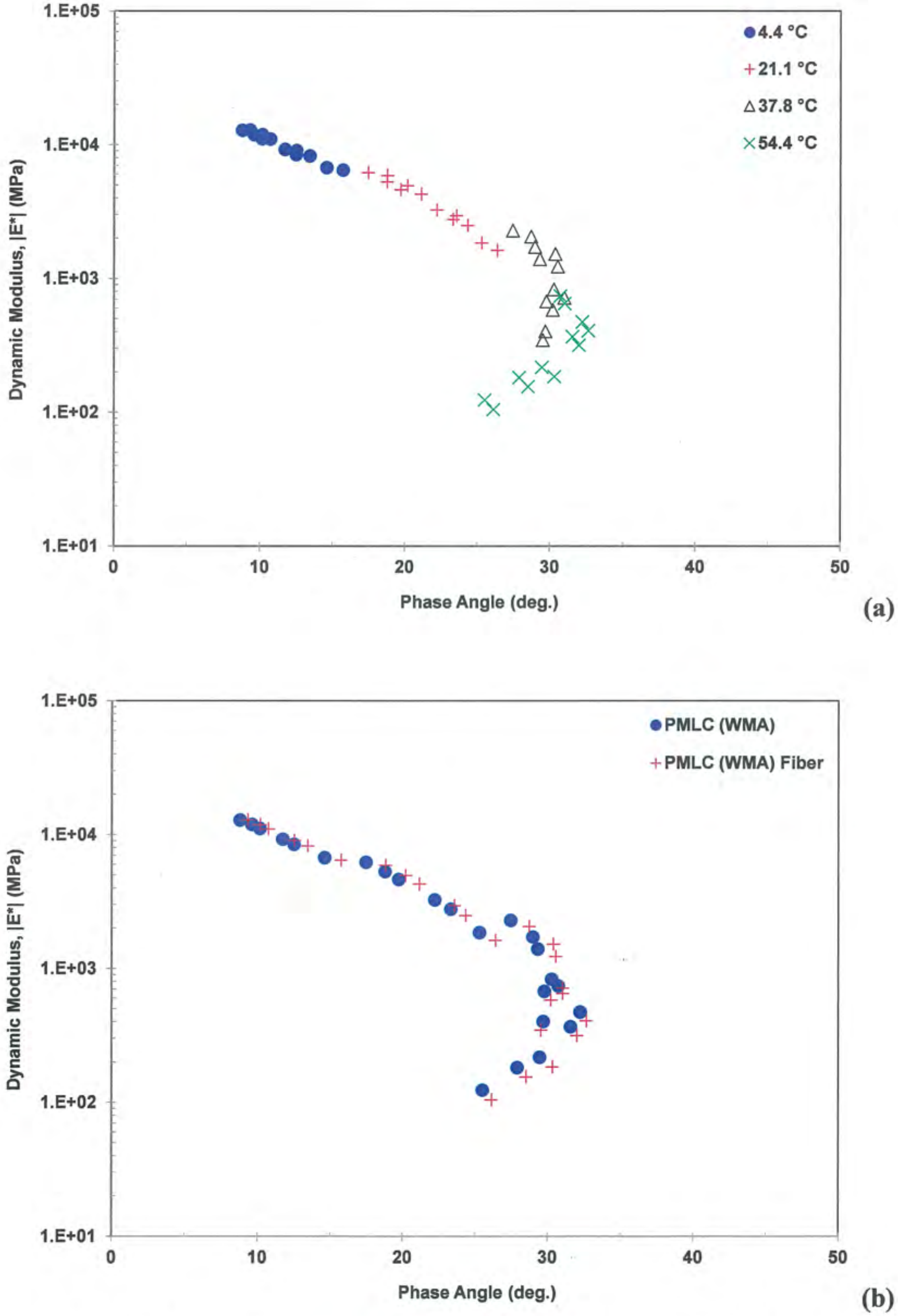


Figure 11. Mixture black space diagram; (a) by temperature and (b) by mix type

Dynamic Modulus Test Results

Dynamic Modulus and Phase Angle

Figures 12 and 13 present the dynamic modulus test results (stiffness and phase angle, respectively) of plant produced asphalt mixtures tested at four temperatures and six frequencies. The error bars shown in these figures indicate the standard deviation of dynamic modulus and phase angle measurements using four test specimen replicates. Generally, at a constant test temperature, the dynamic modulus increases with increasing loading frequency; at a constant loading frequency, the dynamic modulus decreases with increasing test temperature. However, the phase angle of the asphalt mixture slightly decreased when the test frequency increased at the lower test temperatures (4.4 and 21.1 °C) and slightly increased when tested using 37.8 and 54.4 °C. At high temperature and low frequency ranges, the mixture phase angle decreases due to the presence of mastics and fibers. Understanding the data provided in these figures can provide a fundamental characterization of asphalt mixture behavior under various loading and temperature conditions through the use of master curves.

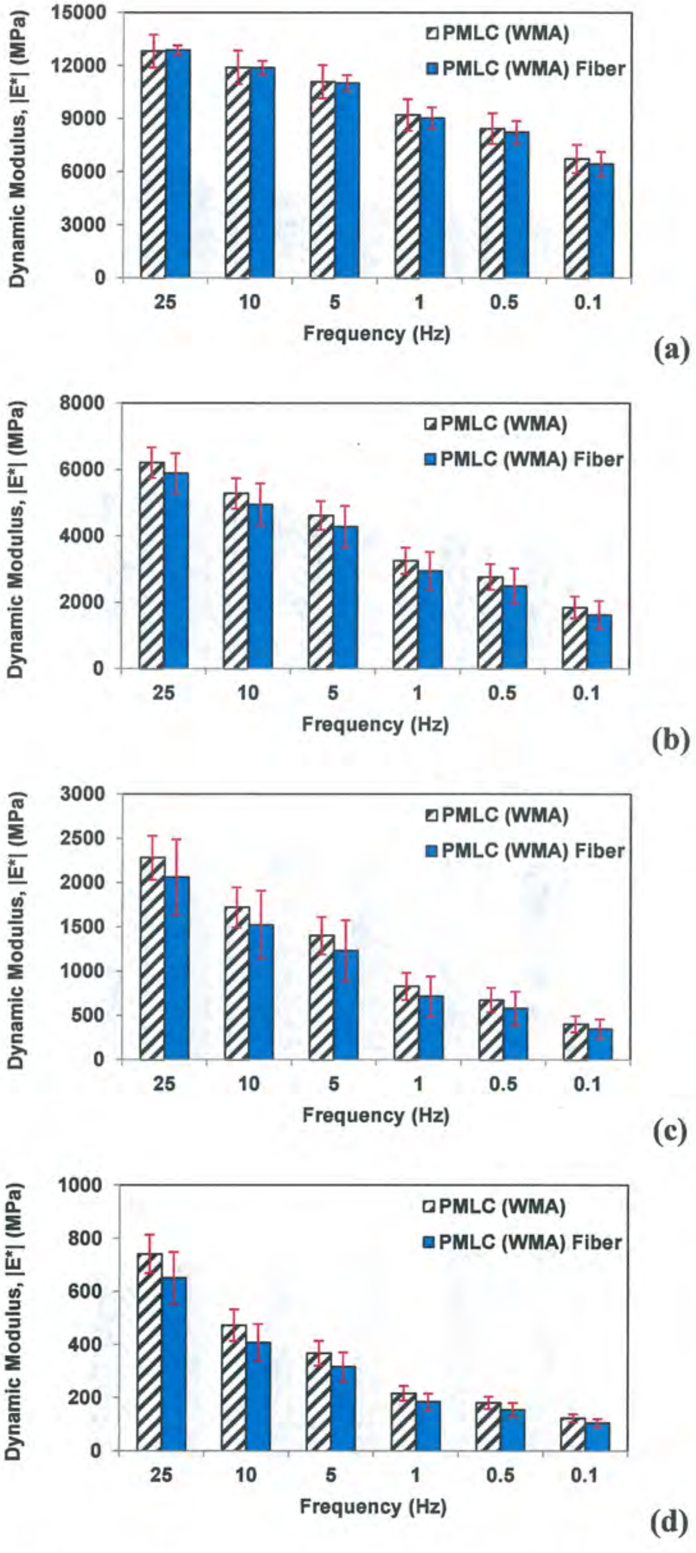


Figure 12. Dynamic modulus, |E*|; (a) 4.4 °C, (b) 21.1 °C, (c) 37.8 °C, and (d) 54.4 °C

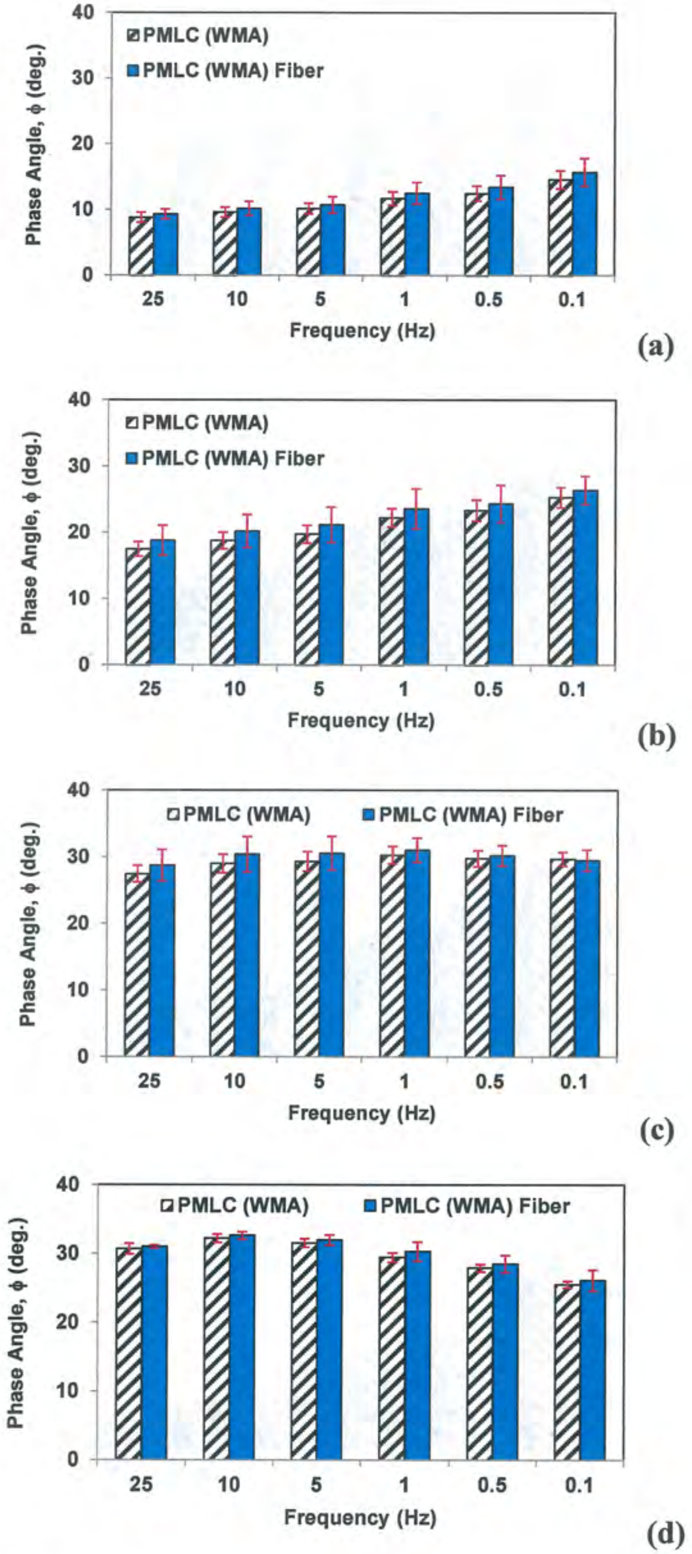


Figure 13. Phase angle, ϕ; (a) 4.4 °C, (b) 21.1 °C, (c) 37.8 °C, and (d) 54.4 °C

It can be seen from the above figures that statistically speaking mixture with and without fibers are behaving similarly. The dynamic modulus and phase angle results are very similar for both mixture types and there is no significant difference between them. Other researchers have reported similar observation regarding dynamic modulus test results for mixture with fibers[13]. Another interesting observation is that the fiber reinforced mixtures show higher variability at some temperatures. This may be attributed to the random distribution of fibers into the matrix. Kaloush et al. reported similar observations for fiber-reinforced asphalt mixtures[14].

Master Curve

The dynamic modulus |E*| test results of an asphalt mixture at various temperatures can be shifted along the temperature or frequency axis to form a single dynamic modulus master curve at a desired reference temperature or frequency. This procedure takes advantage of the time-temperature superposition principle of viscoelastic materials and allows the user to look at the mixture response at multiple loading frequencies and temperatures on a single curve. The master curves are created using the standard sigmoidal function given in Equation 1. Similarly, the phase angle master curves are developed using the modified sigmoidal function (Equation 2).

$$\log|E^*| = \delta + \frac{\alpha}{1+exp^{(\beta+\gamma log\omega_r)}} \qquad (1)$$

$$\phi = -90 \times bd \frac{exp^{(c+d(log\omega_r))}}{[1+exp^{(c+d(log\omega_r))}]^2} \qquad (2)$$

where,

|E*| = dynamic modulus

δ = minimum value of |E*|

---

[13] Huang, H., and White T.D. "Dynamic properties of fiber-modified overlay mixture.", Journal of the Transportation Research Board, No. 1545, 1996, pp. 98-104.

[14] Kaloush, K. E., Zeiada, W., Biligiri, K., Rodezno, M. C., and Reed J.; "Evaluation of Fiber-Reinforced Asphalt Mixtures Using Advanced Material Characterization Tests ", FORTA corporation Report #200903AT101.

$\delta + \alpha$ = maximum value of $|E^*|$

ω_r = reduced frequency

β and γ = parameters describing the shape of the master curve

ϕ = phase angle

b, c, and d = regression coefficient

The dynamic modulus master curves for the asphalt mixtures at a reference temperature of 21.1 °C are shown in Figure 14 (log-log and semi-log scales). Similarly, the phase angle master curves are shown in Figure 15. The WMA mixtures containing fiber reinforcement resulted in statistically similar values for dynamic modulus master curves when compared to the control WMA mixtures. As it can be seen in the below figure, also the shape of master curve is almost the same for both mixtures except at lower frequencies (higher temperatures) which mixture with fibers shows steeper slope.

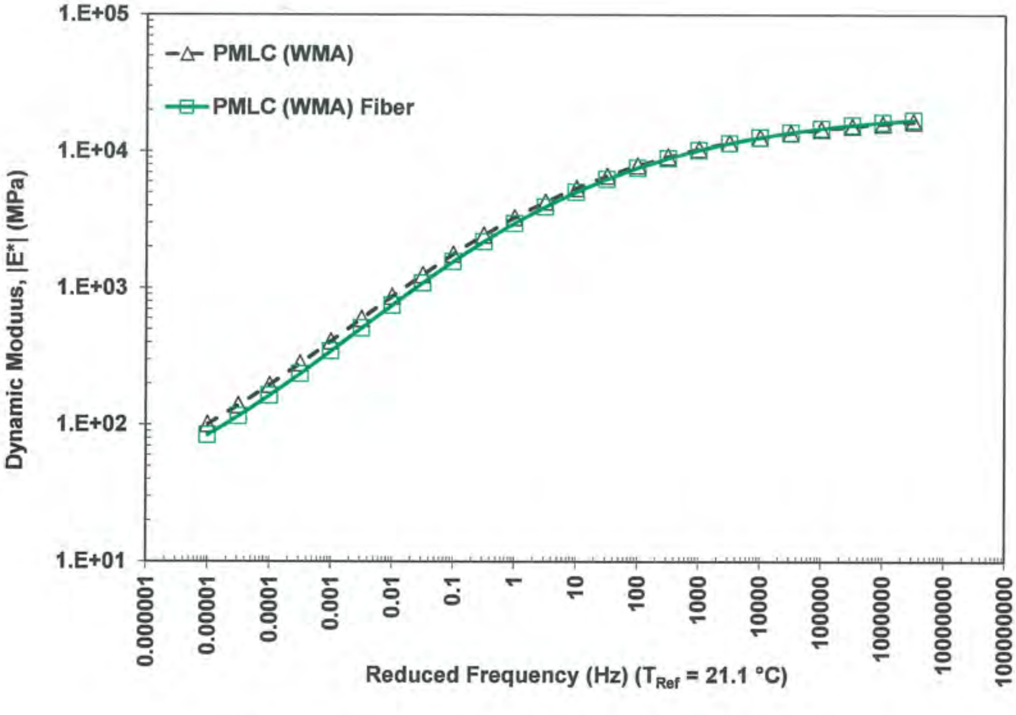


Figure 14. Dynamic modulus master curves; log-log scale

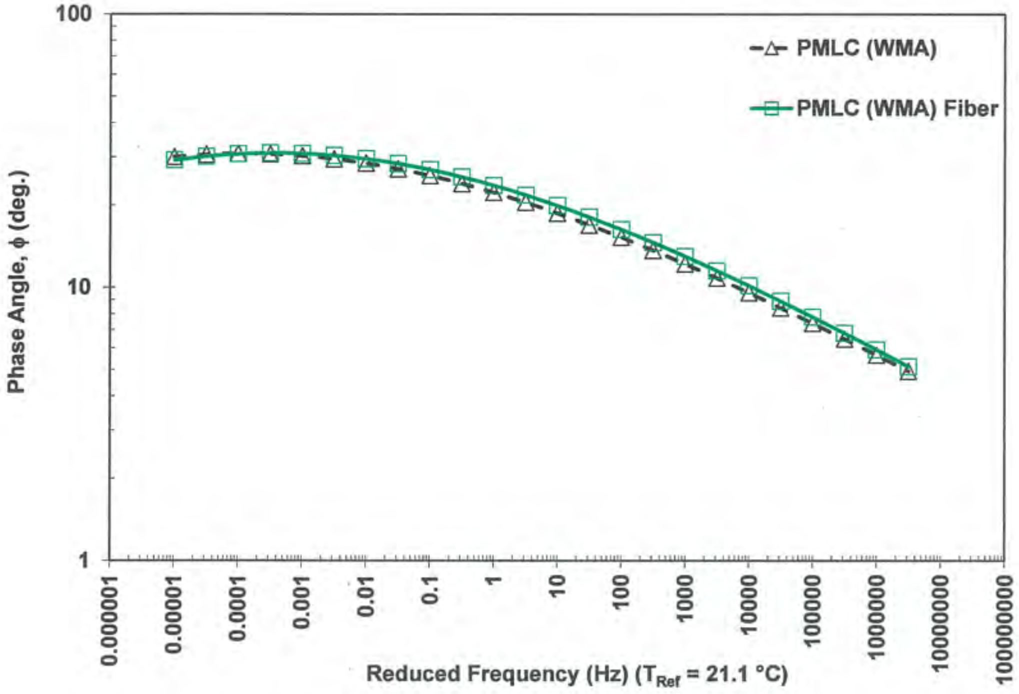


Figure 15. Phase angle master curves; log-log scale

Overall, these results indicate that the fiber modification did not significantly affect the dynamic modules and phase angle properties of the WMA mixtures. Wu et al., (2007) reported similar findings that adding fibers to the asphalt mixtures did not increase the dynamic modulus during investigation of rheological properties of these materials[15]. Some of these results may be attributed to the effect of fiber length or application temperature of fibers. It has been stated in the literature that if the fiber lengths are too long or too short, they may not provide significant reinforcing effect[8]. In addition, another study explained that the performance of fibers is most beneficial if their melting point is being considered because its tackiness glues the fiber to the matrix[16].

---

[15] Wu, S., Ye, Q., and Li N. "Investigation of rheological and fatigue properties of asphalt mixtures containing polyester fibers.", Journal of Construction and Building Materials, No. 22, 2008, pp. 2111-2115.

[8] Abtahi, S. M., Sheikhzadeh, M., and Hejazi S. M.; "Fiber-reinforced asphalt concrete – A review " Journal of Construction and Building Materials , Vol. (24), pp. 871-877, 2010.

[16] Hejazi, S.M., Abtahi, S.M., Sheikhzadeh M. and Semnani D. "Using an artificial neural network (ANN) for the investigation of some fiber parameter performance in fiber reinforced asphalt concrete (FRAC)", 7th International conference sustainable aggregates, asphalt technology and pavement engineering, Liverpool, UK, 2008.

FATIGUE TESTING

Fatigue cracking is one of the major types of distress in asphalt pavements. Fatigue testing of asphalt mixtures involves mainly subjecting specimens to repeated loading using either a controlled stress mode or a controlled strain mode. However, other test approaches also have been used to characterize fatigue behavior of asphalt materials. Over the years, several laboratory test methods have developed to evaluate fatigue performance of asphalt mixtures. Commonly used fatigue tests include the beam fatigue test, semi-circular bending fatigue test, and direct tension or indirect tension fatigue test. These fatigue test methods are empirical in nature. Fatigue cracking in asphalt pavements is a complicated phenomenon and requires mechanistic approaches with rigorous theoretical considerations. Recently, the researchers at the North Carolina State University (NCSU), led by Professor Richard Kim, have developed a Simplified Viscoelastic Continuum Damage (S-VECD) model for characterizing the fatigue properties of asphalt mixtures.

A Simplified Viscoelastic Continuum Damage (S-VECD) Model

The S-VECD model is mathematically rigorous approach. In this model, the fundamental material properties are incorporated. The key function is the damage characteristic curve (*C* versus *S*) that relates the amount of damage (*S*) in a specimen to the material integrity or pseudo stiffness (*C*). Kim and Underwood document a detailed derivation of the S-VECD model[17]. Overall, a complete characterization of damage in asphalt mixtures is obtained using the S-VECD model approach under a wide range of temperature, strain, and frequencies; as well as prediction of endurance limit and number of cycles at failure. The S-VECD model also requires the linear viscoelastic (LVE) material properties to determine viscoelastic damage characteristic relationships. The dynamic modulus and fatigue test results are analyzed by the ALPHA-Fatigue software to generate the model parameters.

---

[17] Underwood, B. S., Baek C., and Y. R. Kim (2012) "Simplified Viscoelastic Continuum Damage Model as Platform for Asphalt Concrete Fatigue Analysis". Journal of the Transportation Research Board, No. 2296, Transportation Research Board of the National Academies, Washington, D.C., 2012, pp. 36-45.

Linear Viscoelastic (LVE) Characterization

The S-VECD model requires LVE testing at multiple temperatures and frequencies. The primary LVE material responses are the mixture dynamic modulus ($|E^*|$) and phase angle (ϕ). Three AMPT dynamic modulus tests are performed for each mix to obtain the LVE properties. Dynamic modulus tests are performed using four temperatures (4.4, 21.1, 37.8, and 54.4 °C) and six frequencies (25, 10, 5, 1, 0.5, and 0.1 Hz). The testing order is from low to high temperatures and from high to low frequencies in order to minimize potential specimen damage. The LVE tests are performed using specimen dimensions of 100 mm diameter x 130 mm height cylindrical specimens. The target on-specimen peak-to-peak strain level during testing is 50 to 75 microstrains.

Hou et al., found that the damage curves collapse better when using Dynamic Modulus Ratio (DMR) rather than other parameters. In order to define DMR, a "fingerprint" dynamic modulus test is performed on each specimen before fatigue testing where the sample is subjected to very low non-damaging strain amplitude. The fingerprint modulus is denoted as $|E^*|_{fp}$. The fingerprint test dynamic modulus value is computed using the final five cycles of the test. Afterwards, the specimen-to-specimen variability can be evaluated using the DMR value, $DMR=|E^*|_{fp} \div |E^*|_{LVE}$. The DMR values of asphalt mixtures typically range between 0.9 and 1.1 suggesting a specimen-to-specimen variability of approximately $\pm$10 percent[18].

Viscoelastic Damage Characterization

The viscoelastic damage characterization is determined by performing controlled strain cyclic tension ("pull-pull") testing according to AASHTO specification TP 107[19]. The fatigue tests are performed using specimen dimensions of 100 mm diameter x 130 mm height cylindrical specimens. Three linear variable displacement transducers (LVDTs) are mounted on the sides of each specimen 120° apart. The axial gauge length on the

---

[18] Hou, T., Underwood, B. S., and Y. R. Kim "Fatigue Performance Prediction of North Carolina Mixtures Using the Simplified Viscoelastic Continuum Damage Model" Association of Asphalt Paving Technologies (AAPT), Vol. (79), pp. 35-73, 2010.

[19] AASHTO TP 107 *"Determining the Damage Characteristic Curve of Asphalt Concrete from Direct Tension Cyclic Fatigue Tests"*

specimens is 70 mm. All fatigue tests for this project were performed at a constant frequency of 10 Hz using a target temperature of 21 °C. Test temperature selection is consistent with AASHTO TP107 guidance. This intermediate temperature is suitable for the material's viscoelastic damage characterization without the effects of viscoplasticity, which leads to severe specimen damage and macro cracks.

Traditional empirical fatigue analysis determines failure as the point where the mixture modulus drops to 50% of its initial value. In the S-VECD approach, failure is defined as the number of cycles at which a sharp decrease in phase angle occurs. It is denoted as number of cycles to failure, N_f (Figure 16). Typical cracking failure patterns at the completion of fatigue testing are shown in Figure 17. The first type of failure is a mid-failure crack where failure occurs within the measurement zone between the LVDT mounting studs where the LVDTs are able to capture the evolution of damage throughout the entire test. A mid-failure is an indication of successful fatigue test result is shown in Figure 18. The second type of failure is an end-failure crack where failure occurs at the end of specimen outside of the LVDT mounting studs. This failure pattern occurs outside the LVDT measurement range and cannot be used.

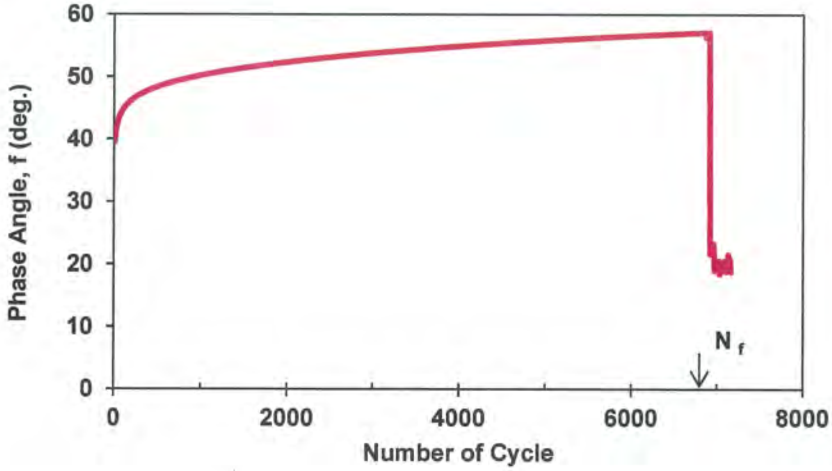
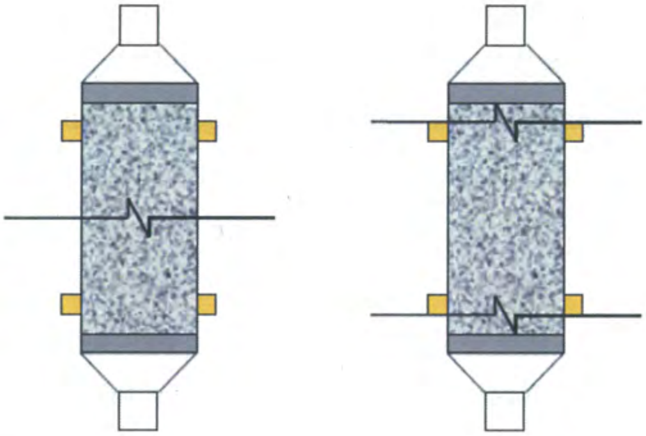


Figure 16. Typical fatigue test result; Phase angle versus Number of cycles



(a) (b)

Figure 17. Failure patterns of fatigue tests: (a) mid-Failure and (b) end-Failure[20]

Figure 18. Photo of Failed Sample due to Fatigue Test showing Mid-Specimen Failure

---

[20] Hou, T., Underwood, B. S., and Y. R. Kim "Fatigue Performance Prediction of North Carolina Mixtures Using the Simplified Viscoelastic Continuum Damage Model" Association of Asphalt Paving Technologies (AAPT), Vol. (79), pp. 35-73, 2010.

The mixture damage characteristic curves (C versus S curves) are shown in Figure 19. They show the mixture's resistance to damage. Comparatively, the WMA mixture containing fiber resulted in more favorable damage characteristic curve. Basically, this curve shows the damage characteristic and damage resistance of material. Material shows lower slope is more favorable due to lower damage accumulation rate. Therefore, material with a higher curve has better damage resistance. However, the curves shown in this figure may not be sufficient to rank mixtures' fatigue performance as it ignores the significant influence of the materials resistance to deformation[21]. The ranking shown in Figure 18 depicts only the material's resistance to damage. Also, under loading conditions where other mechanisms, such as viscoplasticity, begin to contribute significantly, the performance ranking could change. Hence, a more comprehensive method of comparison is needed to characterize fatigue behavior of these materials. Such comparisons are conducted by using predicted endurance limits over a range of test temperatures (5 to 25 °C).

Figure 20 presents the mixtures' predicted endurance limits. Fundamentally, the endurance limit represents material capacity against fatigue damage before failure stage. Therefore, material with higher endurance limit can be a better candidate against fatigue distress. The WMA mixtures containing fiber demonstrated higher endurance limits compared to the control WMA mixtures. This suggests, with all other variables held constant and considered equal, the fiber reinforcement improved the cracking resistance of the WMA mixture. These results confirm the findings of previous studies regarding fatigue resistance of fiber reinforced asphalt mixtures[22].

---

[21] B. S. Underwood, Y. R. Kim, and M. N. Guddati. (2006). "Characterization and Performance Prediction of ALF Mixtures Using a Viscoelastoplastic Continuum Damage Model." Journal of Association of Asphalt Paving Technologists, Vol. 75, pp. 577-636.

[22] S. Joon Lee, Jon P. Rust, Hechmi Hamouda, Y. Richard Kim, and Roy H. Borden, "Fatigue Cracking Resistance of Fiber-Reinforced Asphalt Concrete", Textile Research Journal February 2005, 75: p123-128.

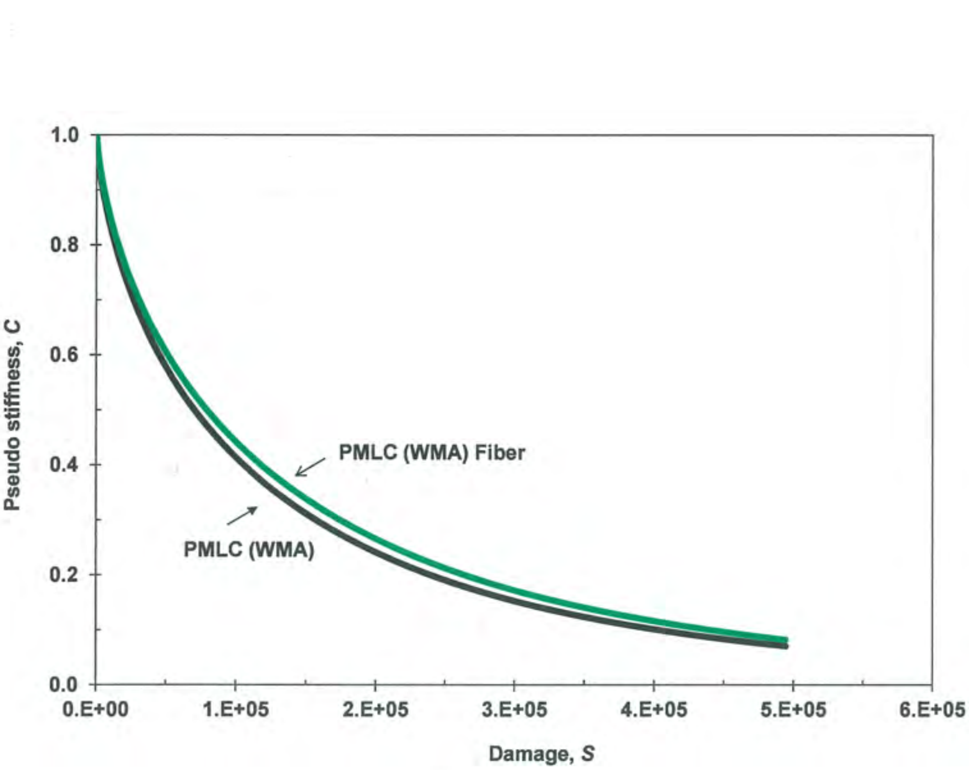


Figure 19. S-VECD fatigue test damage characteristics curves

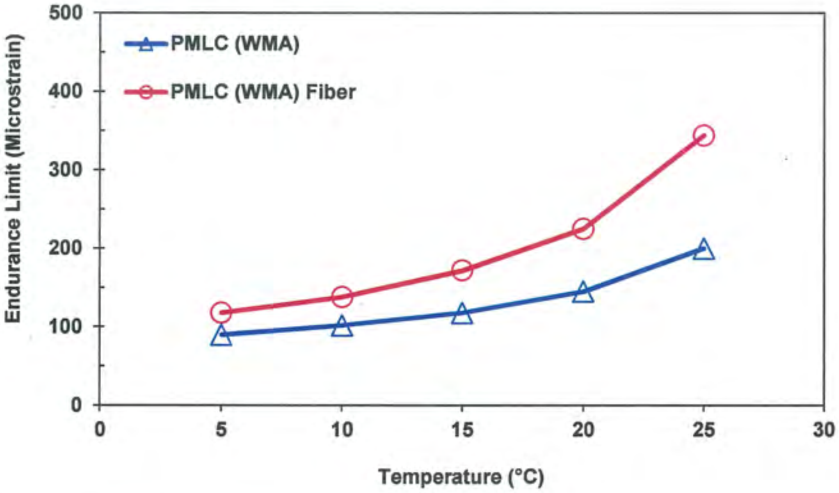


Figure 20. S-VECD fatigue test; endurance limit versus temperature

FLOW NUMBER TEST

The permanent deformation properties of the asphalt mixtures are evaluated using the Flow Number (F_n) Test. F_n testing is a dynamic creep test conducted by applying a repeated axial load of 0.1 second followed by a 0.9 second rest period per cycle. The number of load cycles and cumulative axial strains are continuously monitored and recorded. The number of load cycles corresponding to the minimum strain rate of change is defined as the F_n. This minimum rate of change is an indication of the mixture entering a tertiary flow condition where it begins to deform and rutting would occur. By plotting the total accumulated strain versus number of cycles, three different zones are realized. Primary, secondary, and tertiary zones are identified on the creep curve (Figure 21). The transition from secondary to tertiary creep corresponds to the minima of the rate of change of axial strain as shown in Figure 22.

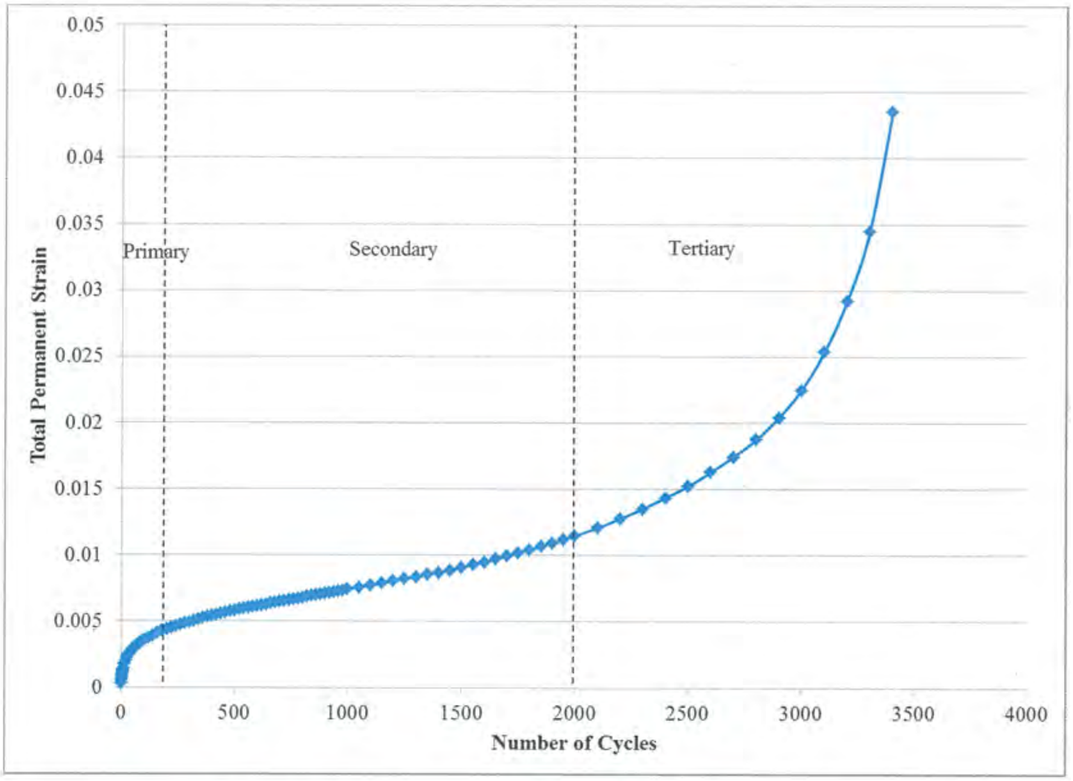


Figure 21. Typical creep curve for asphalt mixture samples

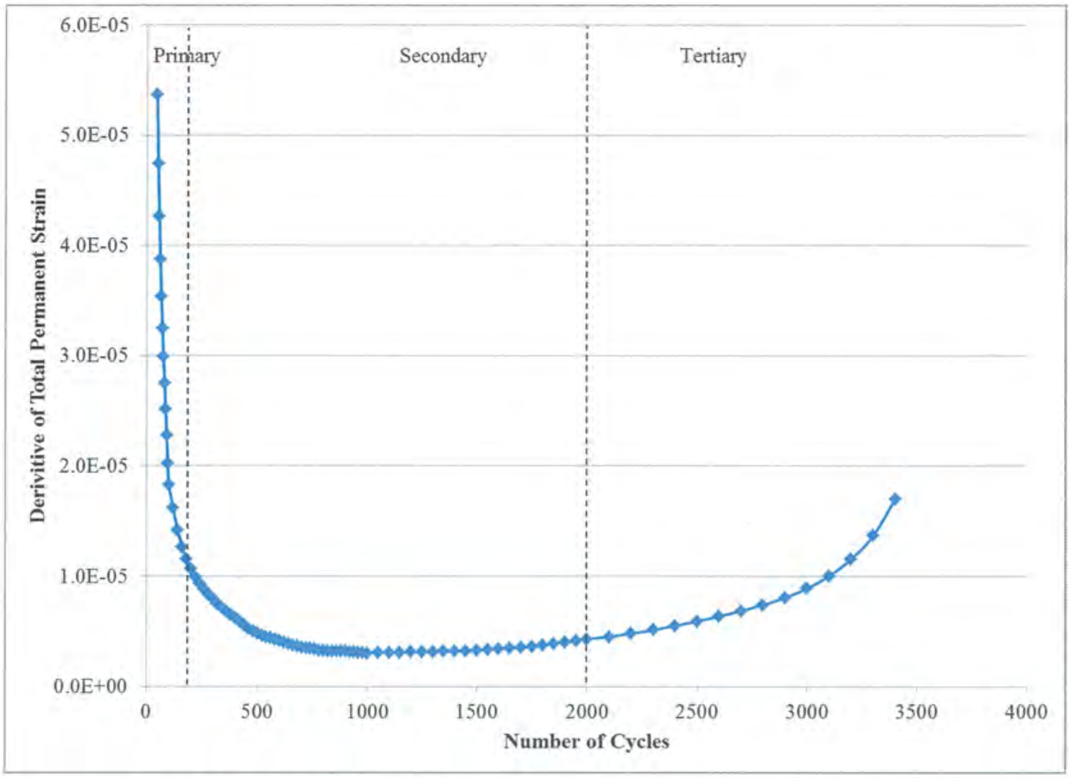


Figure 22. Plot of rate of change of permanent axial strain versus cycles

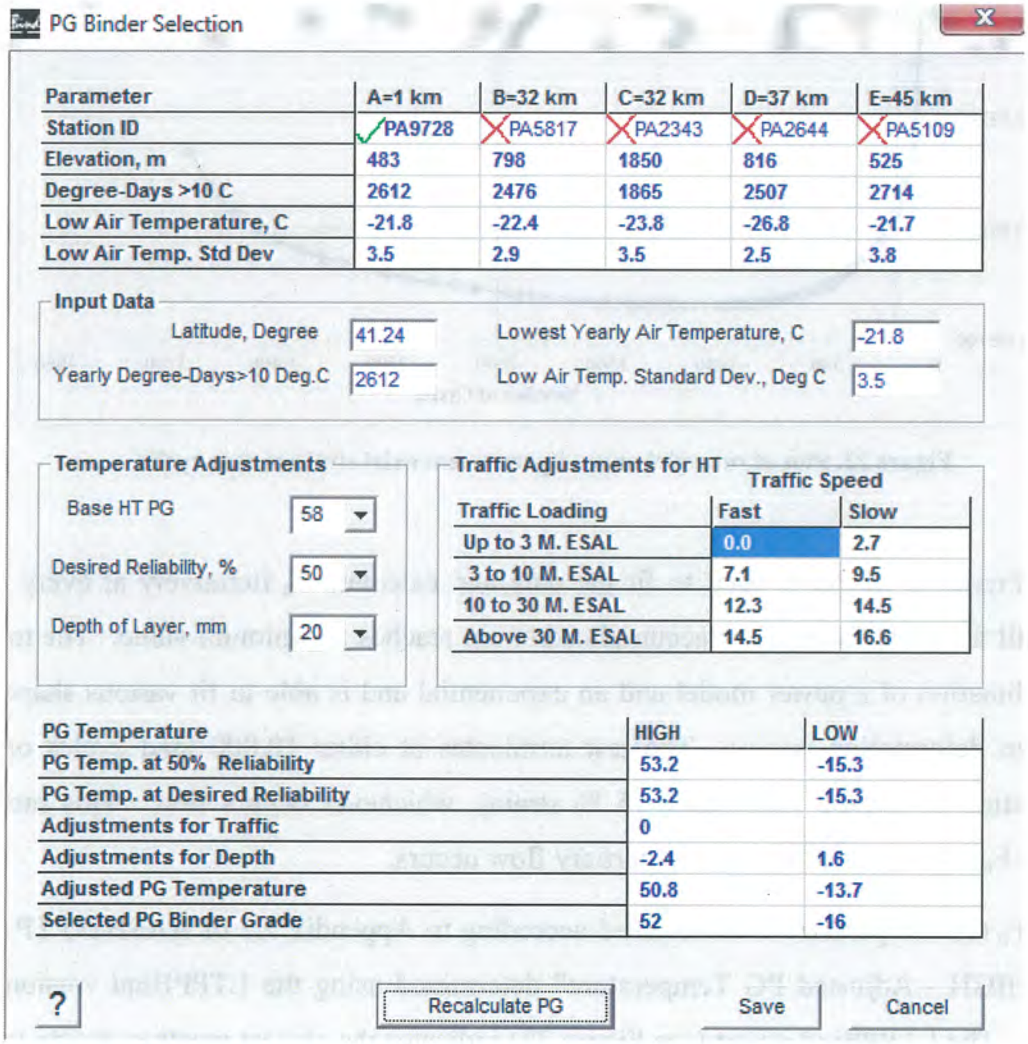
The Francken model is used to fit the data and calculate F_n iteratively at every load cycle until the rate of change of accumulated strain reaches a minimum value. The model is a combination of a power model and an exponential and is able to fit various shapes of permanent deformation curves. The test terminates at either 10,000 load cycles or the accumulation of 50,000 microstrain (5 % strain), whichever occurs first. This method assigns a F_n value of 10,000 when no tertiary flow occurs.

The F_n test temperature is determined according to Appendix X2 of AASHTO TP 79[23] as the "HIGH - Adjusted PG Temperature" determined using the LTPPBind version 3.1 software. The LTPPBind report (see Figure 23) indicates the closest weather station to the project location is station PA 9728. The HIGH - Adjusted PG Temperature is determined at 50 % reliability, 20 mm below the surface and unadjusted for traffic. It was determined as 50.8 °C and used for F_n testing. The F_n test conditions including deviator stress levels

---

[23] AASHTO TP 79-13 Determining the Dynamic Modulus an Flow Number for Asphalt Mixtures Using the Asphalt Mixture Performance Tester (AMPT)

and number of specimens are presented in Table 11. The axial deviator stress levels for these testes included 600 kPa, 690 kPa, and 800 kPa. The mixtures were tested under both unconfined and confined F_n test conditions. A confinement stress of 69 kPa was used for the confined F_n tests. The F_n tests also include a contact stress (5 % of deviator stress) to establish a uniform stress state within the specimen.



Parameter	A=1 km	B=32 km	C=32 km	D=37 km	E=45 km
Station ID	✓PA9728	✗PA5817	✗PA2343	✗PA2644	✗PA5109
Elevation, m	483	798	1850	816	525
Degree-Days >10 C	2612	2476	1865	2507	2714
Low Air Temperature, C	-21.8	-22.4	-23.8	-26.8	-21.7
Low Air Temp. Std Dev	3.5	2.9	3.5	2.5	3.8

Input Data

Latitude, Degree 41.24
Yearly Degree-Days>10 Deg.C 2612
Lowest Yearly Air Temperature, C -21.8
Low Air Temp. Standard Dev., Deg C 3.5

Temperature Adjustments

Base HT PG 58
Desired Reliability, % 50
Depth of Layer, mm 20

Traffic Adjustments for HT

	Traffic Speed	
Traffic Loading	Fast	Slow
Up to 3 M. ESAL	0.0	2.7
3 to 10 M. ESAL	7.1	9.5
10 to 30 M. ESAL	12.3	14.5
Above 30 M. ESAL	14.5	16.6

PG Temperature	HIGH	LOW
PG Temp. at 50% Reliability	53.2	-15.3
PG Temp. at Desired Reliability	53.2	-15.3
Adjustments for Traffic	0	
Adjustments for Depth	-2.4	1.6
Adjusted PG Temperature	50.8	-13.7
Selected PG Binder Grade	52	-16

Figure 23. Screen capture from LTTPBind software showing the calculated project location's HIGH - Adjusted PG Temperature for the pavement[24]

---

[24] LTPPBind version 3.1 software accessible at http://www.fhwa.dot.gov/research/tfhrc/programs/infrastructure/pavements/ltpp/dwnload.cfm

Table 10. Flow number test; temperature 50.8 °C

Flow Number Test	Deviator Stress (kPa)	Mix ID	
		PMLC (WMA)	PMLC (WMA) Fiber
Unconfined	600	4 Replicates	4 Replicates
	690	4 Replicates	4 Replicates
	800	4 Replicates	4 Replicates
Confined	600	4 Replicates	4 Replicates
	690	4 Replicates	4 Replicates
	800	4 Replicates	4 Replicates

Flow Number Test Results

The flow number test results and their overall statistics are summarized in Appendix E. Figure 21 presents the average flow number of the mixtures tested under unconfined and confined $F_n$test conditions. The error bars shown in these figures indicate the standard error of the results using four test specimen replicates. Higher Fn values indicate increased resistance to permanent deformation and rutting.Figure 24 compares the flow numbers results for mixture with and without fibers under confined and unconfined conditions. Some experts suggest that confined condition has a better representation of real field condition due to pavement confinement provided on the roadway. Based on the results shown in Figure 24(b), both mixtures perform great that none of them reached tertiary flow after 10000 passes at three different loading levels. Therefore, to distinguish between rutting resistance of these two mixtures, data at unconfined conditions needs to be compared. As seen in Figure 24(a), the mixture with fiber exhibits significantly better performance than the mixture without fiber, with more than two times higher flow number value. However, as load level was increased to higher value, the results changed. As Figure 24(a) depicts the control mixture performed better in terms of rutting resistance.

This behavior can be attributed to different factors as discussed in previous sections. Also, Kaloush et al., reported that at higher load levels, fiber-reinforced asphalt mixtures showed different behavior in terms of resistance to distresses[7].

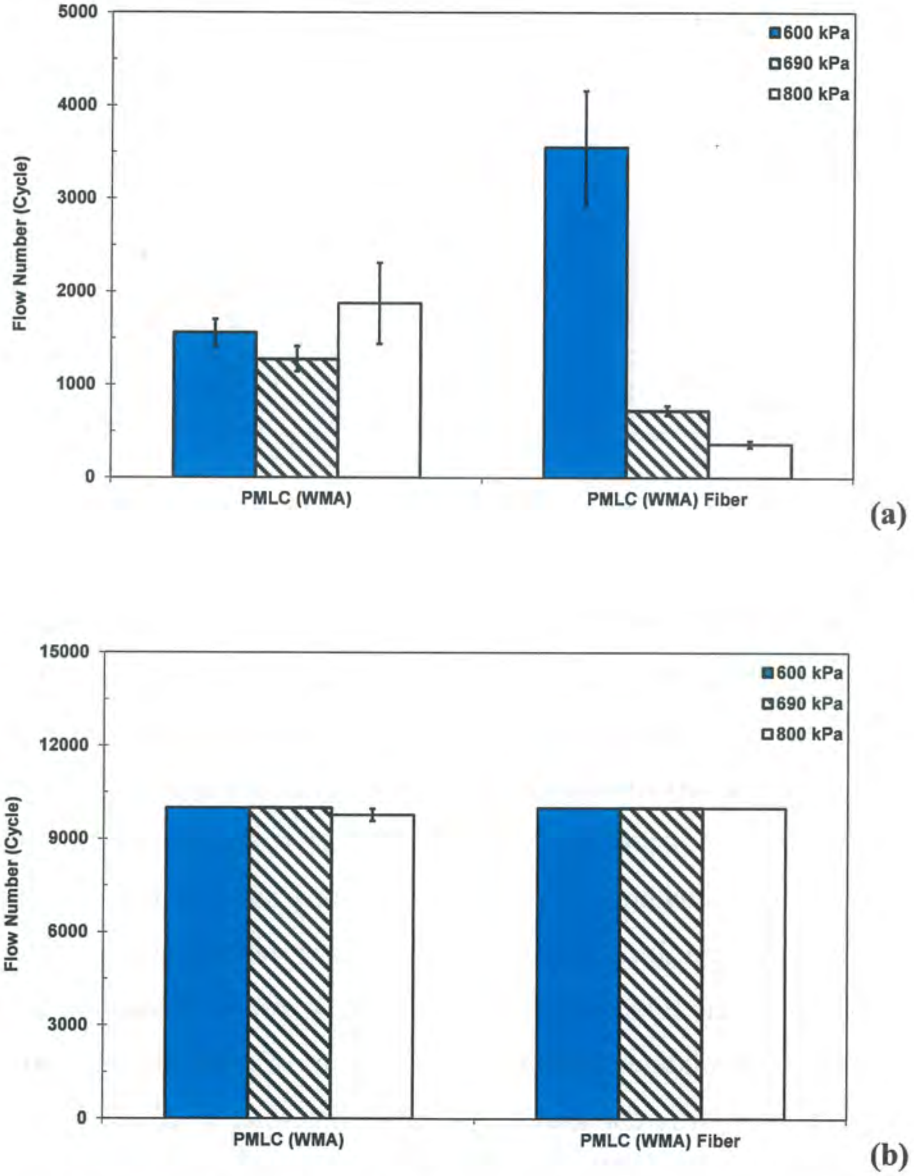


Figure 24. Flow number test results; (a) Unconfined and (b) Confined conditions

---

[7] Kaloush, K. E., Zeiada, W., Biligiri, K., Rodezno, M. C., and Reed J.; "Evaluation of Fiber-Reinforced Asphalt Mixtures Using Advanced Material Characterization Tests ", Journal of Testing and Evaluation 38, no. 4 (2010).

HAMBURG TEST

The permanent deformation and moisture damage (stripping) properties of the asphalt mixtures were evaluated using the Hamburg test in accordance with AASHTO T 324[25]. The Hamburg wheel-track device is shown in Figure 25. It is an electrically powered test device capable of moving a steel wheel (203.2 mm diameter and 47 mm wide) back and forth across a test specimen. The load on the wheel is 705 ± 4.5 N and moves across the specimen at a rate of 50 passes per minute. The maximum speed of the wheel is approximately 0.305 m/s. The device has a water bath capable of controlling the temperature within ± 1.0 °C, over a range of 25 to 70 °C. A gauge capable of measuring the depth of the impression of the wheel within 0.01 mm is mounted on this device to measure the depth at the midpoint of the wheel's path on the test specimens.

A typical Hamburg test results corresponding to non-stripping and stripping mixtures is shown in Figure 26. The Hamburg test parameters include, creep slope, stripping slope, and stripping inflection point. The creep slope is the inverse of the deformation rate within the linear region of the deformation curve. It indicates rutting susceptibility of asphalt mixtures due to traffic loading. The stripping slope is the inverse of the deformation rate after stripping occurs. It measures the accumulation of permanent deformation due to moisture damage. It is used to estimate the relative resistance of the asphalt mixtures to moisture-induced damage. The stripping inflection point is the number of wheel passes corresponding to the intersection of the creep slope and the stripping slope. In other words, it is the number of wheel passes at which moisture damage starts.

The Hamburg test requires two test specimens for each of the wheel-tracks, which are denoted as the left wheel path (LWP) and the right wheel path (RWP). The asphalt mixtures prepared using 7 ± 0.5 % target air voids were compacted in accordance with AASHTO T 312[26]. The resulting specimen dimension was 61 mm height and 150 mm diameter. The control and fiber WMA mixes included four and five specimen replicates, respectively. The Hamburg test was conducted at 50 °C until 20,000 passes or 20 mm rut depth, whichever occurred first.

---

[25] AASHTO T 324-11 *"Standard Method of Test for Hamburg Wheel-Track Testing of Compacted HMA"*

[26] AASHTO T 312-13 *"Standard Method of Test for Preparing and Determining the Density of Hot Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor"*

Figure 25. Photo of the Hamburg test experimental setup with Asphalt Mixtures Samples Placed in the Instrument

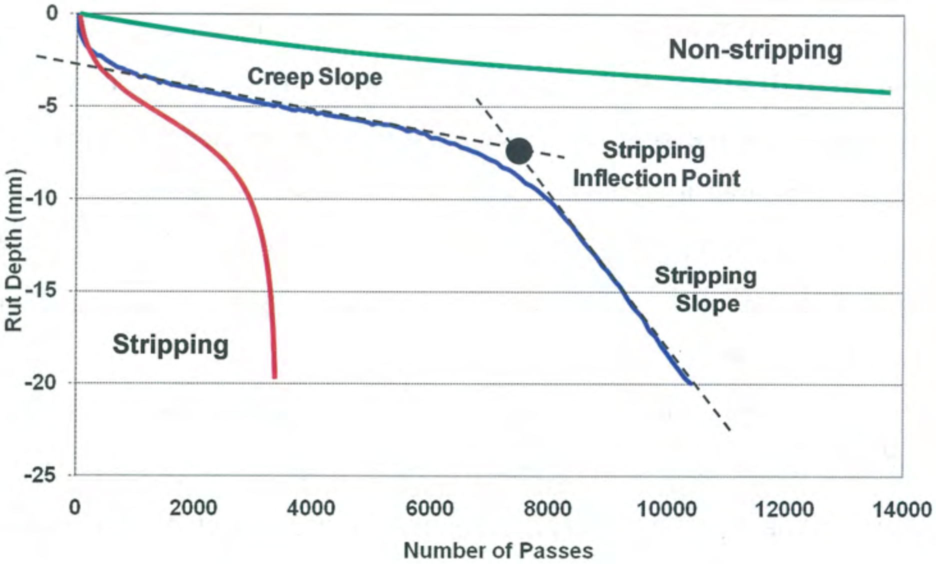


Figure 26. Typical Hamburg test result; Rut Depth versus Number of Passes

Hamburg Test Results

The Hamburg test results are shown in Figure 27. The figure includes pictures of the specimens before and after testing. The test results for each individual specimen are summarized in Figures 28 through 31. In these figures, to differentiate between samples, this naming pattern is used: Plant Mixed Lab Compacted (PMLC), Warm Mix Asphalt (WMA), Specimens number (SP X & X), Left Wheel Path (LWP).

A higher creep slope relates to a higher rate of deformation while a higher stripping slope indicates increased deformation due to moisture damage. The WMA mixture containing fiber resulted in lower creep slopes, lower stripping slopes, higher stripping inflection points, and lower rut depths as compared to the control WMA mixture. This indicates that the fiber reinforcement improved the rutting and moisture induced rutting resistance of the WMA mixtures.

The Texas Department of Transportation (TxDOT) specifies the minimum number of Hamburg wheel passes to reach a rut depth of 12.5 mm when tested at a temperature determined by the performance grade of the asphalt binder. As presented in Table 11, these values are >10,000 for mixtures produced with PG 64-XX binder, >15,000 for mixtures produced with PG 70-XX binder, and >20,000 for mixtures produced with PG 76-XX binder. The Hamburg results were compared to the TxDOT requirements and they did not meet the minimum required number of passes (Table 12).

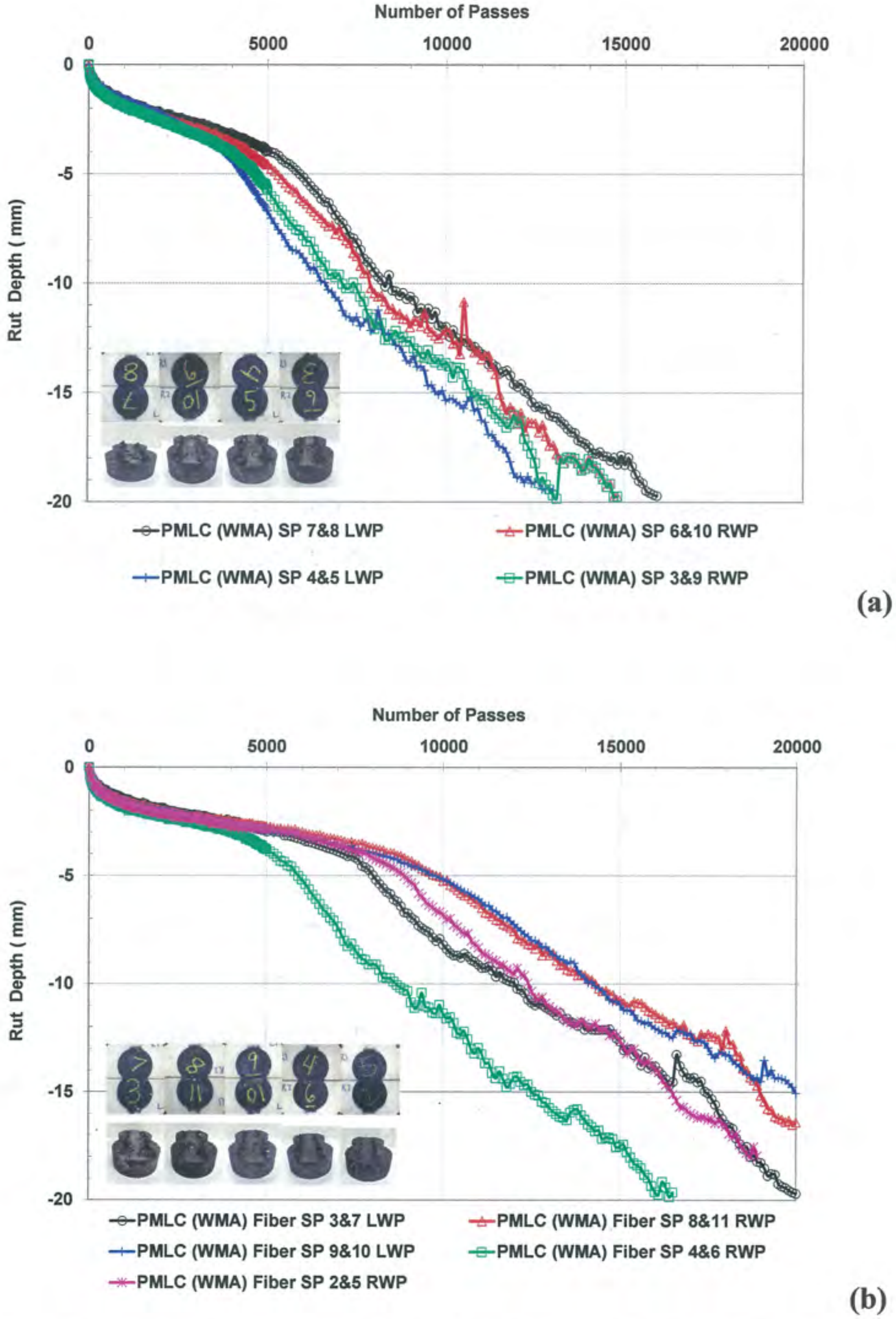


Figure 27. Hamburg test results; (a) Control PMLC (WMA) and (b) PMLC (WMA) with Fiber

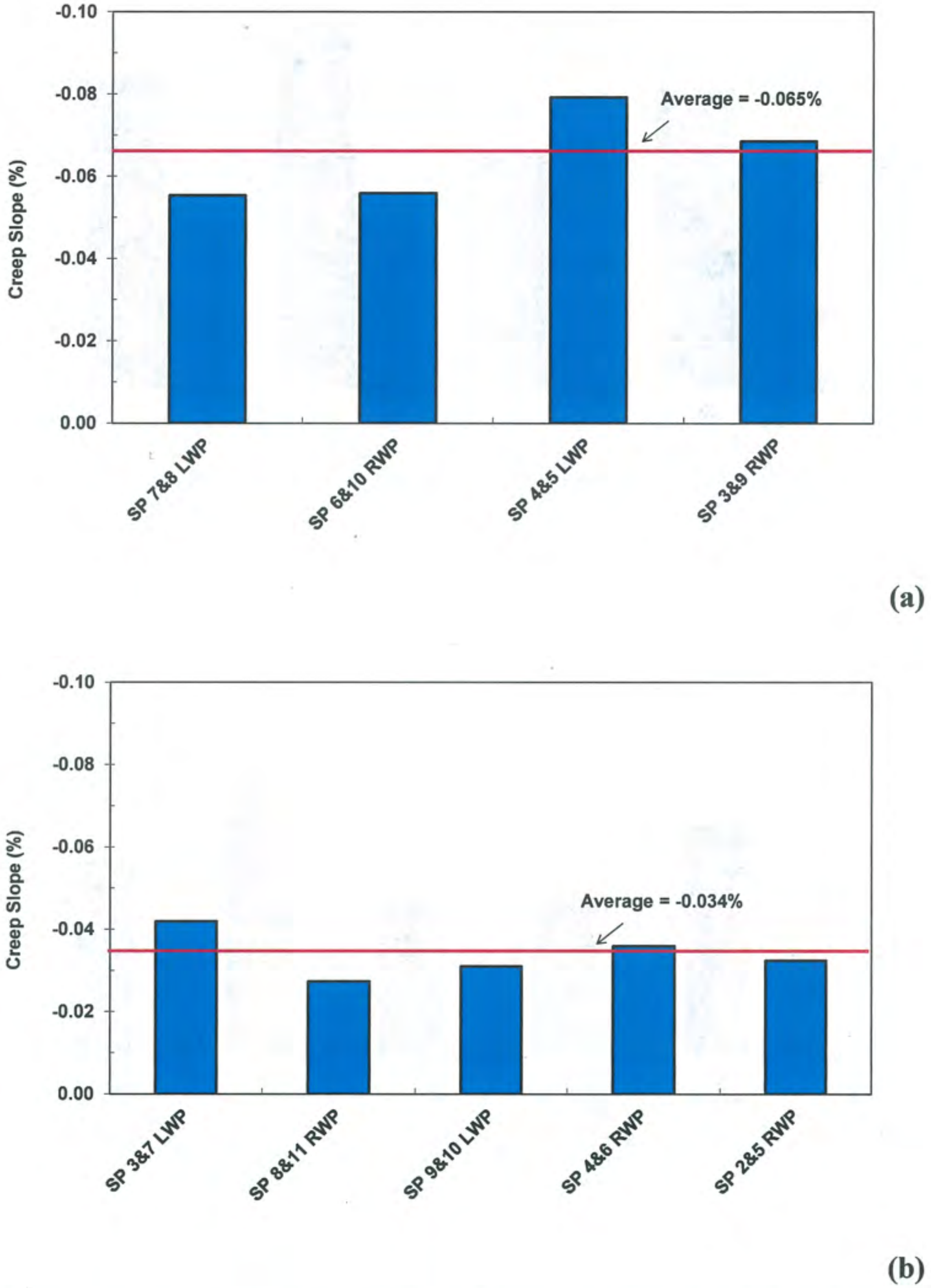
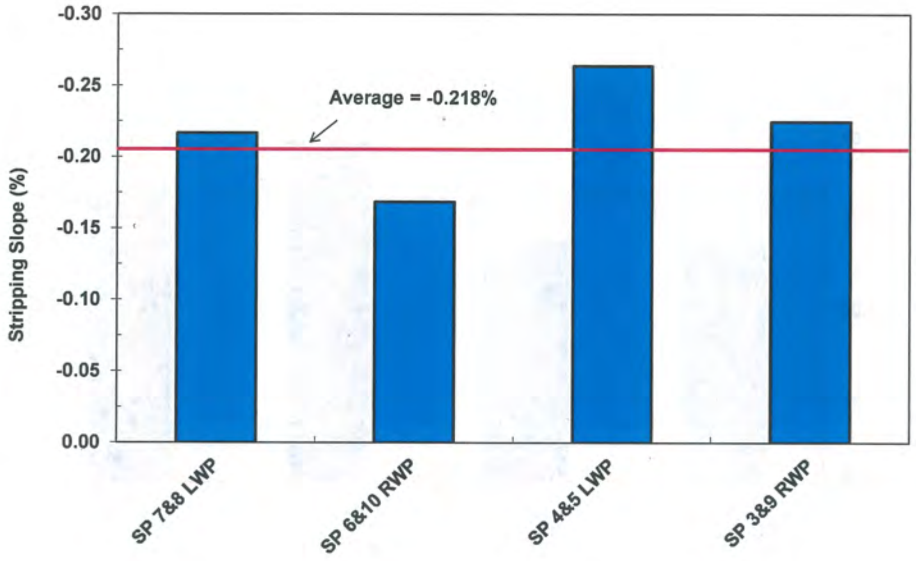
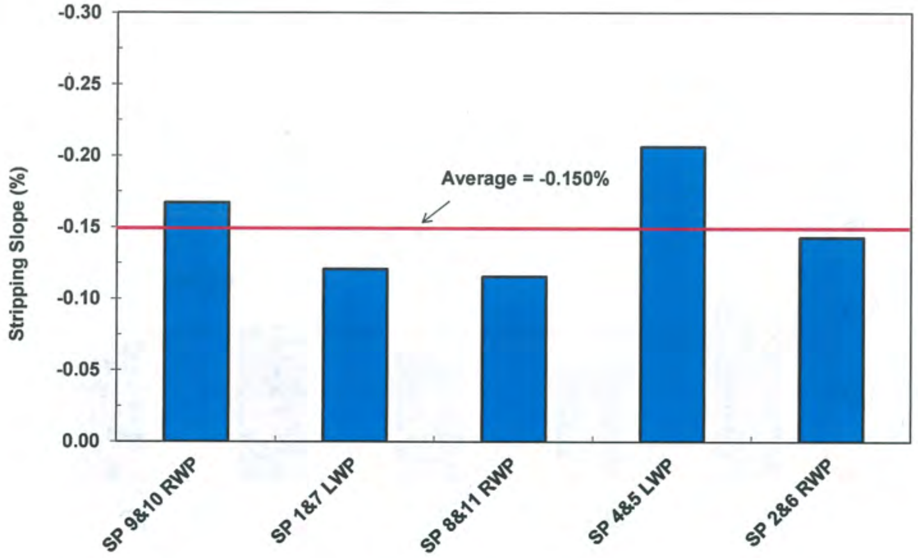


Figure 28. Hamburg creep slope; (a) Control PMLC (WMA) and (b) PMLC (WMA) with Fiber

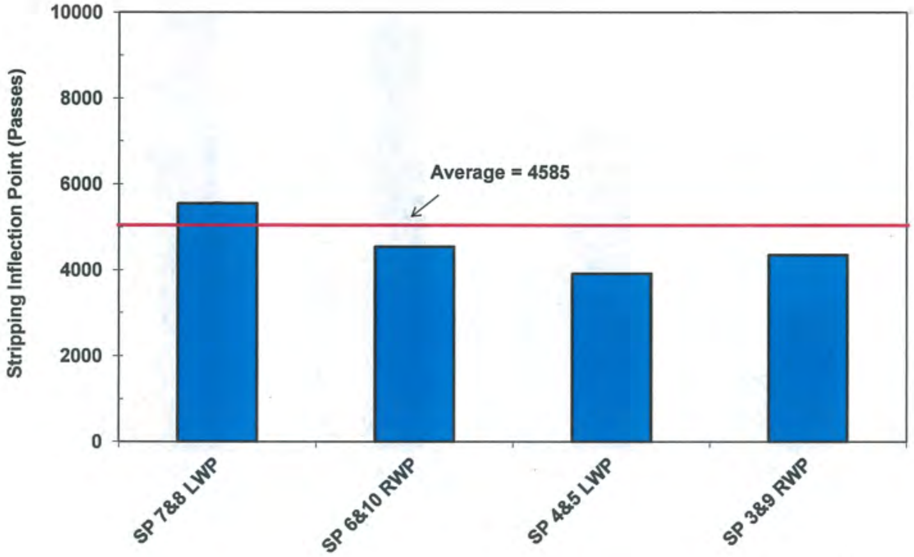


(a)

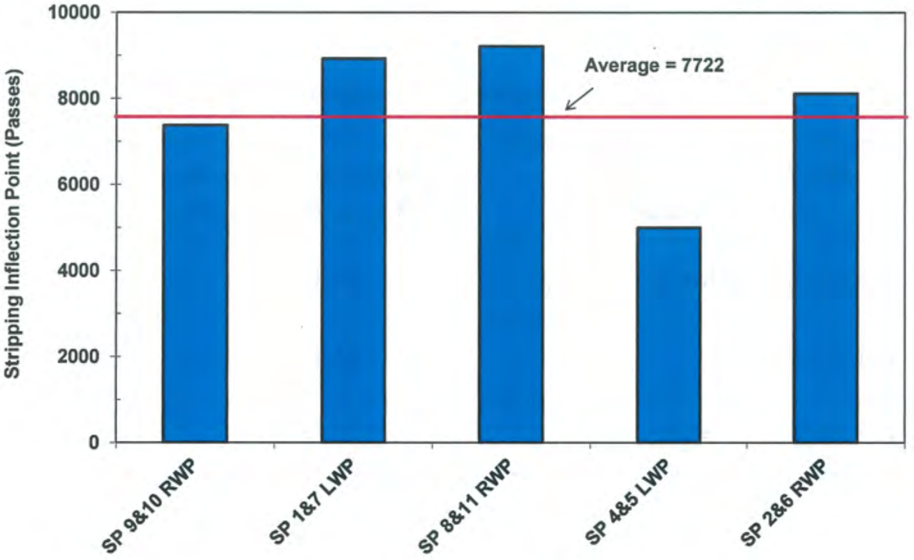


(b)

Figure 29. Hamburg stripping slope; (a) Control PMLC (WMA) and (b) PMLC (WMA) with Fiber



(a)



(b)

Figure 30. Hamburg stripping inflection point; (a) Control PMLC (WMA) and (b) PMLC (WMA) with Fiber

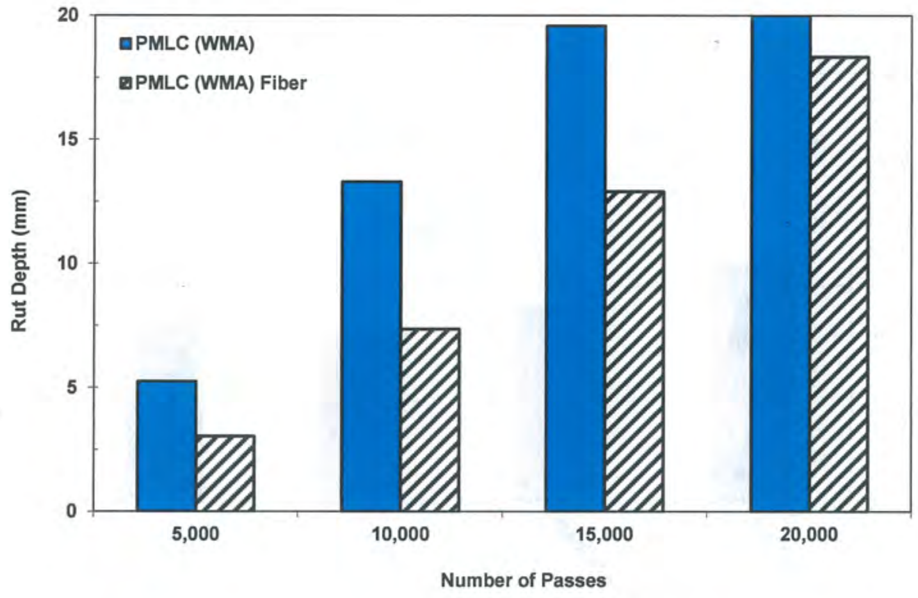


Figure 31. Hamburg rut depth for mixtures with and without fiber; Rut Depth versus Number of Passes

Table 11. TxDOT Hamburg test requirement[27]

High Temperature Binder Grade	Minimum Passes to 12.5 mm Rut Depth
PG 64-XX or lower	10,000
PG 70-XX	15,000
PG 76-XX or higher	20,000

---

[27] A Manual for Design of Hot Mix Asphalt with Commentary, NCHRP Report 673 (2011).

Table 12. Evaluation of Hamburg rutting using TxDOT specification

Mix ID	Specimen ID	Passes to 12.5 mm Rut Depth	Minimum Passes for PG76-XX	Test Result Meets Criteria, YES/NO
PMLC (WMA)	SP 7&8 LWP	10300	20,000	NO
	SP 6&10 RWP	9700		NO
	SP 4&5 LWP	8400		NO
	SP 3&9 RWP	8800		NO
PMLC (WMA) Fiber	SP 3&7 LWP	14800		NO
	SP 8&11 RWP	18000		NO
	SP 9&10 LWP	17000		NO
	SP 4&6 RWP	10600		NO
	SP 2&5 RWP	14900		NO

SUMMARY AND CONCLUSIONS

The laboratory performance properties of plant produced WMA mixtures containing reinforcing fiber were evaluated in this project. Two asphalt mixtures (with and without fiber) were produced using a fine-graded 9.5 mm Superpave mix design compacted to 75 design gyrations (Ndesign = 75). These mixtures were produced using a PG 76-22 binder (with a 0.25% anti-strip) supplied by Suite-Kote asphalt. An aqua black WMA technology (1.5 to 3% by weight of binder) supplied by Maxam Equipment Inc. was used in these mixtures. Four aggregate stockpiles were used to produce these mixtures. The plant produced asphalt mixtures were used as a thin-lift surface layer overlay of the existing pavement structure.

The aggregate shape properties were evaluated using the Aggregate Imaging Measurement System (AIMS) and under the Superpave consensus property requirements. The specific gravity and water absorption properties of the aggregates were measured. The asphalt mixture evaluation included volumetric and performance testing. The Asphalt Mixture Performance Tester (AMPT) was used to perform the dynamic modulus ($|E^*|$), fatigue (S-VECD), and Flow Number (F_n) tests to characterize the stiffness, fatigue cracking, and permanent deformation properties of the asphalt mixtures, respectively. Additionally, the Hamburg wheel-track test was conducted to evaluate both rutting and moisture susceptibility of the asphalt mixtures. Based on the results of the laboratory tests performed, the project findings include:

- The aggregate blends in AIMS testing resulted in medium angularity, medium texture, medium 2D form, and high sphericity.
- Dynamic modulus test data showed that mixture with and without fibers resulted in similar values for viscoelastic properties. The dynamic modulus and phase angle results are very similar for both mixture types and there is no significant statistical difference between them.
- The WMA mixture containing fiber resulted in more favorable damage characteristic curve and demonstrated higher endurance limits compared to the control WMA mixtures. This suggests, with all other variables held constant and considered equal, the fiber reinforcement improved the cracking resistance of the WMA mixture.

- Comparatively, the WMA fiber mixture exhibited higher resistance to deformation when tested under unconfined F_n testing at 600 kPa deviator stress. However, the control WMA mixture resulted in higher F_n values when tested under unconfined 690 kPa and 800 kPa.
- For confined F_n testing (600 kPa, 690 kPa, and 800 kPa), the WMA mixture containing fiber showed similar rutting resistance as that of the control WMA mixture.
- Overall, an increase in F_n deviator stress resulted in increased damage to the specimen and therefore resulted in lower F_n values. Comparatively, higher F_n values were measured for the confined tests.
- In Hamburg testing, the WMA mixture containing fiber showed improvement in rutting and moisture damage resistance as compared to the control WMA mixture.

Overall, the AMPT equipment can be routinely used in a field laboratory to assess mixture performance. The fabrication of test specimens for performance testing in a field laboratory is feasible and practical. Future application of AMPT for quality control and assurance testing will provide pavement performance benefits. Establishing acceptable ranges for dynamic modulus, fatigue, flow number, and Hamburg results may provide a basis for evaluating the performance of other mixtures possessing comparable design properties.

The FHWA MATT and ABTL laboratories are accredited through the AASHTO Accreditation Program and AASHTO R18, Standard Recommend Practice for *"Establishing and Implementing a Quality Management System for Construction Materials Testing Laboratories"*.

All testing was conducted, unless otherwise indicated, in accordance to AASHTO and/or ASTM test methods listed in Table 13.

Table 13. AASHTO and ASTM test methods and specifications

AASHTO Standards	
AGGREGATES	
T 2	Sampling of Aggregates
T 11	Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing
T 19	Bulk Density ("Unit Weight") and Voids in Aggregate
T 27	Sieve Analysis of Fine and Coarse Aggregates

T 30	Mechanical Analysis of Extracted Aggregate
T 37	Sieve Analysis of Mineral Filler for Hot Mix Asphalt (HMA)
T 84	Specific Gravity and Absorption of Fine Aggregate
T 85	Specific Gravity and Absorption of Coarse Aggregate
T 176	Plastic Fines in Graded Aggregates and Soils by Use of the Sand Equivalent Test
T 248	Reducing Samples of Aggregates to Testing Size
T 255	Total Evaporative Moisture Content of Aggregate by Drying
T 304	Uncompacted Void Content of Fine Aggregate
PP 64	Determining Aggregate Source Shape Values from Digital Image Analysis Shape Properties
TP 81	Determining Aggregate Shape Properties by Means of Digital Analysis
MIXTURE	
M 323	Superpave Volumetric Mix Design
R 30	Mixture Conditioning of Hot Mix Asphalt (HMA)
R 35	Superpave Voulmetric for Design for Asphalt Mixtures
R 47	Reducing Samples of Hot Mix Asphalt (HMA) to Testing Size
T 166	Bulk Specific Gravity (G_{mb}) of Compacted Hot Mix Asphalt (HMA) Using Saturated Surface-Dry Specimens
T 209	Theoretical Maximum Specific Gravity (G_{mm}) and Density of Hot Mix Asphalt (HMA)
T 269	Percent Air Voids in Compacted Dense and Open Asphalt Mixtures
T 308	Determining the Asphalt Binder Content of Hot Mix Asphalt (HMA) by the Ignition Method
T 312	Preparing and Determining the Density of Asphalt Mixture Specimens by Means of the Superpave Gyratory Compactor
T 324	Hamburg Wheel-Track Testing of Compacted Hot Mix Asphalt (HMA)
T 329	Moisture Content of Hot Mix Asphalt (HMA) by Oven Method
T 331	Bulk Specific Gravity (G_{mb})and Density of Compacted Hot Mix Asphalt (HMA) Using Automatic Sealing Method
PP 60	Preparation of Cylindrical Performance Test Specimens Using the Superpave Gyratory Compactor (SGC)
PP 61	Developing Dynamic Modulus Master Curves for Asphalt Mixtures Using the Asphalt Mixture Performance Tester (AMPT)
TP 79	Determining the Dynamic Modulus and Flow Number for Asphalt Mixtures Using the Asphalt Mixture Performance Tester (AMPT)
TP 82	Bulk Specific Gravity of Compacted Bituminous Mixtures Using Water Displacement Measured by Pressure Sensor
TP 107	Determining the Damage Characteristic Curve of Asphlt Mixtures from Direct Tension Cyclic Fatigue Tests
BINDER	
M 320	Performance-Graded Asphalt Binder
M332	Performance-Graded Asphalt Binder Using Multiple Stress Creep Recovery (MSCR) Test
R 28	Accelerated Aging of Asphalt Binder Using a Pressurized Aging Vessel (PAV)
R 29	Grading or Verifying the Performance Grade (PG) of an Asphalt Binder

T 40	Sampling Bituminous Materials
T 228	Specific Gravity of Semi-Solid Asphalt Materials
T 240	Effect of Heat and Air on a Moving Film of Asphalt Binder (Rolling Thin Film Oven Test)
T 313	Determining the Flexural Creep Stiffness of Asphalt Binder Using the Bending Beam Rheometer (BBR)
T 314	Determining the Fracture Properties of Asphalt Binder in Direct Tension (DT)
T 315	Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)
T 316	Viscosity Determination of Asphalt Binder Using Rotational Viscometer
TP 92	Determining the Cracking Temperature of Asphalt Binder Using the Asphalt Binder Cracking Device (ABCD)
ASTM Standards	
AGGREGATES	
C29	Bulk Density ("Unit Weight") and Voids in Aggregate
C117	Materials Finer than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing
C127	Density, Relative Density, (Specific Gravity), and Absorption of Coarse Aggregate
C126	Density, Relative Density, (Specific Gravity), and Absorption of Coarse Aggregate
C136	Sieve Analysis of Fine and Coarse Aggregate
C566	Total Evaporative Moisture Content of Aggregate by Drying
C702	Reducing Samples of Aggregate to Testing Size
C1252	Uncompacted Void Content of Fine Aggregate (as Influenced by Particle Shape, Surface Texture, and Grading)
D75	Sampling Aggregates
D546	Sieve Analysis of Mineral Filler for Bituminous Paving Mixtures
D2419	Sand Equivalent Value of Soils and Fine Aggregate
D4791	Flat Particles, Elongated Particles, or Flat and Elongated Particles in Coarse Aggregate
D5821	Determining the Percentage of Fractured Particles in Coarse Aggregate
MIXTURES	
D2041	Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures
D2726	Bulk Specific Gravity and Density of Non-Absorptive Compacted Bituminous Mixtures
D3203	Percent Air Voids in Compacted Dense and Open Bituminous Paving Mixtures
D5444	Mechanical Size Analysis of Extracted Aggregate
D6307	Asphalt Content of Hot-Mix Asphalt by Ignition Method
D6752	Bulk Specific Gravity and Density of Compacted Bituminous Mixtures Using Automatic Vacuum Sealing Method
D6925	Preparation and Determination of the Relative Density of Hot Mix Asphalt Specimens by Means of the Superapve Gyratory Compactor
BINDER	
D7405	Multiple Stress Creep and Recovery (MSCR) of Asphalt Binder Using a Dynamic Shear Rheometer

APPENDIX A: AIMS Test Results

ımmary

Project Name:	PA1398_aims	Date:	10/31/13
Workbook:	PA1398_aims_AIMS_Stockpile_PMLC1 NO FIBER.xlsm	Technician:	matt
Description:	PMLC (WMA)		

s (weighted)

(Fine)	7.09
Fine)	2136.1
larity	2126.6
larity	2676.6
arse)	434.1
arse)	5560.7

Sphericity (Coarse)	%
Low (≤ 0.5)	2.4%
Moderate (0.5 - 0.6)	5.0%
High (0.6 - 0.8.0)	7.7%
Extreme (0.8 - 1.0)	0.7%
Sphericity (Coarse)	0.61

Flat & Elongated Ratio (Coarse)	%
L/S ≥ 1:1	15.8%
L/S > 2:1	13.4%
L/S > 3:1	7.7%
L/S > 4:1	4.0%
L/S > 5:1	2.7%

Flat or Elongated Ratio (Coarse)	Cum.%
F or E ≥ 1:1	15.8%
F or E > 1:2	8.4%
F or E > 1:3	3.4%
F or E > 1:4	2.4%
F or E > 1:5	0.7%

rage	Standard Deviation	Low (≤ 6.5)		(≤ 6.5)	Moderate (6.5 - 8)		(≤ 8)	High (8 - 10.75)		(≤ 10.75	Extreme (10.75 - 20)		(≤ 20)	Out of Range
		#	%	Cum. %	#	%	Cum. %	#	%	Cum. %	#	%	Cum. %	#
7.6	2.0	55	36.7%	36.7%	36	24.0%	60.7%	47	31.3%	92.0%	12	8.0%	100.0%	0
7.8	1.9	35	23.3%	23.3%	62	41.3%	64.7%	42	28.0%	92.7%	11	7.3%	100.0%	0
7.6	2.0	43	28.7%	28.7%	57	38.0%	66.7%	41	27.3%	94.0%	9	6.0%	100.0%	0
6.2	1.7	91	59.5%	59.5%	42	27.5%	86.9%	18	11.8%	98.7%	2	1.3%	100.0%	0
6.2	2.2	109	69.4%	69.4%	29	18.5%	87.9%	10	6.4%	94.3%	9	5.7%	100.0%	0
7.7	2.0	37	30.6%	30.6%	33	27.3%	57.9%	43	35.5%	93.4%	8	6.6%	100.0%	39

rage	Standard Deviation	Low (≤ 2100)		(≤ 2100)	Moderate(2100-3975)		(≤ 3975)	High(3975-5400)		(≤ 5400)	Extreme(5400-10000)		(≤ 10000)	Out of Range
		#	%	Cum. %	#	%	Cum. %	#	%	Cum. %	#	%	Cum. %	#
676.6	612.4	10	20.0%	20.0%	38	76.0%	96.0%	2	4.0%	100.0%	0	0.0%	100.0%	0
975.6	827.6	17	11.3%	11.3%	117	78.0%	89.3%	15	10.0%	99.3%	1	0.7%	100.0%	0
372.9	936.7	7	4.7%	4.7%	112	74.7%	79.3%	28	18.7%	98.0%	3	2.0%	100.0%	0
391.7	1132.6	13	8.7%	8.7%	99	66.0%	74.7%	26	17.3%	92.0%	12	8.0%	100.0%	0
516.7	923.0	53	34.6%	34.6%	90	58.8%	93.5%	9	5.9%	99.3%	1	0.7%	100.0%	0
832.0	1034.6	117	74.5%	74.5%	32	20.4%	94.9%	6	3.8%	98.7%	2	1.3%	100.0%	0
466.1	885.1	105	86.8%	86.8%	12	9.9%	96.7%	4	3.3%	100.0%	0	0.0%	100.0%	39

AIMS Stockpile Summary

Project Name:	PA1398_aims	Date:	10/31/13
Workbook:	PA1398_aims_AIMS_Stockpile_PMLC1 NO FIBER.xlsm	Technician:	matt
Description:	PMLC (WMA)		

Texture

Size	Particles In Range	Average	Standard Deviation	Low (≤ 200)		(≤ 200)	Moderate (200 - 500)		(≤ 500)	High (500 - 750)		(≤ 750)	Extreme (750 - 1000)		(≤ 1000)	Out of Range
				#	%	Cum. %	#	%	Cum. %	#	%	Cum. %	#	%	Cum. %	#
37.5 (1.5")																
25.0 (1.0")																
19.0 (3/4")																
12.5 (1/2")																
9.5 (3/8")																
4.75 (#4)	47	434.1	116.5	3	6.4%	6.4%	28	59.6%	66.0%	16	34.0%	100.0%	0	0.0%	100.0%	3

Sphericity

Size	Particles In Range	Average	Standard Deviation	Low (≤ 0.5)		(≤ 0.5)	Moderate (0.5 - 0.6)		(≤ 0.6)	High (0.6 - 0.8)		(≤ 0.8)	Extreme (0.8 - 1.0)		(≤ 1.0)	Out of Range
				#	%	Cum. %	#	%	Cum. %	#	%	Cum. %	#	%	Cum. %	#
37.5 (1.5")																
25.0 (1.0")																
19.0 (3/4")																
12.5 (1/2")																
9.5 (3/8")																
4.75 (#4)	47	0.61	0.10	7	14.9%	14.9%	15	31.9%	46.8%	23	48.9%	95.7%	2	4.3%	100.0%	3

Flat and Elongated Distribution

Size	Particles In Range	L/S ≥ 1:1		L/S > 2:1		L/S > 3:1		L/S > 4:1		L/S > 5:1		Out of Range
		#	%	#	%	#	%	#	%	#	%	#
37.5 (1.5")												
25.0 (1.0")												
19.0 (3/4")												
12.5 (1/2")												
9.5 (3/8")												
4.75 (#4)	47	47	100.0%	40	85.1%	23	48.9%	12	25.5%	8	17.0%	3

Flat or Elongated Distribution

Size	Particles In Range	F or E ≥ 1:1		F or E >2:1		F or E >3:1		F or E >4:1		F or E >5:1		Out of Range
		#	%	#	%	#	%	#	%	#	%	#
37.5 (1.5")												
25.0 (1.0")												
19.0 (3/4")												
12.5 (1/2")												
9.5 (3/8")												
4.75 (#4)	47	47	100.0%	25	53.2%	10	21.3%	7	14.9%	2	4.3%	3

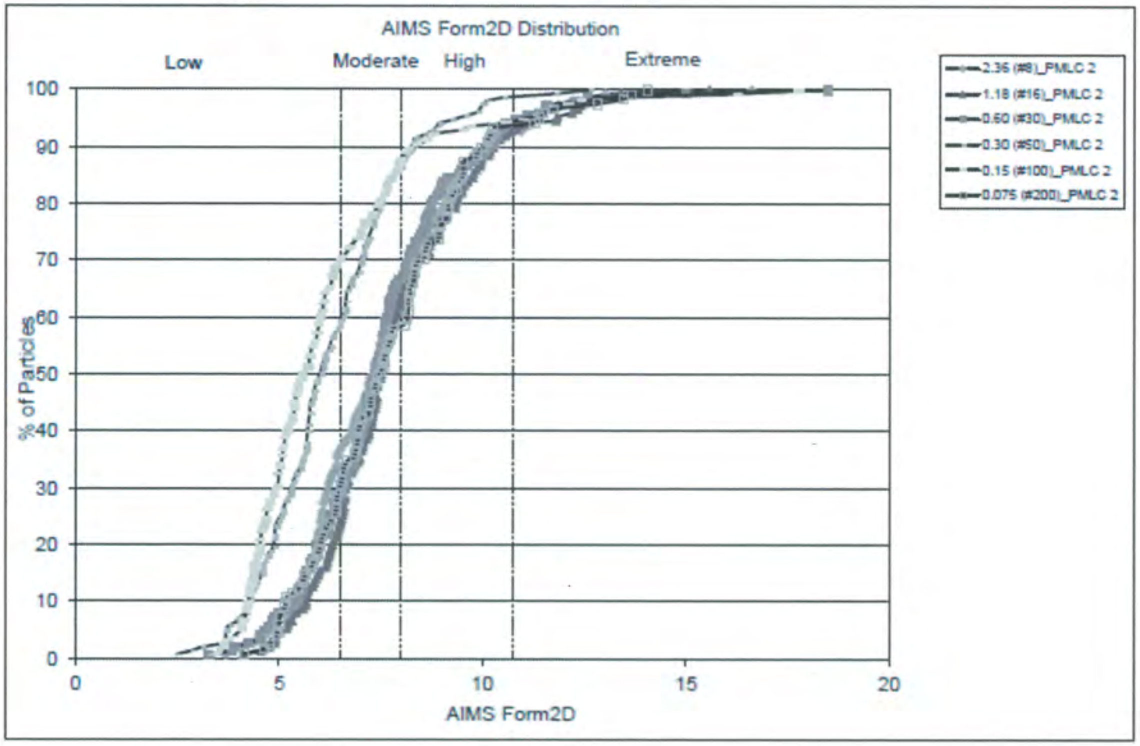
AIMS Form2D

Project Name:	PA1398_aims	Date:	10/31/13
Workbook:	PA1398_aims_AIMS_Stockpile_PMLC1 NO FIBER.	Technician:	matt
Description:	PMLC (WMA)		

Particles in Range	881
Average:	7.16
Std. Deviation	2.11
Median	6.95
Mode	7.57

	#	%		Cum. %
Low (≤ 6.5)	370	42.0%	(≤ 6.5)	42.0%
Moderate (6.5 - 8)	259	29.4%	(≤ 8)	71.4%
High(8 - 10.75)	201	22.8%	(≤ 10.75)	94.2%
Extreme(10.75 - 20)	51	5.8%	(≤ 20)	100.0%
Out of Range	39			

	#	%
$-\sigma < n < \sigma$	631	71.6%
$-2\sigma < n < 2\sigma$	839	95.2%
$-3\sigma < n < 3\sigma$	872	99.0%
$n < -3\sigma$ or $n > 3\sigma$	9	1.0%



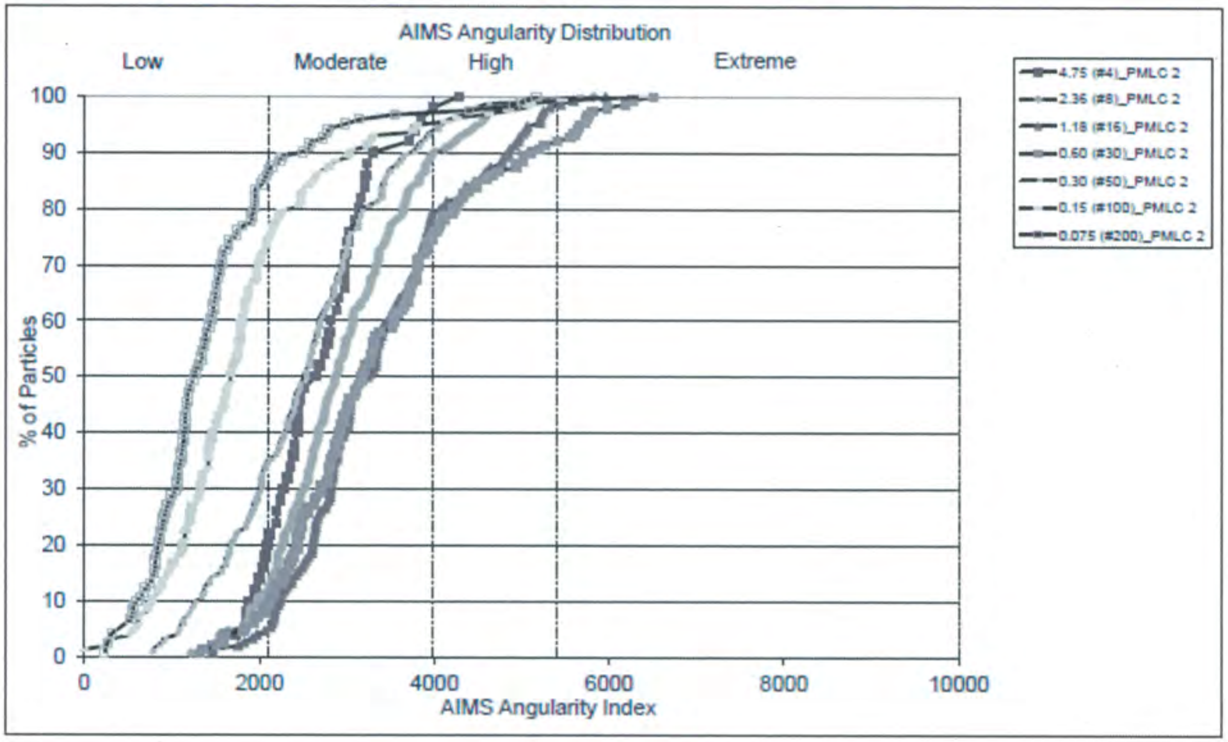
AIMS Angularity

Project Name:	PA1398_aims	Date:	10/31/13
Workbook:	PA1398_aims_AIMS_Stockpile_PMLC1 NO FIBER.	Technician:	matl
Description:	PMLC (WMA)		

Particles in Range	931
Average	2626.1
Std. Deviation	1178.2
Median	2575.2
Mode	531.4

	#	%		Cum. %
Low (≤ 2100)	322	34.6%	(≤ 2100)	34.6%
Moderate (2100 - 3975)	500	53.7%	(≤ 3975)	88.3%
High (3975 - 5400)	90	9.7%	(≤ 5400)	98.0%
Extreme (5400 - 10000)	19	2.0%	(≤ 10000)	100.0%
Out of Range	39			

	#	%
$-\sigma < n < \sigma$	627	67.3%
$-2\sigma < n < 2\sigma$	886	95.2%
$-3\sigma < n < 3\sigma$	927	99.6%
$n<-3\sigma$ or $n>3\sigma$	4	0.4%



AIMS Texture

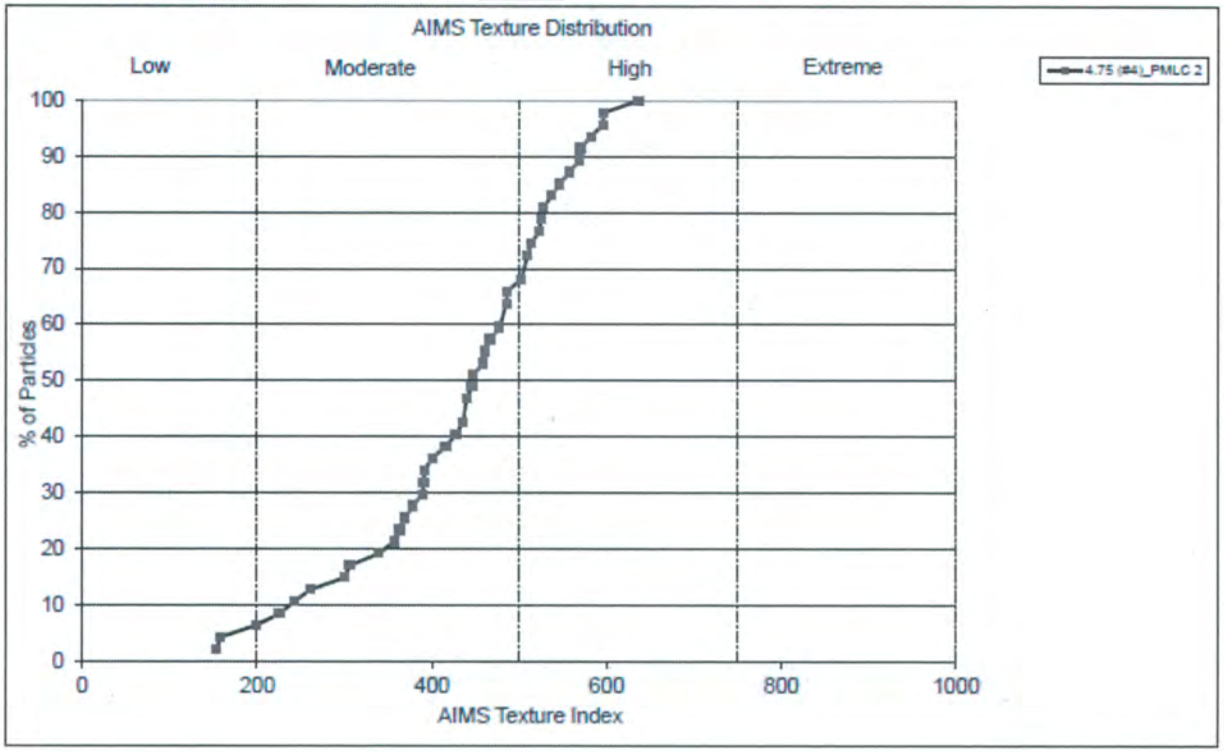
Project Name:	PA1398_aims	Date:	10/31/13
Workbook:	PA1398_aims_AIMS_Stockpile_PMLC1 NO FIBER.	Technician:	matl
Description:	PMLC (WMA)		

Particles in Range	47
Average	434.1
Std. Deviation	116.5
Median	447.0
Mode	439.7

	#	%
Low (≤ 200)	3	6.4%
Moderate (200 - 500)	28	59.6%
High (500 - 750)	16	34.0%
Extreme (750 - 1000)	0	0.0%
Out of Range	3	

	Cum. %
(≤ 200)	6.4%
(≤ 500)	66.0%
(≤ 750)	100.0%
(≤ 1000)	100.0%

	#	%
$-\sigma < n < \sigma$	32	68.1%
$-2\sigma < n < 2\sigma$	44	93.6%
$-3\sigma < n < 3\sigma$	47	100.0%
$n < -3\sigma$ or $n > 3\sigma$	0	0.0%



AIMS Sphericity

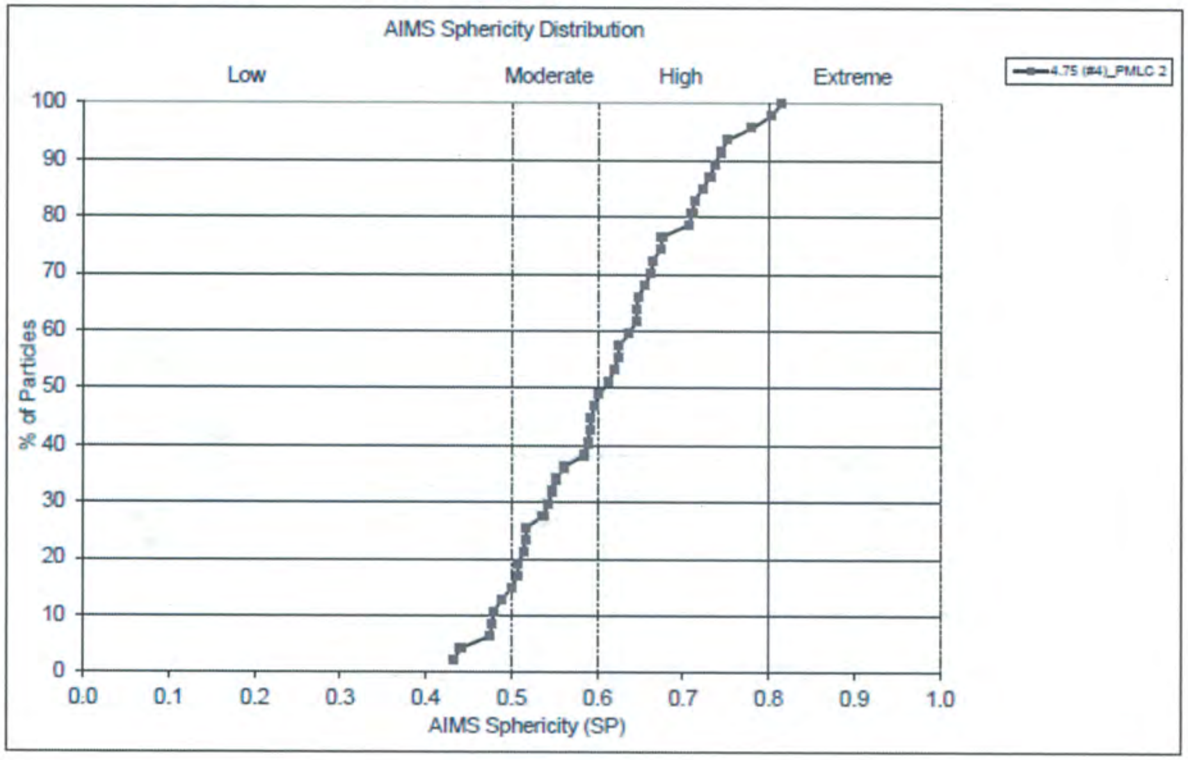
Project Name:	PA1398_aims	Date:	10/31/13
Workbook:	PA1398_aims_AIMS_Stockpile_PMLC1 NO FIBER.	Technician:	matt
Description:	PMLC (WMA)		

Particles in Range	47
Average	0.612
Std. Deviation	0.098
Median	0.613
Mode	#N/A

	#	%
Low (≤ 0.5)	7	14.9%
Moderate (0.5 - 0.6)	15	31.9%
High (0.6 - 0.8)	23	48.9%
Extreme (0.8 - 1.0)	2	4.3%
Out of Range	3	

	Cum. %
(≤ 0.5)	14.9%
(≤ 0.6)	46.8%
(≤ 0.8)	95.7%
(≤ 1.0)	100.0%

	#	%
-σ < n < σ	27	57.4%
-2σ < n < 2σ	46	97.9%
-3σ < n < 3σ	47	100.0%
n<-3σ or n>3σ	0	0.0%



AIMS Stockpile Summary

Project Name:	PA1398_aims	Date:	10/31/13
Workbook:	PA1398_aims_AIMS_Stockpile_PMLC2 WITH FIBER.xls	Technician:	matt
Description:	PMLC (WMA) Fiber		

Combined Properties (weighted)

2D Form (Fine)	7.05
Angularity (Coarse & Fine)	2106.0
Fine Angularity	2099.4
Coarse Angularity	2621.3
Texture (Coarse)	383.7
CAAT (Coarse)	5160.9

Sphericity (Coarse)	%
Low (≤ 0.5)	1.3%
Moderate (0.5 - 0.6)	4.0%
High (0.6 - 0.8.0)	6.7%
Extreme (0.8 - 1.0)	0.5%
Sphericity (Coarse)	0.62

Flat & Elongated Ratio (Coarse)	%
L/S ≥ 1:1	12.6%
L/S > 2:1	10.5%
L/S > 3:1	6.2%
L/S > 4:1	3.2%
L/S > 5:1	1.9%

Flat or Elongated Ratio (Coarse)	Cum.%
F or E ≥ 1:1	12.6%
F or E > 1:2	7.2%
F or E > 1:3	3.2%
F or E > 1:4	1.3%
F or E > 1:5	0.3%

Form2D

Size	Particles In Range	Average	Standard Deviation	Low (≤ 6.5)		(≤ 6.5)	Moderate (6.5 - 8)		(≤ 8)	High (8 - 10.75)		(≤ 10.75)	Extreme (10.75 - 20)		(≤ 20)	Out of Range
				#	%	Cum. %	#	%	Cum. %	#	%	Cum. %	#	%	Cum. %	#
2.36 (#8)	150	7.4	1.8	53	35.3%	35.3%	45	30.0%	65.3%	45	30.0%	95.3%	7	4.7%	100.0%	0
1.18 (#16)	151	8.1	2.1	35	23.2%	23.2%	54	35.8%	58.9%	46	30.5%	89.4%	16	10.6%	100.0%	0
0.60 (#30)	150	7.7	1.9	45	30.0%	30.0%	49	32.7%	62.7%	45	30.0%	92.7%	11	7.3%	100.0%	0
0.30 (#50)	154	6.4	2.0	95	61.7%	61.7%	33	21.4%	83.1%	19	12.3%	95.5%	7	4.5%	100.0%	0
0.15 (#100)	165	6.5	2.9	113	68.5%	68.5%	22	13.3%	81.8%	18	10.9%	92.7%	12	7.3%	100.0%	0
0.075 (#200)	142	7.2	1.8	58	40.8%	40.8%	39	27.5%	68.3%	40	28.2%	96.5%	5	3.5%	100.0%	9

Angularity

Size	Particles In Range	Average	Standard Deviation	Low (≤ 2100)		(≤ 2100)	Moderate(2100-3975)		(≤ 3975)	High(3975-5400)		(≤ 5400)	Extreme(5400-10000)		(≤ 10000)	Out of Range
				#	%	Cum. %	#	%	Cum. %	#	%	Cum. %	#	%	Cum. %	#
37.5 (1.5")																
25.0 (1.0")																
19.0 (3/4")																
12.5 (1/2")																
9.5 (3/8")																
4.75 (#4)	50	2621.3	641.6	9	18.0%	18.0%	39	78.0%	96.0%	2	4.0%	100.0%	0	0.0%	100.0%	0
2.36 (#8)	150	3048.2	714.9	12	8.0%	8.0%	126	84.0%	92.0%	11	7.3%	99.3%	1	0.7%	100.0%	0
1.18 (#16)	151	3363.1	924.6	6	4.0%	4.0%	111	73.5%	77.5%	28	18.5%	96.0%	6	4.0%	100.0%	0
0.60 (#30)	150	3412.3	1107.4	15	10.0%	10.0%	91	60.7%	70.7%	37	24.7%	95.3%	7	4.7%	100.0%	0
0.30 (#50)	154	2436.6	901.3	65	42.2%	42.2%	78	50.6%	92.9%	10	6.5%	99.4%	1	0.6%	100.0%	0
0.150 (#100)	165	1912.0	1212.4	117	70.9%	70.9%	36	21.8%	92.7%	8	4.8%	97.6%	4	2.4%	100.0%	0
0.075 (#200)	142	1387.5	549.0	130	91.5%	91.5%	12	8.5%	100.0%	0	0.0%	100.0%	0	0.0%	100.0%	9

AIMS Stockpile Summary

Project Name:	PA1398_aims	Date:	10/31/13
Workbook:	PA1398_aims_AIMS_Stockpile_PMLC2 WITH FIBER.xls	Technician:	matt
Description:	PMLC (WMA) Fiber		

Texture

Size	Particles In Range	Average	Standard Deviation	Low (≤ 200)		(≤ 200)	Moderate (200 - 500)		(≤ 500)	High (500 - 750)		(≤ 750)	Extreme (750 - 1000)		(≤ 1000)	Out of Range
				#	%	Cum. %	#	%	Cum. %	#	%	Cum. %	#	%	Cum. %	#
37.5 (1.5")																
25.0 (1.0")																
19.0 (3/4")																
12.5 (1/2")																
9.5 (3/8")																
4.75 (#4)	47	383.7	137.3	6	12.8%	12.8%	33	70.2%	83.0%	8	17.0%	100.0%	0	0.0%	100.0%	3

Sphericity

Size	Particles In Range	Average	Standard Deviation	Low (≤ 0.5)		(≤ 0.5)	Moderate (0.5 - 0.6)		(≤ 0.6)	High (0.6 - 0.8)		(≤ 0.8)	Extreme (0.8 - 1.0)		(≤ 1.0)	Out of Range
				#	%	Cum. %	#	%	Cum. %	#	%	Cum. %	#	%	Cum. %	#
37.5 (1.5")																
25.0 (1.0")																
19.0 (3/4")																
12.5 (1/2")																
9.5 (3/8")																
4.75 (#4)	47	0.62	0.10	5	10.6%	10.6%	15	31.9%	42.6%	25	53.2%	95.7%	2	4.3%	100.0%	3

Flat and Elongated Distribution

Size	Particles In Range	L/S ≥ 1:1		L/S > 2:1		L/S > 3:1		L/S > 4:1		L/S > 5:1		Out of Range
		#	%	#	%	#	%	#	%	#	%	#
37.5 (1.5")												
25.0 (1.0")												
19.0 (3/4")												
12.5 (1/2")												
9.5 (3/8")												
4.75 (#4)	47	47	100.0%	39	83.0%	23	48.9%	12	25.5%	7	14.9%	3

Flat or Elongated Distribution

Size	Particles In Range	F or E ≥ 1:1		F or E >2:1		F or E >3:1		F or E >4:1		F or E >5:1		Out of Range
		#	%	#	%	#	%	#	%	#	%	#
37.5 (1.5")												
25.0 (1.0")												
19.0 (3/4")												
12.5 (1/2")												
9.5 (3/8")												
4.75 (#4)	47	47	100.0%	27	57.4%	12	25.5%	5	10.6%	1	2.1%	3

AIMS Form2D

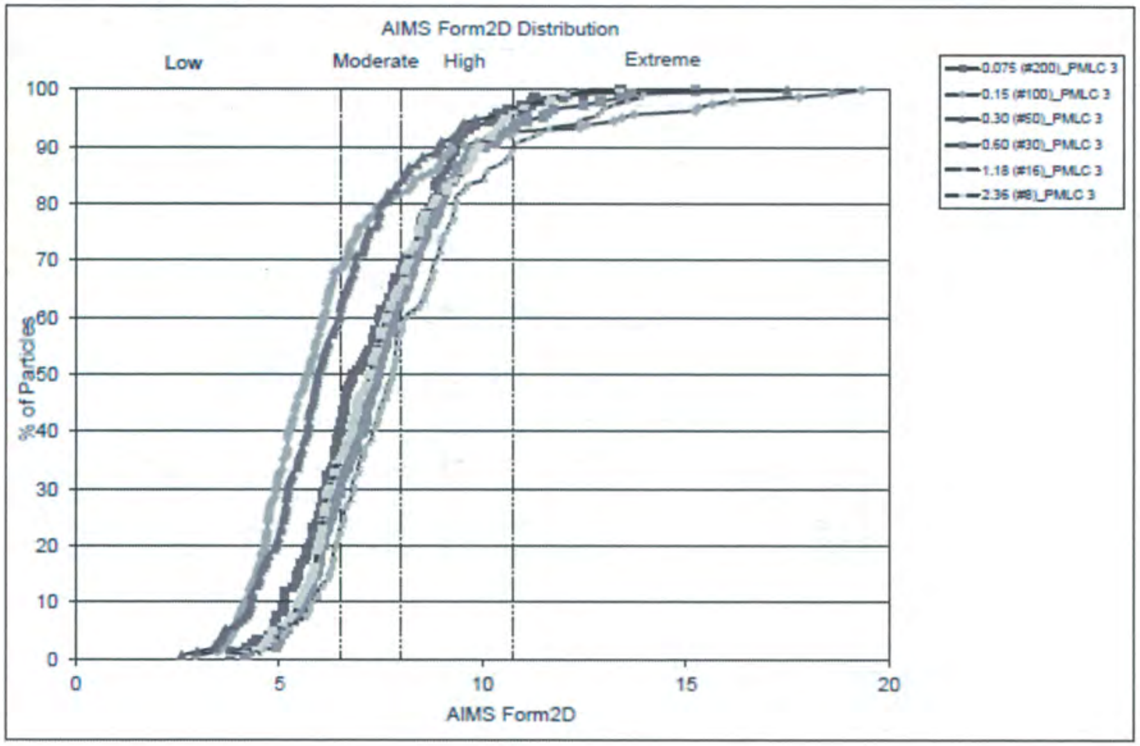
Project Name:	PA1398_aims	Date:	10/31/13
Workbook:	PA1398_aims_AIMS_Stockpile_PMLC2 WITH FIBE	Technician:	matt
Description:	PMLC (WMA) Fiber		

Particles in Range	912
Average:	7.21
Std. Deviation	2.22
Median	6.81
Mode	6.35

	#	%
Low (≤ 6.5)	399	43.8%
Moderate (6.5 - 8)	242	26.5%
High(8 - 10.75)	213	23.4%
Extreme(10.75 - 20)	58	6.4%
Out of Range	9	

	Cum. %
(≤ 6.5)	43.8%
(≤ 8)	70.3%
(≤ 10.75)	93.6%
(≤ 20)	100.0%

	#	%
-σ < n < σ	687	75.3%
-2σ < n < 2σ	875	95.9%
-3σ < n < 3σ	901	98.8%
n<-3σ or n>3σ	11	1.2%



AIMS Angularity

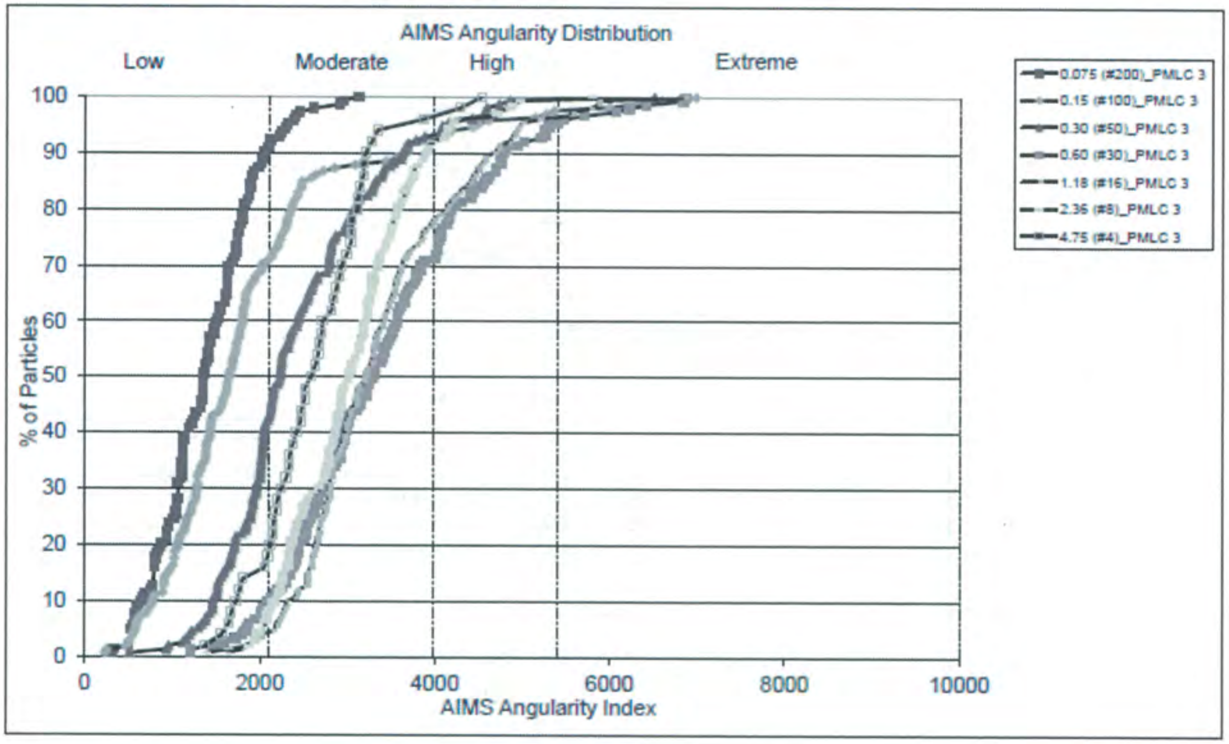
Project Name:	PA1398_aims	Date:	10/31/13
Workbook:	PA1398_aims_AIMS_Stockpile_PMLC2 WITH FIBE	Technician:	matl
Description:	PMLC (WMA) Fiber		

Particles in Range	962
Average	2594.3
Std. Deviation	1175.2
Median	2481.0
Mode	797.1

	#	%
Low (≤ 2100)	354	36.8%
Moderate (2100 - 3975)	493	51.2%
High (3975 - 5400)	96	10.0%
Extreme (5400 - 10000)	19	2.0%
Out of Range	9	

	Cum. %
(≤ 2100)	36.8%
(≤ 3975)	88.0%
(≤ 5400)	98.0%
(≤ 10000)	100.0%

	#	%
-σ < n < σ	666	69.2%
-2σ < n < 2σ	929	96.6%
-3σ < n < 3σ	953	99.1%
n<-3σ or n>3σ	9	0.9%



AIMS Texture

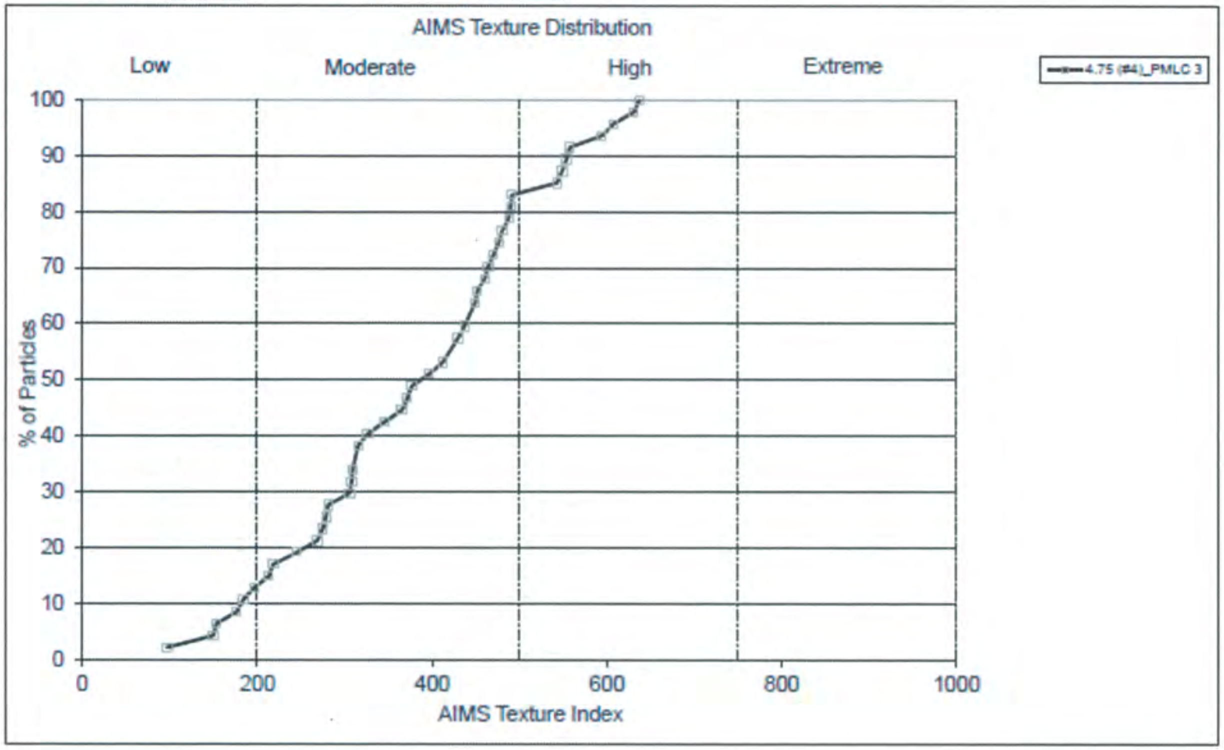
Project Name:	PA1398_aims	Date:	10/31/13
Workbook:	PA1398_aims_AIMS_Stockpile_PMLC2 WITH FIBE	Technician:	matl
Description:	PMLC (WMA) Fiber		

Particles in Range	47
Average	383.7
Std. Deviation	137.3
Median	396.7
Mode	315.6

	#	%
Low (≤ 200)	6	12.8%
Moderate (200 - 500)	33	70.2%
High (500 - 750)	8	17.0%
Extreme (750 - 1000)	0	0.0%
Out of Range	3	

	Cum. %
(≤ 200)	12.8%
(≤ 500)	83.0%
(≤ 750)	100.0%
(≤ 1000)	100.0%

	#	%
-σ < n < σ	30	63.8%
-2σ < n < 2σ	46	97.9%
-3σ < n < 3σ	47	100.0%
n<-3σ or n>3σ	0	0.0%



AIMS Sphericity

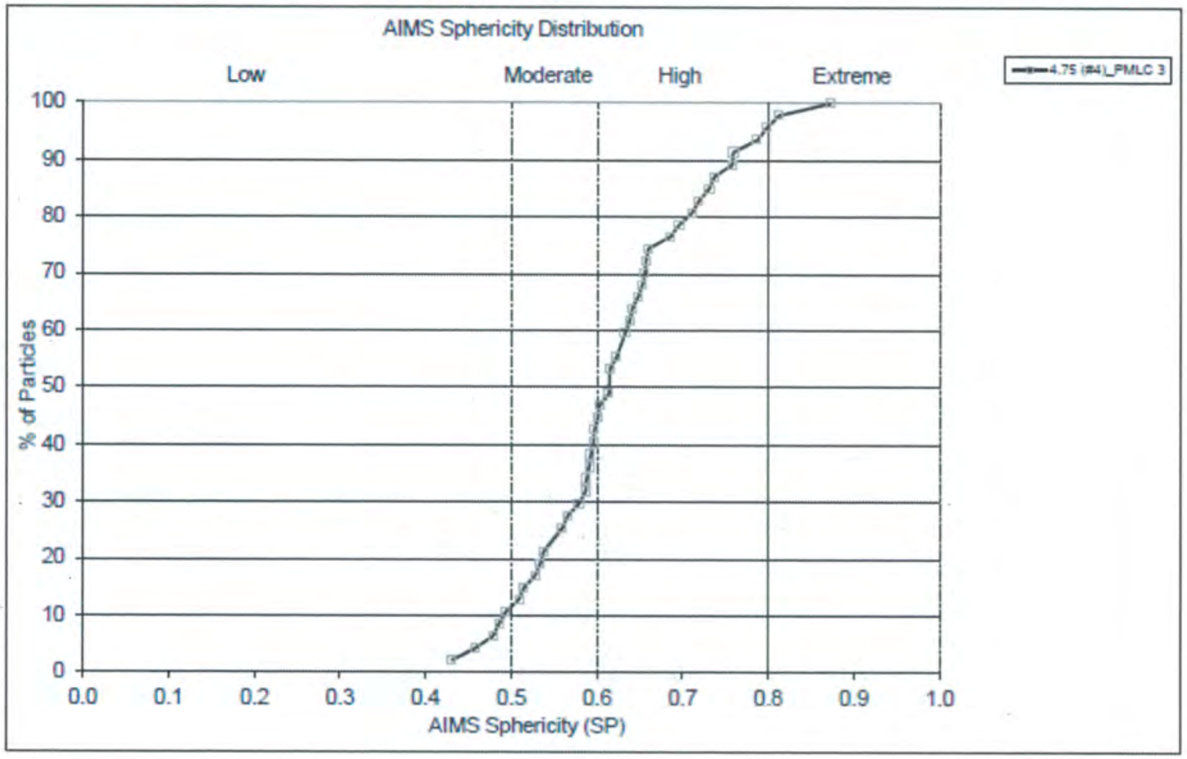
Project Name:	PA1398_aims	Date:	10/31/13
Workbook:	PA1398_aims_AIMS_Stockpile_PMLC2 WITH FIBE	Technician:	matt
Description:	PMLC (WMA) Fiber		

Particles in Range	47
Average	0.624
Std. Deviation	0.097
Median	0.615
Mode	0.560

	#	%
Low (≤ 0.5)	5	10.6%
Moderate (0.5 - 0.6)	15	31.9%
High (0.6 - 0.8)	25	53.2%
Extreme (0.8 - 1.0)	2	4.3%
Out of Range	3	

	Cum. %
(≤ 0.5)	10.6%
(≤ 0.6)	42.6%
(≤ 0.8)	95.7%
(≤ 1.0)	100.0%

	#	%
-σ < n < σ	32	68.1%
-2σ < n < 2σ	45	95.7%
-3σ < n < 3σ	47	100.0%
n<-3σ or n>3σ	0	0.0%



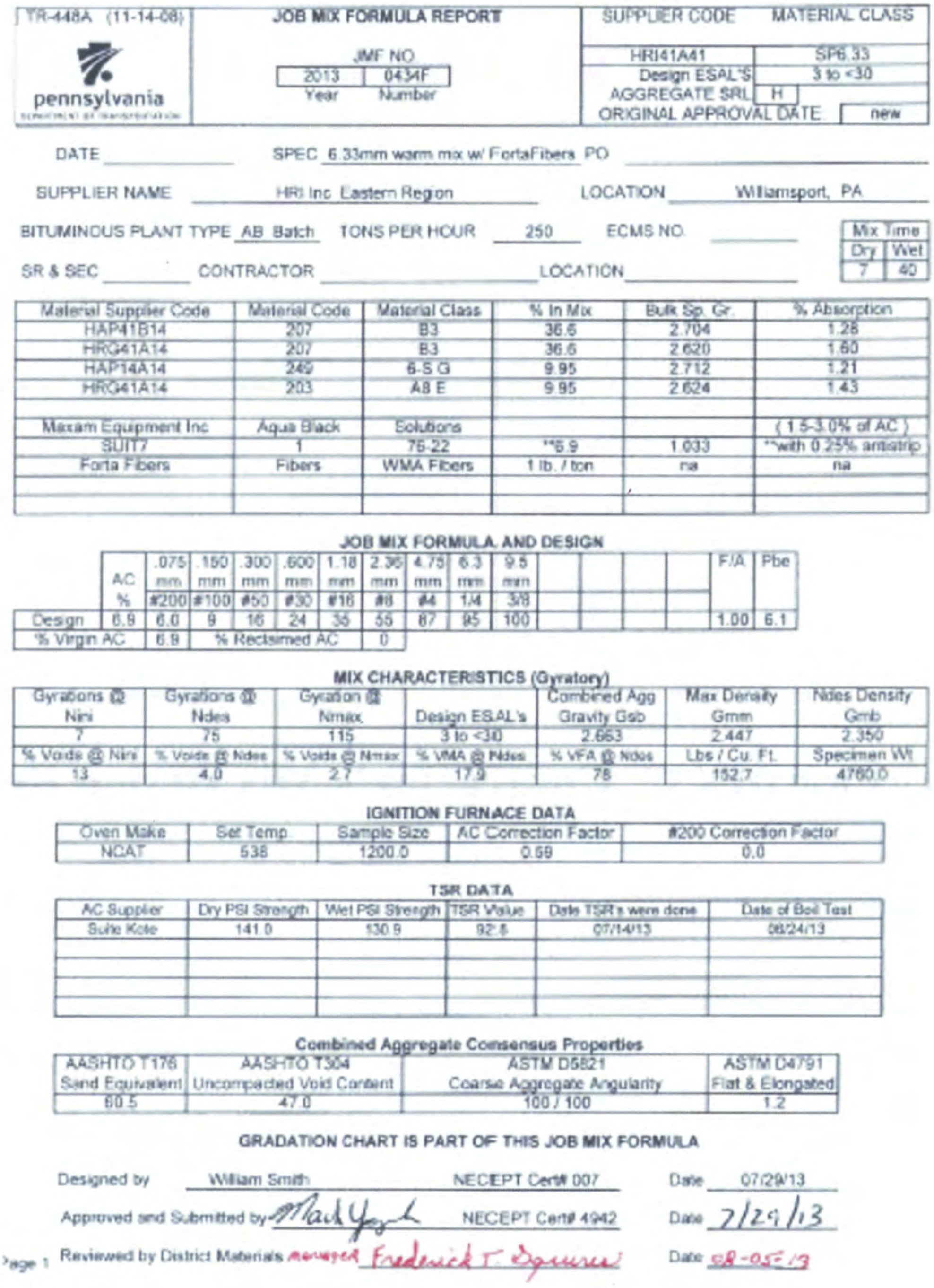
APPENDIX B: Volumetric Test Results

SUPERPAVE VOLUMETRIC DATA SUMMARY SHEET

State	PA
MATL Project ID	PA1398
Plant Location	Williamsport
Type of Mix	WMA/Fiber
JMF #	
Binder	PG 76-22

Sample ID	DATE	Station #	Compaction Temperature ° C	Pb % (Uncorrected)	Gmm		Gmb	Va	VMA	VFA	F/Pbe	% Gmm		Slope Ini~des	Sample H_2O	Rice Absorption	Gsa (MATL)	Gse	Gsb	19	12.5	9.5	#4	#8	#16	#30	#50	#100	#200
					w/db	wo/db						Nini	Ndes																
JMF PMLC (WMA)	na	na	155	6.90		2.447	2.350	4.0	17.9	78.0	1.00								2.663	100.0	100.0	100.0	87.0	55.0	35.0	24.0	16.0	9.0	6.00
JMF PMLC (WMA) Fiber	na	na	155	6.90		2.447	2.350	4.0	17.9	78.0	1.00								2.663	100.0	100.0	100.0	87.0	55.0	35.0	24.0	16.0	9.0	6.00
JMF PMLC (WMA)	Produced: 9/5/2013	na	155	6.62	2.448	2.453	2.365	3.4	17.1	80.1	0.84					0.10	na	2.711	2.663	100	100	99.9	85.9	50.6	32.9	23.7	15.9	8.5	5.19
JMF PMLC (WMA) Fiber	Produced: 9/7/2013	na	155	7.06	2.444	2.450	2.368	3.1	17.4	82.1	0.80					0.10	na	2.727	2.663	100	100	100	87.4	55.8	36.2	25.7	17.2	9.3	5.35

APPENDIX C: Contractor's Mix Design Report



TR-448A (11-14-08)

pennsylvania

JOB MIX FORMULA REPORT

JMF NO

2013	0434F
Year	Number

SUPPLIER CODE	MATERIAL CLASS
HRI41A41	SP6.33
Design ESAL'S	3 to <30
AGGREGATE SRL	H
ORIGINAL APPROVAL DATE	new

DATE ______ SPEC 6.33mm warm mix w/ FortaFibers PO ______

SUPPLIER NAME HRI Inc Eastern Region LOCATION Williamsport, PA

BITUMINOUS PLANT TYPE AB Batch TONS PER HOUR 250 ECMS NO. ______

SR & SEC ______ CONTRACTOR ______ LOCATION ______

Mix Time	
Dry	Wet
7	40

Material Supplier Code	Material Code	Material Class	% In Mix	Bulk Sp. Gr.	% Absorption
HAP41B14	207	B3	36.6	2.704	1.28
HRG41A14	207	B3	36.6	2.620	1.60
HAP14A14	249	6-S G	9.95	2.712	1.21
HRG41A14	203	A8 E	9.95	2.624	1.43
Maxam Equipment Inc	Aqua Black	Solutions			(1.5-3.0% of AC)
SUIT7	1	76-22	**6.9	1.033	**with 0.25% antistrip
Forta Fibers	Fibers	WMA Fibers	1 lb. / ton	na	na

JOB MIX FORMULA AND DESIGN

	AC %	.075 mm #200	.150 mm #100	.300 mm #50	.600 mm #30	1.18 mm #16	2.36 mm #8	4.75 mm #4	6.3 mm 1/4	9.5 mm 3/8					F/A	Pbe
Design	6.9	6.0	9	16	24	35	55	87	95	100					1.00	6.1

% Virgin AC	6.9	% Reclaimed AC	0

MIX CHARACTERISTICS (Gyratory)

Gyrations @ Nini	Gyrations @ Ndes	Gyration @ Nmax	Design ESAL's	Combined Agg Gravity Gsb	Max Density Gmm	Ndes Density Gmb
7	75	115	3 to <30	2.663	2.447	2.350
% Voids @ Nini	% Voids @ Ndes	% Voids @ Nmax	% VMA @ Ndes	% VFA @ Ndes	Lbs / Cu. Ft.	Specimen Wt
13	4.0	2.7	17.9	78	152.7	4760.0

IGNITION FURNACE DATA

Oven Make	Set Temp.	Sample Size	AC Correction Factor	#200 Correction Factor
NCAT	538	1200.0	0.59	0.0

TSR DATA

AC Supplier	Dry PSI Strength	Wet PSI Strength	TSR Value	Date TSR's were done	Date of Boil Test
Suite Kote	141.0	130.9	92.8	07/14/13	08/24/13

Combined Aggregate Consensus Properties

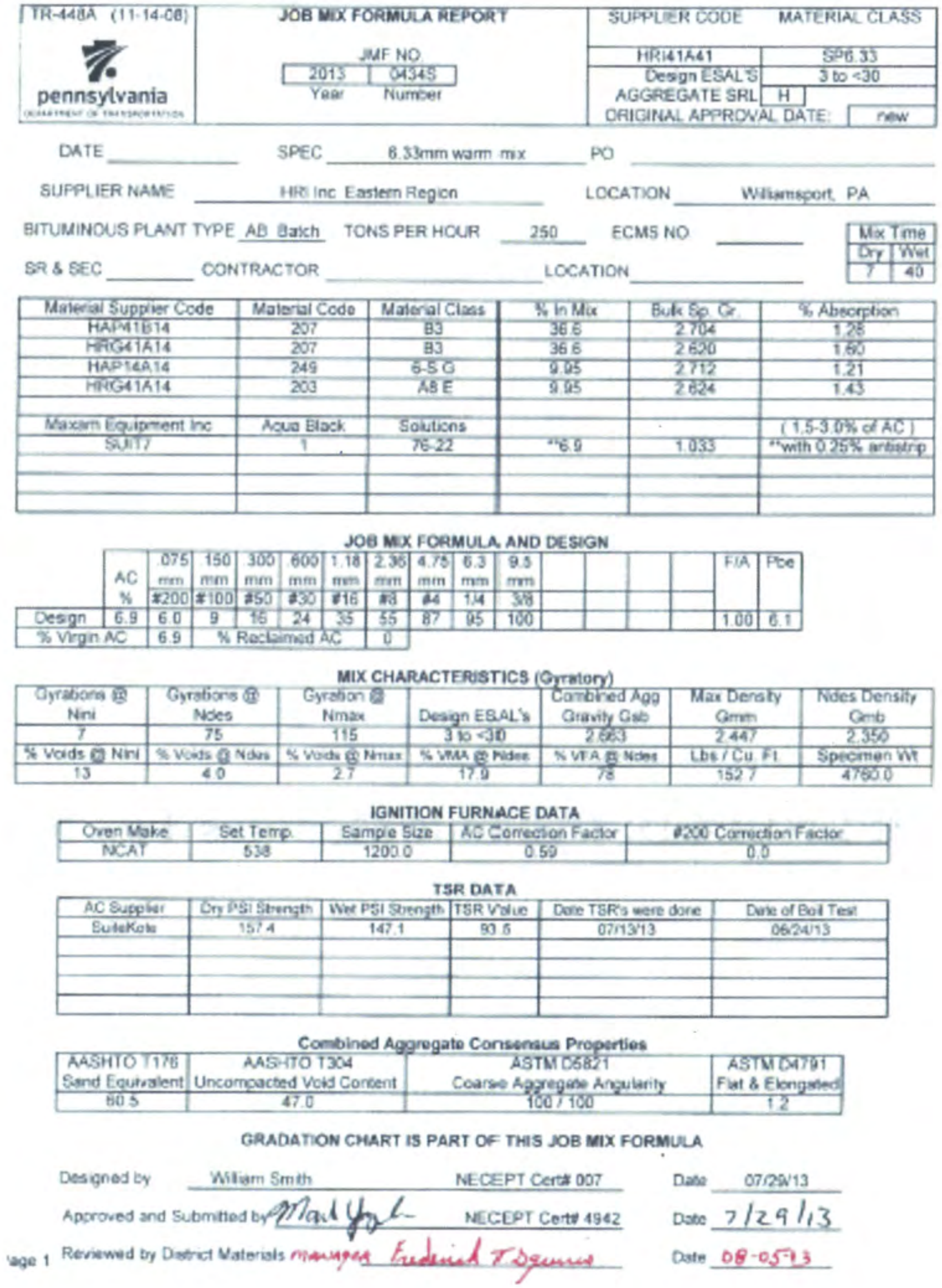
AASHTO T176 Sand Equivalent	AASHTO T304 Uncompacted Void Content	ASTM D5821 Coarse Aggregate Angularity	ASTM D4791 Flat & Elongated
80.5	47.0	100 / 100	1.2

GRADATION CHART IS PART OF THIS JOB MIX FORMULA

Designed by William Smith NECEPT Cert# 007 Date 07/29/13

Approved and Submitted by Mark NECEPT Cert# 4942 Date 7/29/13

age 1 Reviewed by District Materials manager Frederick T. Date 08-05-13



TR-448A (11-14-08) pennsylvania DEPARTMENT OF TRANSPORTATION	**JOB MIX FORMULA REPORT** JMF NO. 2013 | 0434S Year | Number	SUPPLIER CODE: HRI41A41 MATERIAL CLASS: SP6.33 Design ESAL'S: 3 to <30 AGGREGATE SRL: H ORIGINAL APPROVAL DATE: new

DATE ____________ SPEC 6.33mm warm mix PO ____________

SUPPLIER NAME HRI Inc Eastern Region LOCATION Williamsport, PA

BITUMINOUS PLANT TYPE AB Batch TONS PER HOUR 250 ECMS NO ________

SR & SEC ________ CONTRACTOR ____________ LOCATION ____________

Mix Time	
Dry	Wet
7	40

Material Supplier Code	Material Code	Material Class	% In Mix	Bulk Sp. Gr.	% Absorption
HAP41B14	207	B3	36.6	2.704	1.28
HRG41A14	207	B3	36.6	2.620	1.60
HAP14A14	249	6-S G	9.95	2.712	1.21
HRG41A14	203	A8 E	9.95	2.624	1.43
Maxam Equipment Inc	Aqua Black	Solutions			(1.5-3.0% of AC)
SUIT7	1	76-22	**6.9	1.033	**with 0.25% antistrip

JOB MIX FORMULA AND DESIGN

	AC %	.075 mm #200	.150 mm #100	.300 mm #50	.600 mm #30	1.18 mm #16	2.36 mm #8	4.75 mm #4	6.3 mm 1/4	9.5 mm 3/8					F/A	Pbe
Design	6.9	6.0	9	16	24	35	55	87	95	100					1.00	6.1
% Virgin AC		6.9	% Reclaimed AC			0										

MIX CHARACTERISTICS (Gyratory)

Gyrations @ Nini	Gyrations @ Ndes	Gyration @ Nmax	Design ESAL's	Combined Agg Gravity Gsb	Max Density Gmm	Ndes Density Gmb
7	75	115	3 to <30	2.663	2.447	2.350
% Voids @ Nini	% Voids @ Ndes	% Voids @ Nmax	% VMA @ Ndes	% VFA @ Ndes	Lbs / Cu. Ft.	Specimen Wt
13	4.0	2.7	17.9	78	152.7	4760.0

IGNITION FURNACE DATA

Oven Make	Set Temp.	Sample Size	AC Correction Factor	#200 Correction Factor
NCAT	538	1200.0	0.59	0.0

TSR DATA

AC Supplier	Dry PSI Strength	Wet PSI Strength	TSR Value	Date TSR's were done	Date of Boil Test
SuiteKote	157.4	147.1	93.5	07/13/13	06/24/13

Combined Aggregate Consensus Properties

AASHTO T176 Sand Equivalent	AASHTO T304 Uncompacted Void Content	ASTM D5821 Coarse Aggregate Angularity	ASTM D4791 Flat & Elongated
80.5	47.0	100 / 100	1.2

GRADATION CHART IS PART OF THIS JOB MIX FORMULA

Designed by William Smith NECEPT Cert# 007 Date 07/29/13

Approved and Submitted by NECEPT Cert# 4942 Date 7/29/13

Page 1 Reviewed by District Materials manager Date 08-05-13

APPENDIX D: Dynamic Modulus Test Results

|E*|Dynamic Modulus (MPa)

		4.4° C						21.1° C						37.8° C							54.4° C					
	Specimen ID	25 Hz	10 Hz	5 Hz	1 Hz	0.5 Hz	0.1 Hz	25 Hz	10 Hz	5 Hz	1 Hz	0.5 Hz	0.1 Hz	25 Hz	10 Hz	5 Hz	1 Hz	0.5 Hz	0.1 Hz	Specimen ID	25 Hz	10 Hz	5 Hz	1 Hz	0.5 Hz	0.1 Hz
PMLC (WMA)	7	11984	11038	10249	8470	7732	6132	5887	4997	4363	3040	2532	1683	2198	1640	1315	766	614	358	9	678	419	324	193	161	111
	23	12079	11137	10320	8437	7671	5975	5782	4851	4205	2876	2420	1539	2020	1481	1187	671	541	318	22	728	457	354	206	173	116
	26	13468	12623	11771	9789	8952	7123	6393	5421	4718	3307	2820	1877	2294	1733	1412	842	684	408	25	714	460	358	211	179	123
	29	13779	12826	12028	10168	9394	7673	6773	5860	5181	3789	3289	2295	2610	2023	1685	1031	861	526	28	846	557	434	257	215	144
	μ	12828	11906	11092	9216	8437	6726	6209	5282	4617	3253	2765	1849	2281	1719	1400	827	675	402	μ	742	473	368	217	182	123
	SD	929	950	939	894	869	811	461	455	433	399	388	328	247	228	211	153	137	90	SD	73	59	47	28	23	15
	COV	7.2%	8.0%	8.5%	9.7%	10.3%	12.1%	7.4%	8.6%	9.4%	12.3%	14.0%	17.8%	10.8%	13.2%	15.1%	18.4%	20.3%	22.4%	COV	9.8%	12.5%	12.8%	12.8%	12.8%	12.1%
PMLC (WMA) Fiber	3	12532	11354	10385	8223	7346	5467	5005	4031	3384	2136	1744	1033	1513	1032	795	446	357	222	2	522	317	246	150	127	91
	4	12935	11921	11056	9108	8307	6545	6102	5126	4446	3064	2603	1717	2164	1587	1270	720	575	334	5	761	485	379	226	189	126
	7	12914	11976	11163	9248	8450	6684	6048	5141	4470	3130	2647	1736	2037	1511	1222	703	578	344	6	662	421	329	184	157	105
	10	13161	12264	11464	9603	8824	7083	6385	5488	4820	3460	2976	2013	2540	1965	1638	999	817	488	8	659	408	311	179	148	97
	μ	12886	11879	11017	9046	8232	6445	5885	4947	4280	2948	2493	1625	2064	1524	1231	717	582	347	μ	651	408	316	185	155	105
	SD	261	381	455	587	629	691	605	633	621	568	526	417	425	383	345	226	188	109	SD	98	69	55	31	26	16
	COV	2.0%	3.2%	4.1%	6.5%	7.6%	10.7%	10.3%	12.8%	14.5%	19.3%	21.1%	25.7%	20.6%	25.2%	28.1%	31.5%	32.2%	31.5%	COV	15.1%	16.9%	17.3%	17.0%	16.7%	14.8%

Phase Angle, ϕ (deg.)

		4.4° C						21.1° C						37.8° C							54.4° C					
	Specimen ID	25 Hz	10 Hz	5 Hz	1 Hz	0.5 Hz	0.1 Hz	25 Hz	10 Hz	5 Hz	1 Hz	0.5 Hz	0.1 Hz	25 Hz	10 Hz	5 Hz	1 Hz	0.5 Hz	0.1 Hz	Specimen ID	25 Hz	10 Hz	5 Hz	1 Hz	0.5 Hz	0.1 Hz
PMLC (WMA)	7	9.3	10.0	10.4	12.0	12.8	15.2	18.0	19.3	20.3	22.9	24.8	26.6	27.5	29.2	29.9	30.8	30.6	30.6	9	29.9	31.6	30.8	28.5	27.1	24.8
	23	9.3	10.3	11.0	12.8	13.7	15.9	18.4	19.9	20.8	23.3	24.2	26.2	29.1	30.9	31.1	31.9	31.0	30.3	22	30.5	32.3	31.8	29.9	28.3	25.8
	26	9.0	9.4	10.1	11.6	12.4	14.5	17.6	18.9	20.0	22.4	23.3	25.2	27.0	28.3	28.5	29.0	28.5	28.3	25	31.8	33.0	32.2	29.9	28.2	25.7
	29	7.7	8.6	9.1	10.4	11.0	12.8	15.9	17.0	17.8	20.2	21.1	23.2	26.2	27.6	27.9	29.4	29.0	29.5	28	30.7	32.0	31.5	29.6	28.1	25.8
	μ	8.8	9.6	10.2	11.7	12.5	14.6	17.5	18.8	19.7	22.2	23.3	25.3	27.5	29.0	29.3	30.3	29.8	29.7	μ	30.7	32.2	31.6	29.5	27.9	25.5
	SD	0.8	0.7	0.8	1.0	1.1	1.4	1.1	1.3	1.3	1.4	1.6	1.5	1.3	1.4	1.5	1.3	1.2	1.0	SD	0.8	0.6	0.6	0.7	0.5	0.5
	COV	8.8%	7.8%	7.9%	8.8%	9.1%	9.3%	6.2%	6.8%	6.7%	6.3%	6.9%	6.0%	4.6%	4.8%	5.0%	4.3%	4.0%	3.4%	COV	2.5%	1.9%	1.9%	2.3%	1.9%	2.0%
PMLC (WMA) Fiber	3	10.4	11.8	12.6	14.9	16.0	18.8	22.0	23.7	24.9	27.6	28.2	29.2	31.4	33.2	33.1	31.7	30.4	27.9	2	30.7	32.0	31.1	28.8	27.0	24.2
	4	8.9	9.9	10.5	12.2	13.2	15.3	18.4	20.1	21.0	23.9	24.5	26.5	28.6	30.6	31.0	32.1	31.5	31.3	5	31.0	32.5	31.7	29.6	27.9	25.7
	7	8.9	9.6	10.2	11.9	12.8	15.0	18.2	19.1	20.1	22.1	23.3	25.5	29.3	31.0	31.1	32.1	31.0	30.3	6	31.2	32.8	32.2	31.6	29.5	27.3
	10	9.2	9.5	9.7	11.1	11.8	13.9	16.7	17.9	18.6	20.7	21.5	24.3	25.6	26.8	27.1	28.3	28.0	28.6	8	31.3	33.3	32.9	31.4	29.6	27.4
	μ	9.3	10.2	10.7	12.5	13.4	15.7	18.8	20.2	21.2	23.6	24.4	26.4	28.7	30.4	30.6	31.0	30.2	29.5	μ	31.0	32.6	32.0	30.3	28.5	26.1
	SD	0.7	1.1	1.3	1.6	1.8	2.1	2.2	2.5	2.7	3.0	2.8	2.1	2.4	2.6	2.5	1.8	1.5	1.6	SD	0.2	0.5	0.8	1.4	1.3	1.5
	COV	8.0%	10.6%	11.7%	13.2%	13.3%	13.5%	11.9%	12.4%	12.6%	12.7%	11.6%	8.0%	8.3%	8.7%	8.3%	6.0%	5.1%	5.3%	COV	0.8%	1.7%	2.4%	4.6%	4.4%	5.8%

APPENDIX E: Flow Number Test Results

600 kPa Deviator Stress and Unconfined

FN Test @ 53 °C

Francken Model

Mix ID	Specimen ID	Flow Point, cycles	μStrain @ Flow	Test Duration (time)	Total Accumulated Strain	Total Cycles	% loss of height (microstrains)	Initial height of specimen (measured)	Height of specimen after FN test (measured)	% deformation based on msrd heights (calc'd)	Measured deformation during Flow Test (mm)
PMLC (WMA)	10	1384	25137	0:58:34	50003	3514	2.5	150.7	143.3	5.19	7.4
	12	1437	30685	0:52:55	50020	3175	3.1	150.3	144.1	4.30	6.2
	30	1425	27271	0:55:59	50017	3359	2.7	150.6	143.7	4.80	6.9
	45	1986	28644	1:15:44	50011	4544	2.9	150.6	143.6	4.85	7.0
	μ	1558	27934	1:00:48	50013	3648	3	151	144	5	7
	SD	286	2333	0:10:13	8	613	0	0	0	0	1
	SE	143	1167	0:05:07	4	307	0	0	0	0	0
	COV	18%	8%	17%	0%	17%	8%	0%	0%	8%	7%
PMLC (WMA) Fiber	10	4867	25561	2:46:40	39760	10000	2.6	151.6	146.1	3.76	5.5
	9	4221	24538	2:46:40	43386	10000	2.5	151.2	145.8	3.70	5.4
	11	2937	28558	1:54:08	50011	6848	2.9	150.2	143.6	4.62	6.6
	12	2170	29092	1:21:14	50008	4874	2.9	151.1	144.4	4.69	6.8
	μ	3549	26937	2:12:10	45791	7931	3	151	145	4	6
	SD	1220	2230	0:42:02	5091	2522	0	1	1	1	1
	SE	610	1115	0	2545	1261	0	0	1	0	0
	COV	34%	8%	32%	11%	32%	8%	0%	1%	13%	12%

690 kPa Deviator Stress and Unconfined

FN Test @ 53 °C

Francken Model

Mix ID	Specimen ID	Flow Point, cycles	µStrain @ Flow	Test Duration (time)	Total Accumulated Strain	Total Cycles	% loss of height (microstrains)	Initial height of specimen (measured)	Height of specimen after FN test (measured)	% deformation based on msrd heights (calc'd)	Measured deformation during Flow Test (mm)
PMLC (WMA)	24	1628	26499	1:04:42	50010	3882	2.6	148.6333333	142.1	4.57	6.5
	37	1255	28476	0:47:23	50025	2843	2.8	150.7	143.0	5.39	7.7
	41	965	27383	0:36:57	50001	2217	2.7	150.1	143.3	4.77	6.8
	44	1255	26169	0:50:48	50011	3048	2.6	150.2	143.4	4.74	6.8
	µ	1276	27132	0:49:58	50012	2998	3	150	143	5	7
	SD	272	1032	0:11:27	10	687	0	1	1	0	1
	SE	136	516	0	5	344	0	0	0	0	0
	COV	21%	4%	23%	0%	23%	4%	1%	0%	7%	7%
PMLC (WMA) Fiber	16	868	28805	0:32:11	50016	1931	2.9	151.2666667	144.5	4.68	6.8
	17	688	31144	0:23:41	50019	1421	3.1	150.4	143.8	4.57	6.6
	18	702	30443	0:24:37	50003	1477	3.0	151.4	144.6	4.73	6.8
	19	635	30922	0:21:45	50010	1305	3.1	150.6	143.8	4.75	6.8
	µ	723	30329	0:25:33	50012	1534	3	151	144	5	7
	SD	101	1057	0:04:35	7	275	0	0	0	0	0
	SE	50	528	0	4	137	0	0	0	0	0
	COV	14%	3%	18%	0%	18%	3%	0%	0%	2%	2%

800 kPa Deviator Stress and Unconfined

FN Test @ 53 °C

Francken Model

Mix ID	Specimen ID	Flow Point, cycles	µStrain @ Flow	Test Duration (time)	Total Accumulated Strain	Total Cycles	% loss of height (microstrains)	Initial height of specimen (measured)	Height of specimen after FN test (measured)	% deformation based on msrd heights (calc'd)	Measured deformation during Flow Test (mm)
PMLC (WMA)	17	2377	28031	1:35:48	50009	5748	2.8	149.8666667	144.0	4.11	5.9
	26	1272	26008	0:46:46	50006	2886	2.6	149.8	143.8	4.17	6.0
	29	2834	24409	1:59:30	50002	7170	2.4	150.1	143.6	4.53	6.5
	40	1012	32285	0:33:36	50015	2016	3.2	150.0	143.7	4.36	6.3
	µ	1874	27683	1:13:55	50008	4455	3	150	144	4	6
	SD	872	3407	0:40:30	5	2412	0	0	0	0	0
	SE	436	1704	0	3	1206	0	0	0	0	0
	COV	47%	12%	55%	0%	54%	12%	0%	0%	4%	4%
PMLC (WMA) Fiber	20	321	31290	0:10:32	50035	632	3.1	150.4	143.6	4.71	6.8
	21	290	33407	0:10:32	50052	535	3.3	151.1	144.2	4.76	6.9
	22	429	30279	0:14:43	50009	883	3.0	151.3	144.5	4.70	6.8
	23	409	30233	0:14:00	50003	840	3.0	150.4	144.0	4.42	6.4
	µ	362	31302	0:12:27	50025	723	3	151	144	5	7
	SD	67	1486	0:02:14	23	166	0	0	0	0	0
	SE	34	743	0	11	83	0	0	0	0	0
	COV	19%	5%	18%	0%	23%	5%	0%	0%	3%	3%

600 kPa Deviator Stress and 69 Kpa Confining

FN Test @ 53 °C

Francken Model

Mix ID	Specimen ID	Flow Point, cycles	µStrain @ Flow	Test Duration (time)	Total Accumulated Strain	Total Cycles	% loss of height (microstrains)	Initial height of specimen (measured)	Height of specimen after FN test (measured)	% deformation based on msrd heights (calc'd)	Measured deformation during Flow Test (mm)
PMLC (WMA)	13	10000	12216	2:46:40	12284	10000	1.2	151.1333333	149.7	0.96	1.4
	16	10000	14871	2:46:40	14962	10000	1.5	149.4	146.1	2.25	3.3
	27	10000	17164	2:46:40	17273	10000	1.7	150.5	148.6	1.23	1.8
	38	10000	13614	2:46:40	13709	10000	1.4	150.4	148.8	1.08	1.6
	µ	10000	14466	2:46:40	14557	10000	1	150	148	1	2
	SD	0	2100	0:00:00	2116	0	0	1	2	1	1
	SE	0	1050	0	1058	0	0	0	1	0	0
	COV	0%	15%	0%	15%	0%	15%	0%	1%	43%	42%
PMLC (WMA) Fiber	24	10000	17214	2:46:40	17336	10000	1.7	151.2333333	148.5	1.82	2.7
	27	10000	14789	2:46:40	14861	10000	1.5	150.3	148.1	1.44	2.1
	28	10000	14260	2:46:40	14389	10000	1.4	150.2	148.4	1.24	1.8
	29	10000	16225	2:46:40	16343	10000	1.6	149.4	147.3	1.40	2.1
	µ	10000	15622	2:46:40	15732	10000	2	150	148	1	2
	SD	0	1347	0:00:00	1355	0	0	1	1	0	0
	SE	0	674	0	678	0	0	0	0	0	0
	COV	0%	9%	0%	9%	0%	9%	1%	0%	17%	17%

690 kPa Deviator Stress and 69 Kpa Confining

FN Test @ 53 °C

Francken Model

Mix ID	Specimen ID	Flow Point, cycles	µStrain @ Flow	Test Duration (time)	Total Accumulated Strain	Total Cycles	% loss of height (microstrains)	Initial height of specimen (measured)	Height of specimen after FN test (measured)	% deformation based on msrd heights (calc'd)	Measured deformation during Flow Test (mm)
PMLC (WMA)	6	10000	8890.4	2:46:40	8917	10000	0.9	150.3	148.4	1.28	1.9
	15	10000	20313	2:46:40	20313	10000	2.0	149.3	147.3	1.40	2.1
	42	10000	18599	2:46:40	18667	10000	1.9	150.4	148.9	0.99	1.5
	43	10000	18111	2:46:40	18182	10000	1.8	150.3	148.9	0.96	1.4
	µ	10000	16478	2:46:40	16520	10000	2	150	148	1	2
	SD	0	5146	0:00:00	5150	0	1	1	1	0	0
	SE	0	2573	0	2575	0	0	0	0	0	0
	COV	0%	31%	0%	31%	0%	31%	0%	1%	19%	18%
PMLC (WMA) Fiber	30	10000	19903	2:46:40	19982	10000	2.0	151.5	148.7	1.86	2.8
	31	10000	19706	2:46:40	19772	10000	2.0	150.0	147.4	1.79	2.6
	32	10000	23409	2:46:40	23422	10000	2.3	149.8	147.3	1.70	2.5
	33	10000	18742	2:46:40	18772	10000	1.9	150.4	147.9	1.74	2.6
	µ	10000	20440	2:46:40	20487	10000	2	150	148	2	3
	SD	0	2043	0:00:00	2027	0	0	1	1	0	0
	SE	0	1022	0	1013	0	0	0	0	0	0
	COV	0%	10%	0%	10%	0%	10%	0%	0%	4%	4%

800 kPa Deviator Stress and 69 Kpa Confining

FN Test @ 53 °C

Francken Model

Mix ID	Specimen ID	Flow Point, cycles	µStrain @ Flow	Test Duration (time)	Total Accumulated Strain	Total Cycles	% loss of height (microstrains)	Initial height of specimen (measured)	Height of specimen after FN test (measured)	% deformation based on msrd heights (calc'd)	Measured deformation during Flow Test (mm)
PMLC (WMA)	2	9328	23010	2:46:40	23396	10000	2.3	149.6333333	146.6	2.05	3.0
	4	10000	20499	2:46:40	20564	10000	2.0	150.5	147.1	2.33	3.4
	5	10000	20250	2:46:40	20320	10000	2.0	150.7	147.7	2.03	3.0
							0.0			#DIV/0!	0.0
	µ	9776	21253	2:46:40	21427	10000	2	150	147	#DIV/0!	2
	SD	388	1527	0:00:00	1710	0	1	1	1	#DIV/0!	2
	SE	194	763	0	855	0	1	0	0	#DIV/0!	1
	COV	4%	7%	0%	8%	0%	67%	0%	0%	#DIV/0!	67%
PMLC (WMA) Fiber	35	10000	26726	2:46:40	26731	10000	2.7	149.4	145.5	2.68	3.9
	36	10000	26222	2:46:40	26219	10000	2.6	150.0	145.8	2.88	4.2
	38	10000	39248	2:46:40	40312	10000	3.9	151.3	145.9	3.68	5.4
	39	10000	23957	2:46:40	24025	10000	2.4	150.0	145.3	3.21	4.7
	µ	10000	29038	2:46:40	29322	10000	3	150	146	3	5
	SD	0	6912	0:00:00	7420	0	1	1	0	0	1
	SE	0	3456	0	3710	0	0	0	0	0	0
	COV	0%	24%	0%	25%	0%	24%	1%	0%	14%	14%