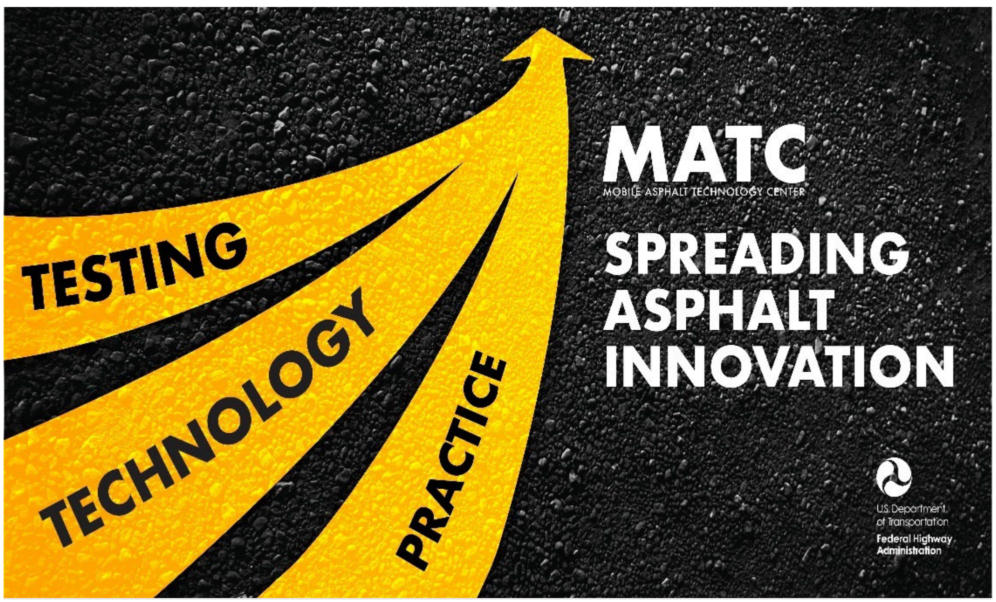
MATC
MOBILE ASPHALT TECHNOLOGY CENTER

U.S. Department of Transportation
Federal Highway Administration

FHWA Mobile Asphalt Technology Center (MATC)
Florida DOT

June 23, 2023



FHWA MATC Project # FL22120

Federal Highway Administration
Office of Preconstruction,
Construction, and Pavements
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List of Acronyms and Abbreviations

^{o}C	Degrees Centigrade
%	Percent
3D	Three Dimensional
AASHTO	American Association of State Highway and Transportation Officials
ABML-ID	FHWA Asphalt Binder and Materials Laboratory – Implementation and Delivery
ACAF	Asphalt Contractors Association of Florida
AMPT	Asphalt Mixture Performance Tester
APT	Accelerated Pavement Testing
ASTM	American Society for Testing and Materials
BMD	Balanced Mix Design
cm	Centimeters
COV	Coefficient of Variation
CPR	Crack Progression Rate
CR-452	Florida County Road 452
DPS	Dielectric Profiling System
DMI	Distance Measuring Instrument
E*	Dynamic Modulus
ESALs	Equivalent Single Axle Loads
FC-5	Florida Friction Course mixture
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
FHWA-FL	Federal Highway Administration Florida Division Office
G_c	Critical Fracture Energy parameter
G_{mb}	Bulk Specific Gravity of the Mixture
G_{mm}	Theoretical Maximum Specific Gravity of Mixture
GPR	Ground Penetrating Radar
GPS	Global Positioning System
HiMA	Highly-Modified Asphalt
HVS	Heavy Vehicle Simulator
Hz	Hertz
HMA	Hot Mix Asphalt

LTS	Laser Texture Scanner
LVDT	Linear Variable Differential Transformer
MATC	Mobile Asphalt Technology Center
mm	Millimeters
MPD	Mean Profile Depth
N/A	Not Applicable
N-mm	Newton-millimeter
OT	Overlay Test
Pave-IR	Paver-Mounted Thermal Infrared
P_b	Percent Binder (Asphalt Content)
P-200/P_{be}	Passing the #200 Sieve to Effective Asphalt Ratio
Φ	Phase Angle
QA	Quality Acceptance
RAP	Recycled Asphalt Pavement
RSI	Rutting Strain Index parameter
S_{app}	Cyclic Fatigue Index parameter
SR-19	Florida State Route 19
SR-821	Florida State Route 821
SSR	Stress Sweep Rutting Test
VFA	Voids Filled with Asphalt
VMA	Voids in Mineral Aggregate
VTM	Voids in Total Mix

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Mobile Asphalt Technology Center (MATC) Site Visit to Florida

June 23, 2023

About the Program

The mission of the Federal Highway Administration (FHWA) Mobile Asphalt Technology Center (MATC) is to:

- Bring new and emerging asphalt materials and construction technologies to the pavement community, bridging the gap between research and implementation;
- Provide leadership and technology for the delivery of long-life pavements that meet our stakeholders' needs and are safe, sustainable, and effectively maintained;
- Assist in advancement of new and underutilized technologies and innovations into common practice; and
- Raise awareness and assist FHWA field offices, State Departments of Transportation, and their private sector, local agency, and academic partners in the area of pavements and materials.

Project Details

In November of 2021 the Florida Department of Transportation (FDOT) and the FHWA Florida (FHWA-FL) Division office began discussions with the MATC Team regarding a field visit to their state. The primary reason for the visit was to provide assistance with testing and evaluating various asphalt mixtures that were currently being evaluated by FDOT for both rutting and fatigue cracking performance. Along with the asphalt mixture evaluation, other laboratory and field-testing technologies were also demonstrated both at MATC laboratory and on two different live field projects selected by FDOT. The MATC arrived at the FDOT State Materials Office in Gainesville on February 3rd and remained onsite until March 9th. Figure 1 shows the location of the MATC in Gainesville, as well as the locations and project details of the two field projects on which field technology demonstrations were conducted while the MATC was in state.

The U.S. Government does not endorse products or manufacturers. Equipment and test names appear in this report because they were used during the Florida field visit.

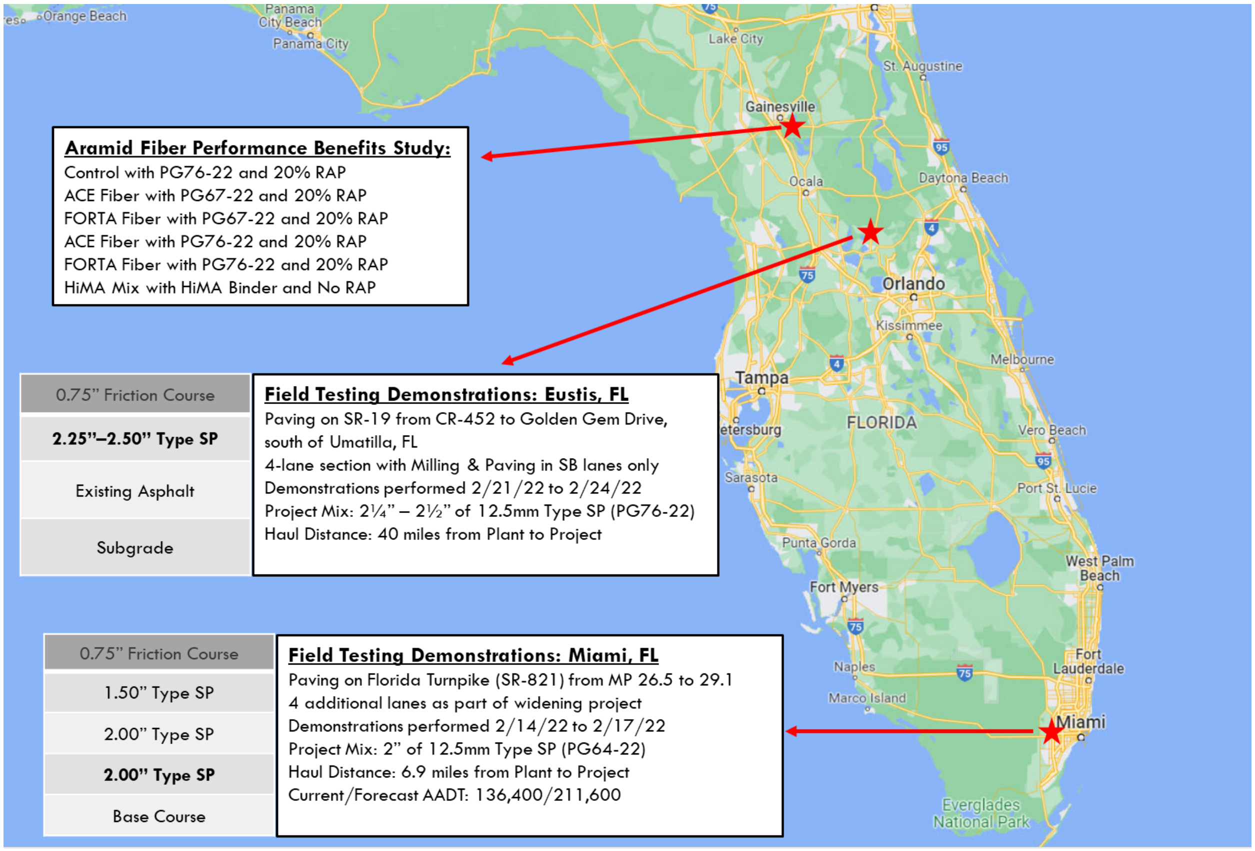

Figure 1: Key Project Details for MATC Visit to Florida

The primary goals of the testing plan for the site visit were as follows:

- Mixture Performance Testing: Perform both the Asphalt Mixture Performance Test (AMPT) suite of testing (Cyclic Fatigue, Dynamic Modulus, and Stress Sweep Rutting) and the Overlay Test (OT) on six (6) different asphalt mixtures (as shown in Figure 2) that FDOT was currently evaluating for rutting and bottom-up cracking performance at their Accelerated Pavement Testing (APT) facility with their Heavy Vehicle Simulator (HVS). These mixtures were part of an aramid fiber performance benefits study, and both the AMPT and the OT testing results were to compliment that effort. Also, although the initial test plan included the Hamburg Wheel Tracking Test (HWTT), it was decided that FDOT would perform that testing with their own HWTT equipment.

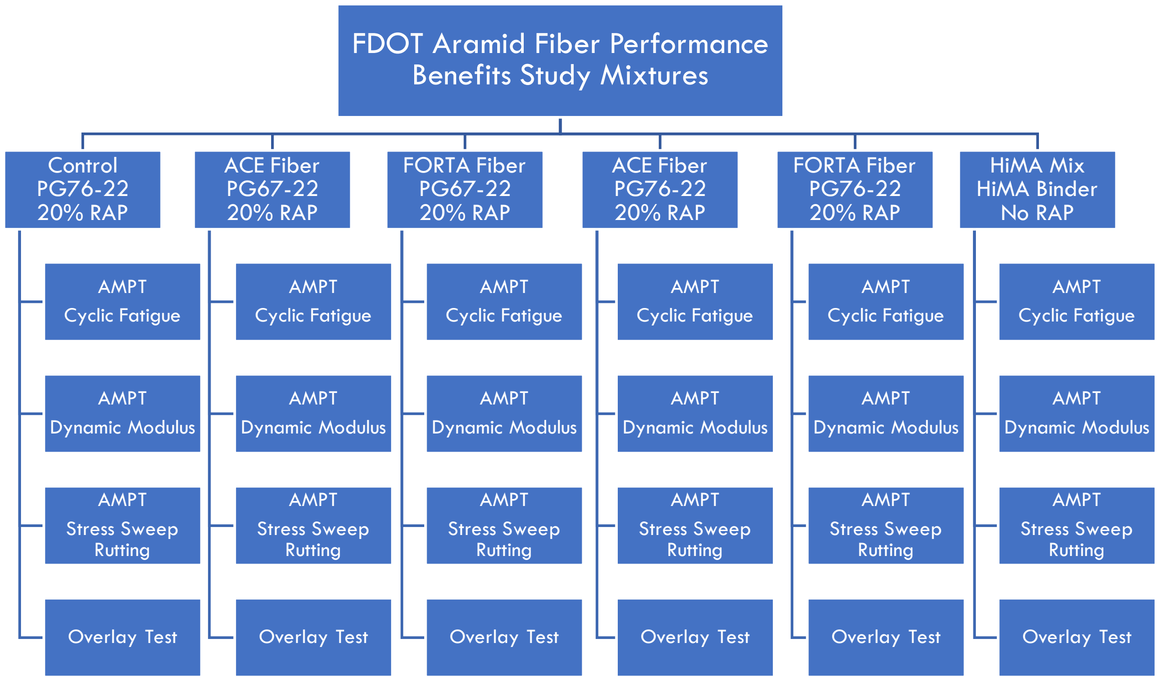

Figure 2: Performance Testing Evaluation of FDOT Mixtures

- Field Testing Demonstrations: On two different paving projects as coordinated by FDOT, ACAF, and Contractors, the MATC Team demonstrated the Paver-Mounted Thermal Profiler (PMTP) as a high precision real-time thermal profiler to detect pavement mat defects before compaction, the Dielectric Profiling System (DPS) as a non-destructive tool to continuously assess asphalt pavement compaction quality through measuring the pavement's dielectric constant, the use of Pulse Induction Technology as a non-destructive test to measure pavement layer thickness, and the Laser Texture Scanner (LTS) to measure surface macrotexture of the asphalt mat.

Sampling & Fabrication

For the mixture performance testing portion of the test plan, all loose mix samples of the six (6) mixture types were previously sampled and set aside by FDOT. Using these samples, the MATC Team fabricated specimens for each of the performance tests included in this part of the test plan. For purposes of targeting test specimen parameters, the MATC Team relied on volumetric mixture data provided by FDOT. Table 1 below details the necessary specimens for each performance test and the associated requirements, for each of the individual mixture samples obtained.

Table 1: Mixture Performance Testing Requirements (per Mix Type)

Requirement	AMPT Tests			Overlay Test (CPR)
	Cyclic Fatigue (S_{app})	Dynamic Modulus (E*)	Stress Sweep Rutting (RSI)	
Test Method	AASHTO TP133	AASHTO TP132	AASHTO TP134	ASTM D8225
Number of Specimens	4	4	4	3+
Specimen Geometry	38 mm diameter 110 mm height	38 mm diameter 110 mm height	100 mm diameter 150 mm height	150 mm diameter 62 mm height
Specimen Air Voids	7.0 ± 0.5%	7.0 ± 0.5%	7.0 ± 0.5%	7.0 ± 0.5%
Test Temperature (°C)	PG Binder Based [a]	4, 20 and 40	Based on Project Location [b]	25
Mass Required *(25% fabrication failure rate)*	60 lbs+	60 lbs+	110 lbs+	60 lbs+

[a] *Based on different standard PG Binder Grades*
[b] *Based on LTPPBind v. 3.1*

For the purposes of completing some of the field-testing demonstrations, roadway cores were taken from both projects. To complete the surface macrotexture evaluation using the Laser Texture Scanner (LTS), six (6) 6-inch roadway cores were needed from two different days of production (3 per production day) to perform laboratory comparison scans. Also, for the mat thickness measurements made using the Pulse Induction Technology, three (3) of the six (6) cores taken for surface macrotexture would be used to verify the readings by measuring the actual core thicknesses. As for the demonstrations of both the Paver-Mounted Thermal Profiler (PMTP) and the Dielectric Profiling System (DPS), no roadway cores were needed. Along with coring, the surface macrotexture evaluations also required loose mixture samples to be taken during the same days of production as the field testing. These loose mix samples were used to fabricate laboratory compacted specimens that were also tested with the LTS to compare against in-place field mean profile depth measurements. Table 2 below details the roadway cores that were taken (per field project) to complete the demonstrations of the various field-testing technologies.

Table 2: Roadway Cores Acquired for Field Testing Demonstrations

Thermal Profile	Mat Density	Mat Thickness	Surface Macrotexture	Total 6" Cores (per project)
Paver-Mounted Thermal Profiler (PMTP)	Dielectric Profiling System (DPS)	Pulse Induction Technology	Laser Texture Scanner (MPD)	
0 cores	0 cores	3 cores *3 of the 6 taken for Surface Macrotexture testing*	6 cores *3 per day on two separate days of production*	6 cores

Tests and Analyses Performed

The tests and analyses performed by the MATC comprised of two categories:

- Mixture Performance Testing
- Field Testing Demonstrations

Table 3 below shows the MATC's test plan that was developed in coordination with both FDOT and the FHWA-FL Division office. The test results are summarized in the next few pages; however, t1he reader who is unfamiliar with a test or who wishes to review the details of a test and its results can examine the discussion of that test in Appendix A – Mixture Performance Testing or Appendix B – Field Testing Demonstrations.

Table 3: MATC Test Plan for Florida Site Visit

Mixture Performance Testing	Field Testing Demonstrations
AMPT – Cyclic Fatigue (S_{app}) [a]	Paver-Mounted Thermal Profiler (PMTP)
AMPT – Dynamic Modulus (E*)	Dielectric Profiling System (DPS)
AMPT – Stress Sweep Rutting (RSI) [b]	Pulse Induction Technology (thickness)
Overlay Test (CPR)	Laser Texture Scanner (MPD)

[a] *Testing temperature based on different standard PG binder grades.*
[b] *Testing temperature based on LTPPBind v. 3.1*

Summary of Results

Mixture Performance Testing & Analysis

AMPT Tests:

- Cyclic Fatigue testing showed the HiMA mixture to vastly outperform the other mixture types, and this improvement is likely highly influenced by the absence of RAP in the mixture. Also, the addition of the fibers did not appear to have any noticeable effect on the S_{app} value. These results should be viewed with the understanding that there were issues experienced with the cyclic fatigue testing.
- Dynamic Modulus testing showed no noticeable effect by the addition of the fibers; however, a decrease in stiffness was evident for the HiMA mixture, likely due to a combined effect of 0% RAP and the reduced intermediate temperature stiffness properties of the HiMA binder.
- Stress Sweep Rutting testing showed no noticeable effect by the addition of the fibers; however, the combination of the %RAP and the PG of the binder appears to have the most impact. Also, the reduced intermediate temperature stiffness properties of the HiMA binder appears to influence the mixture's rutting resistance (according to SSR test criteria).

Overlay Test:

- Overlay Test results showed increased crack propagation resistance with all four of the fiber mixtures, as well as the HiMA mixture, when compared to the Control mixture.

Field Testing Demonstrations & Analysis

- PMTP demonstration showed the operational challenges faced by the crew when paving in congested urban areas and their effects on minimum mat temperatures and overall consistency.
- The MATC Team showed that the DPS system can be used on any moisture-free pavement surface to help paving contractors and agencies to assess pavement compaction uniformity and field densities, especially at joints. It can also be used to identify critical factors that influence in achieving higher density in the field.
- Pulse Induction Technology accurately measured mat thicknesses as compared to the planned laydown thickness. This is of particular interest for use on paving jobs that accept on thickness, such as county or city projects.
- Laser Texture Scanner measurements to determine the mean profile depth (MPD) of the mixtures correlated well with anticipated results based on the 2022 AASHTO Guide for

Pavement Friction (American Association of State Highway and Transportation Officials (AASHTO), 2022).

Parting Considerations

- Mixture performance testing seemed to demonstrate that the %RAP has a noticeable impact on both rutting and cracking properties of the mixture; the addition of fibers slightly improved the mixture's resistance to crack propagation; and the reduced intermediate temperature stiffness properties of the HiMA binder greatly impacts the crack resistance of the mixtures
- The PMTP technology should be considered to ensure consistent, uniform mat temperatures behind the paver, and bring awareness to the impact of both truck exchanges and extended paver stops on achieving mat density. The MATC demonstration to two contractors, an FDOT District, and FL Turnpike staff showed how a paver-mounted thermal profiler can be used on any newly-paved mats, demonstrating the possibility of improving communications between plant and paver personnel to reduce temperature differential on the mat to the lowest value; determining when the contractor needs to take corrective actions; and, allowing real-time adjustments. It is a great visual on-site training aid for contractor paving crews.
- The PIT device accurately measured mat thicknesses as compared to roadway cores. The results show that the measured thickness and the actual field core thickness were close for each location. All three measurements compared favorably between the two methods of mat thickness determination, showed excellent correlation to field core measurements, close to a millimeter. The measurements were found to be repeatable between MATC operators. The device has a built in GPS to quickly find the reflectors again if needed in the future and is a proven technology for Quality Control and Agency Acceptance (on concrete pavements side to-date).
- The DPS technology should be considered as it can be helpful to paving contractors in Florida by giving a much broader image of the overall consistency of mat density behind the paver. MATC Team showed that density profiling can be used on any moisture-free pavement surface to help paving contractors and agencies to assess pavement compaction uniformity and field densities, especially at joints. It can also be used to identify critical factors that influence in achieving higher density in the field and is ready for use as a QC tool to identify potential issues with paving & compaction operations.

Appendix A — Mixture Performance Testing

Mixture Properties

The mixtures from FDOT's Aramid Fiber Performance Benefits Study were both designed and produced by FDOT according to their required specifications. The Control mix was designated to be a Traffic Level C, SP-12.5 Structural mixture. It was designed using an N_{des} compaction level of 75 gyrations and incorporated both 20% RAP and a PG76-22 asphalt binder. A summary of the design parameters of the Control mix are provided in Table 4 below:

Table 4: Control Mix Parameters for FDOT Performance Benefits Study

Property	Job Mix Formula	Control Points
Gradation (Percent Passing)		
3/4"	100	100 min
1/2"	98	90 – 100
3/8"	89	89 max
#4	64	-
#8	49	40 – 58
#16	40	29 min
#30	34	22 min
#50	20	16 min
#100	9	-
#200	5.1	2 – 10
Volumetric Properties		
RAP Content (%)	20%	20% max of Total Aggregate
Binder from RAP (%)	0.94	20% max of Total Binder
Virgin Binder (%)	4.16	80% min of Total Binder
Total Binder (%)	5.10	-
Max. Gravity (G_{mm})	2.477	-
Bulk Gravity (G_{mb})	2.378	-
VTM (%)	4.0	4.0
VMA (%)	15.1	14.0 min
VFA (%)	74	65 – 75
P-200/Pbe	1.0	0.6 – 1.2

FDOT's study was to evaluate any potential performance benefit that might occur with the addition of aramid fiber into the mixture. To carry this out, five different variations of the original Control mix were designed and produced to be evaluated at their HVS test facility. The six different mixtures evaluated are shown in Table 5.

Table 5: Sample ID's and Descriptions of FDOT Test Mixtures

Sample ID	Mixture
20001	Control with PG76-22 & 20% RAP
20002	ACE Fiber with PG67-22 & 20% RAP
20003	FORTA Fiber with PG67-22 & 20% RAP
20004	ACE Fiber with PG76-22 & 20% RAP
20005	FORTA Fiber with PG76-22 & 20% RAP
20006	HiMA Mix with HiMA Binder & 0% RAP

Including the Control mix, all six mixtures were produced and placed at FDOT's HVS testing facility for evaluation. At the time of production FDOT obtained and stored samples from each of the six mixture types for the MATC's use to carry out the additional mixture performance testing. As can be seen in Table 6 below, production control of each of the six mixtures was very good with regards to asphalt content, gradation, mixture specific gravities, and air voids (VTM).

Table 6: Production Control for FDOT Performance Benefits Study Mixtures

Property	Control PG76-22 20% RAP	ACE Fiber PG67-22 20% RAP	FORTA Fiber PG67-22 20% RAP	ACE Fiber PG76-22 20% RAP	FORTA Fiber PG76-22 20% RAP	HiMA Mix HiMA Binder 0% RAP
Asphalt Content & Gradation						
%AC by Ignition (%)	4.99	5.29	5.03	5.08	5.21	5.06
3/4"	100	100	100	100	100	100
1/2"	98.2	99.1	98.1	99.3	99.0	98.3
3/8"	91.3	92.3	89.4	90.3	91.6	89.9
#4	69.7	69.0	65.2	66.9	68.5	71.3
#8	50.5	50.3	47.2	48.9	49.6	54.0
#16	41.7	41.5	39.0	40.5	40.9	42.7
#30	35.3	35.2	33.2	34.5	34.7	35.9
#50	20.8	20.9	19.8	20.5	20.4	21.4
#100	9.2	9.3	8.7	9.0	8.8	9.7
#200	5.2	5.3	4.9	5.0	4.9	5.1
Mixture Specific Gravities & Air Voids						
Max. Gravity (G_{mm})	2.484	2.479	2.479	2.474	2.485	2.465
Bulk Gravity (G_{mb})	2.379	2.386	2.383	2.384	2.383	2.350
VTM (%)	4.23	3.75	3.87	3.64	4.10	4.66

Mixture Performance Tests

For alternative means of evaluating the performance properties of the six FDOT mixtures, a variety of both rutting performance and cracking performance tests were performed. The Asphalt Mixture Performance Tester (AMPT) was used to determine engineering properties such as, the S_{app} Index parameter from the Cyclic Fatigue test, Dynamic Modulus (E*), and the Rutting Strain Index (RSI) parameter from the Stress Sweep Rutting (SSR) test. The AMPT can simulate changing field conditions such as traffic loading, rate of loading, temperature, and confinement of the pavement experiences during its design life. In addition to AMPT testing, the Overlay Test (OT) was performed to provide additional cracking performance analysis by determining the Crack Progression Rate (CPR) for each of the six mixtures. All performance testing was performed on specimens compacted to a target air void range of 7.0 $\pm$ 0.5%.

AMPT – Cyclic Fatigue Test

Cyclic Fatigue is a cyclic tension test in the AMPT used to determine the cracking potential of asphalt mixtures. The Cyclic Fatigue test uses cyclic tension controlled by a constant actuator amplitude in the AMPT. The small-scale specimens (38mm diameter by 110mm tall) were used to perform this test on three replicate specimens. Platens were glued to the ends of the specimens and gauge points were glued to the side of the specimens for LVDT attachments. The testing was conducted in accordance with AASHTO TP 133 at 21°C. The cyclic fatigue test (along with data from dynamic modulus testing) generates the index-parameter S_{app} (used in modelling and FlexPAVE^{TM}). The larger the S_{app} value, the better the cracking resistance.

The Cyclic Fatigue data was analyzed using the FlexMAT v2.1 software and the results are shown in Table 7. However, upon analyzing the Cyclic Fatigue output data the software showed that the data did not meet the required Data Quality Indicators (DQI) due to incorrect proportional-integral-derivative (PID) tuning on the AMPT-PaveTest software. Essentially, the weighted sum of these three actions is used to adjust the hydraulic control valve of the AMPT so that the load measured by the load cell closely matches the command signal. Since the stiffness of asphalt mixture varies dramatically with temperature, the AMPT will have different proportional, integral, and derivative gains depending on the test temperature. Attempts were made to re-analyze the raw test data to generate "true" representative S_{app} values, but those attempts were also unsuccessful. Furthermore, due to limitations of test mixture quantities, additional test replicates were not able to be prepared in attempt to repeat the testing. The PID errors and tuning offsets were consistent across all mixtures and specimens, so the MATC believes that a comparative analysis of the mixtures against one another is still valid. However, although there are recommended S_{app} threshold values from a study conducted by North Carolina State University and FHWA, due to this testing error, the S_{app} values shown below are in question, so comparisons were not made to the recommended criteria.

Table 7: AMPT Cyclic Fatigue S_{app} Values for FDOT Mixtures

Sample ID	Mixture	(FlexMAT v2.1)	
		Representative S_{app}	Standard Deviation
20001	Control with PG76-22 & 20% RAP	7.7	1.2
20002	ACE Fiber with PG67-22 & 20% RAP	3.2	1.9
20003	FORTA Fiber with PG67-22 & 20% RAP	5.3	1.4
20004	ACE Fiber with PG76-22 & 20% RAP	8.6	4.2
20005	FORTA Fiber with PG76-22 & 20% RAP	6.6	1.8
20006	HiMA Mix with HiMA Binder & 0% RAP	30.0	2.9

The results of the Cyclic Fatigue testing shown in the table above appears to primarily show the impact of the 20% RAP on the cracking susceptibility of the mixture. Also, the lack of polymer modification in samples 20002 and 20003 seems to indicate additional susceptibility to cracking. It does not appear from the results that the addition of either of the fiber types improved the cracking resistance of the mixtures, according to Cyclic Fatigue testing criteria. On the other hand, the HiMA mixture (20006) did show improved cracking resistance with a representative S_{app} value of 30.0. This improvement is likely mostly impacted by the mixture utilizing 0% RAP, as compared to the other five mixture types. Additionally, many HiMA binders also have enhanced low temperature properties as compared to typical binders, resulting in reduced stiffness at intermediate temperatures, which may further explain the increase in crack resistance. These two mixture characteristic differences of the HiMA likely explain the apparent increase in cracking resistance with Cyclic Fatigue testing.

AMPT – Dynamic Modulus Test

The small-scale specimens were used to perform unconfined dynamic modulus tests on three replicate specimens. The testing was conducted in accordance with AASHTO TP 132 at the three different testing temperatures of 40°C (high temperature), 20°C (intermediate temperature), and 4°C (low temperature) and at the three different frequencies of 10Hz (fast moving traffic), 1Hz (moderate speed traffic) and 0.1Hz (slow moving traffic). Figure 3 represents the average dynamic modulus (E*) values obtained from the six different mixtures at a 20°C testing temperature, for each testing frequency. The dynamic modulus values showed the expected trend that the E* values increased by increasing the frequency. Figure 4 represents the average phase angle (ϕ) values obtained for the corresponding dynamic modulus values from the 20°C testing temperature. The phase angle also showed the expected trend with the ϕ angle decreasing with increasing frequency.

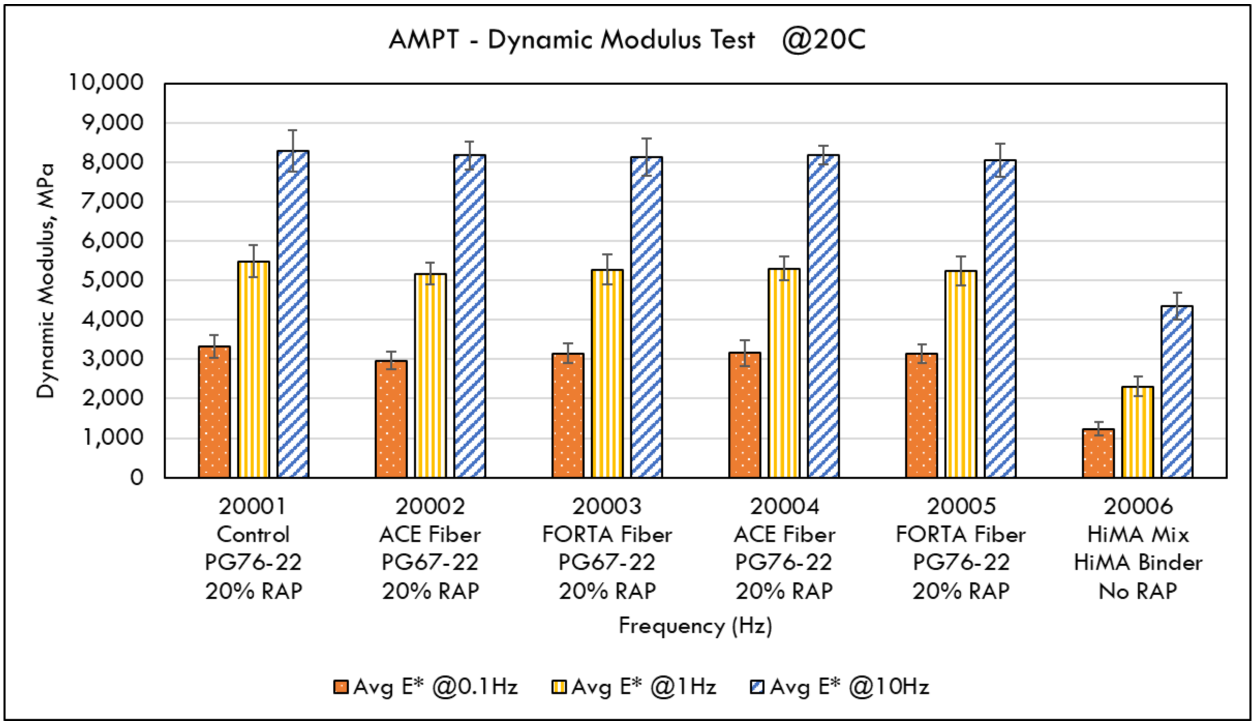

Figure 3: Average Dynamic Modulus at 20°C Test Temperature

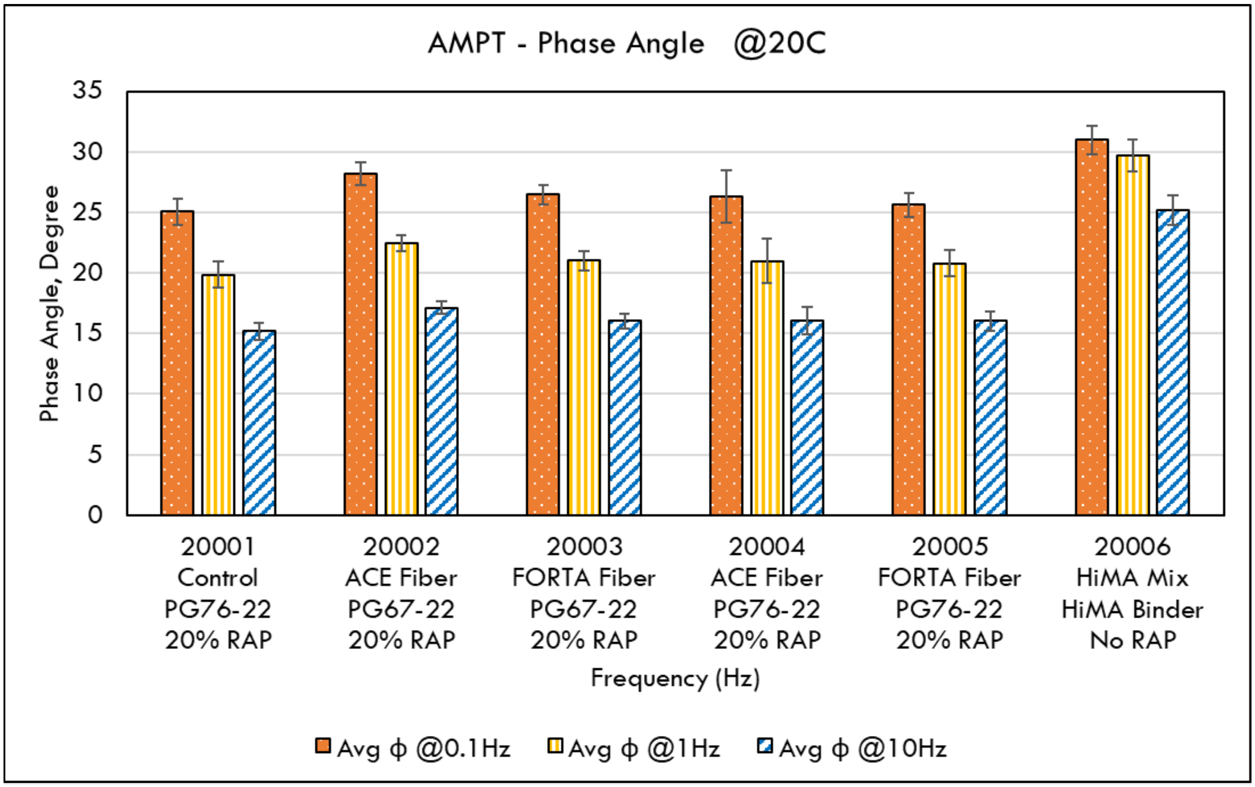

Figure 4: Average Phase Angle at 20°C Test Temperature

Both the Dynamic Modulus and Phase Angle results from the testing (as shown in the figures above) indicate that neither the addition of the fibers nor the change in PG of the asphalt binder had a noticeable effect on the dynamic modulus testing properties of the final mixture. However, the HiMA mixture (20006) did show a noticeable decrease in dynamic modulus as compared to the other five mixtures. The data seems to indicate that the removal of the 20% RAP in the final mixture may have the most significant effect on the stiffness properties. Also, as noted earlier, the enhanced low temperature properties of the HiMA binder likely results in reduced stiffness at intermediate temperatures, which may further explain the decrease in dynamic modulus results.

AMPT – Stress Sweep Rutting Test

The permanent deformation properties of the asphalt mixtures were evaluated using the Stress Sweep Rutting (SSR) Test and conducted in accordance with AASHTO TP 134, a voluntary, nonbinding specification. The test was conducted on large scale (100mm by 150mm) specimens at high temperature of 53°C and at low temperature of 32°C. This test is a cyclic compression test which applies various levels of deviatoric stress upon the performance specimens over a series of three loading blocks at 200 cycles each. The SSR test is terminated after 600 cycles. The shift model obtained from this test can be used to predict the permanent deformation of asphalt mixtures under various loading and temperature conditions using two high-temperature and two low-temperature SSR tests. The results were processed with the FlexMAT™ Rutting program (www.fhwa.dot.gov/pavement/asphalt/analysis/) (FHWA, 2020) to calculate the shift model coefficients and the Rutting Strain Index (RSI) value. The RSI parameter captures the effects of changing temperature, stress level, and loading time along pavement depth on the permanent deformation of asphalt pavements using realistic loading and changing climatic conditions.

Figure 5 below shows the RSI values determined for each of the test mixtures, however, it should be noted that high variability was observed between testing replicates for two of the six test mixtures, Sample 20002 and Sample 20005. Furthermore, although there are again recommended RSI threshold values from that same study conducted by North Carolina State University and FHWA, due to this test replicate variability, comparisons were not made to the recommended criteria, but simply noted that the lower the RSI value the better the rutting resistance of the mixture.

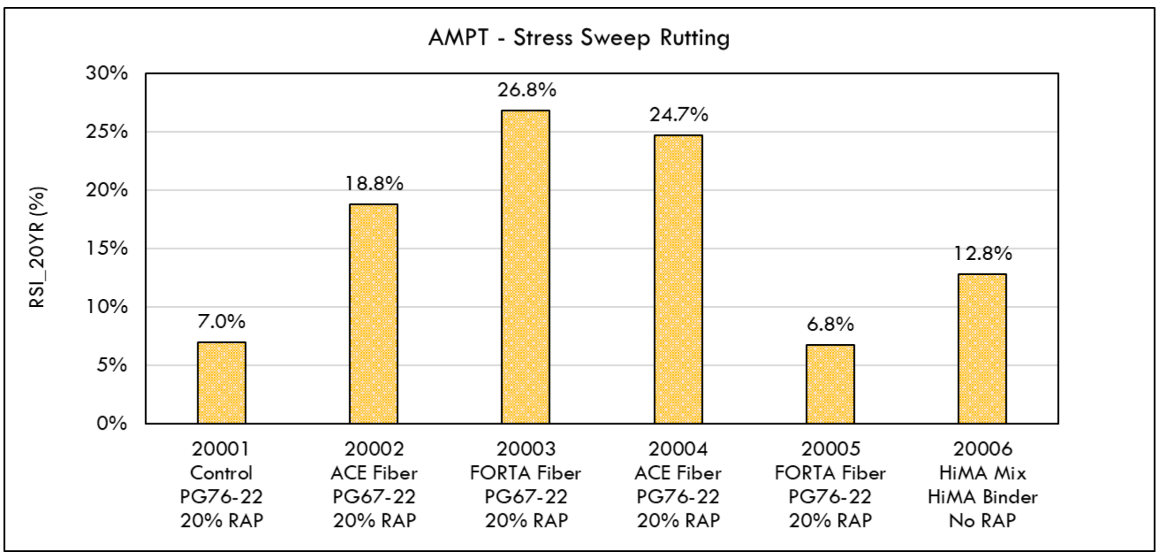

Figure 5: Average RSI values from the Stress Sweep Rutting Test

Figure 6 below illustrates the test replicate variability that was experienced when testing one of the mixtures, Sample 20005. As can be seen in the figure, the viscoplastic strain (permanent strain) response of the two replicates tested at low temperature (plot on the right) were very different. The permanent strain curve for Rep 2 appears to be inaccurate from 0 to 200 cycles; thus, resulting in a very different curve and final permanent strain as compared to Rep 1. This high variability in the observed viscoplastic strain between test replicates would have an impact on the generated RSI value and may not be the most representative value for that mixture. Again, due to limitations of test mixture quantities, additional test replicates were not able to be prepared to attempt to reduce that variability. As a result, the RSI values determined for the two mixtures in question were calculated based on a single replicate at that test temperature.

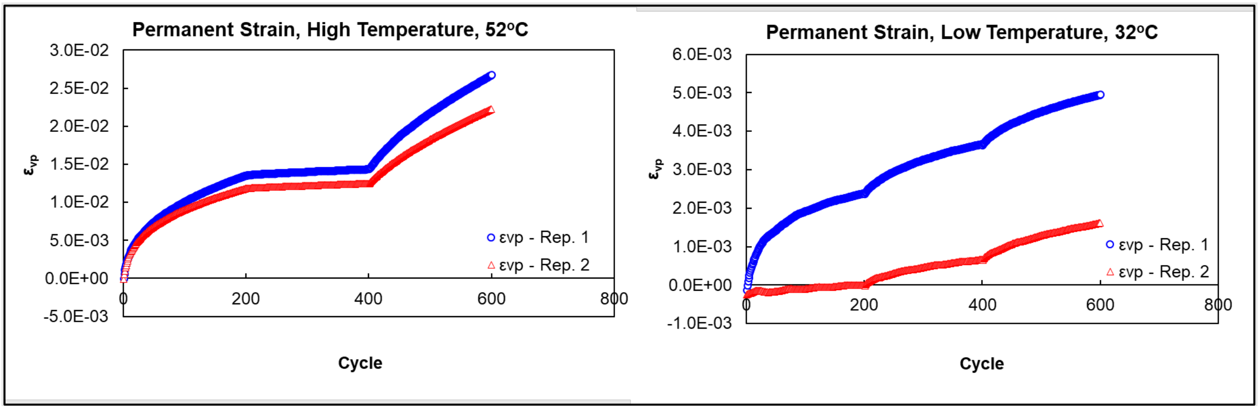

Figure 6: Sample 20005 Permanent Strain Curves Showing Low Temperature Test Variability

As can be seen in the SSR test results below in Table 8, for each mixture combination the final permanent strain value and the standard deviation for both the high temperature and low temperature testing are reported, along with its resultant RSI value.

Table 8: Viscoplastic Strain (Permanent Strain) at 600th Load Cycle

Sample ID	Mixture	Test Temperature (T_H = 52°C)		Test Temperature (T_L = 32°C)		RSI (%)
		Avg. ε_{vp} (N=600)	SD	Avg. ε_{vp} (N=600)	SD	
20001	Control with PG76-22 & 20% RAP	0.021	0.001	0.004	0.001	7.0
20002	ACE Fiber with PG67-22 & 20% RAP	0.038	N/A	0.003	0.001	18.8
20003	FORTA Fiber with PG67-22 & 20% RAP	0.036	0.016	0.005	0.000	26.8
20004	ACE Fiber with PG76-22 & 20% RAP	0.040	0.006	0.007	0.001	24.7
20005	FORTA Fiber with PG76-22 & 20% RAP	0.024	0.003	0.005	N/A	6.8
20006	HiMA Mix with HiMA Binder & 0% RAP	0.026	0.003	0.009	0.001	12.8

First, when comparing the Control mixture (20001) to the two fiber mixtures utilizing the PG67-22 binder, the inclusion of neither the ACE fiber (20002) nor the FORTA fiber (20003) appear to compensate for the decrease in PG with RSI values increasing from 7.0% for the Control to values of 18.8% and 26.8%, respectively. Secondly, when comparing the two fiber mixtures utilizing the same PG76-22 binder as the Control, the FORTA fiber mixture (20005) showed essentially no change from the Control with an RSI of 6.8%, while the ACE fiber mixture (20004) showed a decrease in rutting resistance with an RSI value of 24.7%. And finally, the HiMA mixture (20006) also showed a slightly lower rutting resistance than the Control with an RSI value of 12.8%. Again, it should be noted that although the HiMA mixture's asphalt binder has high temperature properties at least equal to or likely stiffer than the PG76-22 in the Control, it also utilized 0% RAP, which likely contributed to the rutting resistance of the Control mixture. Furthermore, as noted earlier, the enhanced low temperature properties of the HiMA binder likely results in reduced stiffness at intermediate temperatures. This effect is evidenced by the HiMA mixture having the highest average permanent strain at the low testing temperature, with a value of 0.009. These two mixture characteristic differences of the HiMA likely explain the apparent lower rutting resistance with SSR testing.

Overlay Test

The Overlay Test (OT) was conducted in a repeated direct tension test method to determine the reflective cracking potential of asphalt mixtures. The OT applies repeated direct tension loads to asphalt mixture specimens by fixing one side of the specimen to one block and allowing the other side to slide to apply tension in a cyclic triangular waveform to a constant maximum displacement of 0.025 inches. The result of the OT is an evaluation of the specimen's Critical Fracture Energy (G_c) parameter and its Crack Progression Rate (CPR). Specimens are cut from a gyratory pill, with

7.0 ± 1.0% air voids, and conditioned at the test temperature of 25°C (77°F) for at least one hour before testing. Figure 7 shows the Overlay Test setup.

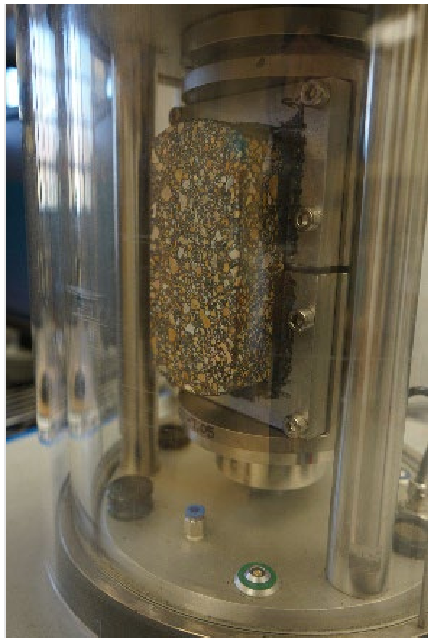

Figure 7: Overlay Test Setup

Figure 8 shows the design interaction plot between the CPR and G_c values and indicates the six different FDOT mixtures' fracture properties by the various shape icons as identified in the legend. The average CPR value of the Control mixture was 0.549 with an average G_c of 0.538 N-mm/mm^2. The results indicate that all five other mixture combinations improve the mixture's resistance to crack propagation, however, three of the mixtures do drop below the G_c threshold of 0.5 N-mm/mm^2, indicating that those mixtures may be more susceptible to crack initiation. The analysis of these results is based on information reported in a study conducted by the University of Texas at El Paso (Garcia, 2017).

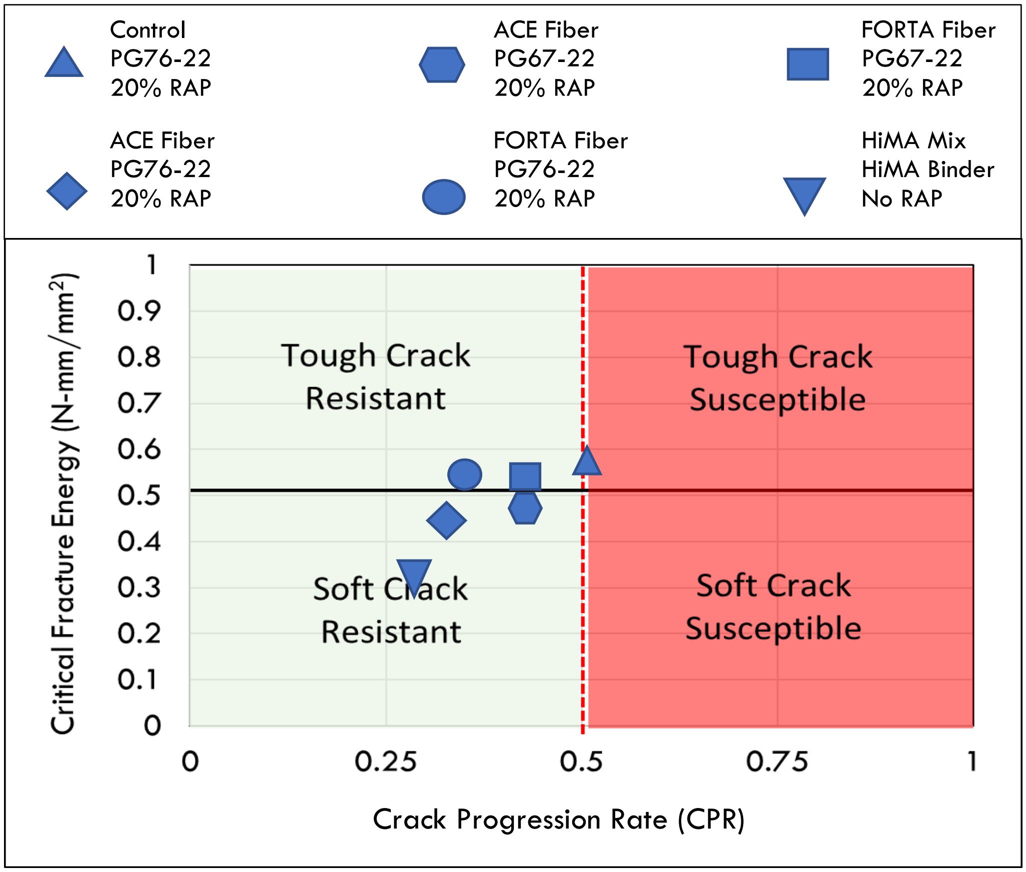

Figure 8: Design Interaction Plot for the FDOT Mixtures

Appendix B — Field Testing Demonstrations

On two different paving projects as coordinated by a mix of the FDOT, ACAF, Florida Turnpike Authority, and paving contractors, the MATC Team demonstrated a variety of new field-testing technologies that have the potential of improving the asphalt paving process from both a quality control and/or quality acceptance standpoint. The technologies included the Paver-Mounted Thermal Infrared (Pave-IR) as a high precision real-time thermal profiler to detect pavement mat defects before compaction, the Dielectric Profiling System (DPS) as a non-destructive tool to continuously assess asphalt pavement compaction quality through measuring the pavement's dielectric constant, the use of Pulse Induction Technology as a non-destructive test to measure pavement layer thickness, and the Laser Texture Scanner (LTS) to measure surface macrotexture of the asphalt mat. The two projects visited by the MATC Team were as follows:

<u>Project 1 – Florida Turnpike (SR-821) Widening Project</u>

- MATC Team onsite February 14th – 17th
- Paving between Mileposts 26.5 and 29.1 in Miami
- 2" lift of FDOT 12.5mm Type SP (PG64-22) placed as a lower structural layer
- Layer to be covered by 3 more lifts totaling 4¼" before opening to traffic

<u>Project 2 – SR-19 Milling and Paving Project</u>

- MATC Team onsite February 21st – 24th
- Milling and Paving in the southbound lanes near Eustis
- 2¼" – 2½" lift of FDOT 12.5mm Type SP (PG76-22) structural layer
- Layer to be covered by ¾" of a Friction Course FC-5 before opening to traffic

To help simplify the discussion of the field-testing demonstrations, the actual testing, resulting data, and analysis from both field projects are discussed separately in each of the field-testing technology sections below.

Thermal Profile Testing

The Paver-Mounted Thermal Profiler (PMTP) system was demonstrated by FHWA to show how to detect pavement mat defects before compaction by providing two-dimensional infrared thermal maps of the mat behind the paver to detect thermal segregation during construction. Specifically, the MATC Team demonstrated the PMTP device, which involves the use of non-contact surface temperature measurements to diagnose sub-surface pavement conditions. The PMTP involves four components: IR mast and base plate, the IR scanner, the distance measuring instrument (DMI), and a viewing monitor which are all mounted on the paver itself, as can be seen in Figure 9. The installation process of these components typically takes less than 2 hours to complete for most pavers. Testing is real time and continuous, and it measures the surface temperature of the pavement as the paver is moving forward. Figure 10 shows a typical thermal infrared image that is generated as the paver moves down the road.

Figure 9: PMTP Device Mounted to Rear of Paver

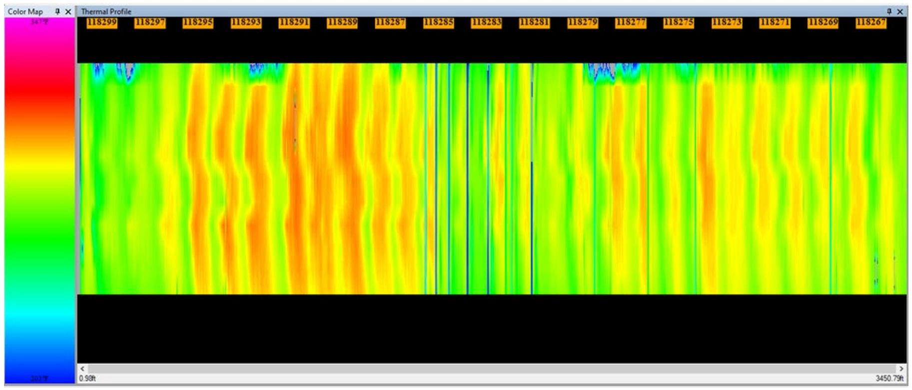

Figure 10: Typical Thermal Infrared Image of Mat Surface Behind Paver

The MATC Team showed how the paver-mounted thermal infrared technology can be used on any newly-paved mats, demonstrating the possibility of improving communications between plant and paver personnel to reduce temperature differential on the mat to the lowest value; determining when the contractor needs to take corrective actions and allowing real-time adjustments. It is a great visual on-site training aid for contractor paving crews. In addition, it can be used as a helpful forensic tool to investigate low and/or non-uniform mat density.

Project: Florida Turnpike (SR-821), Miami

At the time of the MATC visit, the Florida Turnpike (SR-821) paving was being performed on a lower 2” structural lift that would eventually be covered by an additional 4.25” of pavement, achieved by three (3) more individual paver lifts of 2”, 1.5”, and 0.75”, respectively. Because of this, final surface smoothness was not required on the current lift, so continuous paver operations were not of concern. The mixture was being introduced to the paver hopper directly from the end-dump haul trucks. Also, although the haul distance was relatively short, due to the traffic and congestion of the project location, the delivery of mix was not continuous and there were stoppages of the paver while waiting for mix to arrive. As can be seen in Figure 11, the PMTP technology was able to identify thermal segregation in the mat temperature as a result of “truckload-to-truckload” style paving. As can be seen in the lower “Speed Diagram” of the figure, even though the paver was not coming to a complete stop in this pavement section, the mat temperature was obviously being affected by the truck exchanges. This effect is further confirmed in Table 9 below, which summarizes the thermal segregation ranges for the 23 total profiles measured.

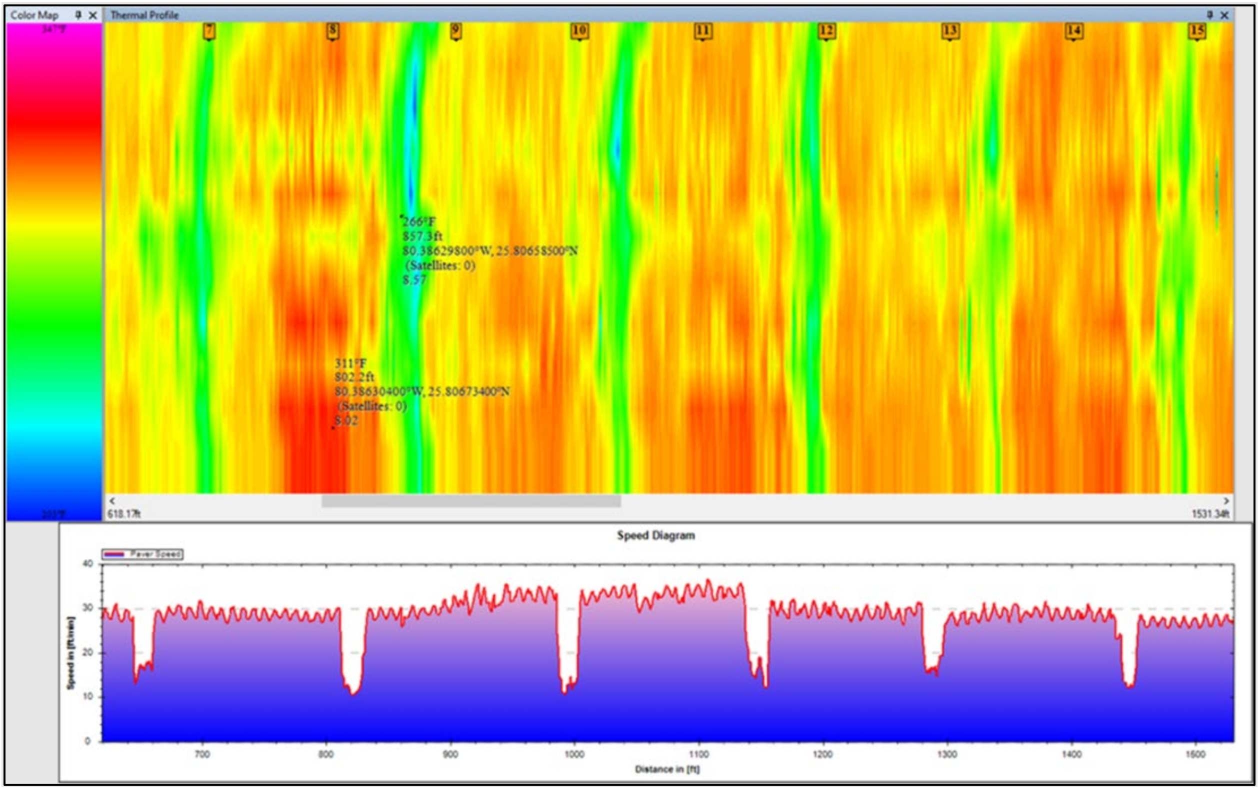

Figure 11: Thermal Infrared Image vs Paver Speed on Florida Turnpike (SR-821) Project

Table 9: Thermal Segregation Summary for Florida Turnpike (SR-821) Project

Total Profiles	**Moderate Thermal Segregation (25.0°F < Differential ≤ 50.0°F)**		**Severe Thermal Segregation (Differential > 50.0°F)**	
	Number of Profiles	**Percent**	**Number of Profiles**	**Percent**
23	9	39%	14	61%

<u>Project: SR-19, Eustis</u>

At the time of the MATC visit, the SR-19 paving near Eustis was being performed on a 2.25" structural lift that would eventually be covered by an additional 0.75" of FC-5 Friction Course. As with the Florida Turnpike project, the paving on this project was also not using a continuous paver operation, but again the mixture was being introduced to the paver hopper directly from the end-dump haul trucks. One difference, however, was with the haul distance being much further and thus, again leading to an inconsistent delivery of mix requiring stoppages of the paver. As can be seen in Figure 12, the PMTP technology was able to again identify thermal segregation in the mat temperature as a result of "truckload-to-truckload" style paving. As can be seen in the lower "Time Diagram" of the figure, the paver did have three extended stoppages in this pavement section, which resulted in the mat temperature at those stop locations to be obviously affected and much colder than when the paver is moving continuously. Once again, this effect is further confirmed in Table 10 below, which summarizes the thermal segregation ranges for the 23 total profiles measured.

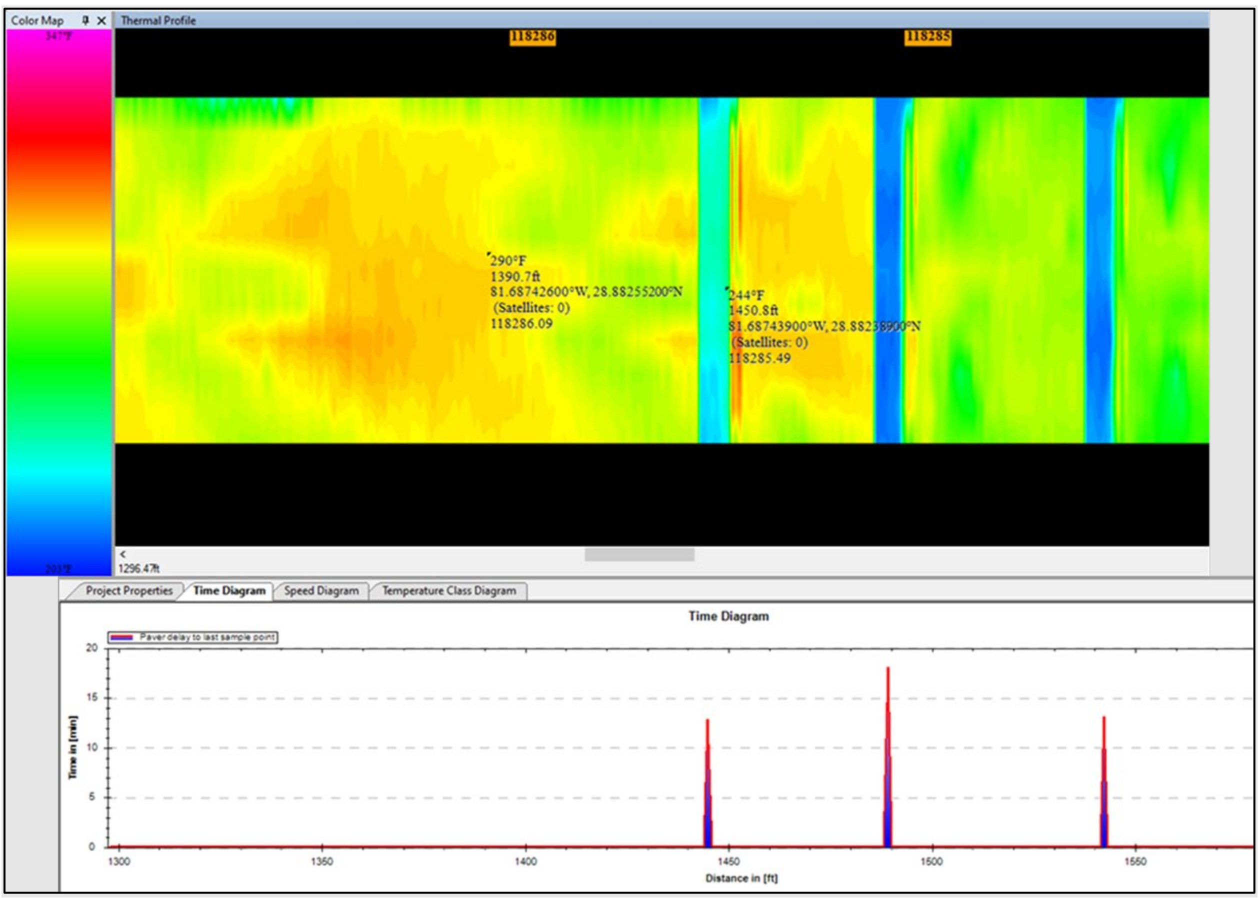

Figure 12: Thermal Infrared Image vs Paver Stop Times on SR-19 Project

Table 10: Thermal Segregation Summary for the SR-19 Project

Total Profiles	Moderate Thermal Segregation (25.0°F < Differential ≤ 50.0°F)		Severe Thermal Segregation (Differential > 50.0°F)	
	Number of Profiles	Percent	Number of Profiles	Percent
23	13	57%	8	43%

Mat Density Testing

The Dielectric Profiling System (DPS), a non-destructive tool to continuously assess asphalt pavement compaction quality through measuring the pavement's dielectric constant, was demonstrated by the MATC Team and showed how pavement dielectrics can be correlated to pavement percent air voids/density. The DPS technology demonstrated consists of air-coupled Ground Penetration Radar (GPR) antennas that are placed at a certain height above the pavement surface, as can be seen mounted to the front of the device in Figure 13.

Figure 13: DPS Device Being Used in the Field

These antennas transmit and receive electromagnetic energy signals through the pavement which are used to determine surface dielectric properties. These dielectric properties are then correlated to pavement percent air voids/density by calibrating the dielectric values with field cores and/or field obtained project lab pucks of known air voids/density. The preparation time of this device is relatively quick as it involves 3 GPR antennas, battery and a display monitor and the test results (as seen in Figure 14) are provided in real time and are continuous during operation.

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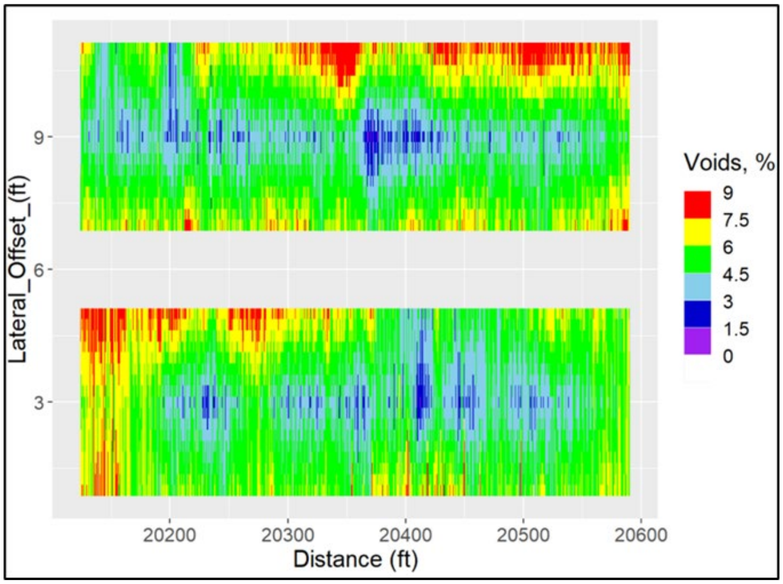

Figure 14: Typical Dielectric Map Generated by DPS Device

As a part of quality assurance, swerve testing was first performed in the field to evaluate each sensor. The results of this testing showed that both the highest median dielectric reading and lowest median dielectric reading were within 0.10 of the middle median dielectric reading as per Minnesota DOT protocol for QA requirements. As a result, the sensors were validated, and routine data collection was continued on the finished mat.

The dielectric data collected from the field tests were analyzed using the Veta software. Veta is a map-based tool for viewing and analyzing geospatial data that featured DPS machines recently. Veta can import data from the dielectric profile systems (DPS) to perform viewing, filtering, sublotting, spot test imports, and analysis. Veta displays compaction information in easy-to-read formats, including histograms, graphs, and maps. With Veta, you can view multiple maps and store data.

The MATC Team showed that density profiling can be used on any moisture-free pavement surface to help paving contractors and agencies to assess pavement compaction uniformity and field densities, especially at joints. It can also be used to identify critical factors that influence in achieving higher density in the field.

Project: Florida Turnpike (SR-821), Miami

As an example, DPS dielectrics collected on the Florida Turnpike (SR-821) project containing valid GPS recordings were mapped to the road using Google Earth and is shown below in Figure 15.

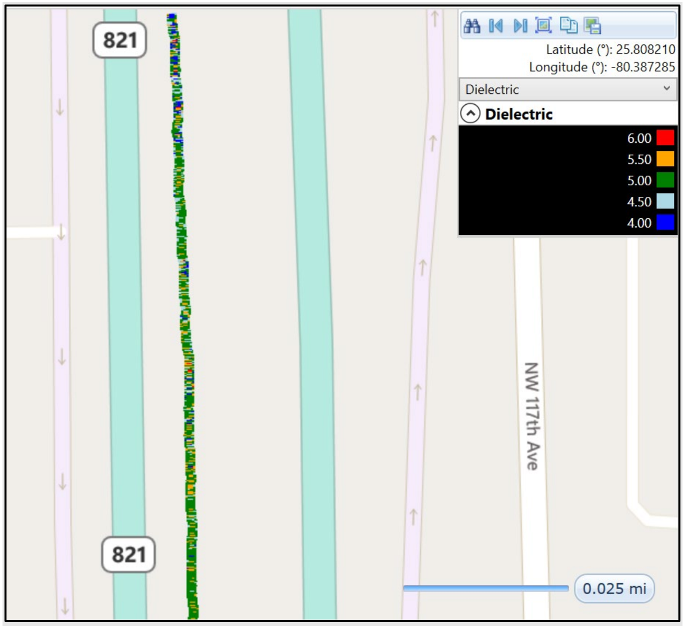

Figure 15: Dielectric Condition Map of Florida Turnpike (SR-821) Test Section

The distribution of dielectric data obtained from the Veta software is shown in Figure 16. The data analysis showed that the for the test section a total sample size of the dielectric data was 3,006 and the average mat dielectric reading was 5.17 with a standard deviation of 0.38 and a COV of 7%.

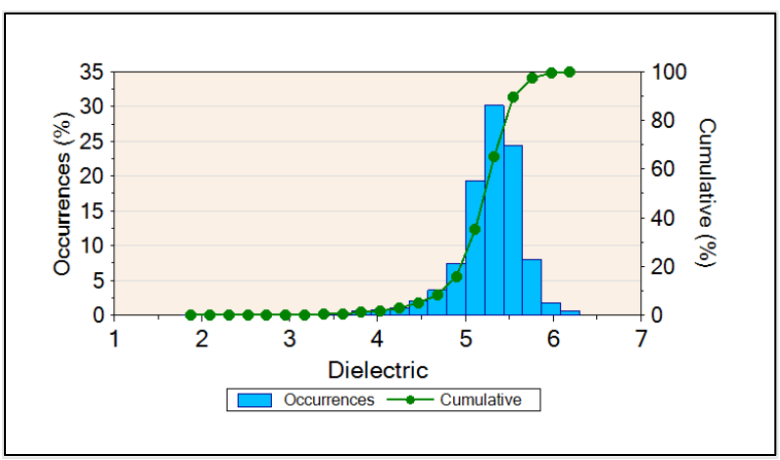

Figure 16: Cumulative Distribution of Dielectrics for Florida Turnpike (SR-821) Test Section

Project: SR-19, Eustis

For the SR-19 project near Eustis, a similar image was created using Google Earth based on both the DPS dielectrics collected on the project and their corresponding GPS recordings and is shown below in Figure 17.

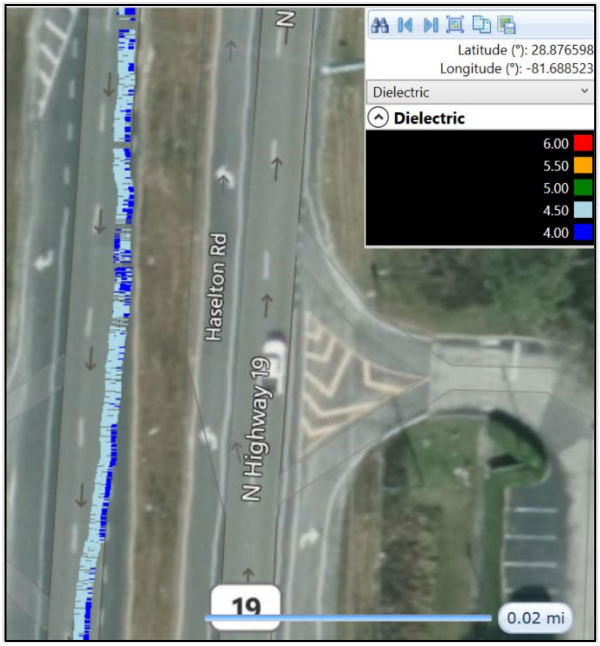

Figure 17: Dielectric Condition Map of SR-19 Test Section

Again, the distribution of dielectric data obtained from the Veta software is shown in Figure 18. The data analysis showed that for the test section the total sample size of the dielectric data was 3,030 and the average mat dielectric reading was 4.61 with a standard deviation of 0.20 and a COV of 4%.

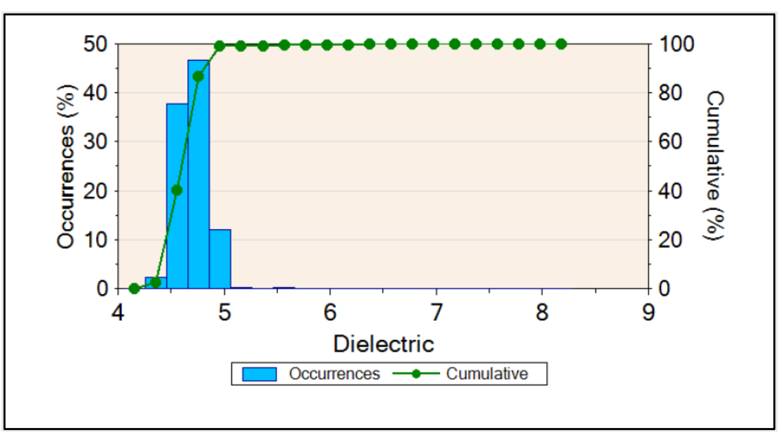

Figure 18: Cumulative Distribution of DPS Dielectrics for SR-19 Test Section

Mat Thickness Testing

Pulse Induction Technology is a non-destructive method to determine the pavement thickness without taking cores. For this test, a 2.76-inch (7cm) diameter metal "target" (plate) was nailed on the existing pavement surface (Figure 19) at three (3) different locations, prior to placement of the new asphalt mat. After the paving and compaction process was completed, the device is first used to detect the target. Once the plate is detected below the pavement lift, the distance between the plate and the pavement surface is measured by the device to determine the pavement lift thickness. Figure 19 also shows the device being used in the field.

Figure 19: Pulse Induction Target Plate and Performing the Scan

Field cores were also obtained at the locations where the target plates were placed to verify the accuracy of the device. Figure 20 and Figure 21 show the results that the measured thickness and the actual field core thickness were close for each location. As can be seen in the figures, all three measurements, from both of the field demonstration projects, compared favorably between the two methods of mat thickness determination. For the Florida Turnpike (SR-821) project, the target mat placement thickness was 2" (50.8 mm) and for the SR-19 project near Eustis, the target was thickness was 2.25" (57.2 mm).

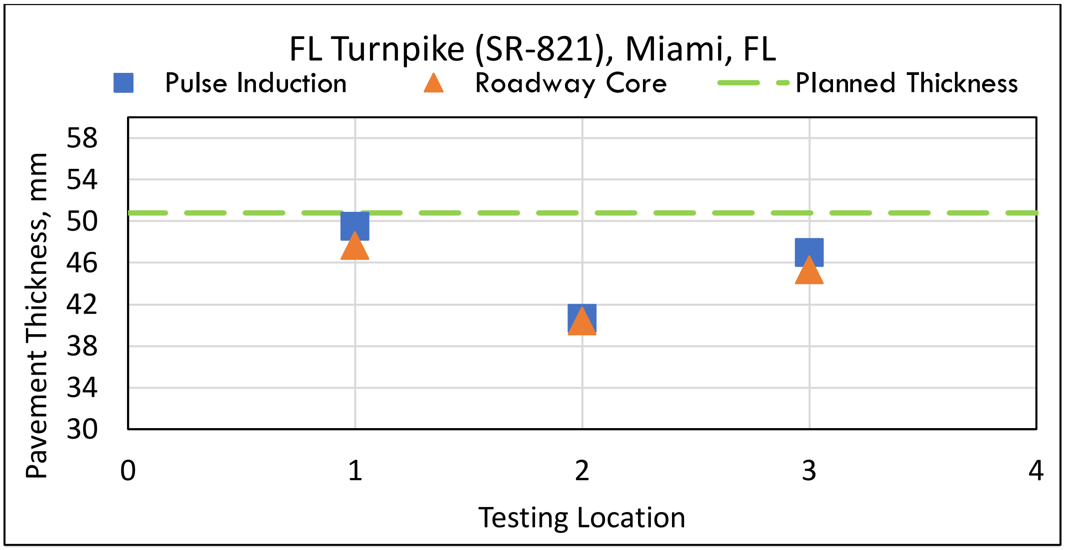

Figure 20: Pulse Induction vs. Roadway Core for the Florida Turnpike (SR-821) Project

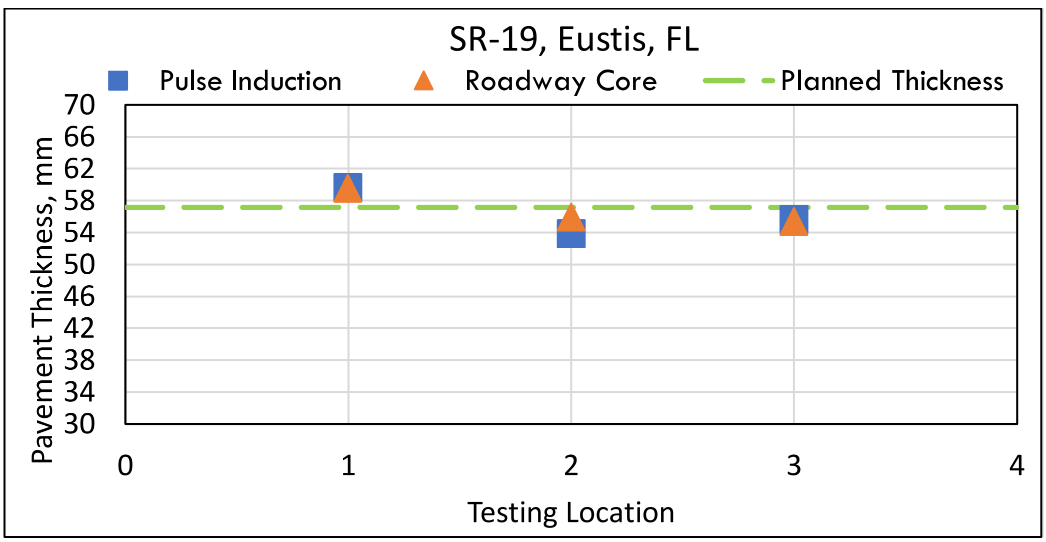

Figure 21: Pulse Induction vs. Roadway Core for the SR-19 Project

Surface Macrotexture Testing

The Laser Texture Scanner (LTS) shown in Figure 22 is a lightweight, portable, rapid, 3D scanner capable of measuring the macrotexture of asphalt mixture pavement surfaces. It utilizes a 100 mm laser line and travels 100 mm to collect a square area of the sample, and it can read measurements on a 150 mm diameter core/gyratory sample. Upon activation, the unit begins scanning and provides macrotexture measurements within 90 seconds.

Figure 22: Laser Texture Scanner

This equipment can be used to measure the mean profile depth, which is an indicator of macrotexture, on laboratory-prepared gyratory specimens and on freshly compacted mats in the field. The typical scanned surface of a gyratory specimen and the line scan macrotexture plot are shown in Figure 23 and Figure 24, respectively.

Figure 23: LTS Scanned Image of Gyratory Specimen

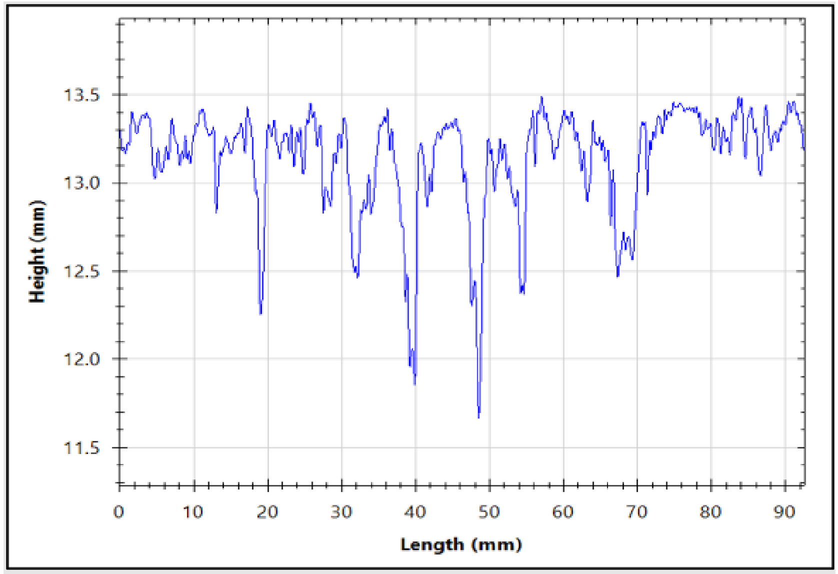

Figure 24: Typical LTS Line Scan Macrotexture Plot

Project: Florida Turnpike (SR-821), Miami

It was decided that since the asphalt mixture being placed on the Florida Turnpike project during the time of the MATC visit was a non-surface layer, laboratory LTS scans would not be performed on either roadway cores or lab-compacted loose mixture samples. However, scans were performed on the asphalt mat following final compaction, and the mean profile depths measured by the LTS on the SR-821 project were approximately 0.22 mm, which is a fairly low mean profile depth. However, it should be noted again that this mixture was not being placed as a surface layer, but instead as a structural layer much deeper in the pavement where surface friction would not be of concern.

Project: SR-19, Eustis

For the SR-19 project near Eustis, the mean profile depths measured on the finished mat in the field, for both Production Days 1 and 2, were approximately 0.30mm, as can be seen below in Figure 25. This is also a low mean profile depth, but again, it should be noted that this mixture was also not being placed as the surface layer, but instead as an intermediate layer prior to the final FC-5 Friction Course surface layer. Further testing in the laboratory showed similar MPD values of approximately 0.30mm for both roadway cores, as well as lab samples compacted to the N_{des} number of gyrations. And finally, lab-compacted samples targeting 7.0% air voids did show a slightly higher MPD of 0.35mm.

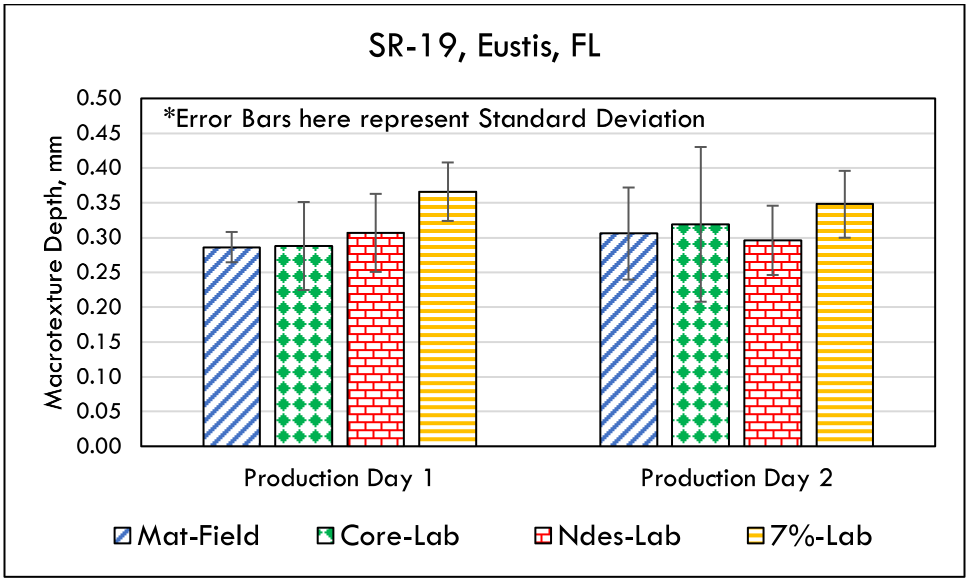

Figure 25: LTS Field vs. Lab Measurements for the SR-19 Project

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FHWA. (2020, January 23). *Asphalt Pavement Performance Analysis Software*. Retrieved from www.fhwa.dot.gov/pavement/asphalt/analysis/

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