Technical Brief

Advanced Polymer Fiber Technology for Asphalt

Testing By:

Advanced Asphalt Technologies
Asphalt Institute
Florida DOT / TTI
Florida DOT Test Track (In Progress)
Hi-Tech Asphalt Solutions
Ingios Geotechnics
Michigan Technological University (TRB Poster)
MNROADS Test Track (IN Progress)
NCAT Test Track (In Progress)
ORIL (ODOT/FHWA)
Oregon State University
Pave-Tex
Southern Alberta Institute Technology
Texas Transportation Institute (TTI)
University of California – Pavement Research Center
University of Missouri
Western New England University

*The following testing information has been extracted from reports and test results as performed by the testing agencies listed above and summarized here to show the improved performance of Aramid Fiber Reinforced Asphalt Concrete when reinforced by **ACE XP Polymer Fiber**. The testing performed and summarized on the following pages were selected by the testing agency to show improved performance in cracking, rutting, and strength of the FRAC mix as compared to standard asphalt concrete mixes. The following lab and field tests were performed:*

- *The Overlay Tester (Lab)*
- *DC(T) – Disk Shaped Compact Tension Test (Lab)*
- *ID(T) – Indirect Tensile Test, Strength and Compliance (Lab)*
- *Hamburg Wheel Tracker Test (Lab)*
- *APLT – Static Creep (Field)*
- *APLT – Dynamic Modulus (Field)*
- *FWD Testing – Falling Weight Deflectometer Testing for Moduli (Field)*
- *Chemical Extraction Test (Lab)*
- *Aramid State Dispersion Ratio Test – ADSR Test (Lab)*
- *Flow Number Testing (FN) – Rutting Resistance Test (Lab)*
- *Flexibility Index Test (FI) – Fatigue Cracking Test (Lab)*
- *IDEAL CT – Crack Test (Lab)*
- *Bending Beam Fatigue Testing – (BBF - Lab)*
- *AMPT Repeated Loading Test – For Rutting Resistance (Lab)*
- *In-place crack count studies*

Lab Testing Summary – Cracking Improvement

Lab Test Description	ACE XP Results	Page #
Lab - TTI Overlay Tester *Thermal/Reflective Cracking*	+140%	7
Lab - DC(T) Test *Low Temperature Fracture Energy*	+19% to +21%	9
Lab - IDT Strength Test (@ 15 Degree C) *Low Temperature Strength @ Critical Crack Temperature* *(Ran both ¾" and 1 ½" ACE XP Lengths)*	+16% to +44%	10
Lab - IDT Creep Compliance Test *Determine Low Temperature Critical Cracking Value* *(Bottom PG Number)*	-4.3° C (-1 PG – Bottom Number)	14 to 15
Lab - IDT Strength Test (@ -12 Degree C) *Low Temperature Strength @ Critical Crack Temperature* *(Ran both ¾" and 1 ½" ACE XP Lengths- 2.1, 4.0, 5.0 oz. aramid)*	+8% to 31%	16
Lab – IDT Strength Test (@ 25 Degree C) *High Temperature Strength run with 3 different asphalt contents, 4.5%, 5.5% and 6.5%. ACE Reinforced improved all three mixes, but 6.5% AC by 51.7%. (1 ½" ACE XP Lengths)*	Average +34.7%	17
Lab – Flexibility Index Test (FI) *Determine Fatigue Cracking Resistance of ODOT Level 3 mix vs Control* *(Ran both ¾" and 1 ½" ACE XP Lengths)*	+37%	30 to 31
Lab – IDEAL CT Cracking Test (PAVETEX) *Determine IDEAL CT Crack Index of TxDOT Dense Grade 64-22 vs Control – (1 ½" ACE XP Lengths)*	+36%	36
Lab – IDEAL CT Cracking Test (PAVETEX) *Determine IDEAL CT Crack Index of lab prepared TxDOT SuperPave PG76-22 vs Control (1 ½" ACE XP Lengths)*	+58%	36
Lab – IDEAL CT Cracking Test *Determine the IDEAL CT Crack Index of a lab prepared KYTC PG64-22 Dense Grade Mix used on Medium ESAL Roads. (1x Dose – 1 ½" ACE XP Lengths)*	+30%	37
Lab – IDEAL CT Cracking Test *Determine the IDEAL CT Crack Index of a lab prepared KYTC PG64-22 Dense Grade Mix used on Medium ESAL Roads. (2x Dose – 1 ½" ACE XP Lengths)*	+60%	37
Plant Produced – IDEAL CT – LOVES Corp. (Obetz, Ohio Project) *Compared cracking resistance of PG64-22 with 2x dose of ACE XP vs PG70-22M (Polymer Modified) with 1x Dose of ACE XP.*	+56%	38
Plant Produced –IDEAL CT – LOVES Corp. (Brookville, PA Project) *Compared cracking resistance of PG64-22 with 2x dose of ACE XP vs PG64-22 with 1x dose of ACE XP.*	+58%	38
Lab – IDEAL CT Cracking Test (Plant Produced) *KYTC – Christian County Project produced by The Rogers Group – Compare PG64-22 with 1x dose of ACE XP vs PG64-22 without ACE XP*	+48.9%	39
Lab – Ideal CT Cracking Test (Plant Produced) *MoDOT Project – Route VV produced by MD West – Compare PG64-22 with 1x Dose vs PG64-22 without ACE XP*	+47%	39
Lab – IDEAL CT Cracking Test (Plant Produced) *Added ACE XP to PG58-28 mix with 38% RAP for Brevard County Florida on Falcon Blvd. FDOT Materials ran the IDEAL CT Test in their Lab.*	+35%	40

Cracking Improvement Continued

Lab Test Description	ACE XP Results	Page #
Lab – Bending Beam Fatigue Testing – (BBF) *Cyclic loading on a 4-point bending beam machine to crack failure. Failure determined at various strain levels to predict reflective crack control. (1 ½" ACE XP Lengths)*	+90% (600 *ms*) +200% (900*ms*)	41 to 42
Lab – IDEAL CT Cracking Test *Determine the crack performance of PG58-22 with ACE XP and Forta-fi funded by ORIL (ODOT/FHWA). Forta-fi = -39%*	+25%	48
Lab – SCB (IFIT) Crack Testing *Determine the crack performance of PG58-22 with ACE XP and Forta-fi funded by ORIL (ODOT/FHWA). Forta-fi = -17%*	+32%	48
Lab – SCB/IFIT Cracking Test (Plant produced – Field Cores) *City of Plainfield, IN wanted to see immediate crack data from their polit project of PG76-22 with and without ACE XP.*	+44%	60
Lab – Ideal CT Cracking Test (FDOT / TTI) *Added ACE XP and Forta-Fi to PG76-22 control to measure cracking performance using IDEAL CT crack method*	+39.6% (ACEXP) -25.8% (Forta-fi)	62 to 63
Lab – SCB-FI Cracking Test (FDOT / TTI) *Added ACE XP and Forta-Fi to PG76-22 control to measure cracking performance using SCB-FI crack method*	Equal to Control (ACEXP) -19.1% (Forta-fi)	64
Lab – DCT Cracking Test (Michigan Tech University) *Added ACE XP to PG64-22 control to measure cold weather cracking resistance using DCT test method measuring energy (J/m2) at -12 C (Plant Produced)*	570 (ACE XP) 440 (Control) +29%	67 to 68

Lab Testing Summary – Rutting Improvement

Lab Test Description	ACE XP Results	Page #
Lab - Hamburg Wheel Tracking Rut Test *Determine Rut Resistance of Various Asphalt Mixes* *(Top PG Number)*	PG64-22 (w/ ACE) = PG70-22 (+1 PG – Top Number)	18 to 19
Lab - Hamburg Wheel Tracking Rut Test *Determine Rut Resistance of Various Asphalt Mixes* *(Top PG Number)*	PG64-22 (w/ ACE) = PG76-22 (+2 PG – Top Number)	18 to 19
Lab – Hamburg Wheel Tracking Rut Test (Plant Produced) *MoDOT Project – Route VV produced by MD West – Compare PG64-22 with 1x Dose vs PG64-22 without ACE XP*	+67%	20
Lab – Hamburg Wheel Tracking Rut Test (Plant Produced) *LOVES Corp. (Obetz, Ohio Project)* **-** *Compared rutting resistance of PG64-22 with 2x dose of ACE XP vs PG70-22M (Polymer Modified) with 1x Dose of ACE XP*	Equal	20
Lab – Hamburg Wheel Tracking Rut Test (Plant Produced) *LOVES Corp. (Brookville, PA Project) - Compared rutting resistance of PG64-22 with 2x dose of ACE XP vs PG64-22 with 1x dose of ACE XP*	+46%	21
Lab – Hamburg Wheel Tracker (The Asphalt Institute) *1x dose to 12x dose was added to PG64-22 Mix with 5.4% AC Content and No RAP. Mixture was less than 1 million ESAL KYTC Design*	28 to 45% Less Rutting depth at 15,000 passes	21
Lab – Flow Number Test (FN) *Determine Rut Resistance of ODOT Level 3 mix vs Control* *(Ran both ¾" and 1 ½" ACE XP Lengths)*	+37.5%	33
Lab – AMPT Permanent Deformation Testing (Plant Produced) *Mix produced by Teichert for UCPRC - Test counts the cycle of load to reach 5% permanent deformation of the sample. Test run at both 45 and 55 Degree C. (1 ½" ACE XP Lengths)*	+46% (45 Deg C) +18% (55 Deg C)	44
Lab – APA Rut Test (FDOT / TTI) *Added ACE XP and Forta-Fi to PG76-22 control to measure rutting performance using APA Rut Test (8,000 cycles @ 64 deg C)*	3.5mm (Control, ACE & Forta-fi all about same)	64
Lab – Hamburg Wheel Tracker Rut Test (FDOT / TTI) *Added ACE XP and Forta-Fi to PG76-22 control to measure rutting performance using HWT Rut Test (20,000 passes @ 50 deg C)*	4.21mm Control, ACE & Forta-fi all about same)	65
Lab – IDEAL RT Rut Test (FDOT / TTI) *Added ACE XP and Forta-Fi to PG76-22 control to measure rutting performance using APA Rut Test (R/T Index @ 50 deg C)*	88.9 (ACEXP) 89.3 (Forta-fi) 95.0 (Control)	65
Lab – Hamburg Wheel Tracker (Michigan Tech University) *Added ACE XP to PG64-22 control to measure rutting performance using the HWT Rut Test (Plant Produced)*	+140% (5,000 passes to 12,500 passes)	67 to 68

Field Testing Summary

Field Test Description	ACE XP Results	Page #
Field – APLT (Automated Plate Load Test) Static Creep *Measure Plastic Deformation of In-Place Asphalt (Rut) vs Control*	+11 to 19% Rebound Ratio over Control	24
Field – APLT (Automated Plate Load Test) *Measure Plastic Deformation of In-Place Asphalt (Rut) vs Control at various simulated tire pressures ranging from 150 to 750psi*	24% to 31% Less Rutting Depth	25
Field – APLT (Automated Plate Load Test) *Measure Plastic Deformation of In-Place Asphalt (Rut) vs Control at constant load of 20,000 lbs. for 15 minutes*	61% Less Rutting Depth	26
Field – APLT (Automated Plate Load Test) Elastic Modulus *Measure Elastic Modulus of In-Place Asphalt w/ ACE Fiber*	+150%	28
Field – APLT (Automated Plate Load Test) *SN Layer Coefficient, a_1 Back Calculate SN Layer Coefficient, a_1 using Measured Elastic Modulus*	+40% (Use 25%in Design)	28
Field – APLT (Automated Plate Load Test) *ESAL Prediction Using AASHTO 93 Calculate Increase ESAL Capacity of In-Place Asphalt Reinforced w/ ACE XP Polymer Fiber*	+100% or more Depending on Depth of Asphalt	29
Field – Falling Weight Deflectometer Testing for in situ Moduli *Measure in-place asphalt Modulus with and without ACE XP reinforcement – US31, South of Louisville, KY*	+425% Moduli Improvement	53 to 54
Field – Falling Weight Deflectometer Testing for in situ Moduli *Measure in-place asphalt Modulus with and without ACE XP reinforcement – Man O' War Blvd, Lexington, KY*	+183%, +204%, +176% Moduli Improvement	55 to 57
Field – Ongoing Crack Counts – US31, Louisville, KY *After 7 years of observation, starting in 2018, the ACE XP reinforced lanes show 43% fewer cracks and less crack widths compared to control*	43% Fewer Cracks	58 to 59
Field – Ongoing Crack Counts – Stafford Rd, Plainfield, IN *After 4 years of observation the ACE XP reinforced lanes show 91% fewer cracks compared to control*	91% Fewer Cracks	60 to 61

Aramid Mix & Dispersion Lab Validation

Lab Test Description	ACE XP Results	Page #
Lab – Aramid Chemical Extraction Test (AI) *Measure the amount of Aramid Fibers in each Sample & Ton*	2.8 to 7.4 oz./ton	45
Lab – Aramid Chemical Extraction Test (AAT) *Measure the amount of Aramid Fibers in each Sample & Ton*	2.1 to 4.5 oz./ton	45
Lab – Aramid Dispersion State Ratio – ADSR (AI) *Classify the dispersion of the recovered Aramid Fibers from Extraction*	86.4%	46
Lab – Aramid Dispersion State Ratio – ADSR (AAT) *Classify the dispersion of the recovered Aramid Fibers from Extraction*	86.2%	46

Life Cycle Cost Analysis

ORIL (ODOT/FHWA) – Cracking Report Summary	ACE XP Results	Page #
Project Contributors & Study Summary *Study Crack Resistance of PG64-22 with Aramid Reinforcing compared to PG70-22 (Polymer Modified)*		47
Lab – IDEAL CT and SCB Cracking Test Results on Lab Mix *Sample of Testing Performed in the 2-year study*	+25% to +32%	48
Predicting Service Life by Calculating Fatigue Life *Using FHWA ALF Data to Estimate the Service Life*		49 to 50
Predicted Service Life *PG64-22* *PG70-22M* *PG64-22 (ACE XP – 1.5” Length)* *PG64-22 (FORTA-FI – ¾” Length)*	- 9 yrs 10.5 yrs 18.4 yrs 14.9 yrs	51
Life Cycle Cost Analysis *Calculate the cost of roadway over the life of the pavement*	30% Savings	52

The Sentinel Automated Dosing Machine Delivers the Right Dosage of ACE XP Polymer Fiber Every Time

The Overlay Tester

Developed by Texas Transportation Institute

Performed by Hi-Tech Asphalt Solutions

Test Summary:

In this test one plate is locked and the other cycles back and forth a distance of 0.025 inches, with 5 second openings and 5 second closings, which **simulates an HMA overlay over a thermally active crack or joint.** The number of complete cycles for the crack to reach the surface is recorded.

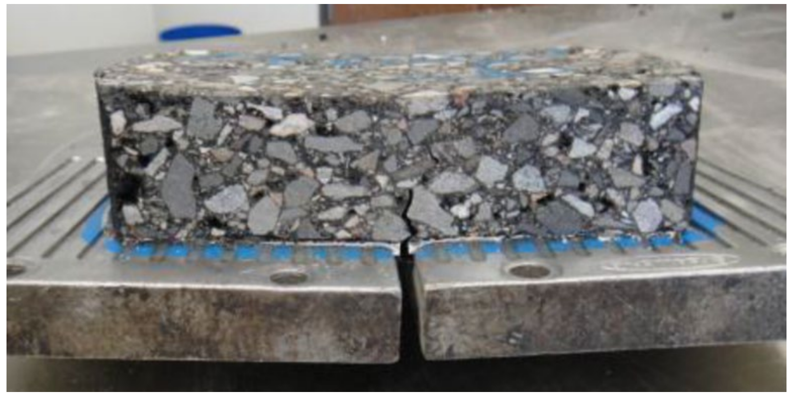
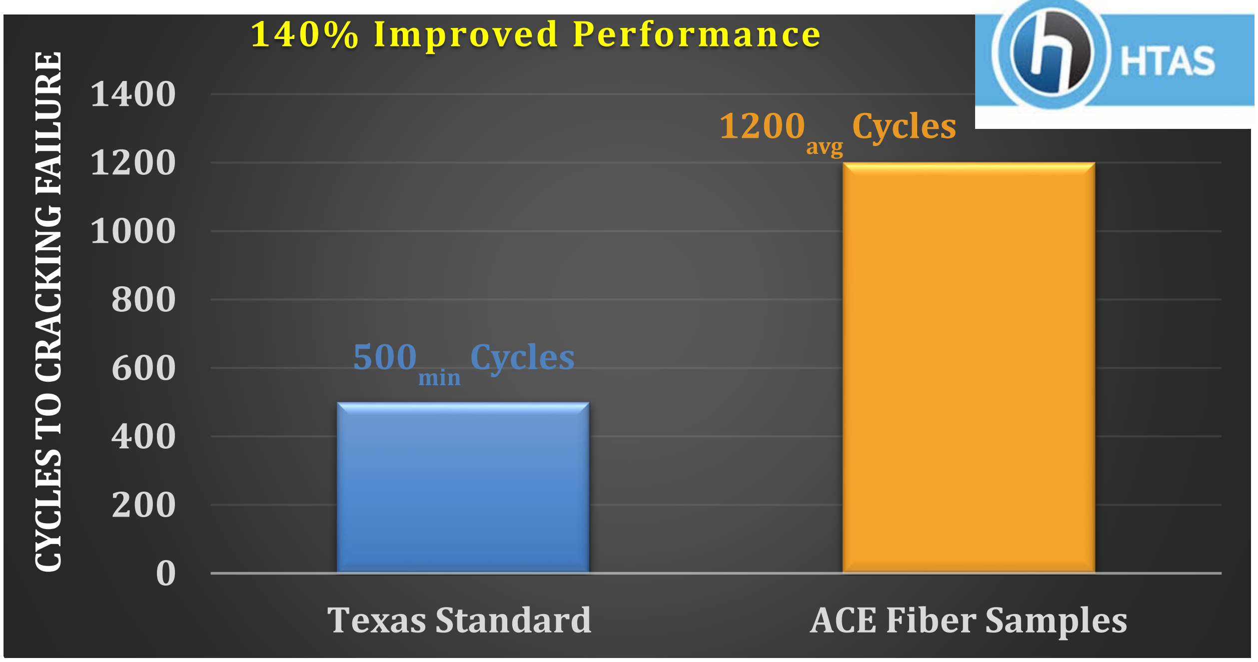


Figure 1 – Overlay Tester Apparatus

Results:

In 2014, Hi-Tech Asphalt Solutions (HTAS) ran the TTI Overlay Tester on Ace Fiber reinforced asphalt concrete samples using PG64-22 Binder. To compare the results of the FRAC samples, HTAS compared the performance to a standard adopted in the State of Texas. These standard states that all asphalt concrete mixes used as an overlay must provide a minimum of 500 cycles to failure in the Overlay Tester. HTAS prepared 6 samples of the ACE Fiber reinforced asphalt mix, and all 6 samples were run to 1200 cycles which was set as the test maximum. The results are shown in Table 1 below.

Table 1



The DC(T) Test

The Disk-Shaped Compact Tension Test

Performed by Western New England University

Test Summary:

The Disk-shaped Compact Tension test [DC(T)] was conducted in accordance with ASTM D7313-07 to assess the fracture resistance of asphalt mixtures. DC(T) tests were performed in the materials laboratory at the University of Illinois. Figure 2 shows DC(T) testing setup and Figure 3 shows the sample dimensions.

Figure 2

The DC(T) testing temperature was selected based on the ASTM standard that recommends testing temperature to be 10°C warmer than the PG low temperature (PGLT) of the mixture. Prepared DC(T) samples were conditioned at testing temperature for two hours prior to starting the test. The DC(T) test was conducted through applying a monotonic tensile load to the specimen such that a constant crack mouth opening displacement (CMOD) rate of 1 mm/min was achieved.

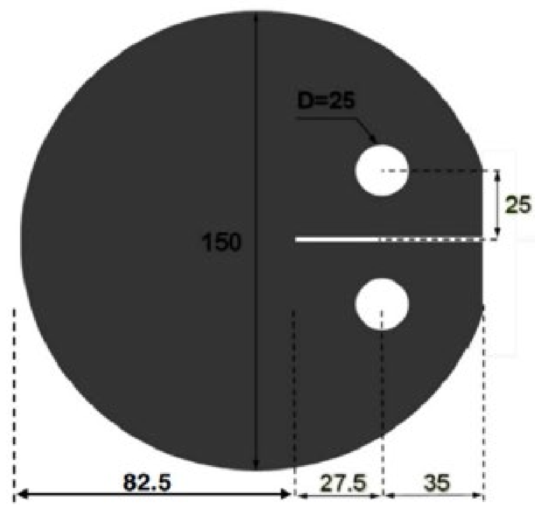


Figure 3

The test is completed when the post peak level has reduced to 0.1 kN. Fracture energy of the specimens was determined by calculating the normalized area under the Load-CMOD curve.

Results:

The DC(T) fracture energy test results of two sets of PG64-22 mixtures; each set containing four fiber mixtures with different amounts of fiber ranging from 0 to 10 (oz./ton) are presented in Table 2 and Table 3 below. DC(T) tests were performed at -12°C for all samples. Results show that adding ACE fiber improved the cracking performance of mixtures by increasing the fracture energies of the material. It is observed that the higher the fiber content of the mixture, the higher its fracture energy. Moreover, the rate of increase in the mixtures' fracture energy as a result of adding fiber is also impressive. The average rate of gaining fracture resistance for the fiber mixtures is around 13.5 J/m2 per ounce of fiber added. *This test was performed by WNEU on two separate occasions: the first in July of 2016 and the second in November of 2016. The goal was to test a higher quality mix the second time around and see the results.*

Table 2 – July 2016

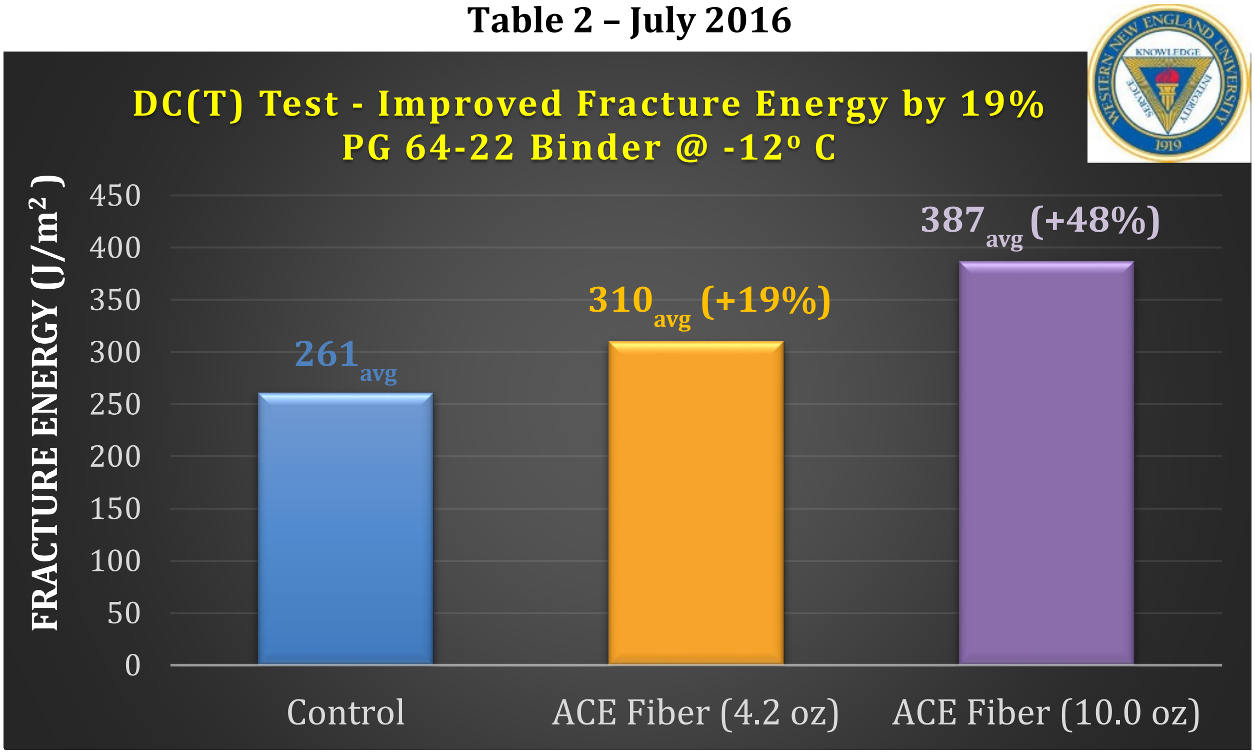
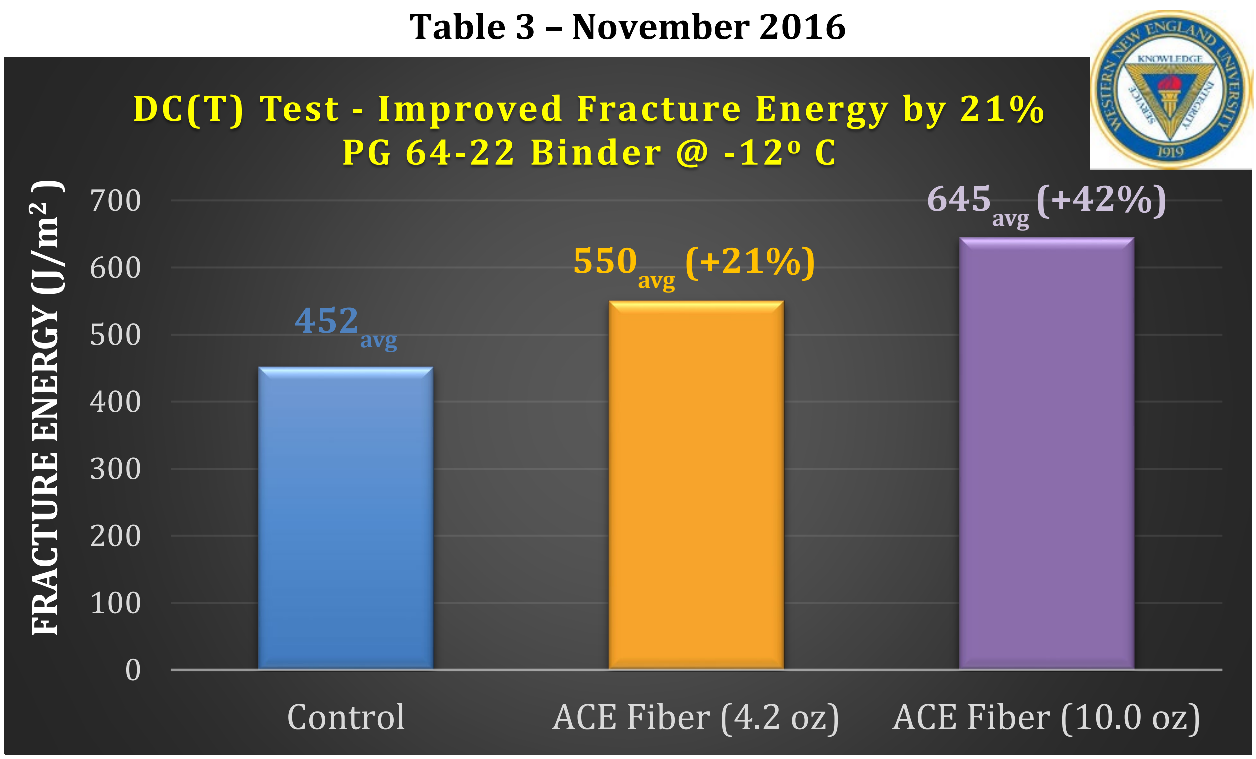


Table 3 – November 2016

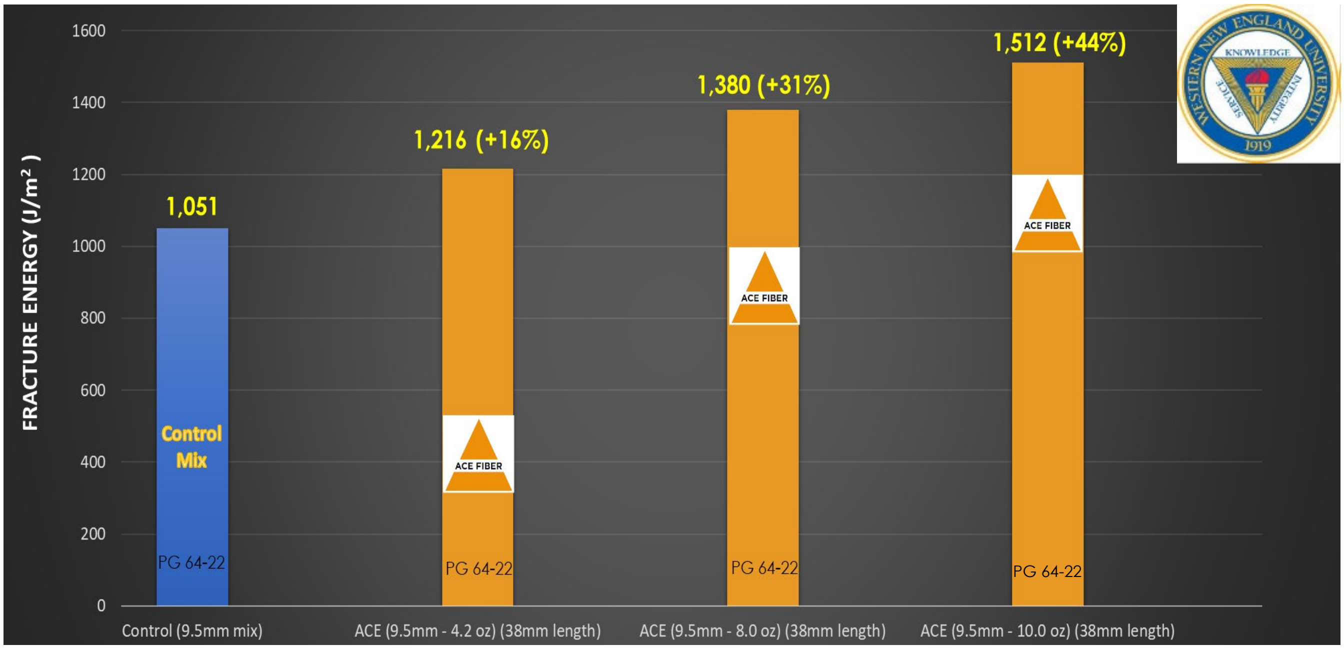


The DC(T) Test

The Disk-Shaped Compact Tension Test

Performed by Western New England University

Table 4 – November 2016, DC(T) Run at 15° C for Fatigue Cracking Using 1 ½" ACE Fiber Length vs. Control



The (IDT) Test

The Indirect Tensile & Compliance Test

Performed by Advanced Asphalt Technologies And Asphalt Institute

Test Summary:

The IDT test for critical low temperature cracking was performed to determine the low temperature critical cracking or the bottom number of the Performance Graded Asphalt Binder (PG).

Each IDT specimen was tested at three (3) temperatures: -10, -20, -30°C for Creep Compliance testing. Samples were conditioned at the test temperature for a minimum of 4 hours prior to testing. Extensometers were attached to samples to measure the indirect displacement of the sample under constant loading at each temperature. Samples were loaded into the test frame (Figure 4) and a vertical constant load was applied and indirect displacement was measured for 300 s.

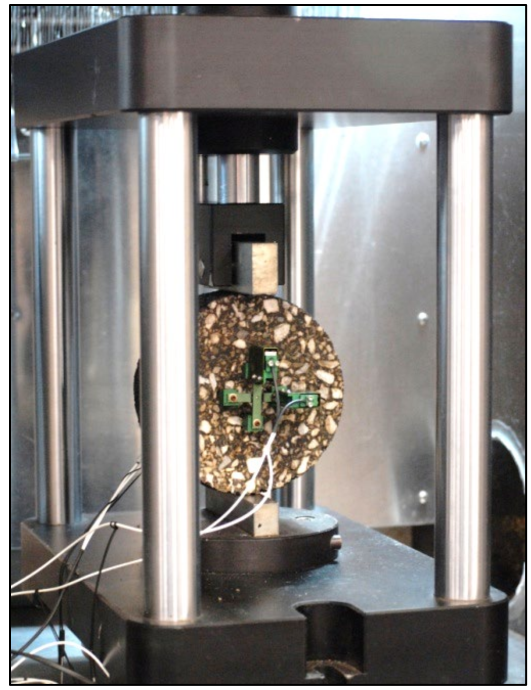


Figure 4

After Creep Compliance testing, samples were tested for tensile strength at each of the test temperatures. The static load must produce a horizontal deformation of 1.25 to 19.0 microns for 150 mm diameter specimens. Similar preconditioning of test samples was conducted prior to breaking. Samples, without extensometers, were loaded into the test frame and a load was applied at a constant rate of 12.5 mm/min. Peak load and vertical deformation was recorded and tensile strength of each specimen was determined.

Results:

The low temperature critical cracking temperature is predicted from the IDT test. To do this the relaxation (compliance) and tensile strength of the samples must be examined. This is done by shifting the isotherms (various temperature responses plotted on the same graph), Figure 5, to form a shifted compliance curve, Figure 6. From this shift, we understand the time-temperature relation of the samples that allows us to then plot the measured stress and overlay with the fracture stress of the samples. The intersection of these lines is where the asphalt sample's strength equals its thermal stress from cooling and is the predicted critical cracking temperature, shown in Figure 7 for Advanced Asphalt Technologies.

The (IDT) Test

Isotherms from Compliance Testing

Performed by Advanced Asphalt Technologies And Asphalt Institute

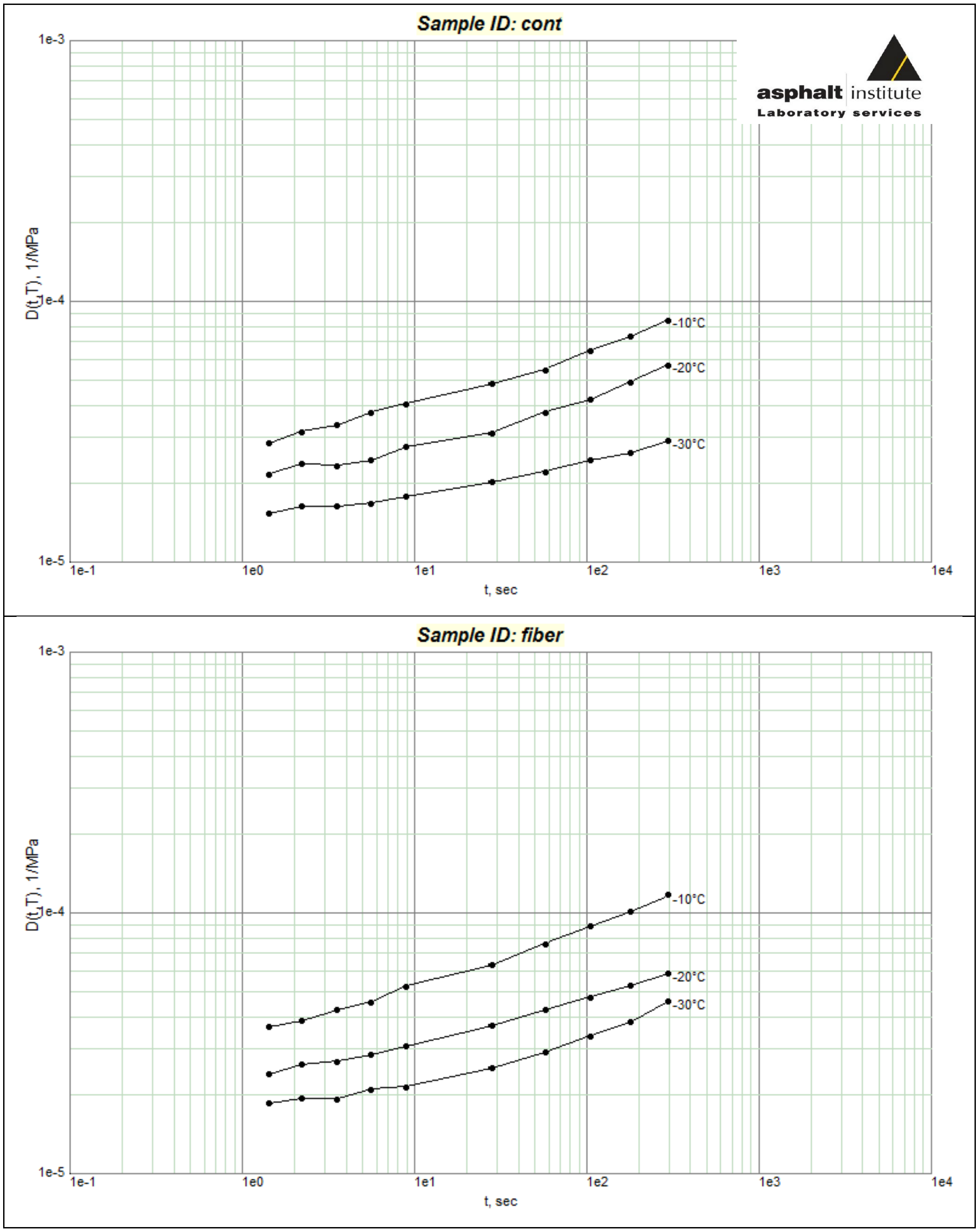


Figure 5
Isotherms from Compliance Testing of the Control and ACE Fiber Samples

The (IDT) Test

Shifted Compliance Curves (to determine time temperature shift)

Performed by Advanced Asphalt Technologies And Asphalt Institute

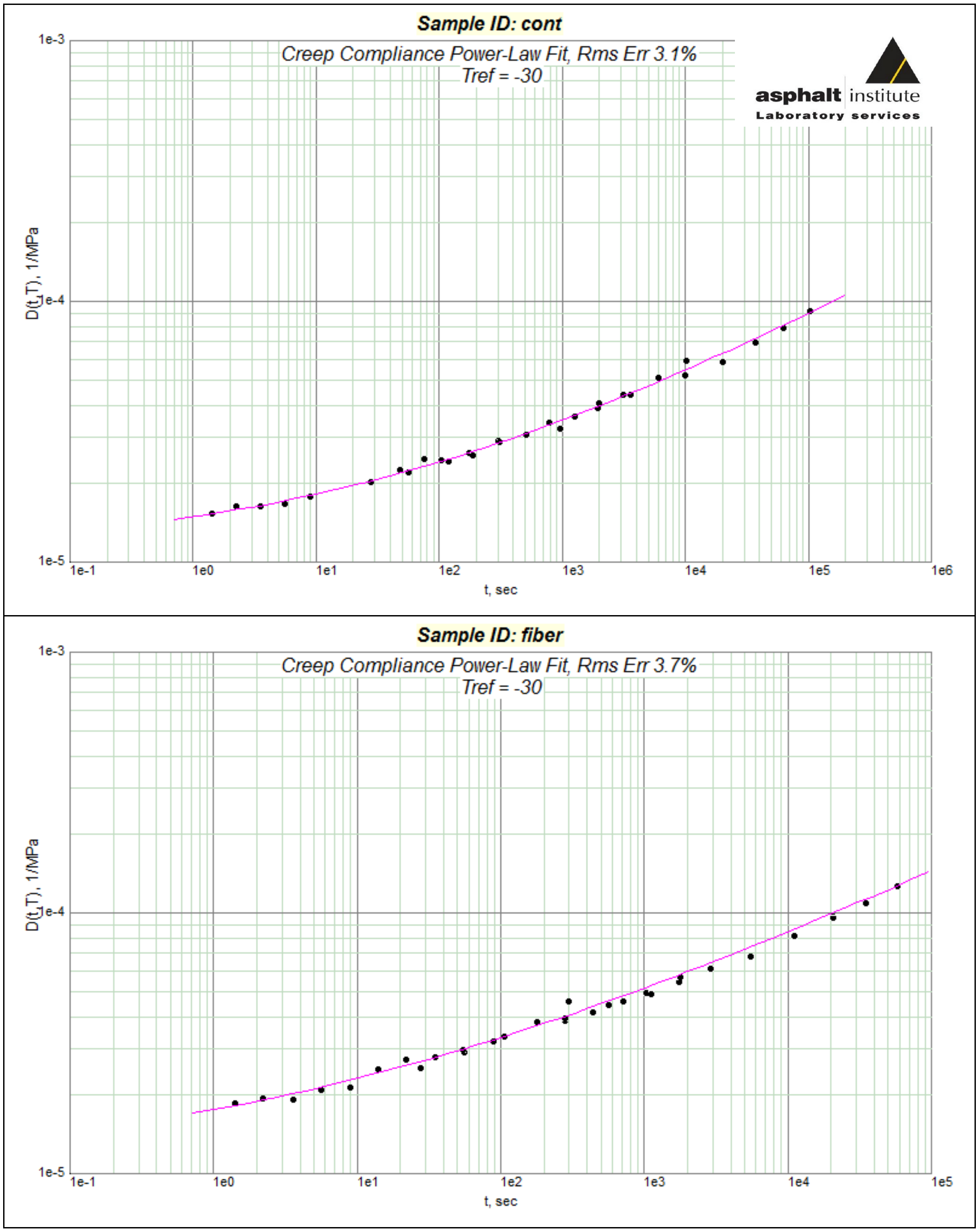


Figure 6
Shifted Compliance Curves (to determine time temperature shift) of the Control and ACE Fiber Samples

The (IDT) Test

Estimated Thermal Stress & Critical Cracking Temperature

Performed by Advanced Asphalt Technologies And Asphalt Institute

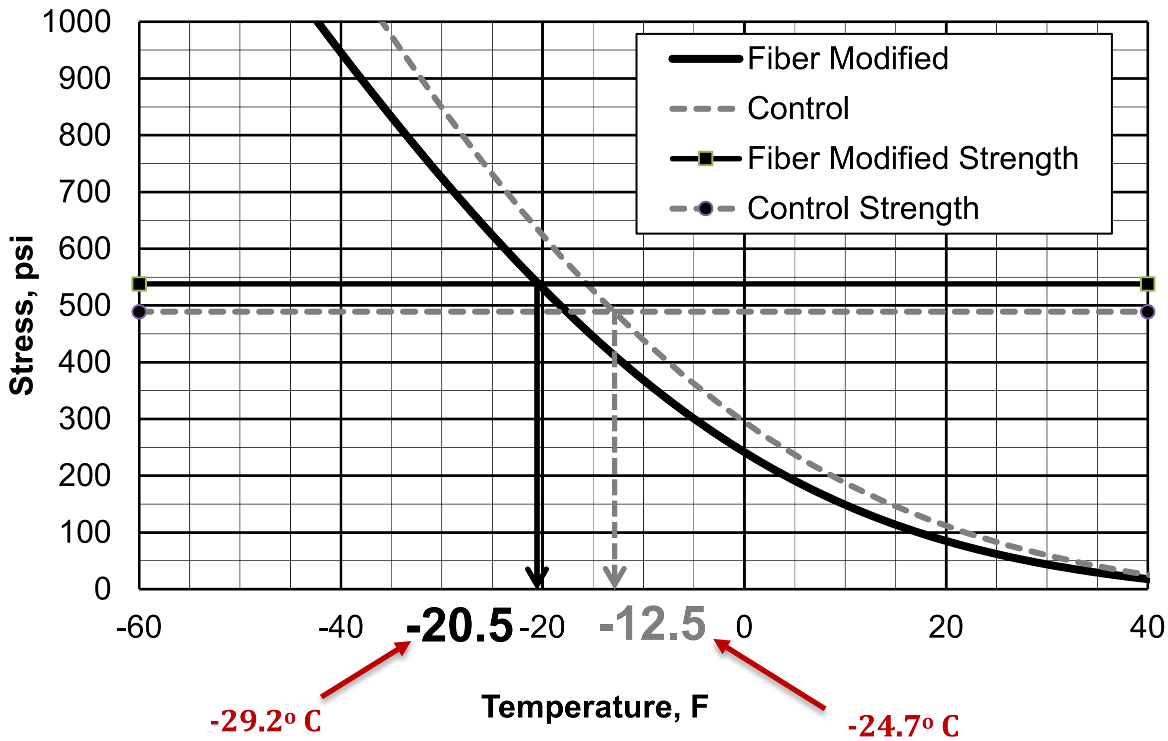
The control samples that were tested were averaged to produce a predicted low temperature critical cracking temperature:

- Control sample (-24.7° C) and ACE Fiber sample (-29.2° C) – (AAT results)
- Control sample (-25.4° C) and ACE Fiber sample (-29.5° C) – (AI results)

While the ACE Fiber roots into asphalt binder making the mix stiffer, it appears that the ACE Fiber in these cases also improved the low temperature properties by -4.5° C (AAT) and -4.1 °C (AI), which is not typically shown by stiffer asphalt mixes. Essentially one could conclude that since the ACE fiber improves the low temperature properties, it is equivalent to lowering the PG low temperature grade to some extent.

This finding could lead to a cracking improvement of mixtures containing Reclaimed Asphalt Pavement (RAP) or Reclaimed Asphalt Shingles (RAS).

Figure 7
Estimated Thermal Stress



The (IDT) Test Summary

The Indirect Tensile & Compliance Test

Performed by Advanced Asphalt Technologies
And Asphalt Institute

Table 5 – IDT Improved Strength

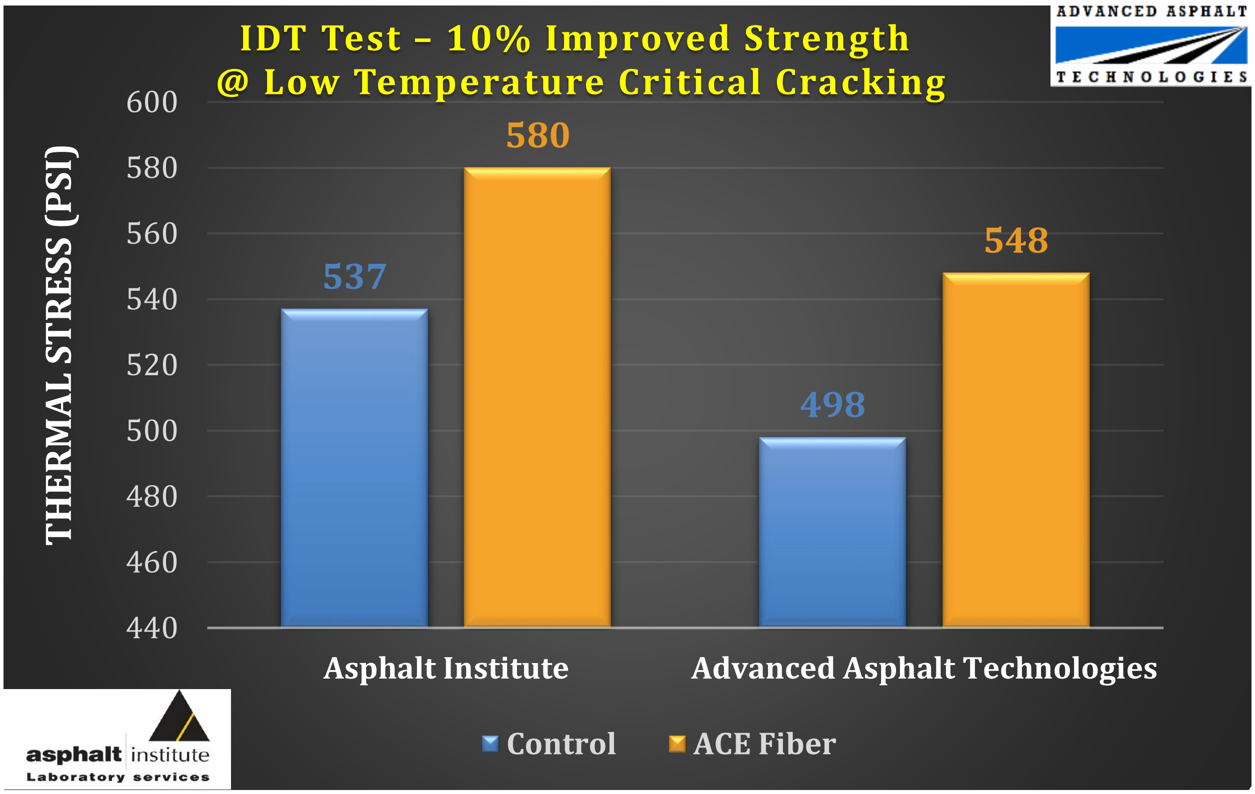
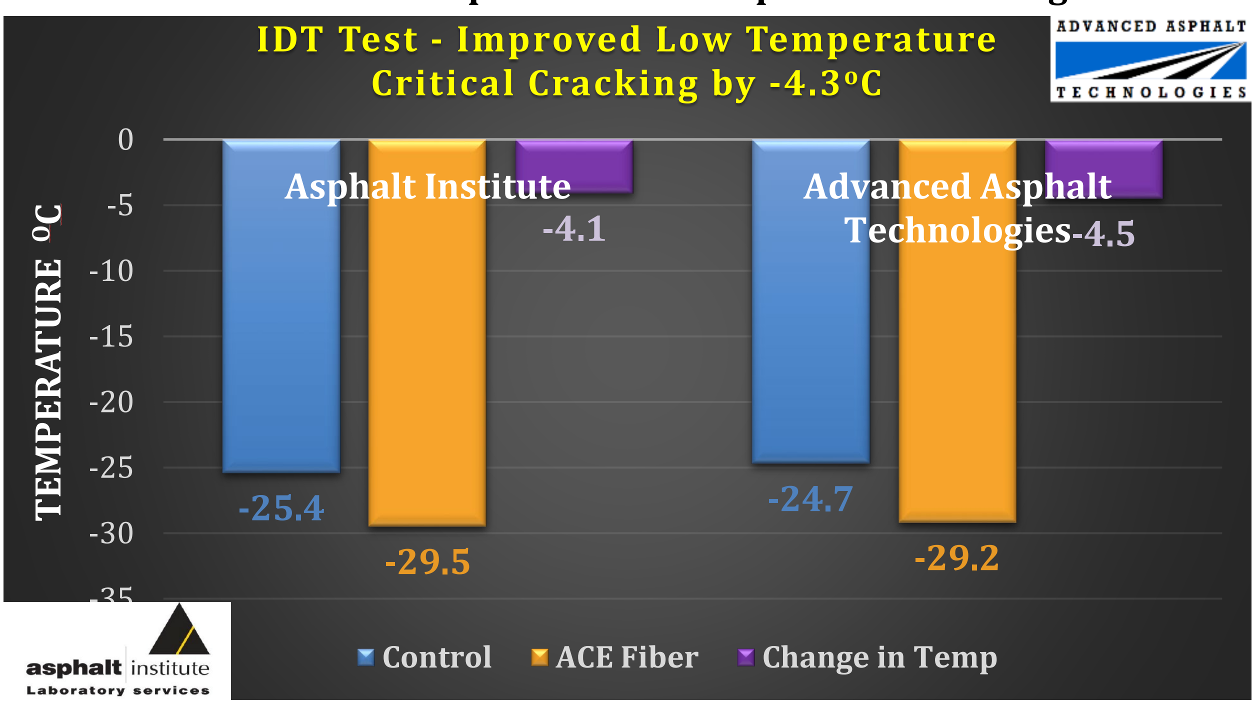


Table 6 – IDT Improved Low Temperature Cracking

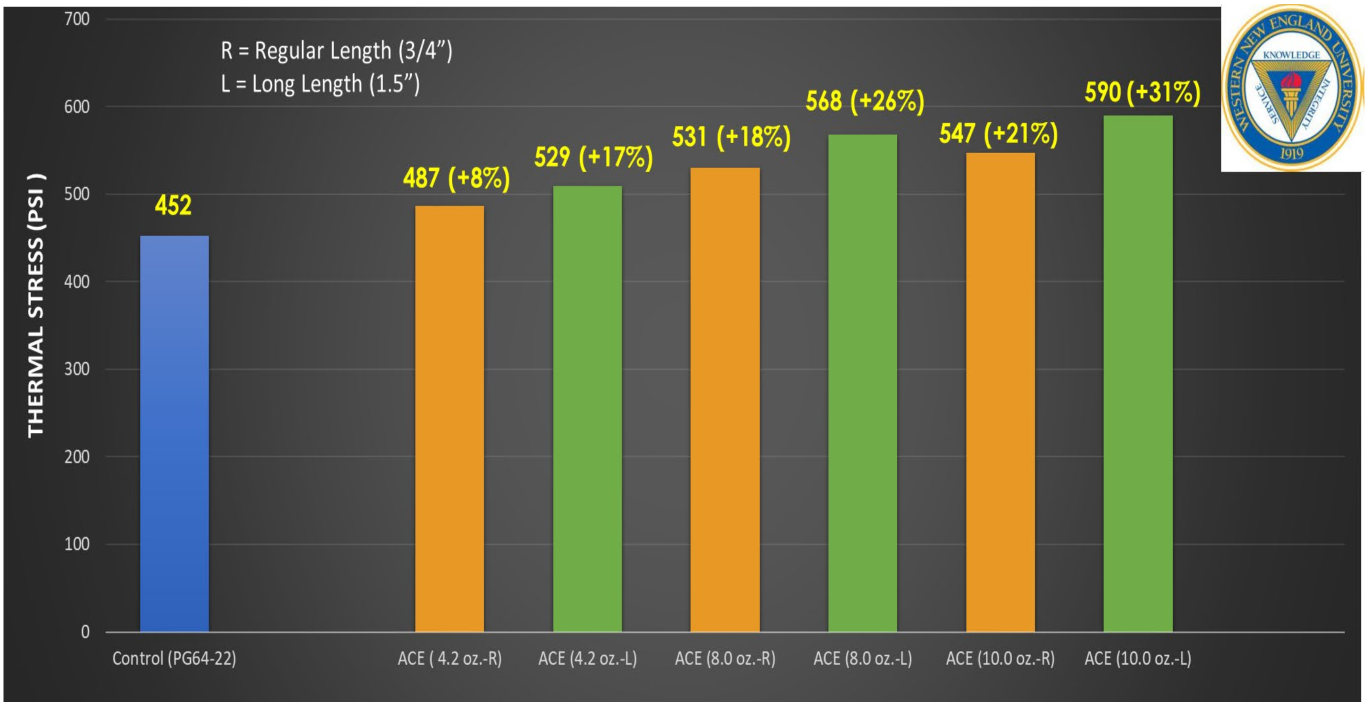


The (IDT) Test Summary

The Indirect Tensile @ -12° C

Performed by Western New England University

Table 7 – IDT Improved Low Temperature Cracking Resistance
Both ¾" & 1 ½" Length ACE XP Polymer Fiber



The (IDT) Test Summary

The Indirect Tensile @ 25° C

Performed by Southern Alberta Institute Technology

Detailed Procedure – ASTM D6931 Indirect Tensile Strength of Asphalt Mixtures
Using a caliper, the thickness of each briquette was obtained by averaging 3 measurements equidistant from each other on the specimen face. Next the briquettes were conditioned and brought to the testing temperature of 25°C by submersion in a water bath. The specimens were taken one-by-one and placed in the IDT Strength-Loading fixture on the bottom loading strip. The top and bottom loading strips were positioned so that they were along the vertical diametric plane of the asphalt briquette. The loading fixture was then placed in the compression machine and loaded at 50±5mm/min until the maximum stress was reached.

Table 8 – IDT Improved High Temperature Cracking Resistance with 3 Different Asphalt Contents - 38mm Length ACE XP Polymer Fiber

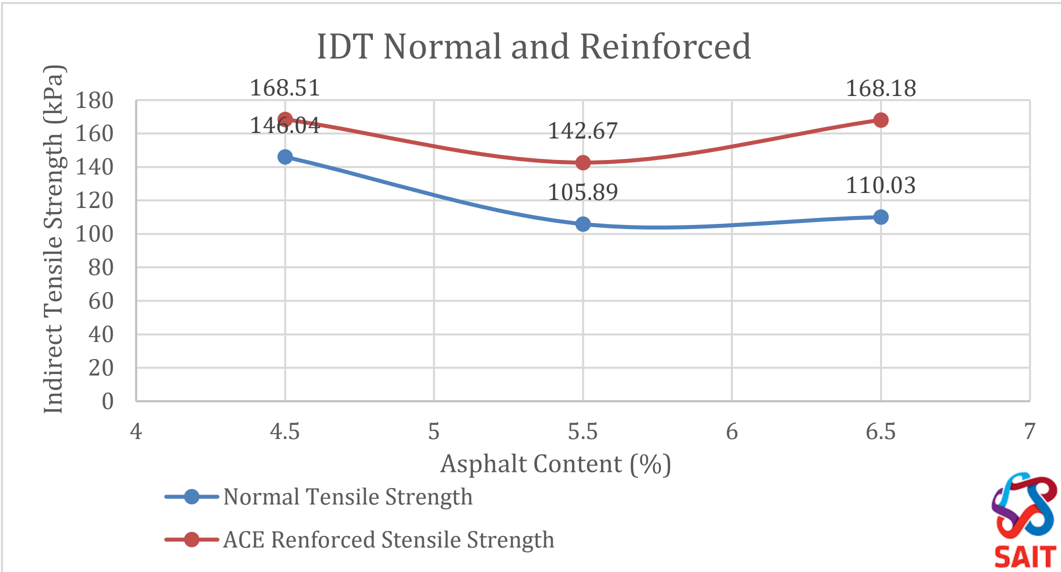


Table 9 – IDT Strength Comparisons with 3 Different Asphalt Contents - 38mm Length ACE XP Polymer Fiber

IDT			
IDT Strength Comparison Data			
AC content (%)	4.5%	5.5%	6.5%
Normal IDT Strength (kPa)	146.04	105.89	110.84
Reinforced IDT strength (kPa)	168.51	142.67	168.18
Increment	22.47	36.78	57.34
% Increase in Strength	15.4%	34.7%	51.7%

Hamburg Wheel Tracking Test

TxDOT Test Method 242F

Performed by Texas Transportation Institute
And Hi-Tech Asphalt Solutions

Test Summary:

The Hamburg Wheel Tracking Test is run under a water bath capable of controlling the test temperature within ± 2°C (4°F) over a range of 25 to 70°C (77 to 158°F). The steel wheel has a diameter of 203.6 mm (8 in.) and width of 47 mm (1.85 in.) over a test specimen. The load applied by the wheel is 705 ± 22 N (158 ± 5 lbs.). The wheel shall make approximately 50 passes across the test specimen per minute. The maximum speed of the wheel must be approximately 0.305 m/s (1.1 ft./sec).

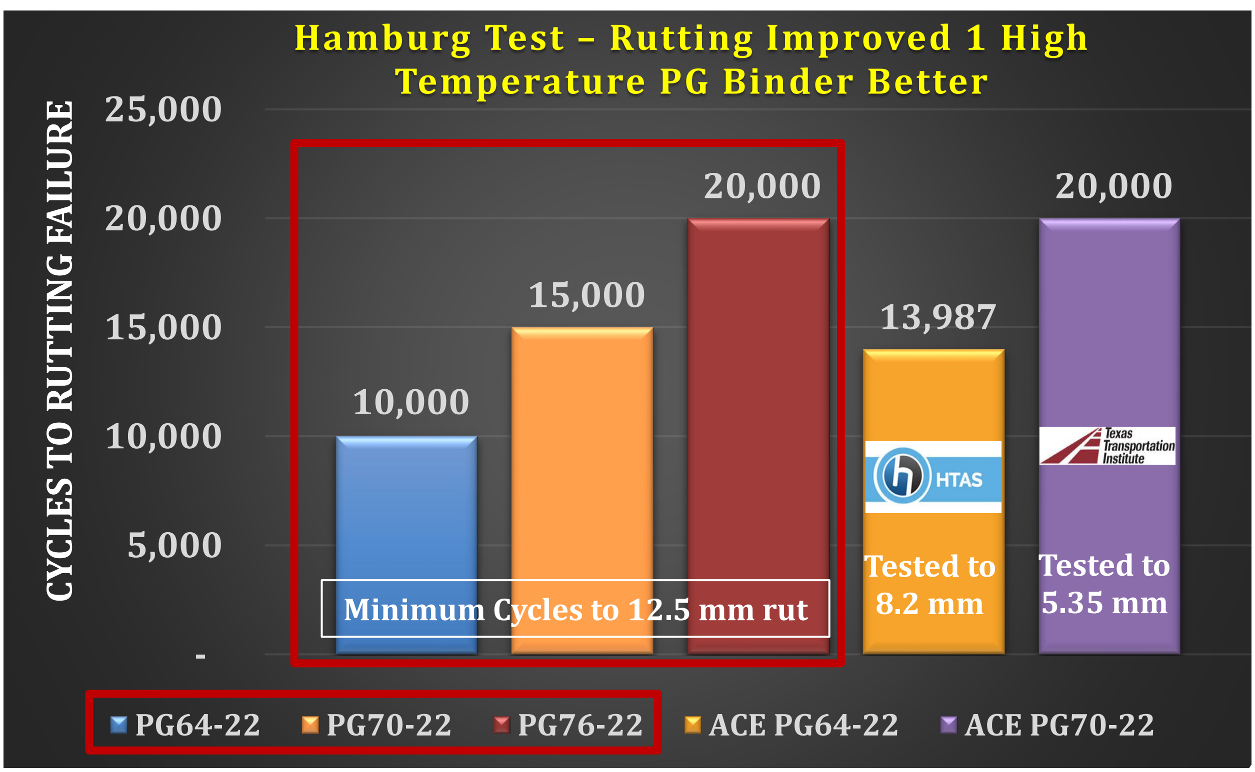
Figure 8

The rut depth induced by the steel wheel is automatically measured during the test. The test is run until the **rut depth** exceeds 12.5mm (0.50 inches). Test apparatus is shown in Figure 8.

Results:

PG64-22 with ACE Fiber tested by HTAS performed like PG70-22 & the PG70-22 with ACE Fiber tested by TTI performed like PG76-22. One Performance Grade Higher (Top Number).

Table 10 –Improved Rut Resistance



Hamburg Wheel Tracking Test

TxDOT Test Method 242F

Performed by West Texas Paving and Century Asphalt

Table 11 – Improved Rut Resistance (West Texas Paving PG64-22 Mix)

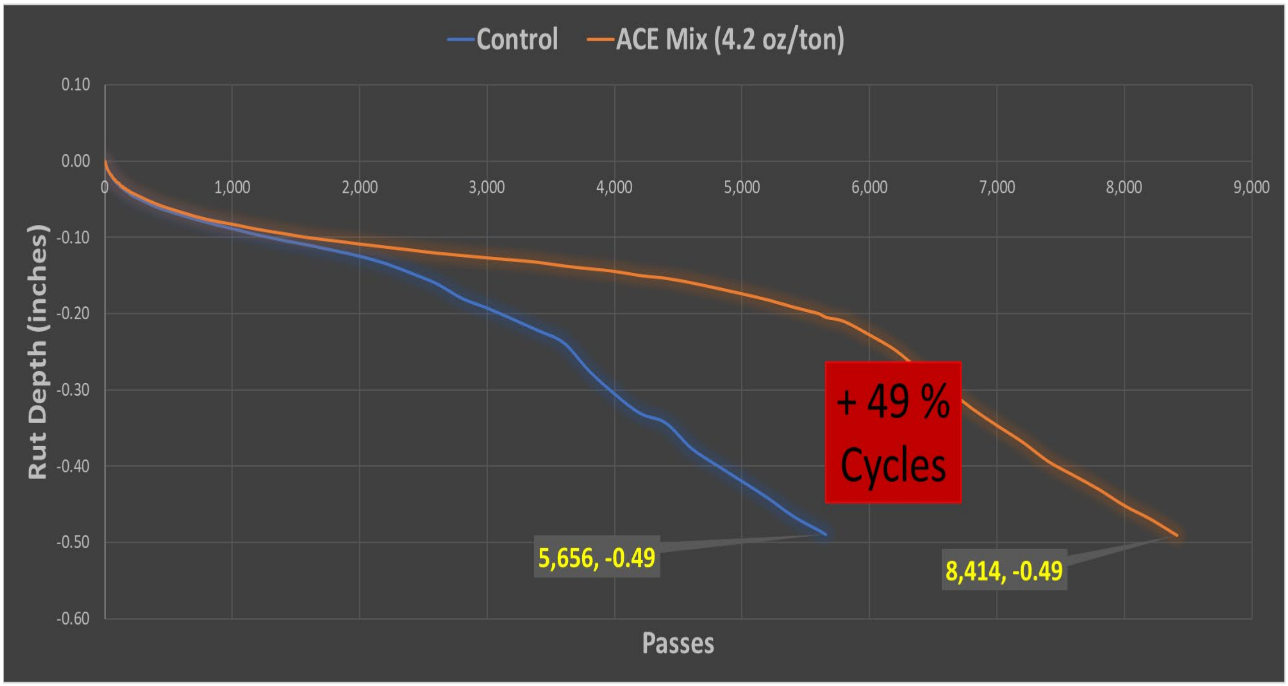
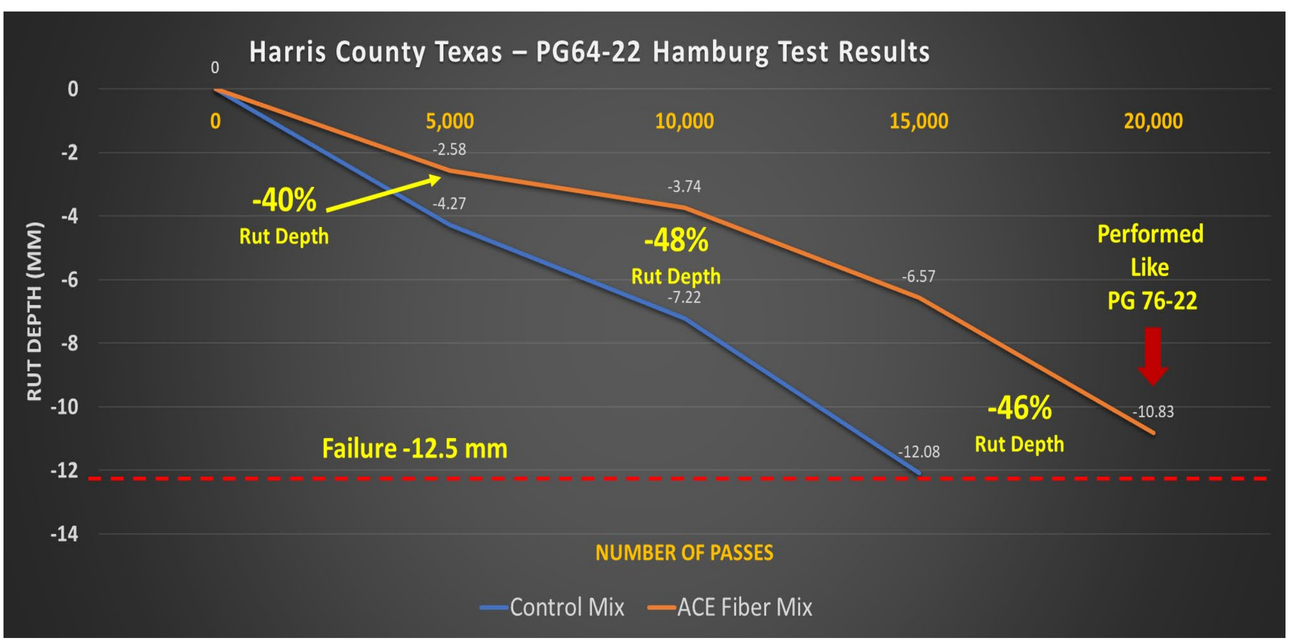


Table 12 – Improved Rut Resistance (Century Asphalt)

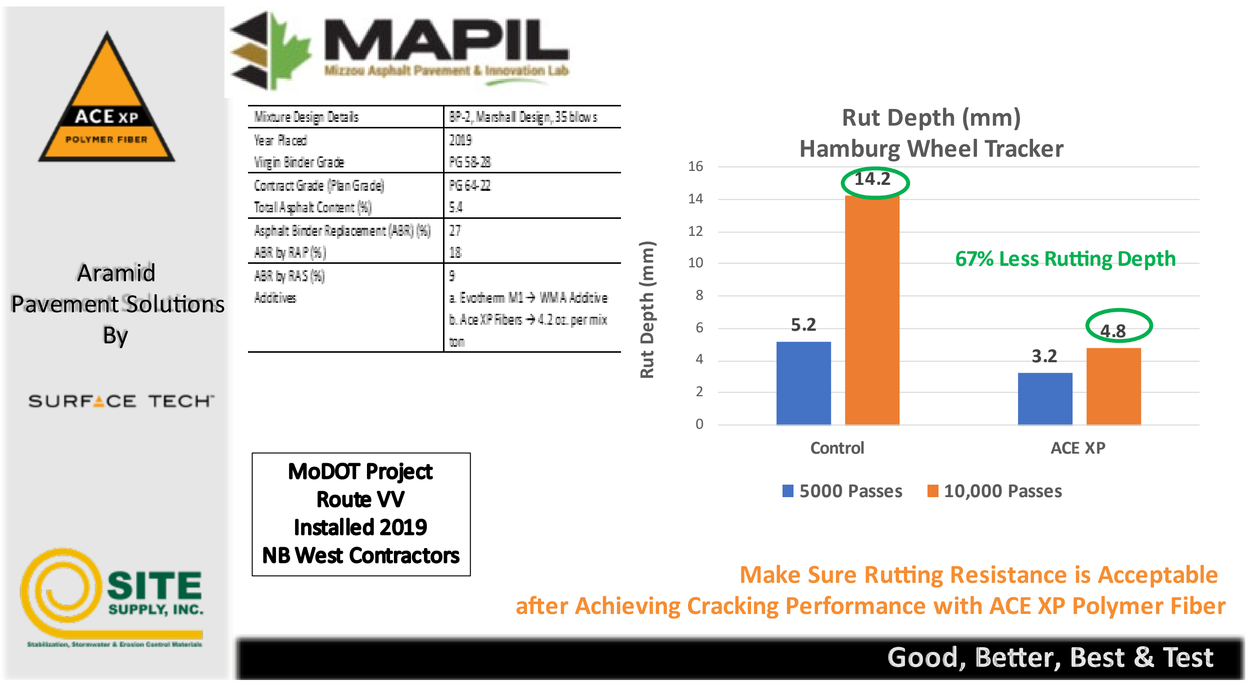


Hamburg Wheel Tracking Test

TxDOT Test Method 242F

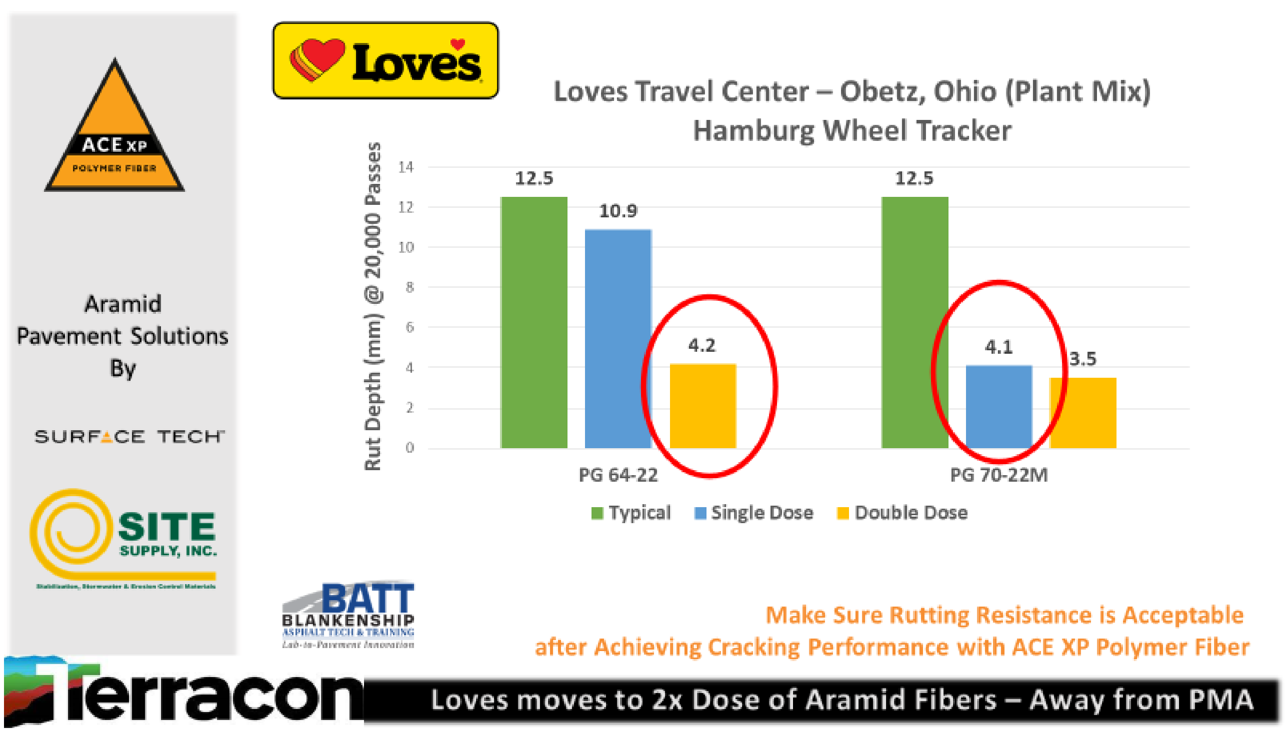
Performed by MAPIL & the BATT Lab

Table 13 – Improved Rut Resistance – MoDOT Route VV Produced by NB West Contractors – 67% Less Rutting in PG64-22



Mixture Design Details	BP-2, Marshall Design, 35 blows
Year Placed	2019
Virgin Binder Grade	PG 58-28
Contract Grade (Plan Grade)	PG 64-22
Total Asphalt Content (%)	5.4
Asphalt Binder Replacement (ABR) (%)	27
ABR by RAP (%)	18
ABR by RAS (%)	9
Additives	a. Evotherm M1 → WMA Additive b. Ace XP Fibers → 4.2 oz. per mix ton

Table 14 – Improved Rut Resistance – Loves Corp. (Obetz, Ohio Project) 2x dose of ACE XP PG64-22 rutting = 1x dose ACE XP PG70-22M (Polymer Modified)



Hamburg Wheel Tracking Test

TxDOT Test Method 242F

Performed by the BATT Lab

Table 15 – Improved Rut Resistance – Loves Corp. (Brookville, PA) – 2x dose ACE XP P64-22 vs 1x dose PG64-22

Aramid Pavement Solutions By

SURFACE TECH

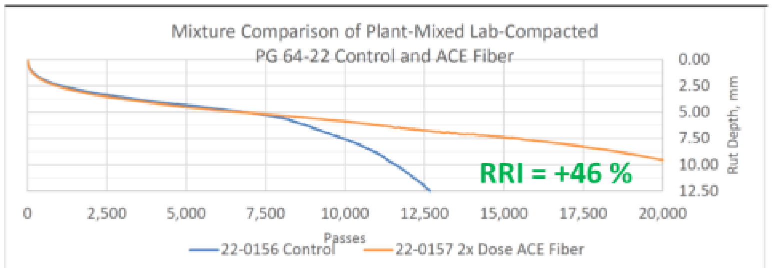
SITE SUPPLY, INC.

Loves Travel Center - Brookville, PA – Installed June 2022

Test	AASHTO T 324	Temperature	50°C	Loading Rate	52 mm/min
				Wheel Load	705 N

Mixture	Voids	Disp (mm) 5,000	10,000	15,000	20,000	Total Passes	Rut Depth	SIP	RRI
22-0156 Control	7.0%	4.32	6.27	12.50	12.50	**13,538**	12.50	10,974	6,876
	7.2%	4.35	8.87	12.50	12.50	**11,812**	12.50	8,889	5,999
22-0157 2x Dose ACE Fiber	6.5%	4.17	5.43	7.10	9.60	**20,000**	9.60	13,186	12,441
	6.7%	4.89	6.33	7.71	9.52	**20,000**	9.52	13,475	12,504

Hamburg Guidelines (# Passes to 12.5 mm)	
PG64-22	10,000
PG70-22	15,000
PG76-22	20,000



BATT BLANKENSHIP ASPHALT TECH & TRAINING

Make Sure Rutting Resistance is Acceptable after Achieving Cracking Performance with ACE XP Polymer Fiber

Terracon

Loves moves to 2x Dose of Aramid Fibers – Away from PMA

Table 16 – Improved Rut Resistance – Dosing Study performed by the Asphalt Institute – 1x dose to 12x dose

SURFACE TECH

Hamburg Rut Testing – 38mm ACEXP Dosage Study
Asphalt Institute – PG64-22 with 5.4% AC & No RAP

Table 6 – Summarized HWT test results for total number of passes to reach maximum rut depth of 12.5 mm.

	Replicate	Avg. %AV	Temp, °C	Rut Depth at # of Passes 1,000	5,000	10,000	15,000	20,000	Total # of Passes	Stripping Inflection Point (SIP)
Control	1, 2	7.1	45.0	1.49	2.60	3.82	6.52	N/A	18,232	15,317
	3, 4	7.1	45.0	1.65	2.75	3.90	6.14	N/A	18,442	15,623
2.1 oz	1, 2	7.3	45.0	1.49	2.57	3.58	4.94	9.52	21,750	18,321
4.2 oz	1, 2	7.2	45.0	1.69	2.71	3.48	4.83	9.45	21,406	18,005
8.4 oz	1, 2	7.4	45.0	1.72	2.68	3.50	4.61	8.12	22,334	18,828
12.6 oz	1, 2	7.4	45.0	1.68	2.63	3.44	4.36	6.42	24,266	20,485

@ 15,000 Passes Rut Depth was less by 28% to 45%

@ 12.5 mm Rut Total Passes Improved by 19% to 32%

Superior Asphalt Performance

The (APLT) Static Creep Test

The Automated Plate Load Test

Performed by Ingios Geotechnics, Inc.

Test Summary:

The Automated Plate Load Test (APLT)
Ingios Geotechnics, Inc. has developed rapid in-situ testing using Automated Plate Load Testing (APLT) and analysis methods to characterize the in-situ **dynamic modulus (*E*)** and repeated and static load creep or permanent deformation properties of the AC layer. Equipment developed by Ingios is shown in Figure 9.

"The major advantage of in-situ testing is that it does not suffer from the effects of sample preparation, sample size, equipment, and boundary conditions associated with laboratory tests"

Figure 9

In situ testing was performed at three test locations on September 14, 2016 in a medium duty test section in the parking lot of Love's Travel Stop in Sadieville, KY. The test section consisted of 2 in. AC surface course layer, 4.5 in. of AC base course layer, 8 in. of dense graded aggregate base layer, Type 2 geogrid, and subgrade. A second Love's Travel Stop location, Greenwood, LA, was tested on March 8, 2017. This location had both an ACE Fiber Reinforced Section and a Control Section. The LA test section consisted of 2 in. AC surface course layer, 6 in. of AC base course layer, 10 in. of dense graded aggregate base layer, Type 2 geogrid, and lime stabilized subgrade.

Results:

Static creep test results showed that permanent deformation (δ_p) at the end of the static creep test with applied contract stress of 150 psi averaged about 0.14 in. Forecasting power models show that at all three test locations the number of loading cycles to achieve 0.5 inch permanent deformation (i.e., definition of "rut") are greater than 25,000 hours for all tests.

The static loading tests demonstrated resilient behavior during un-loading from 250 psi to 0 psi where the deformation after loading from 150 to 250 psi was fully recovered. This behavior suggests that the fiber reinforced AC stores energy during loading (energy is not dissipated in plastic deformation), which partially explains how the fibers can potentially help resist deformation. Tertiary flow was not observed in any of the three static tests, therefore flow time could not be calculated.

Static creep test using a 4 in. diameter spherical dome plate using 20,000 lbs. constant load was conducted which produced an indentation in the fiber reinforced AC layer. No radial tension cracks were developed around the indentation. The observation of no radial cracks in this test can be partly attributed to the improved shear resistance in the fiber reinforced AC mixtures.

The (APLT) Static Creep Test

(6" Flat Plate)

Performed by Ingios Geotechnics, Inc.

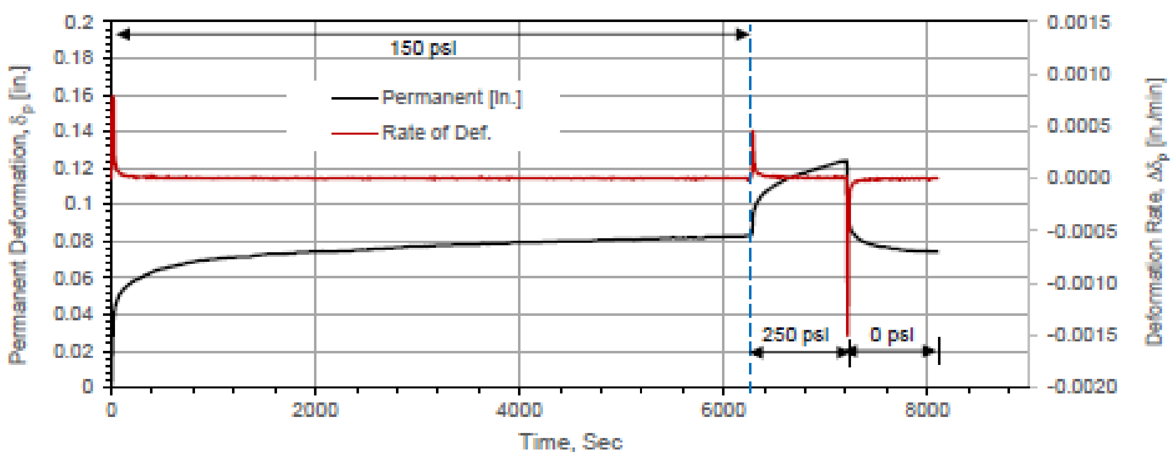
(Kentucky Site)

Figure 10 – APLT Static Creep Test Result

Automated Plate Load Test [APLT]

Test:	Static Creep Test [2 steps: 150 psi and 250 psi]				
Date:	9/14/2016	Time:	1:48:32 PM	Test ID	Static_6inch_flat_3
Tested By	DW/BF/PV	Location:	Sadieville, KY	Sta.	NA
Latitude:	38.381820	Longitude, W:	84.573160	Elev. (ft):	916

Comments: Test performed in medium duty test section with nominal 2 in. asphalt surface course, 4.5 in. asphalt base course, 8 in. dense graded aggregate, and geogrid over subgrade. ACE fibers in aspahlt layers. 6 in. diameter flat plate.



Rebound Ratio = 121%

Permanent Deformation Prediction Parameters

Based on 150 psi loading

C =	0.0332	
d =	0.1053	
R^2 =	0.9789	
T^* =	152	Min.
δ_p at T^* =	0.0868	in.
Adj. δ_p at T^* =	0.0536	in.
$T_{0.05}$ =	0.8	Min.
$T_{0.1}$ =	584	Min.
$T_{0.15}$ =	27,469	Min.
$T_{0.20}$ =	422,051	Min.
$T_{0.25}$ =	3,513,222	Min.
$T_{0.30}$ =	>>10,000,000	Min.
$T_{0.40}$ =	>>10,000,000	Min.
$T_{0.50}$ =	>>10,000,000	Min.
Mid-Depth Temp. =	100 to 109	°F

Perm. Deformation Model: $\delta_p = CT^d$

δ_p = permanent deformation

C = plastic deformation in first few seconds

d = scaling component

T = loading time

T^* = loadig time at $\Delta\delta_p$ = 1E-06 in./sec

Adj. δ_p at $T^* = \delta_p$ at $T^* - C$

T_x = loading time to achieve δ_p of x in.

Static Creep Test: Permanent Deformation [δ_p] and Deformation Rate [δ_{rate}] Monitoring

Project Name:	Love's Travel Stop
Project ID:	BreakThrough Technologies
Location:	313 Porter Road I-75 Exit 136, Sadieville, KY 40370

The (APLT) Static Creep Test

(6" Flat Plate)

Performed by Ingios Geotechnics, Inc.

(Louisiana Site)

Figure 11 – APLT Static Creep Test Result ACE Fiber vs Control

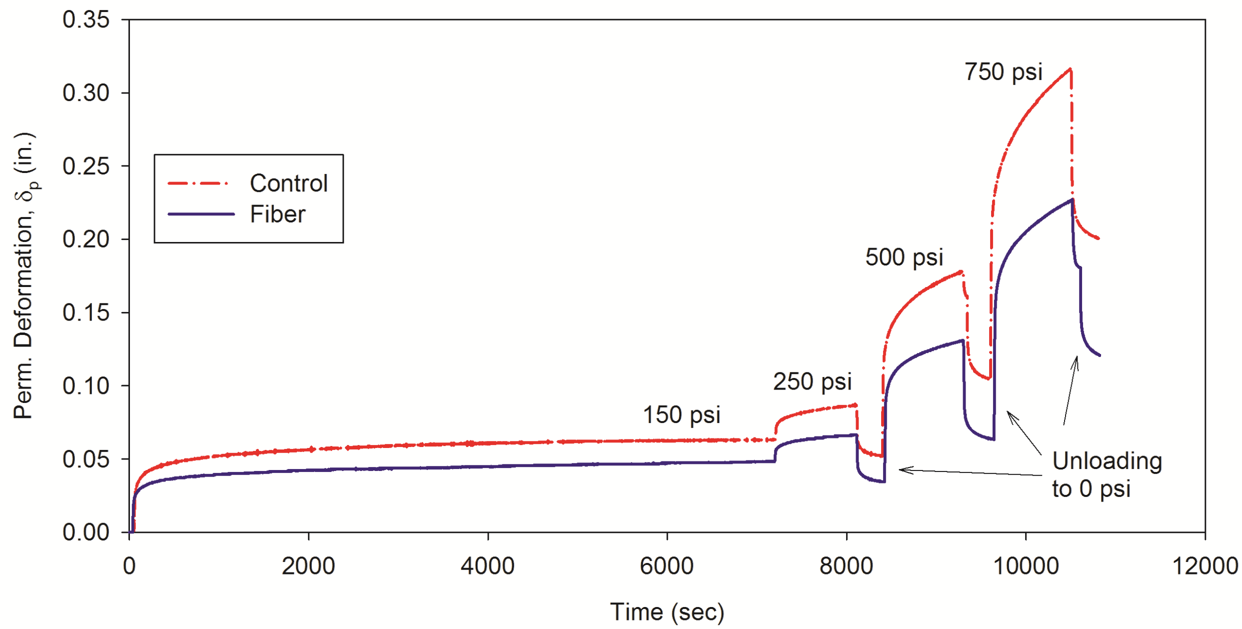
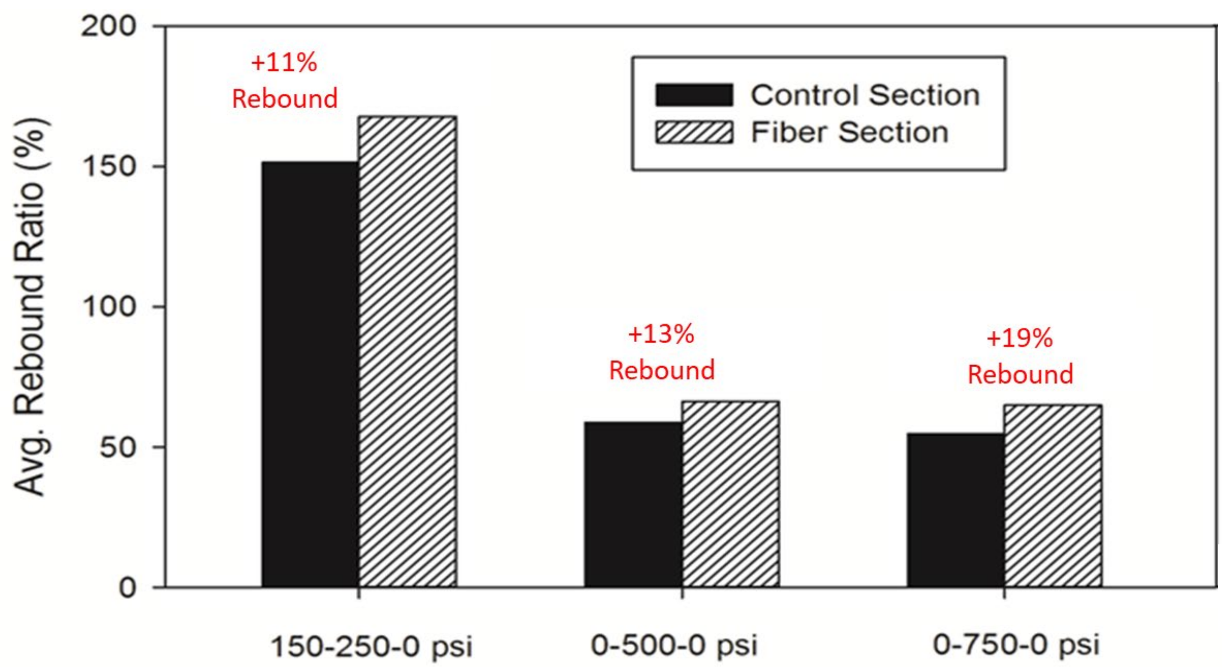


Figure 12 – APLT Static Creep Test Result ACE Fiber vs Control Rebound % Comparison



The (APLT) Static Creep Test
(6" Flat Plate)
Performed by Ingios Geotechnics, Inc.
(Louisiana Site - Continued)

Figure 13 – APLT Static Creep Test Result ACE Fiber vs Control Rut Depth Comparison

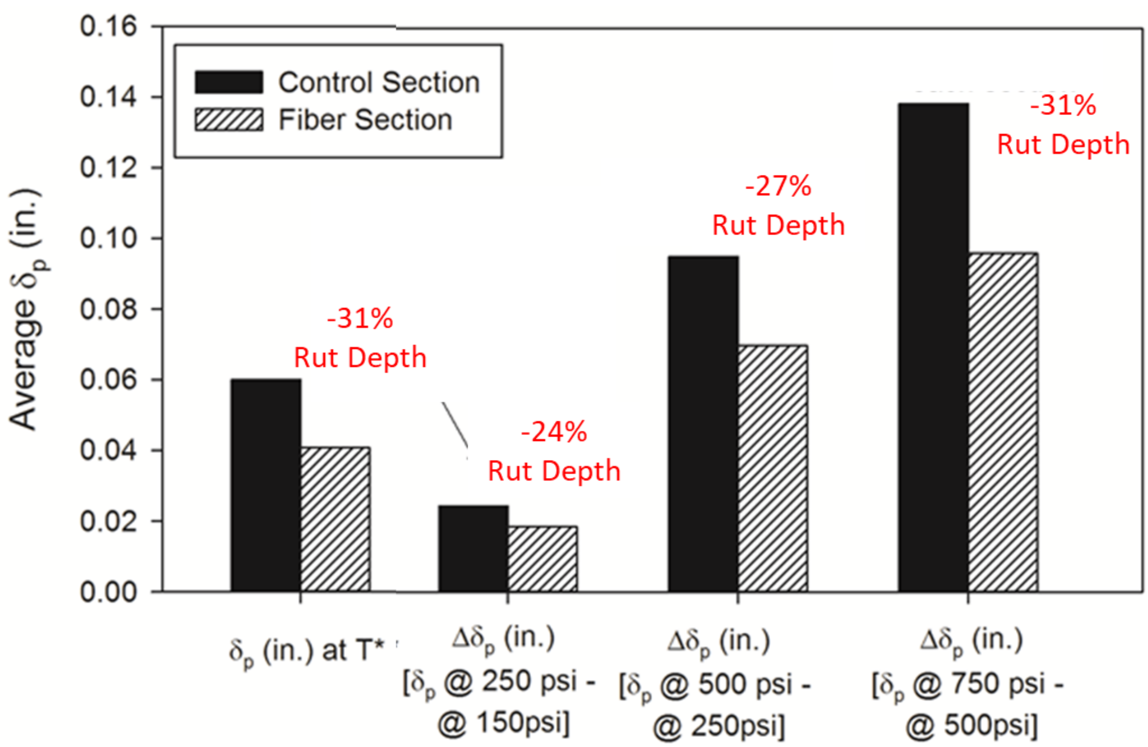


Figure 15
Permanent ACE Fiber Section Deformation after test completion

Figure 14
6 in. diameter flat plate - ***Repeated Load and Static Load Creep Test***

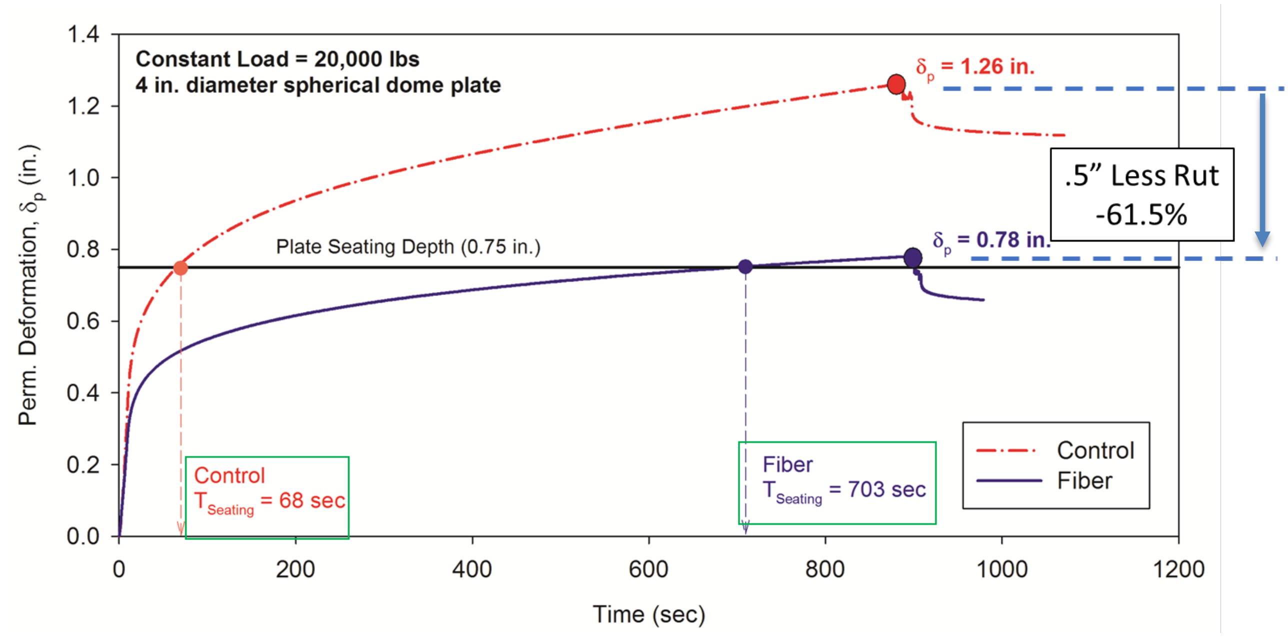
The (APLT) Static Creep Test

(4" Spherical Dome)

Performed by Ingios Geotechnics, Inc.

(Louisiana Site)

Figure 16 – APLT Static Creep Test Result ACE Fiber vs Control Rut Depth & Time to Rutting Comparison



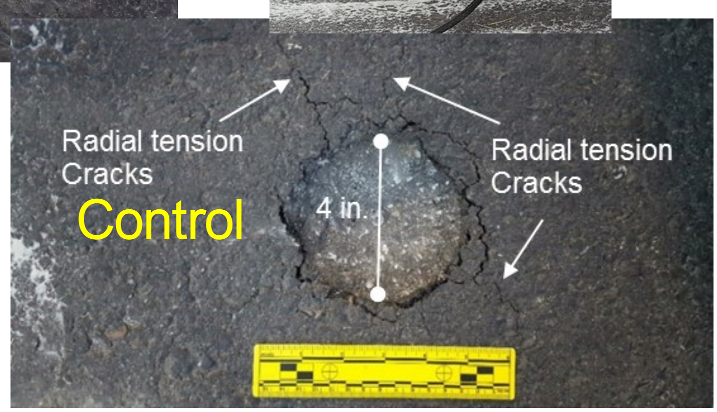


Figure 17
Radial Tension Cracks after the 4" Domed Test Completion

The (APLT) Dynamic Modulus Test

The Automated Plate Load Test

Performed by Ingios Geotechnics, Inc.

Test Summary:

The Automated Plate Load Test (APLT)

Ingios Geotechnics, Inc. has developed rapid in-situ testing using Automated Plate Load Testing (APLT) and analysis methods to characterize the in-situ **dynamic modulus (*E*)** and repeated and static load creep or permanent deformation properties of the AC layer. Equipment developed by Ingios is shown in Figure 10.

"The major advantage of in-situ testing is that it does not suffer from the effects of sample preparation, sample size, equipment, and boundary conditions

Figure 18

In situ testing was performed at three test locations on September 14, 2016 in a medium duty test section in the parking lot of Love's Travel Stop in Sadieville, KY. The test section consisted of 2 in. AC surface course layer, 4.5 in. of AC base course layer, 8 in. of dense graded aggregate base layer, Type 2 geogrid, and subgrade. A second Love's Travel Stop location, Greenwood, LA, was tested on March 8, 2017. This location had both an ACE Fiber Reinforced Section and a Control Section. The LA test section consisted of 2 in. AC surface course layer, 6 in. of AC base course layer, 10 in. of dense graded aggregate base layer, Type 2 geogrid, and lime stabilized subgrade.

Results:

The in-situ back calculated and temperature corrected ACE Fiber reinforced AC layer moduli (E'_{AC}) values averaged between the two sites at about 1,155,000 psi for 70 psi cyclic stress and loading frequency of 1.59 Hz. Likewise, an average of the control with AASHTO standard was about 469,568 psi. The ACE Fiber reinforced AC layer showed about 150% increase in Modulus between the two sites.

ESAL calculations were performed using the measured subgrade M_R values. Results and analysis from the two test sites produced an average structural layer coefficient for the fiber reinforced AC layer (a_1) of 0.59 and an average of 54.3 million ESALs.

Considering a_1 = 0.44 which represents an unreinforced AC layer and keeping all other input parameters constant, the number of ESALs is calculated as 12.7 million. ESAL calculations showed that compared to an unreinforced AC layer case (a_1 = 0.44), the ACE fiber reinforced AC layer (a_1 = 0.59) increased the average number of ESALs by about 4.3 times.

The (APLT) Dynamic Modulus Test

(Combined Results from both Ketucky & Louisianna Sites)

Performed by Ingios Geotechnics, Inc.

Table 17 –Improved Elastic Modulus

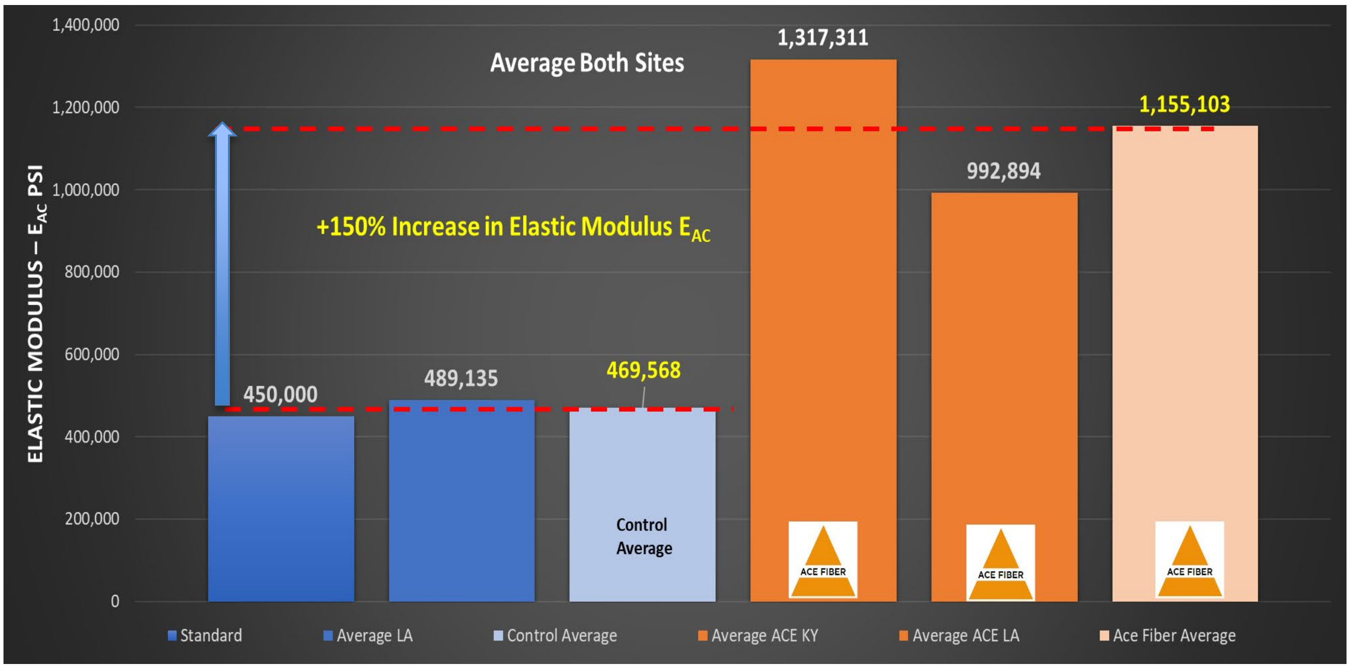
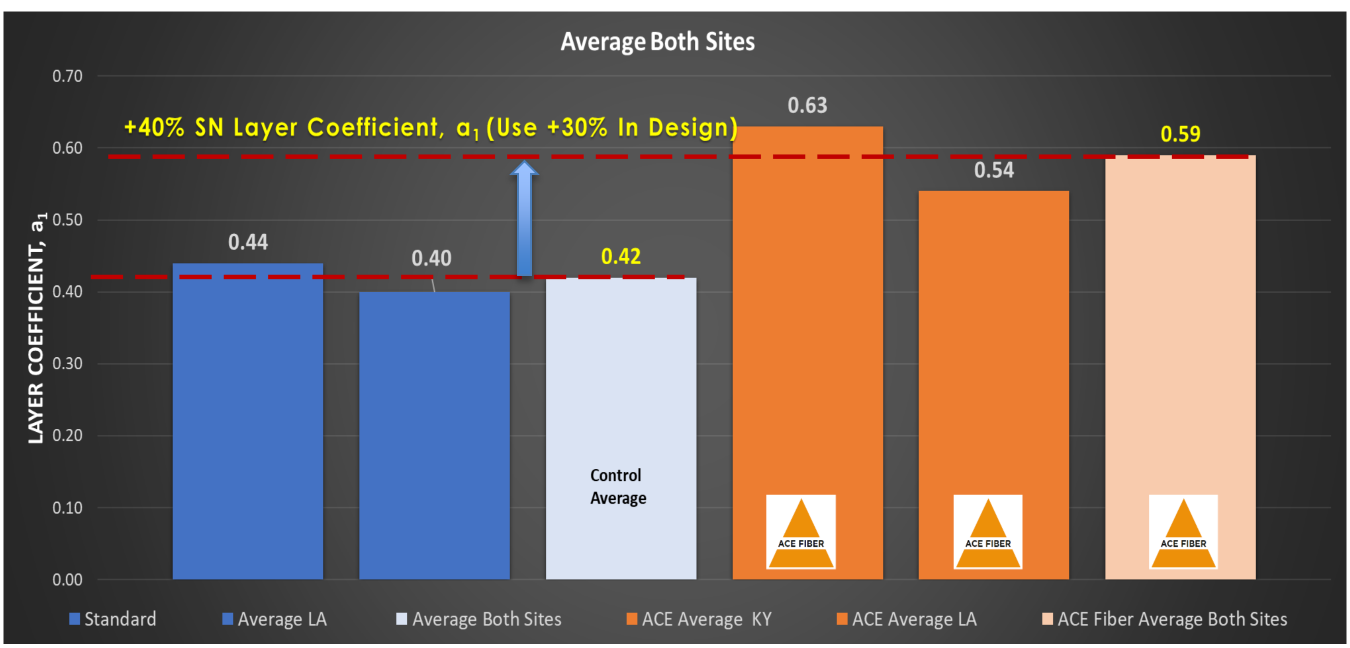


Table 18 –Improved SN Layer Coefficient

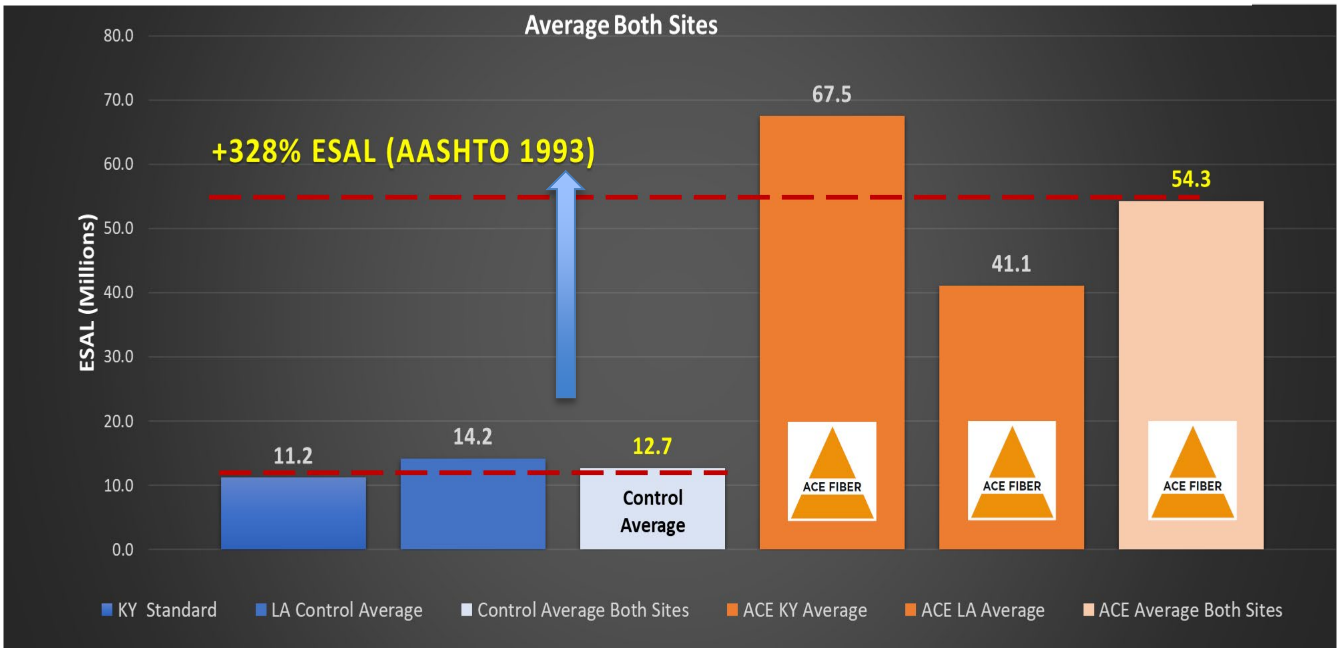


The (APLT) Dynamic Modulus Test

(Combined Results from both Ketucky & Louisianna Sites)

Performed by Ingios Geotechnics, Inc.

Table 19 –Improved ESAL Count



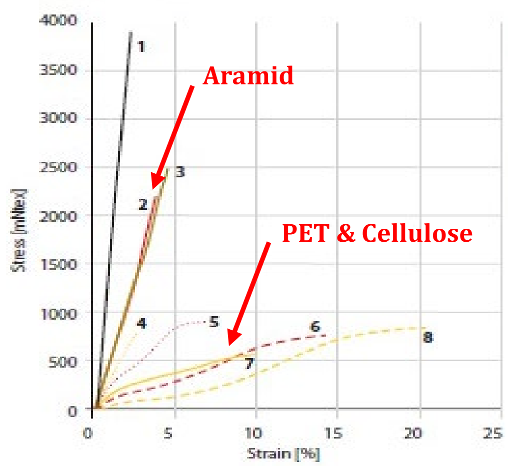
ACE XP Polymer Fiber™ is Engineered for Performance

Aramid Fibers are used extensively in many industries and applications including ballistic protection, heat & cut protection, automotive, ropes & cables, conveyor belts, etc. However, it takes a special fiber to withstand the extreme production temperatures of asphalt concrete without changes occurring to the reinforcement properties of the fiber. That is why ACE XP Polymer Fiber™ uses aramid fibers exclusively. Aramid is a unique man-made, high-strength fiber boasting high tensile strengths over 400,000 psi (5 x steel), a superior stress/strain relationship, and decomposition temperatures exceeding 800°F (well above asphalt mixing temperatures of 400°F).

Aramid Specifications

Material Property	Value
Density (g/cm3)	1.44
Tensile Strength (N/tex)	2.4-3.6
Modulus (GPa)	60-120
Elongation at Break (%)	2.2-4.4
Tenacity (N/tex)	1.65-2.5
Decomposition Temperature	800

Aramid Stress/Strain Curves



Semi-Circular Bend Test (SCB)

Flexibility Index Test (FI)

Performed by Oregon State University

Test Summary:

FI is a ratio of the fracture energy (G_f) to the slope of the line at the post-peak inflection point of the load-displacement curve and is a parameter specific to asphalt pavement, which correlates to the brittleness of the material. It has been shown in recent studies to be highly indicative of pavement cracking resistance and is considered the most comprehensive way of assessing cracking resistance.

Figure 19 – SCB Test Samples

Results:

Test results are presented below. The blue bars represent the average FI from four replicate experiments while the length of the error bar on each bar represents the variability of the measured FI for each set (error bar length = two standard deviations). The mix with 1-1/2" fibers had the highest FI compared to the other two mixtures. It was observed that there is no significant difference between FI of the control mixture and the 3/4" aramid fiber mixture. However, with the use of 1-1/2" fibers, there was an approximate 37% increase in the FI value, suggesting that longer fibers significantly improve the cracking performance of asphalt mixtures.

Figure 20 – SCB Test Set-up

Coleri et al. (2017a) tested three different ODOT Level 4 production mixes with different mix designs and obtained FI values ranging from 9 to 14. The asphalt mixture with 1-1/2" fibers in this study provided an average FI of 18.5 that is higher than the highest FI observed by Coleri et al. (2017a). However, it should be noted that mixtures from the Coleri et al. (2017a) study were different from the mixtures tested in this study and should not be used as control results.

$$FI = A * \frac{G_f}{abs(m)}$$

Where:

G_f	= fracture energy (KJ/m^2),
abs(m)	= absolute value of the slope at inflection point of post-peak load-displacement curve,
A	= unit conversion factor and scaling coefficient.

Semi-Circular Bend Test (SCB)

Flexibility Index Test (FI)

Performed by Oregon State University

Flexibility index (FI) is the ratio of the fracture energy (G_f) to the slope of the line at the post-peak inflection point of the load-displacement curve (Figure 21). FI correlates with brittleness and it was developed for asphalt materials by Ozer et al. (2016). Lower FI values show that the asphalt mixtures are more brittle and have a higher crack growth rate (Ozer et al. 2016).

Figure 21 - Illustration of load-displacement curve and slope at inflection point (m)

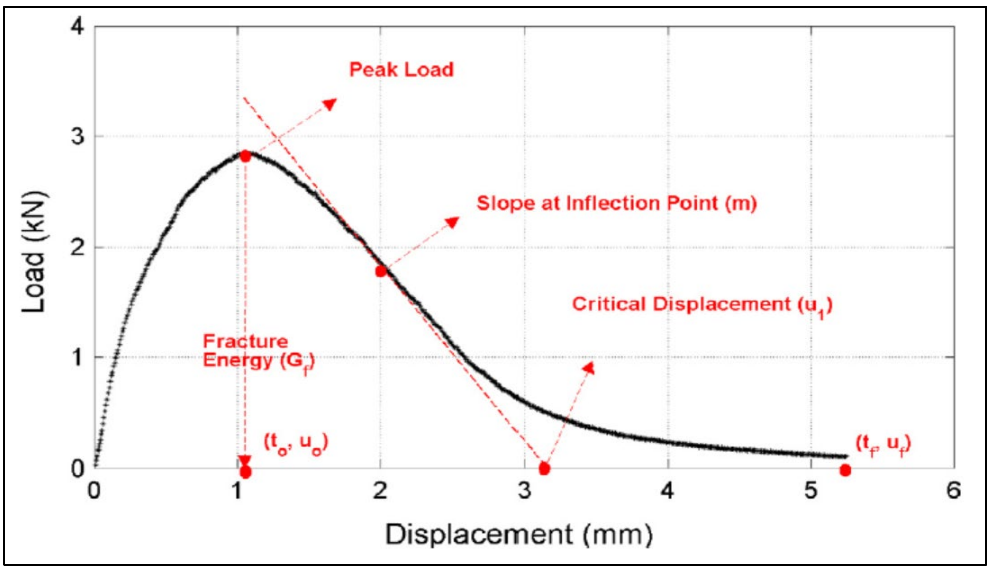
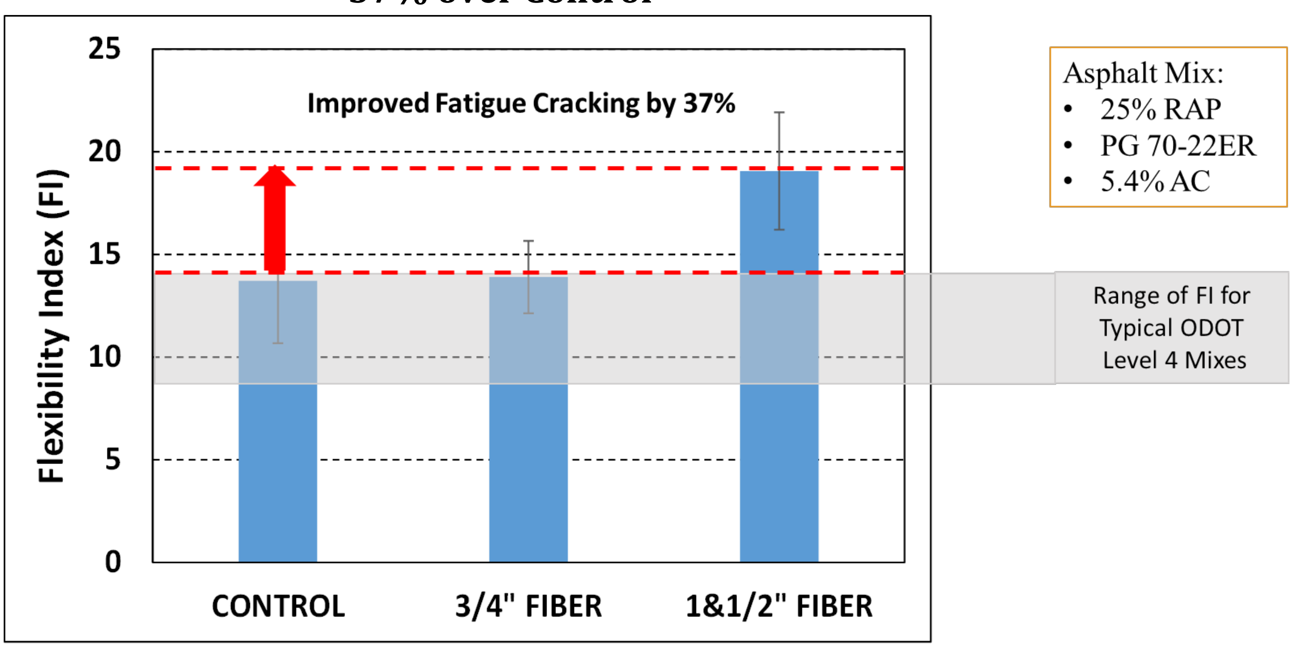


Figure 22 – ACE Fiber 1.5" Lengths improved the FI by 37% over Control



Asphalt Mix:
- 25% RAP
- PG 70-22ER
- 5.4% AC

Flexibility index from SCB tests for ODOT Level 3 PMLC samples.

The Flow Number Test (FN)

Rut Resistance Index

Performed by Oregon State University

Test Summary:

The flow number (FN) test is a performance test for evaluating rutting resistance of asphalt concrete mixtures (Bonaquist et al. 2003). In this test, while a constant deviator stress is applied at each load cycle on the test sample, the permanent strain at each cycle is measured (Figure 23). Permanent deformation of asphalt pavement has three stages: 1) primary or initial consolidation, 2) secondary and 3) tertiary or shear deformation (Biligiri et al. 2007). Figure 23 shows three stages of permanent deformation. FN is taken as the loading cycle at which the tertiary stage begins following the secondary stage. Justification for selection of FN criteria is determined using the Francken model, which is discussed

Results:

The flow number (FN) test is a simple performance test for evaluating rutting performance of asphalt concrete mixtures (Bonaquist et al. 2003). High FN values indicate that asphalt mixtures have high rutting resistance. Since the DM test is a non-destructive test (low strain level), the same samples prepared for DM tests were used for FN tests to compare the rutting resistance of HMA mixtures. Therefore, a total of six tests were conducted (two replicate tests for each mix type). Figure 24 illustrates the FN results for all three mixes. From this figure, it can be observed that the mixture with 1-1/2" aramid fibers had the highest flow number followed by the mixture with 3/4" aramid fibers and the control mixture. It is quite evident that the use of aramid fibers significantly improved the rutting resistance of asphalt mixtures. The use of 1-1/2" fibers increased the rutting resistance by about 37.5%.

Coleri et al. (2017a) tested three different ODOT Level 4 production mixes with different mix designs and obtained FN values ranging from 400 to 750. The asphalt mixture with 1-1/2" fibers in this study provided an average FN of 560 that is within the FN range observed by Coleri et al. (2017a). However, it should be noted that mixtures from the Coleri et al. (2017a) study were different from the mixtures tested in this study and should not be used as control results.

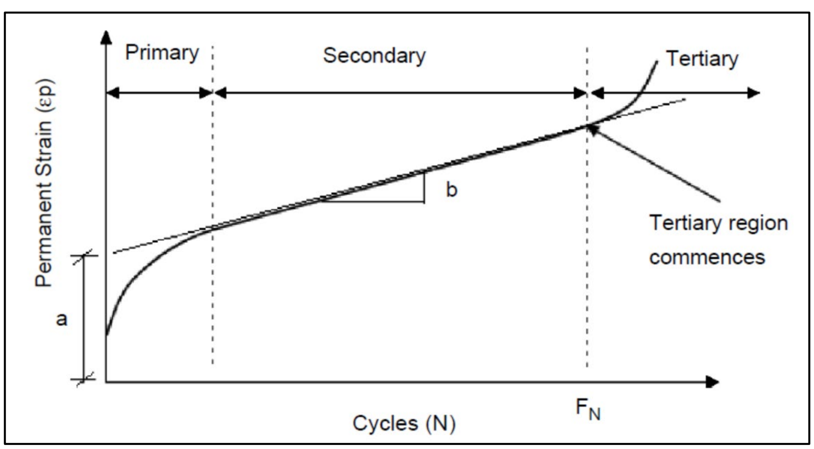


Figure 23 – Relationship between permanent strain and load cycles in FN test **(Biligiri et al. 2007)**

The Flow Number Test (FN)

Rut Resistance Index

Performed by Oregon State University

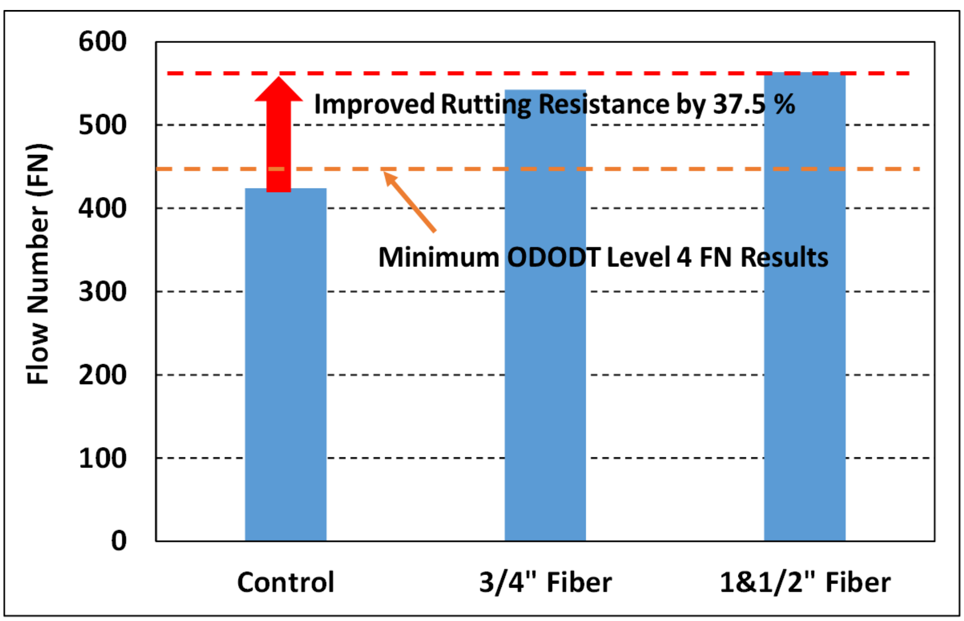
In this study, testing conditions and criteria for FN testing described in AASHTO TP 79-13 for unconfined tests were followed. The recommended test temperature, determined by LTPPBind Version 3.1 software, is the average design high pavement temperature at 50% reliability for cities in Oregon with high populations and at a depth of 20 mm (0.79 in) for surface courses (Rodezno et al. 2015). Tests were conducted at a temperature of 54.7°C with an average deviator stress of 600 kPa and minimum (contact) axial stress of 30 kPa. For conditioning, samples were kept in a conditioning chamber at the testing temperature for 12 hours prior to testing. To calculate FN in this study, the Francken model was used (discussed below).

Minimum FN values (calculated by using the Francken model) for different traffic levels recommended by AASHTO TP 79-13 are given in 12 (Rodezno et al. 2015).

Table 20 : Minimum average FN requirement for different traffic levels

Traffic (million ESALs)	Minimum Average FN Requirement
<3	NA
3 to <10	50
10 to <30	190
≥30	740

Figure 24 – ACE Fiber 1.5" Lengths improved the FN by 37.5% over Control



Asphalt Mix:
- 25% RAP
- PG 70-22ER
- 5.4% AC

Flow number for ODOT Level 3 PMLC samples

IDEAL CT – Crack Index Testing

Test Method Developed by TTI (2019 AASHTO Ballot)

Performed by Pave-Tex

Texas Transportation Institute

Test temperature: 25 °C

Loading rate: 50mm/min.

Specimen: cylindrical specimen without cutting, gluing, instrumentation, drilling, and notching.

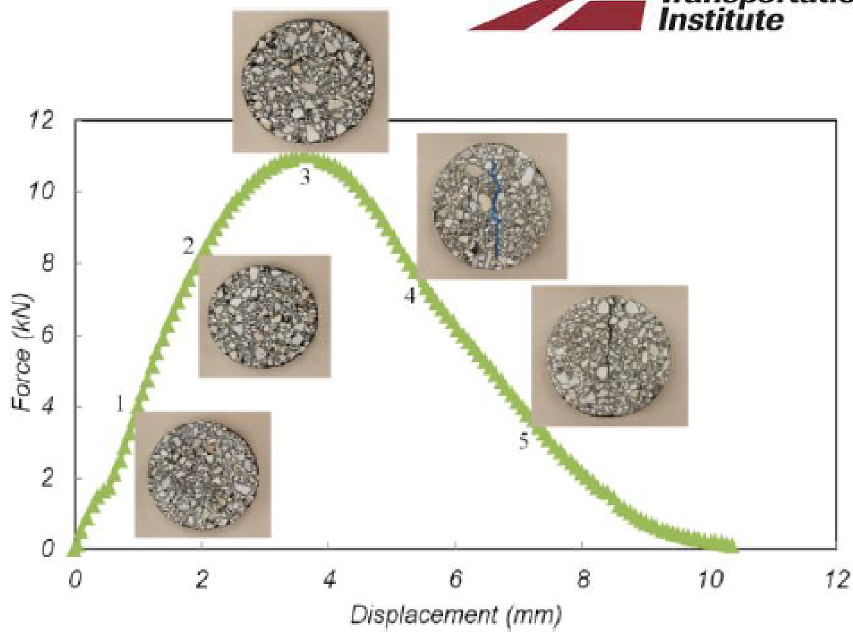


Figure 1. *IDEAL-CT: Specimen, Fixture, Test Conditions, and Typical Result*

Test Summary:

The IDEAL-CT is similar to other traditional indirect tensile strength test, and it is run at room temperature with cylindrical specimens at a loading rate of 50mm/min. in terms of cross-head displacement. Any size of cylindrical specimens with various diameters (100 or 150mm) and thicknesses (38, 50, 62, 75mm, etc.) can be tested. For mix design and laboratory QA/QC, the authors proposed to use the same size specimen as the Hamburg wheel tracking test: 150 mm diameter and 62 mm height with 7±0.5 percent air voids, since agencies are familiar with molding such specimens. Figure 1 shows a typical IDEAL-CT: cylindrical specimen, test fixture, test temperature, loading rate, and the measured load vs. displacement curve.

The purpose of the test method is to determine the cracking behavior of the asphalt sample all the way through the cracking process. This test will deliver an Indirect Tensile load as well measure the resistance of the asphalt from first crack all the way through failure. Both the load and the displacement are recorded creating a displacement curve shown in Figure 1. The work or fracture energy created by the asphalt sample is calculated by the area under the displacement curve shown in Figure 2 below.

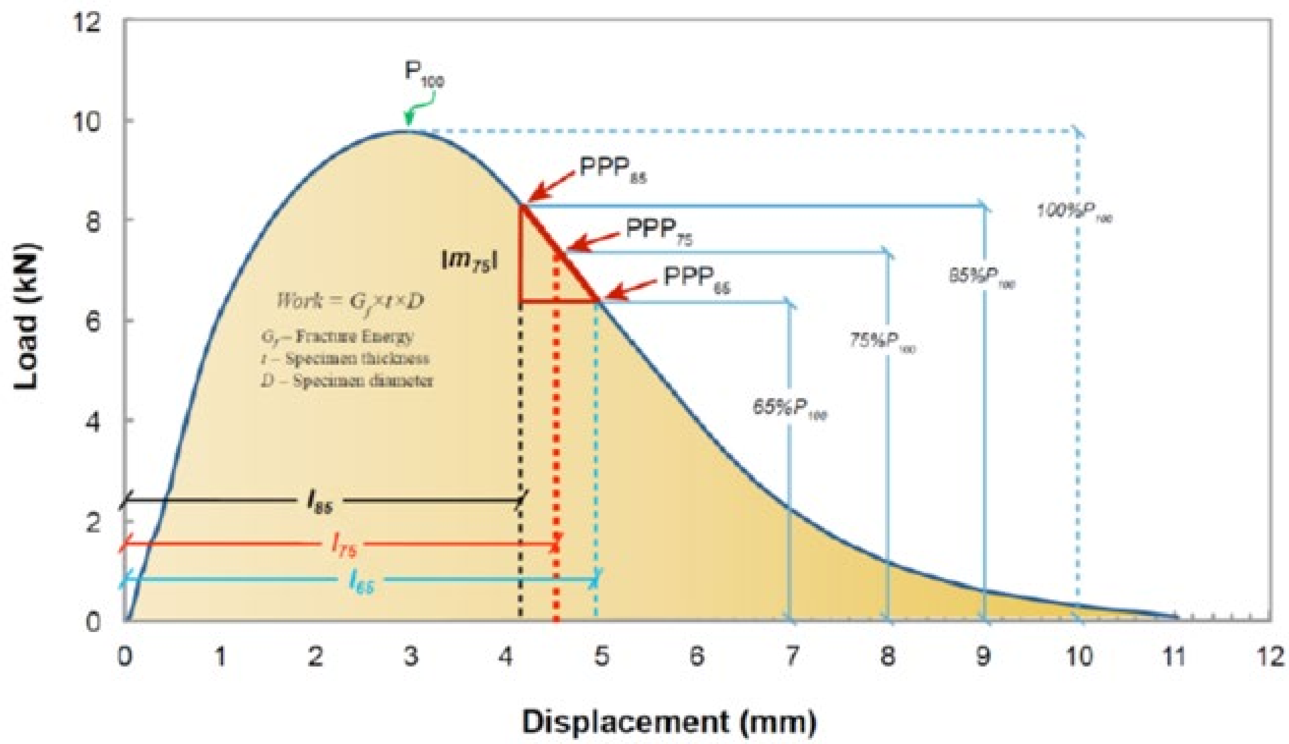


Figure 2. *Illustration of the PPP75 Point and Its Slope* $|m_{75}|$

The Ideal CT Crack Index is calculated as follows:

Detailed derivation and rationales for this new parameter are described in the Appendix. When used for laboratory mix design and QC/QA where specimen thickness can always be 62 mm, the proposed new cracking test index (CT_{Index}) is given in Equation 7. The larger the CT_{Index}, the slower the cracking growth rate:

$$CT_{Index} = \frac{G_f}{\frac{P}{l}} \times \left(\frac{l}{D}\right) \qquad [7]$$

In case of field cores where the core thickness is not 62 mm, CT_{Index} is defined in Equation 8:

$$CT_{Index} = \frac{t}{62} \times \frac{G_f}{\frac{P}{l}} \times \left(\frac{l}{D}\right) \qquad [8]$$

where fracture energy G_f is the work of fracture (the area of the load vs. vertical displacement curve) divided by area of cracking face; parameter P/l is a "*modulus*" parameter (or the slope of the load-displacement curve) and parameter l/D a "*strain*" tolerance parameter (or the deformation tolerance under a load).

Table 21 – IDEAL CT with 2 TxDOT Mixes using 20% RAP – 38mm Length ACE XP Polymer Fiber

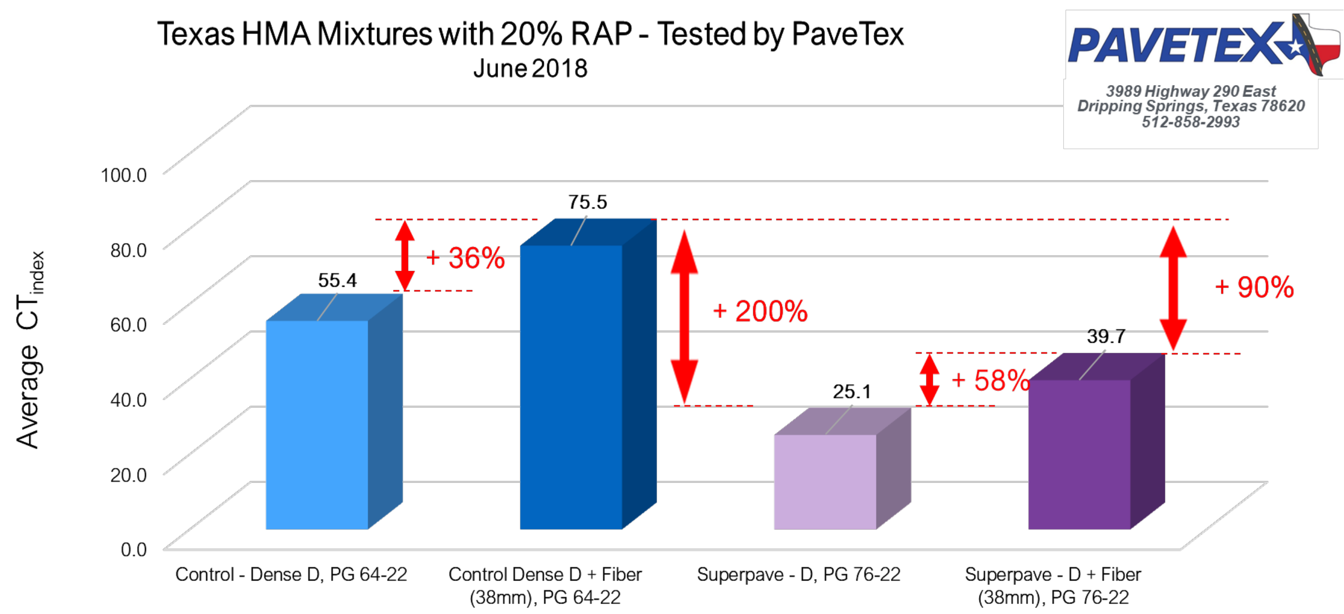


Table 22 – IDEAL CT vs Indirect Tensile Strength Results

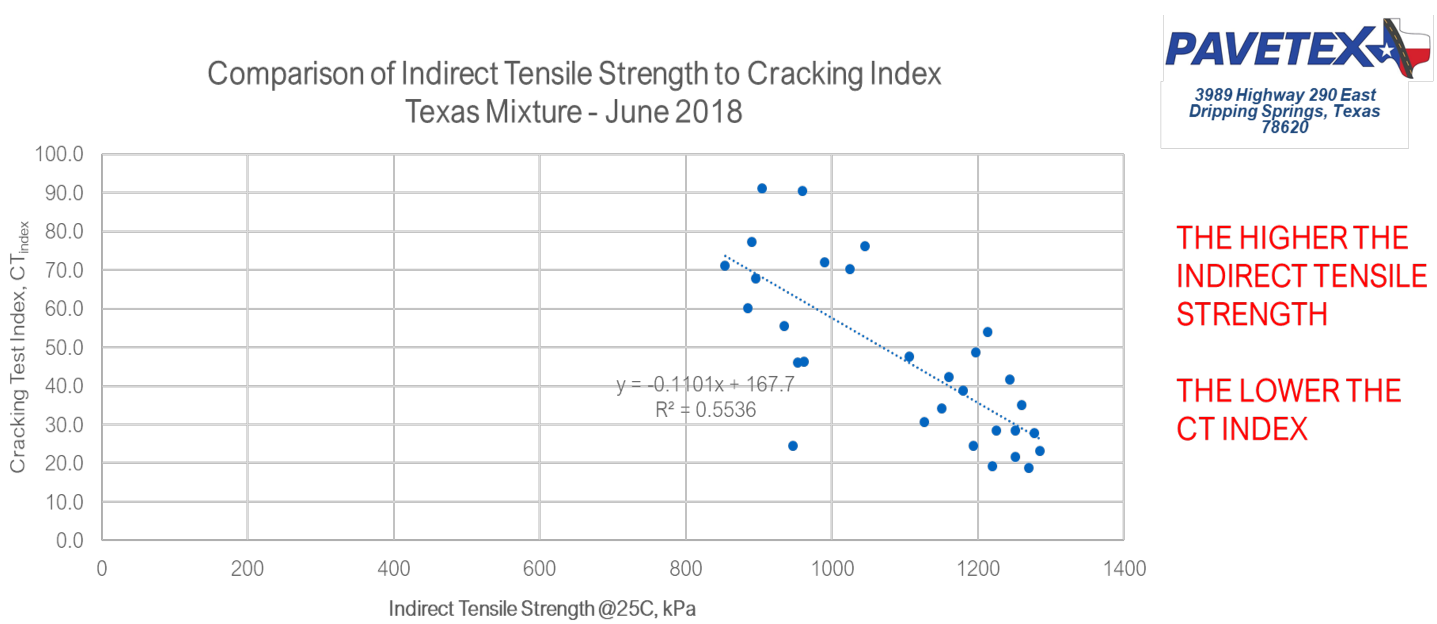


Table 23 – IDEAL CT Dosing Study for Lab Produced KYTC PG64-22 Mix Design – 38mm Length ACE XP Polymer Fiber

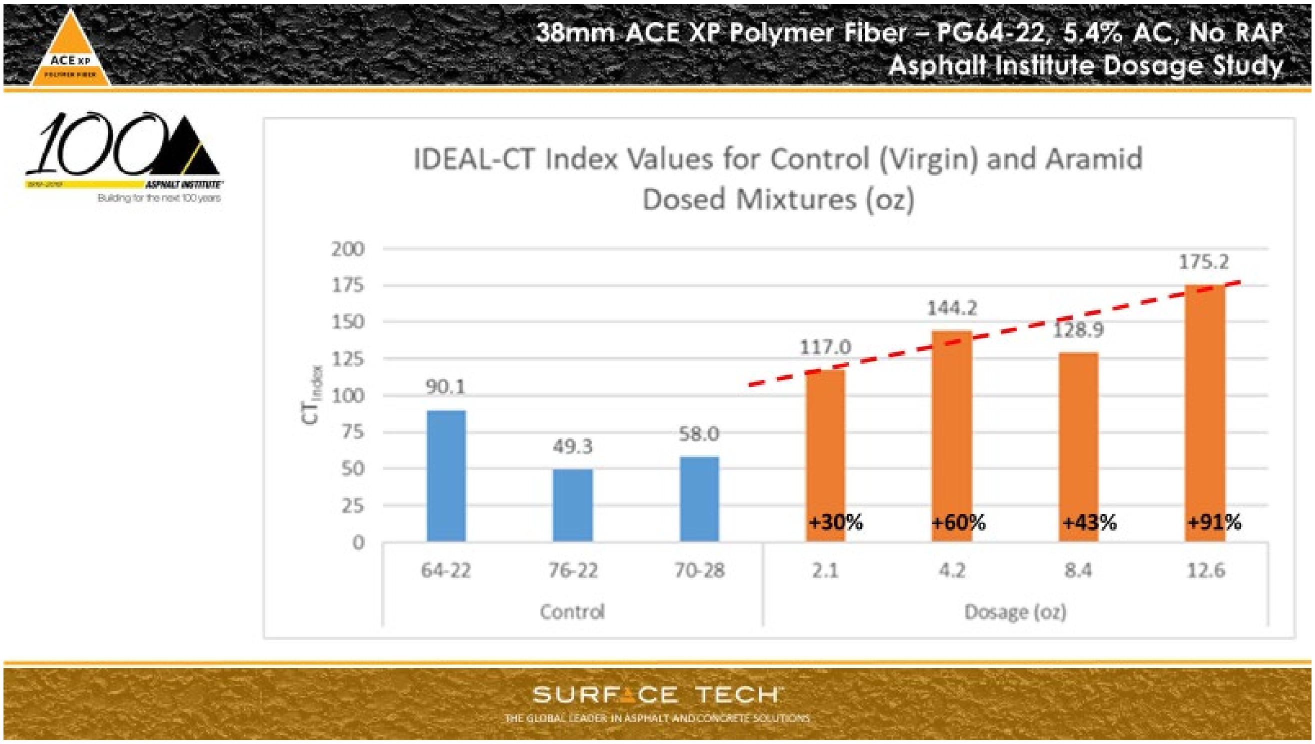


Table 24 – IDEAL CT Dosing Study for Plant Produced KYTC PG64-22 Mix Design – 38mm Length ACE XP Polymer Fiber

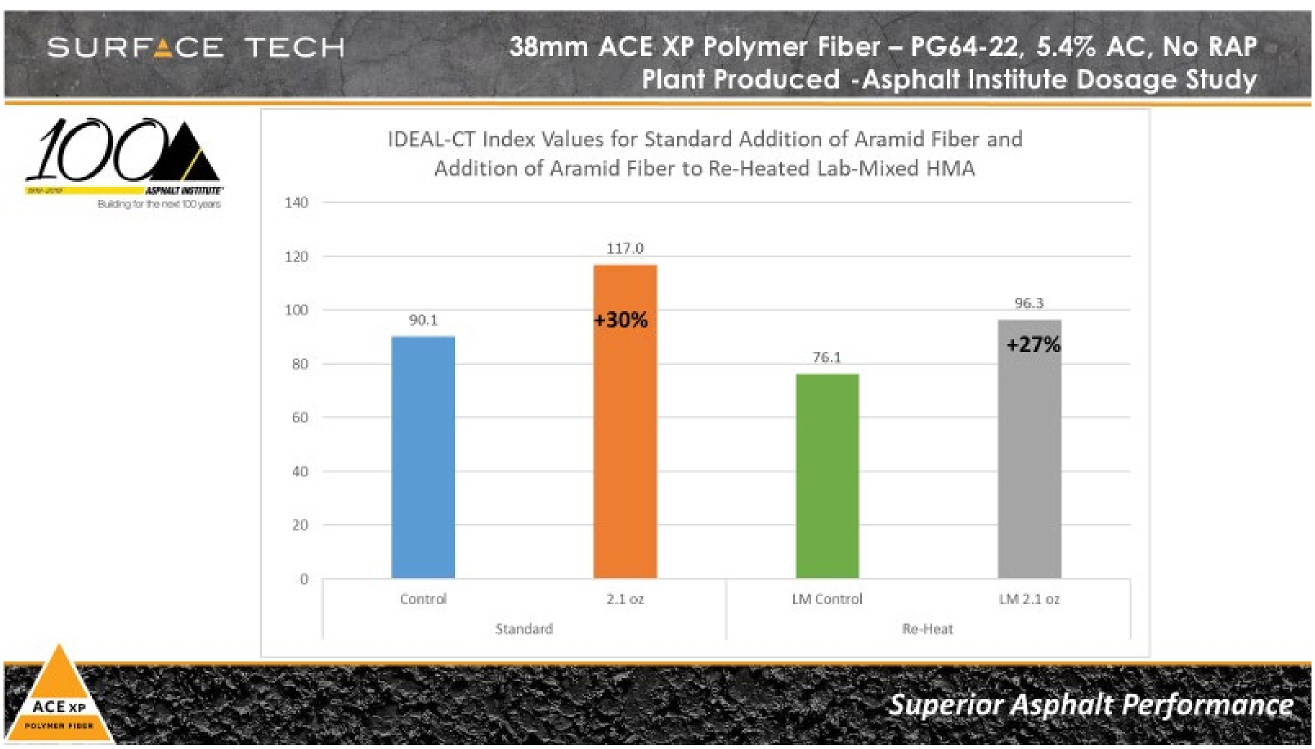


Table 25 – IDEAL CT Dosing Study for The Loves Corporation – Plant Mix to compare 2x Dose of ACE XP in PG64-22 vs 1x Dose of ACE XP in PG70-22M (Polymer Modified)

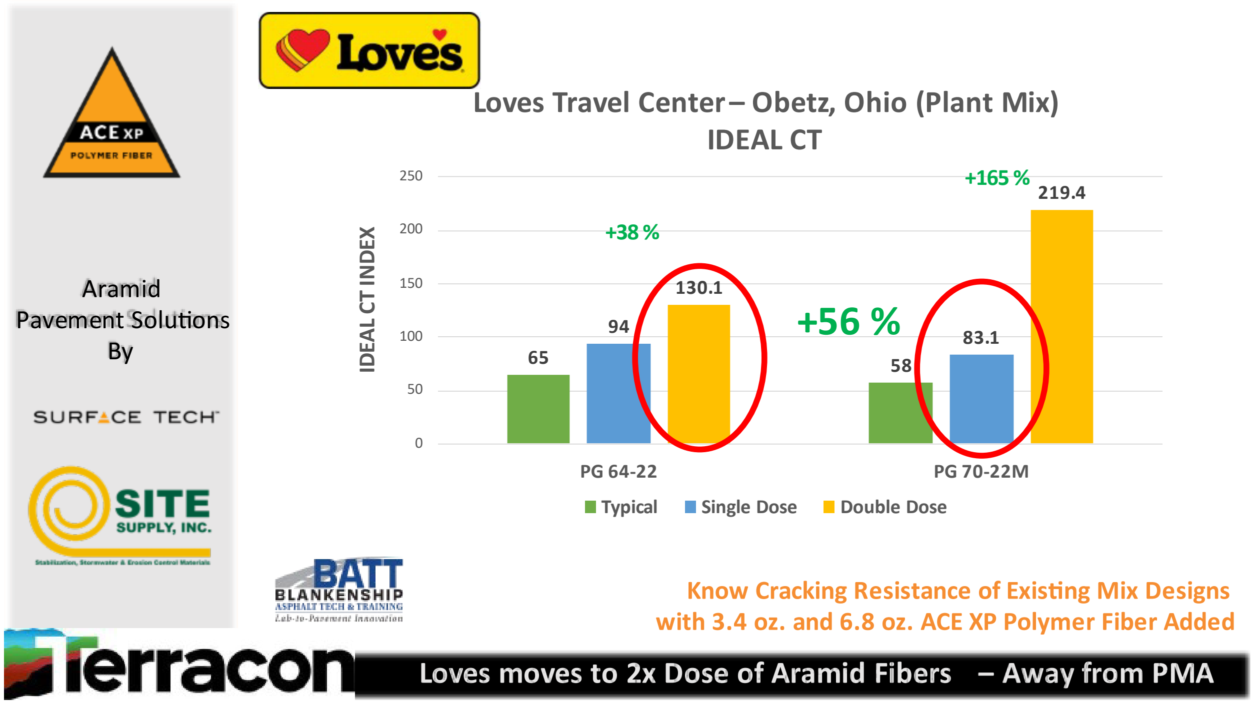
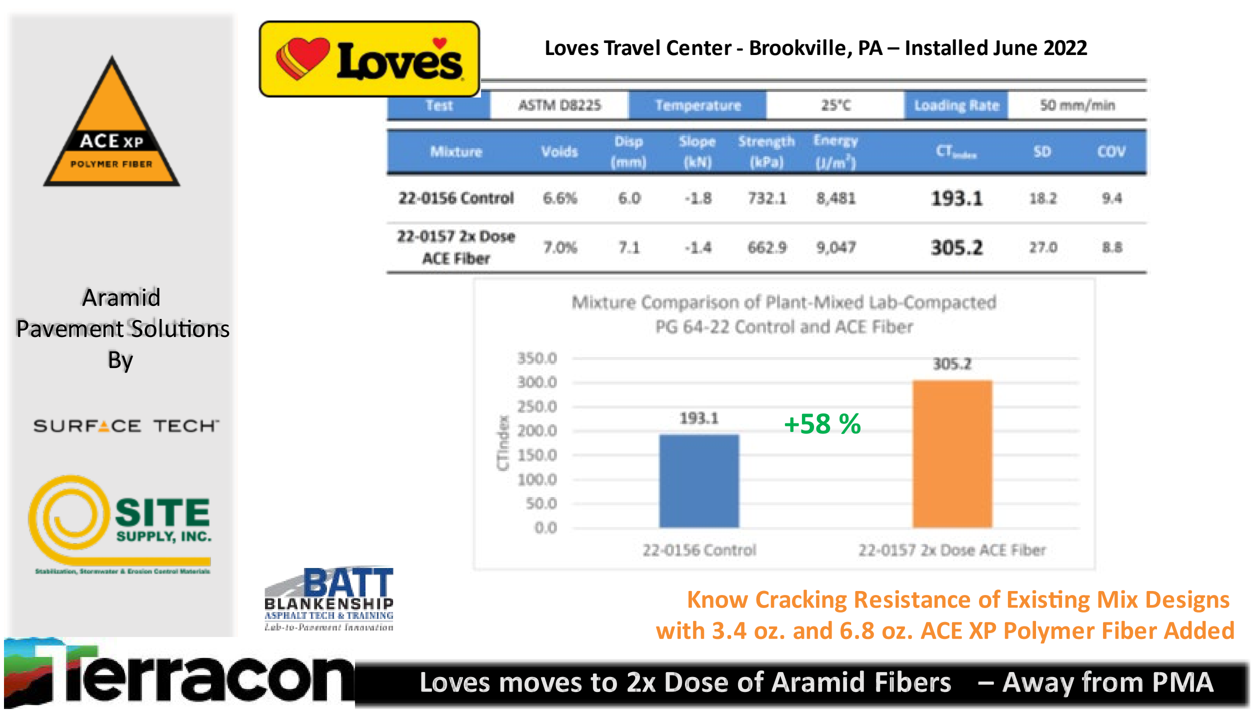


Table 26 – IDEAL CT for The Loves Corporation – Plant Mix to compare 2x Dose of ACE XP in PG64-22 vs 1x Dose of ACE XP in PG64-22


Loves Travel Center - Brookville, PA – Installed June 2022

Test	ASTM D8225	Temperature	25°C	Loading Rate	50 mm/min

Mixture	Voids	Disp (mm)	Slope (kN)	Strength (kPa)	Energy (J/m²)	CT_{index}	SD	COV
22-0156 Control	6.6%	6.0	-1.8	732.1	8,481	193.1	18.2	9.4
22-0157 2x Dose ACE Fiber	7.0%	7.1	-1.4	662.9	9,047	305.2	27.0	8.8

Table 27 – IDEAL CT for KYTC Christian County Project – Plant Produced by Rogers Group – PG64-22 with & without ACE XP

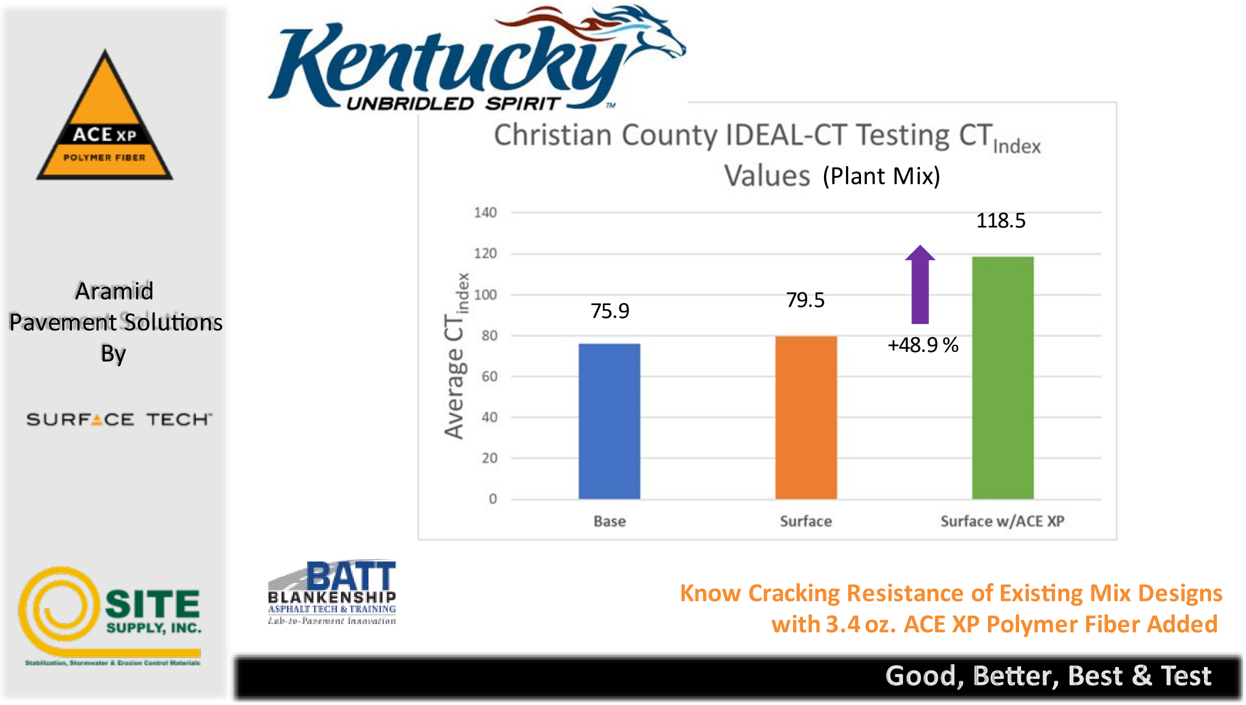
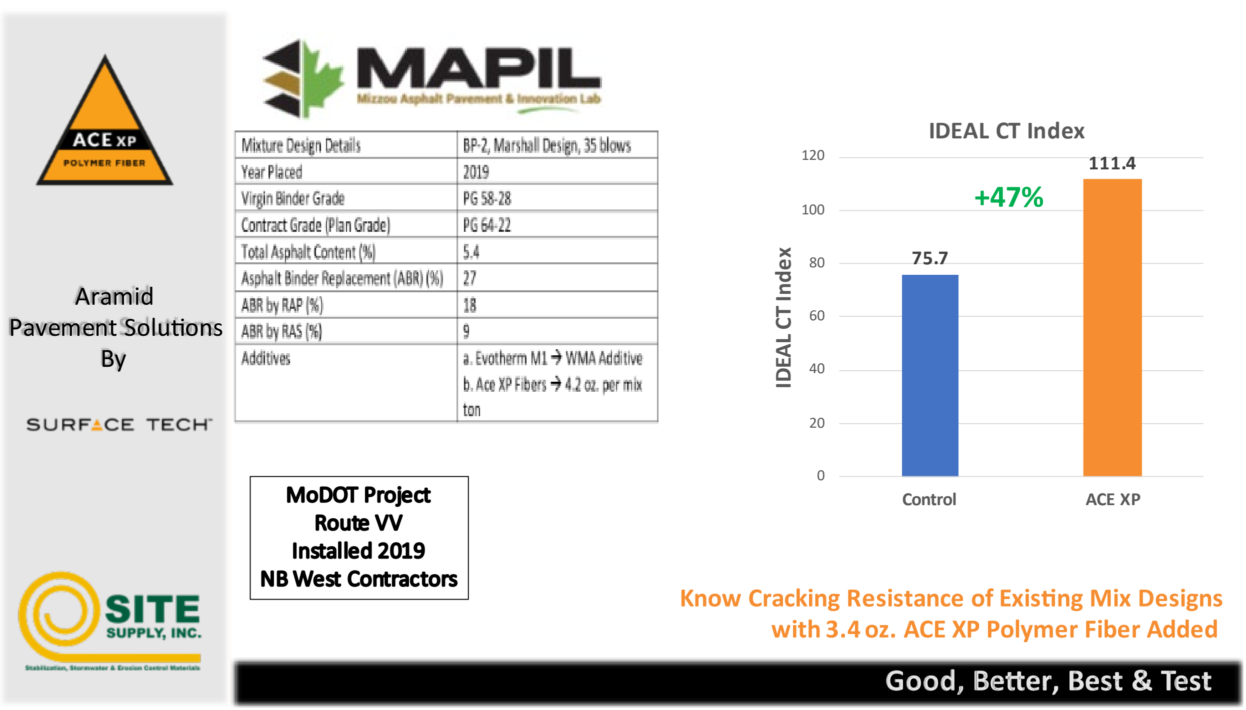


Table 28 – IDEAL CT by MAPIL for MoDOT – Plant Produced by NB West for Route VV outside St. Louis. PG64-22 with and without ACE XP



Mixture Design Details	BP-2, Marshall Design, 35 blows
Year Placed	2019
Virgin Binder Grade	PG 58-28
Contract Grade (Plan Grade)	PG 64-22
Total Asphalt Content (%)	5.4
Asphalt Binder Replacement (ABR) (%)	27
ABR by RAP (%)	18
ABR by RAS (%)	9
Additives	a. Evotherm M1 → WMA Additive b. Ace XP Fibers → 4.2 oz. per mix ton

Table 29 – IDEAL CT by FDOT for Brevard County Florida – Plant Produced by VA Paving for Falcon Blvd using PG58-28 with 38% RAP with and without ACE XP

ACE XP POLYMER FIBER

Aramid Pavement Solutions By

SURFACE TECH

SITE SUPPLY, INC.

FDOT

Fiber Study 2019 **+35.0 %**

Ace Control			Ace Fiber		
Gmm		2.473	Gmm		
Specimen ID	% Va	Ideal-CT Index	Specimen ID	% Va	Ideal-CT Index
Specimen 1	6.7	20.8	Specimen 1	7.2	29.7
Specimen 2	7.0	16.3	Specimen 2	7.2	21.1
Specimen 3	6.9	22.2	Specimen 3	7.0	26.2
Specimen 4	6.8	20.6	Specimen 4	7.0	30.7

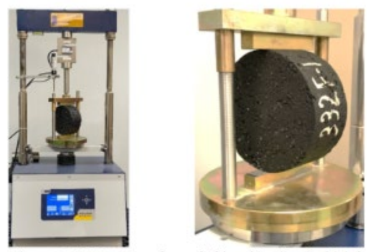
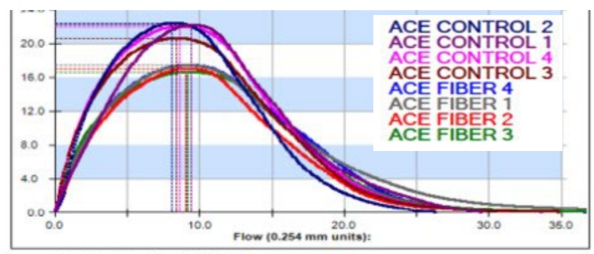


Figure 1 – IDEAL-CT test frame (left) and loading jig (right)



In order of peak load (High to Low):

35% Average Improvement in IDEAL CT Crack Test

Bending Beam Fatigue Test (BBF)

Test Method per ASTM D8237-18

Performed by University of California – Pavement Research Center

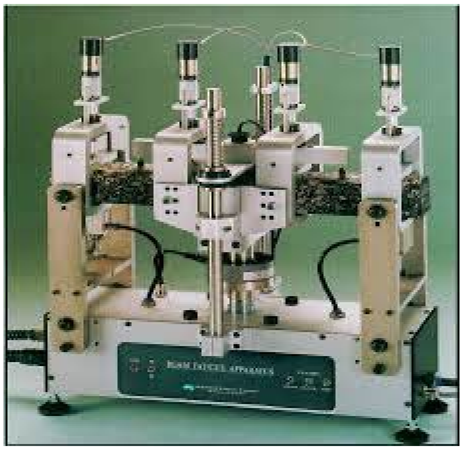


Fig. 25 – 4 Point Bending Beam Apparatus

Test Summary:

The flexural fatigue test is performed by placing a beam of HMA in repetitive four-point loading at a specified strain level. During the test, the beam is held in place by four clamps and a repeated haversine (sinusoidal) load is applied to the two inner clamps with the outer clamps providing a reaction load (Figure 25). The load rate is variable but is normally set at 1 to 10 Hz. This setup produces a constant bending moment over the center portion of the beam (between the two inside clamps). The deflection caused by the loading is measured at the center of the beam. The number of loading cycles to failure can then give an estimate of a particular HMA mixture's fatigue life. Small HMA beams (15 x 2 x 2.5 inches (380 x 50 x 63 mm)) are made and placed in a 4-point loading machine, which subjects the beam to a repeated load.

Fig. 26 – Preparation of Asphalt Concrete Beams

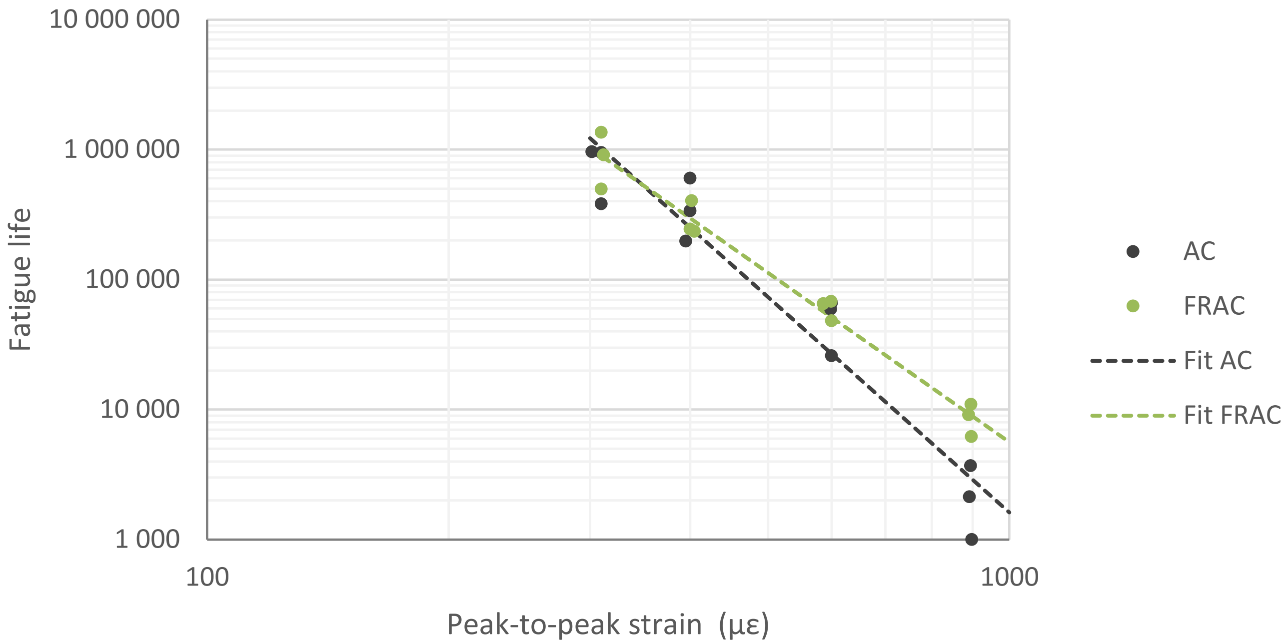
Beam fatigue testing is performed at intermediate temperatures, usually 68°F (20°C), because fatigue cracking is thought to be a primary HMA distress at these intermediate temperatures. At higher in-service temperatures (above about 100°F (38°C)) rutting is usually the HMA distress of greatest concern, while at lower temperatures (below about 40 °F (4°C)) thermal cracking is usually the HMA distress of greatest concern.

Fig. 27 – Typical Beam Test Sample

Results:

Three strain levels were initially applied in order to test the two mixes' fatigue resistance: 300, 400, and 600 με (peak to peak). At the two lower strain levels, 300 and 400 με, the fibers did not seem to impact the asphalt mix's fatigue life. However, figure 28 below shows that at the 600 με strain level, addition of the fibers resulted in a ***90 percent*** increase in fatigue life. After these results were obtained, a decision was made to conduct additional testing at 900 με to verify that the impact on fatigue resistance was strain-dependent. This additional testing confirmed the strain sensitivity of the fibers' reinforcing effect: at 900 με, addition of the fibers resulted in a ***200 percent*** increase in asphalt mix fatigue life. A strain level as high as this may occur in asphalt overlays of jointed concrete pavements or on overlays of pavements with considerable cracking. Importantly, this indicates that the addition of the aramid fibers to the asphalt mix should provide improved resistance to cracking when subjected to high strains in the field as seen in reflective cracking.

Figure 28: Fatigue resistance of the asphalt mixes (4PB flexural beam testing, 20°C/68°F and 10 Hz).



Stiffness & Rutting Resistance

Test Method per AASHTO T 378-17

(using the asphalt mixture performance tester, AMPT)

Performed by University of California – Pavement Research Center

UCPRC
UNIVERSITY of CALIFORNIA | PAVEMENT RESEARCH
Davis • Berkeley | CENTER

Test Summary:

This test method describes procedures for measuring the dynamic modulus and flow number for asphalt mixtures.

In the flow number procedure, a specimen at a specific test temperature is subjected to a repeated haversine axial compressive load pulse of 0.1 s every 1.0 s. The test may be conducted with or without confining pressure. The resulting permanent axial strains are measured as a function of the load cycles and numerically differentiated to calculate the flow number. The flow number is defined as the number of load cycles corresponding to the minimum rate of change of permanent axial strain.

Test temperature and frequency ranges for this specific stiffness tests were, respectively, 4 to 40°C (39 to 104°F) and 0.1 to 25 Hz. Rutting resistance was determined with unconfined repeated loading test at 45 and 55°C (113 and 131°F).

The test was concluded when permanent deformation of 5% was reached. The number of cycles to reach 5% was counted and compared.

Fig. 29 – Typical AMPT Set Up

Fig. 30 – Typical AMPT Set Up

Results:

The mixes' resistance to permanent deformation was tested with the unconfined repeated loading test at 45 and 55°C (113 and 131°F). The results are shown in **Error! Reference source not found.**31. Adding the fibers increased the mix's resistance to permanent deformation considerably. At 45°C (113°F), the number of load repetitions to reach 5 percent permanent deformation increased ***46 percent*** (FRAC versus the original mix), while the increase was ***18 percent*** at 55°C (131°F). The fact that the increase was larger at 45°C than at 55°C may be related to the stronger adhesion between the fibers and binder at 45°C compared to 55°C.

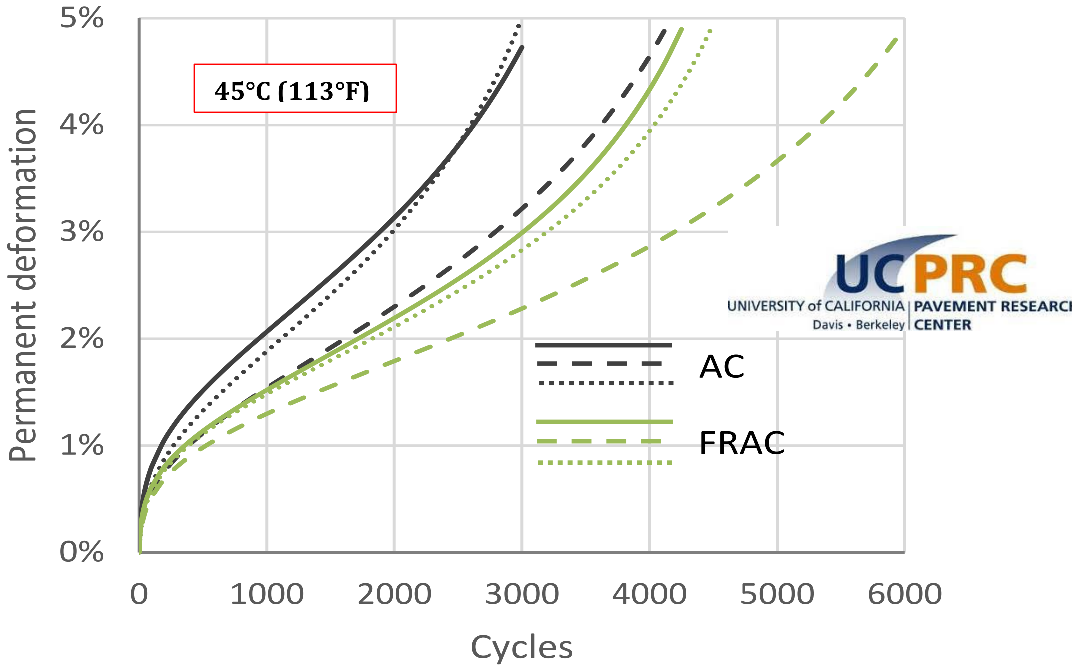
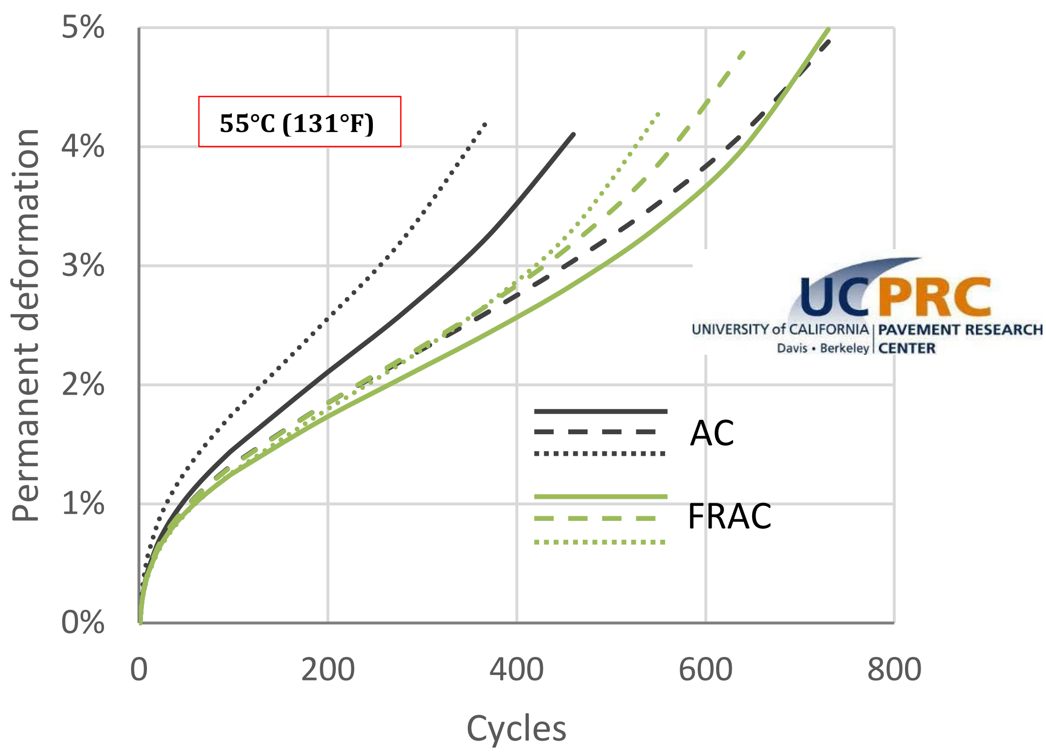


Figure 31: Permanent deformation of the asphalt mixes (AMPT repeated loading testing)



Extraction Test of Aramid Fibers

Test Method per ASTM D2172

Performed by Advanced Asphalt Technologies And Asphalt Institute

Test Summary:

The purpose of the test method is to determine the amount of recovered fiber from fiber reinforced asphalt concrete (FRAC) and calculate the Aramid Dispersion State Ratio (ADSR). The test method utilizes ASTM D2172 to extract the asphalt binder from FRAC samples. The amount of fiber remaining after extraction is measured by washing, sieving, manually removing the fiber, and recording total fiber mass. Due to the light weight nature of aramid fiber and residual AC binder present on the fiber after extraction, the extracted fiber content will measure higher than the amount of fiber added at the time of mixing. The amount of extracted fiber is reported as a percentage of total sample size. The Solvent used as part of ASTM D2172 is Trichloryl Ethylene, which was found to yield no negative reaction with the fiber produce. CAUTION should be used when handling this solvent.

Figure 32

Results:

Both Advanced Asphalt Technologies (AAT) and Asphalt Institute (AI) ran this extraction test. The samples containing ACE Fiber were individually removed from the sieves after the sieving operation. These ACE Fibers were added to the bulk ACE Fibers collected. The ACE Fibers were then soaked with solvent, washed, and dried to constant mass at 110°C and the mass of the ACE Fibers in each sample was determined. All results of the extraction of ACE Fibers from the mixture samples are listed in Table 22 Below.

Table 30 - ACE XP Polymer Fiber Extraction Test Results per ASTM

ACE Fiber Sample	Test Lab	% Extracted Fibers (%)	Weight of Fibers (oz./ton)
ACE XP Sample 1	AAT	.007	2.3
ACE XP Sample 2	AAT	.007	2.4
ACE XP Sample 3	AI	.014	4.5
ACE XP Sample 4	AI	.009	2.9
ACE XP Sample 5	AI	.008	2.4
ACE XP Sample 6	AI	.005	2.1
Average:		**.008**	**2.8**

ADSR Test of Aramid Fibers

Aramid Dispersion State Ratio

Performed by Advanced Asphalt Technologies And Asphalt Institute

Test Summary:

The purpose of the test method is to determine the amount of recovered fiber from fiber reinforced asphalt concrete (FRAC) and calculate the Aramid Dispersion State Ratio (ADSR). The test method utilizes ASTM D2172 to extract the asphalt binder from FRAC samples. The amount of fiber remaining after extraction is measured by washing, sieving, manually removing the fiber, and recording total fiber mass. Due to the light weight nature of aramid fiber and residual AC binder present on the fiber after extraction, the extracted fiber content will measure higher than the amount of fiber added at the time of mixing. The amount of extracted fiber is reported as a percentage of total sample size. The Solvent used as part of ASTM D2172 is Trichloryl Ethylene, which was found to yield no negative reaction with the fiber produce. CAUTION should be used when handling this solvent.

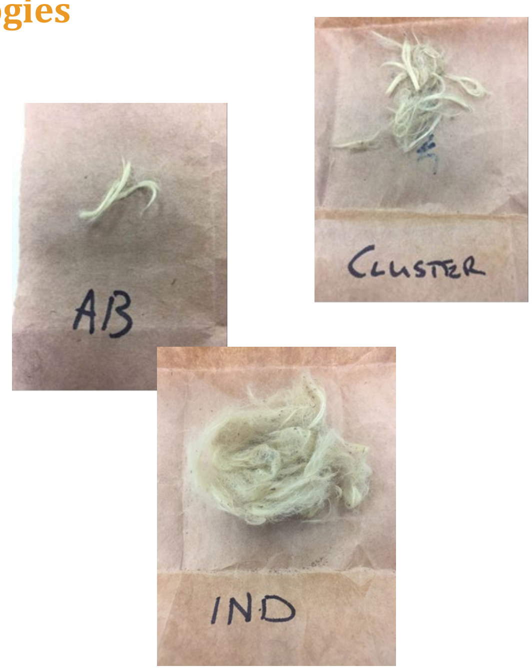


Figure 33

Results:

Both Advanced Asphalt Technologies (AAT) and Asphalt Institute (AI) ran this ADSR classification. This is a visual observation and subject to human judgement and thus not the most repeatable process. Extreme care should be taken when separating the fibers for ADSR classification. Table 23 shows the dispersion classification and % weights of each dispersion state of the extracted fiber. The *"bundled state"* is the worst case where the extracted fiber does not disperse, followed by the *"agitated bundle"*, *"cluster"*, and finally the ***"individual"*** classification, which indicates the ***best*** dispersion.

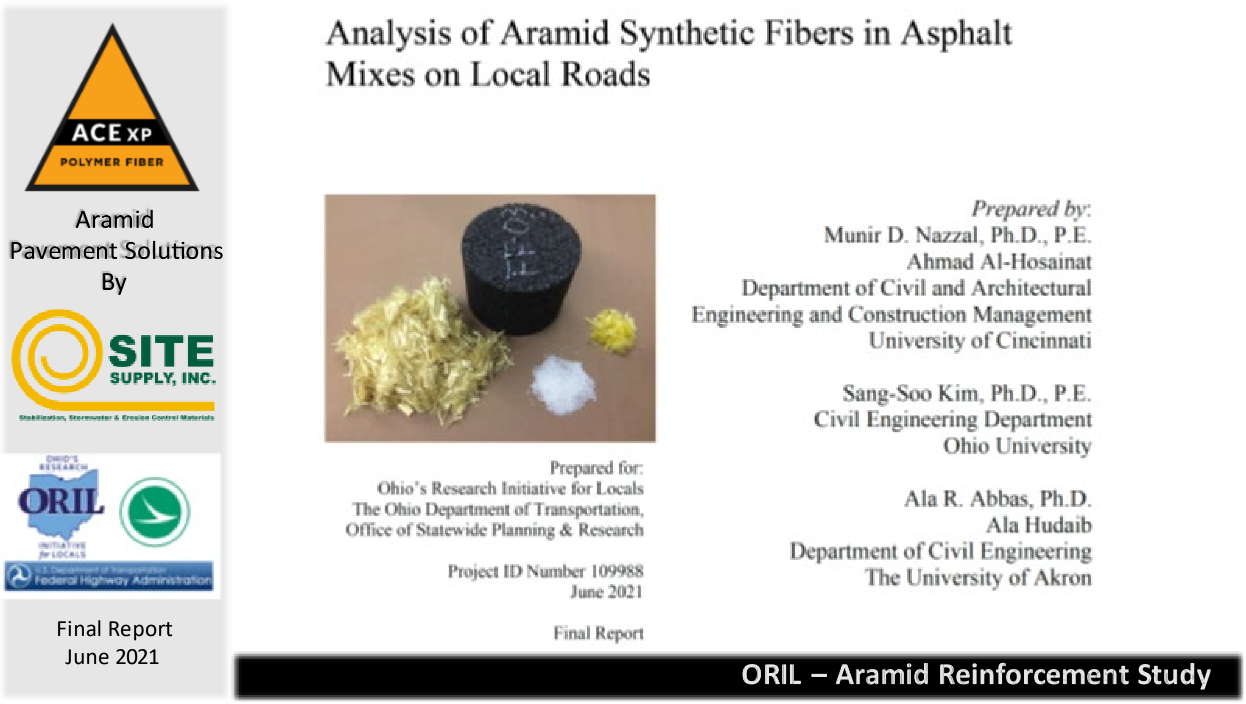
Table 31 - ACE XP Polymer Fiber ADSR Classification

ACE Fiber Sample	Test Lab	Bundled Fibers (%)	Agitated Bundle (%)	Cluster (%)	Individual (%)	ADSR (%)
ACE XP Sample 1	AAT	0.0	0.0	10.9	89.1	89.1
ACE XP Sample 2	AAT	0.0	0.0	16.8	83.2	83.2
ACE XP Sample 3	AI	0.0	0.0	20.0	80.0	80.0
ACE XP Sample 4	AI	0.0	2.2	9.2	88.6	88.6
ACE XP Sample 5	AI	0.0	0.0	14.8	85.2	85.2
ACE XP Sample 6	AI	0.0	0.0	8.2	91.8	91.8
Average:						**86.3%**

Life Cycle Cost Analysis – Aramid Fiber

Crack study performed for the City of Columbus, Ohio

Performed by university of Cincinnati, Ohio, and Akron for Ohio Research Initiative for Locals (ORIL) Sponsored by ODOT & FHWA



Program Summary:

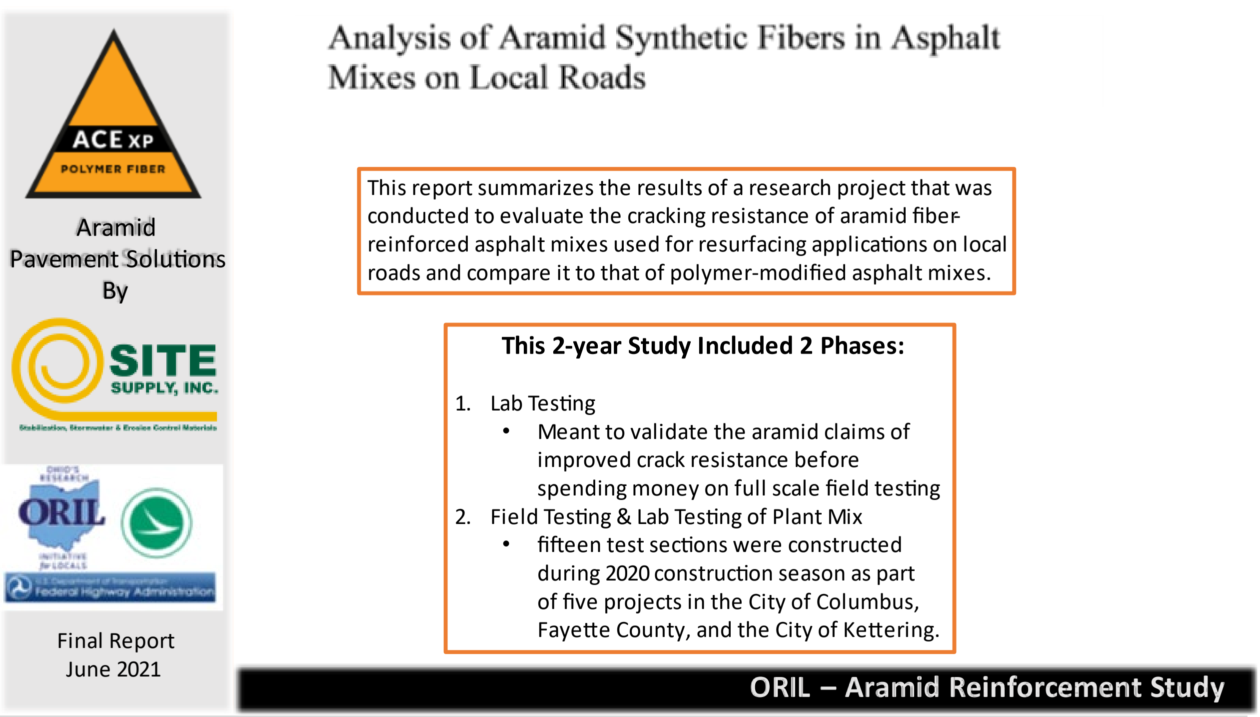
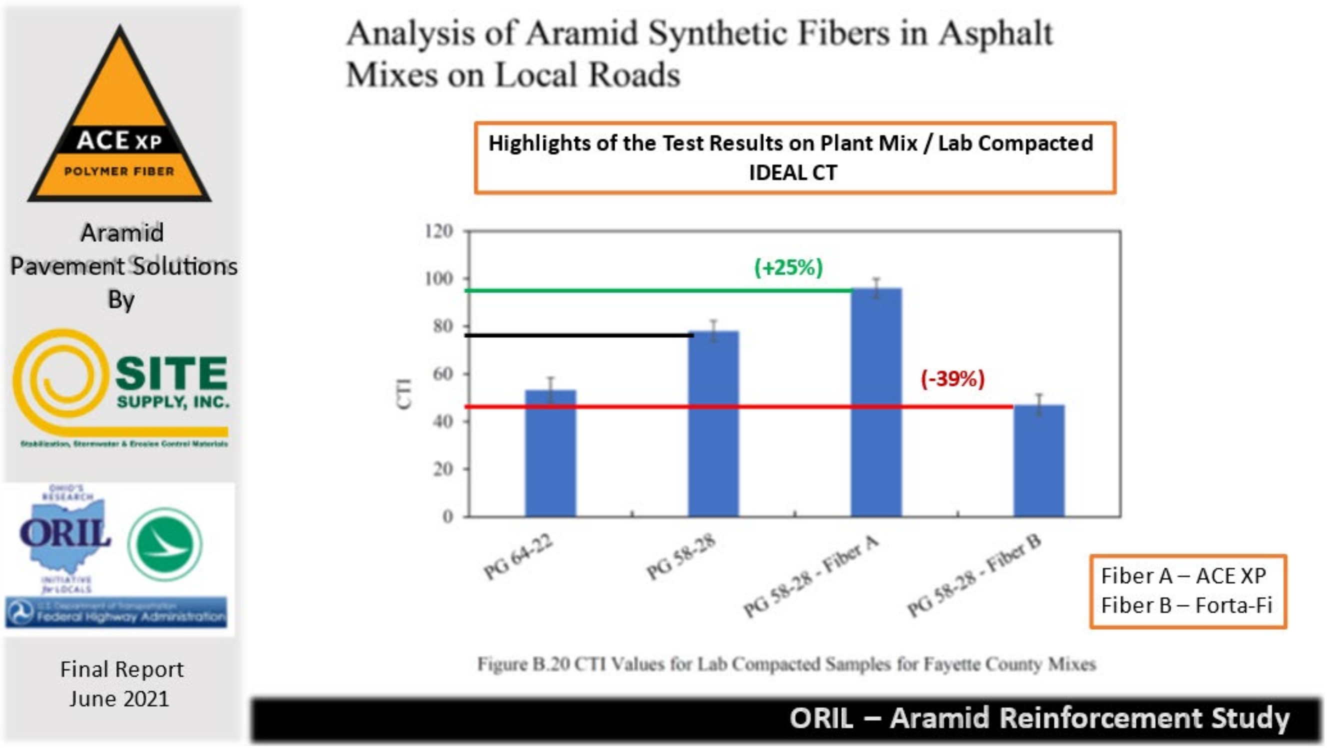
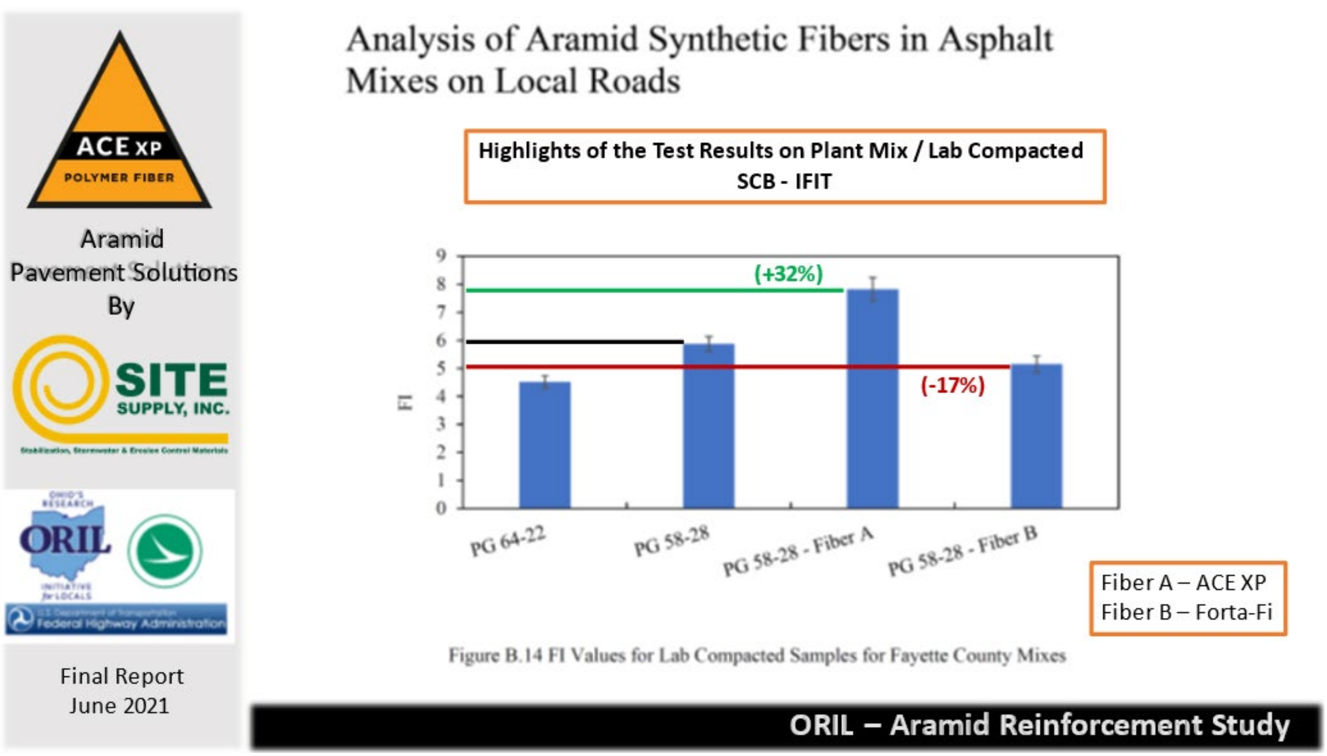


Table 32 – ORIL Study (ODOT/FHWA) – IDEAL CT & SCB Cracking Test Lab results comparing Mix Designs with and without ACE XP and Forta Fibers





Life Cycle Cost Analysis – Aramid Fiber

Crack study performed for the City of Columbus, Ohio

Performed by university of Cincinnati, Ohio, and Akron for Ohio Research Initiative for Locals (ORIL)

Sponsored by ODOT & FHWA

Table 33 – Predicting Service Life by Calculating the Fatigue Life Using FHWA ALF Data

ACE XP POLYMER FIBER

Aramid Pavement Solutions By SITE SUPPLY, INC.

Final Report
June 2021

Analysis of Aramid Synthetic Fibers in Asphalt Mixes on Local Roads

Predicting Service Life by Calculating the Fatigue Life Using FHWA ALF Data

FHWA constructed test sections at the FHWA Pavement Test Facility (Figure E.1) with various asphalt mixtures with identical pavement structure to study fatigue behavior of asphalt mixes. While continuously applying traffic loading using two units of Accelerated Loading Facility (ALF), the fatigue performance characteristics of these test sections were recorded and have been compared with various laboratory test results including SCB Flexibility Index (FI) (1), IDEAL-CT Cracking Tolerance Index (2) and the number of cycles to failure in Overlay Tester (3). These relationships between FHWA ALF data and the laboratory test data are presented in Figures E.2, E.3, and E.4 for SCB, IDEAL-CT, and Overlay Tester, respectively. All three relationships showed high goodness of fit with R-square values ranging from 89% to 96%.

ORIL – Aramid Reinforcement Study

ACE XP POLYMER FIBER

Aramid Pavement Solutions By SITE SUPPLY, INC.

Final Report
June 2021

Analysis of Aramid Synthetic Fibers in Asphalt Mixes on Local Roads

Predicting Service Life by Calculating the Fatigue Life Using FHWA ALF Data

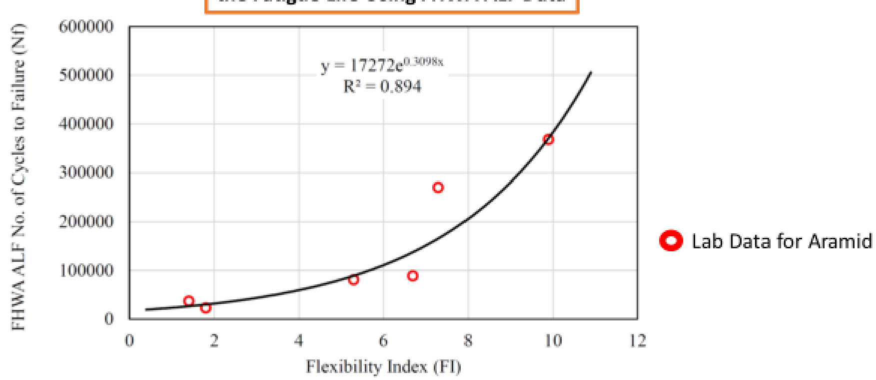


Figure E.2 FHWA ALF number of cycle to fatigue failure versus SCB Flexibility Index (FI)

ORIL – Aramid Reinforcement Study

Table 33 (continued) – Predicting Service Life by Calculating the Fatigue Life Using FHWA ALF Data

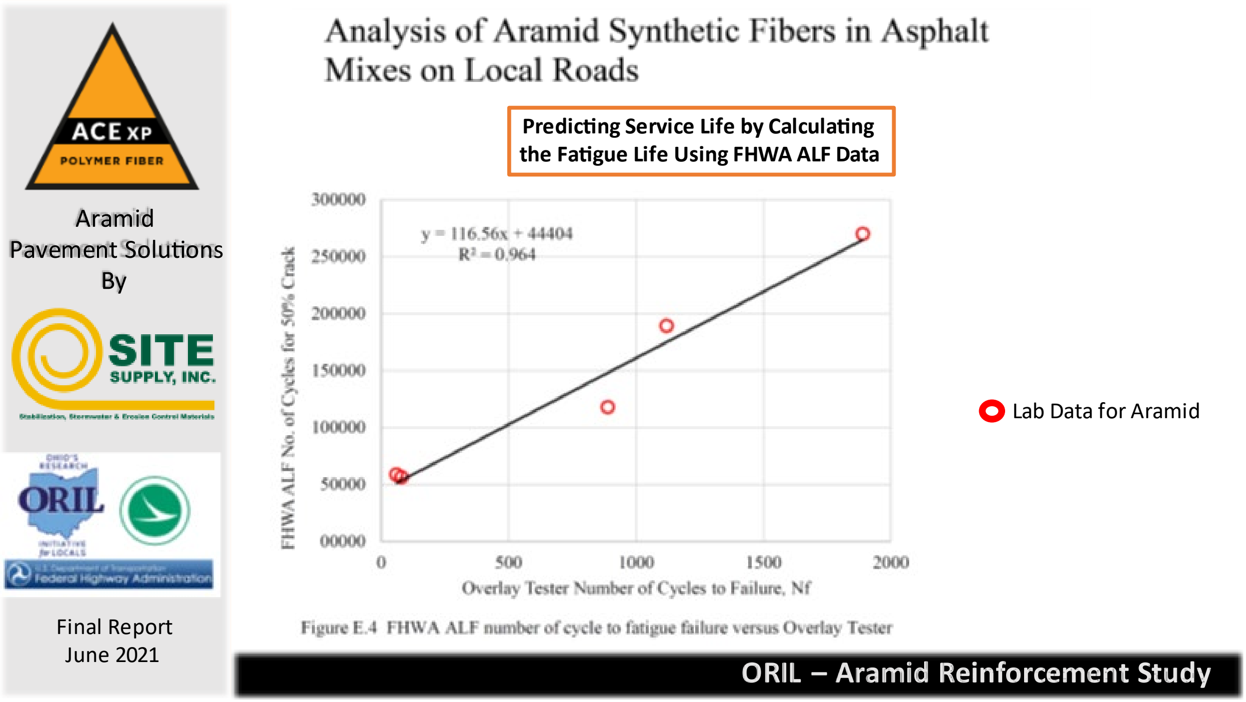


Figure E.4 FHWA ALF number of cycle to fatigue failure versus Overlay Tester

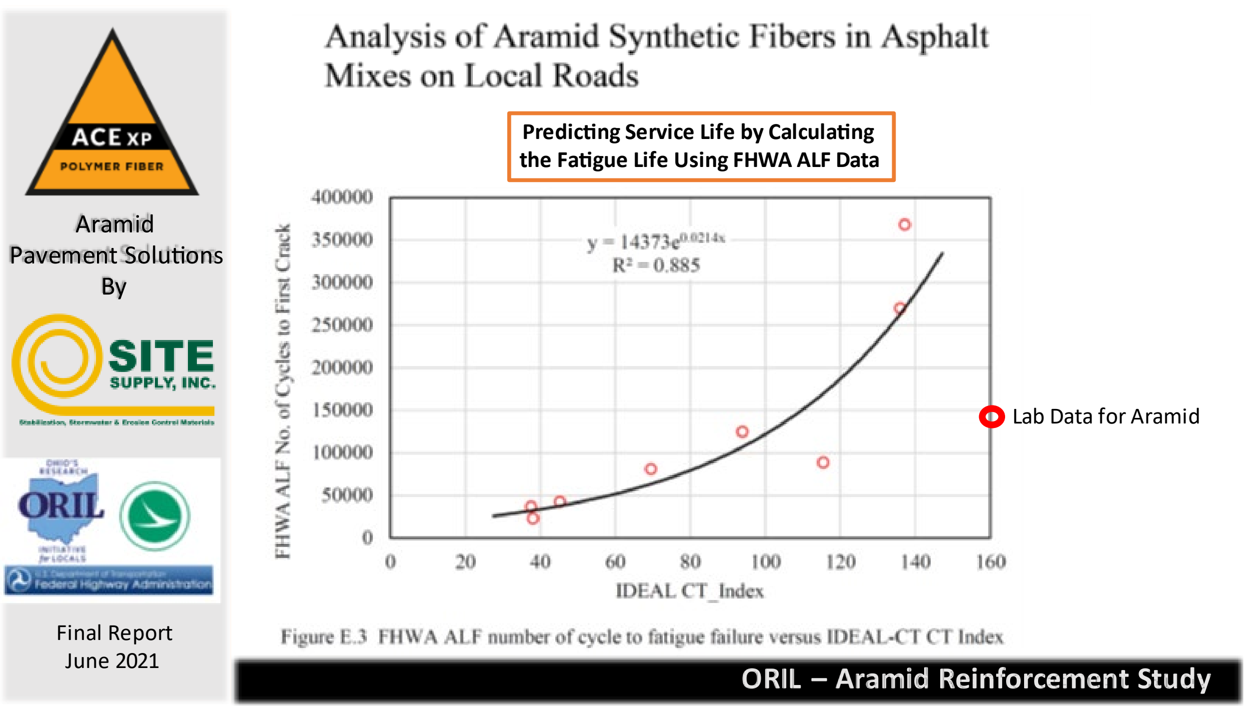


Figure E.3 FHWA ALF number of cycle to fatigue failure versus IDEAL-CT CT Index

Table 34– Predicting Service Life by Calculating the Fatigue Life Using FHWA ALF Data – Summary & Results

Aramid Pavement Solutions By

Final Report
June 2021

Analysis of Aramid Synthetic Fibers in Asphalt Mixes on Local Roads

Predicting Service Life by Calculating the Fatigue Life Using FHWA ALF Data

Table E.1 Predicted service life of asphalt mixes

	Predicted Nf (x 1000)			% Increase of Nf with Respect to PG 64-22 Mix				Service Life, year
Mix ID	OT	IDEAL	SCB	OT	IDEAL	SCB	Average	
PG 64-22	45	29	27	-	-	-	-	9.0
PG 70-22M	45	41	30	-1%	40%	11%	17%	10.5
64AL1.5	47	60	57	3%	105%	109%	72%	15.5
64AL1	45	50	93	0%	70%	241%	104%	18.4
64BS1	46	35	74	2%	21%	172%	65%	14.9

It should be noted that the expected service life for an unmodified PG 64-22 mix overlay with a typical 1.5 in. thickness was assumed to be 9 years. The service lives of other mixes were calculated by proportionally increasing the 9 year service life as much as the average percent increase of predicted number of cycles to failure with respect to PG 64-22 mix.

ORIL – Aramid Reinforcement Study

Aramid Pavement Solutions By

Final Report
June 2021

Analysis of Aramid Synthetic Fibers in Asphalt Mixes on Local Roads

Table E.2 Unit cost of materials used for initial cost calculation

Material	Unit Cost
PG 64-22 Asphalt Mix	$149.50 per Cubic Yard
PG 70-22M Asphalt Mix	$174.96 per Cubic Yard
Type A Aramid Fiber	$8.50 per ton of mix
Type B Aramid Fiber	$6.75 per ton of mix

Predicting Cost Savings by Calculating the Fatigue Life Using FHWA ALF Data

ACE Fiber = $6.50 / TE
Service = $2.00 / TE

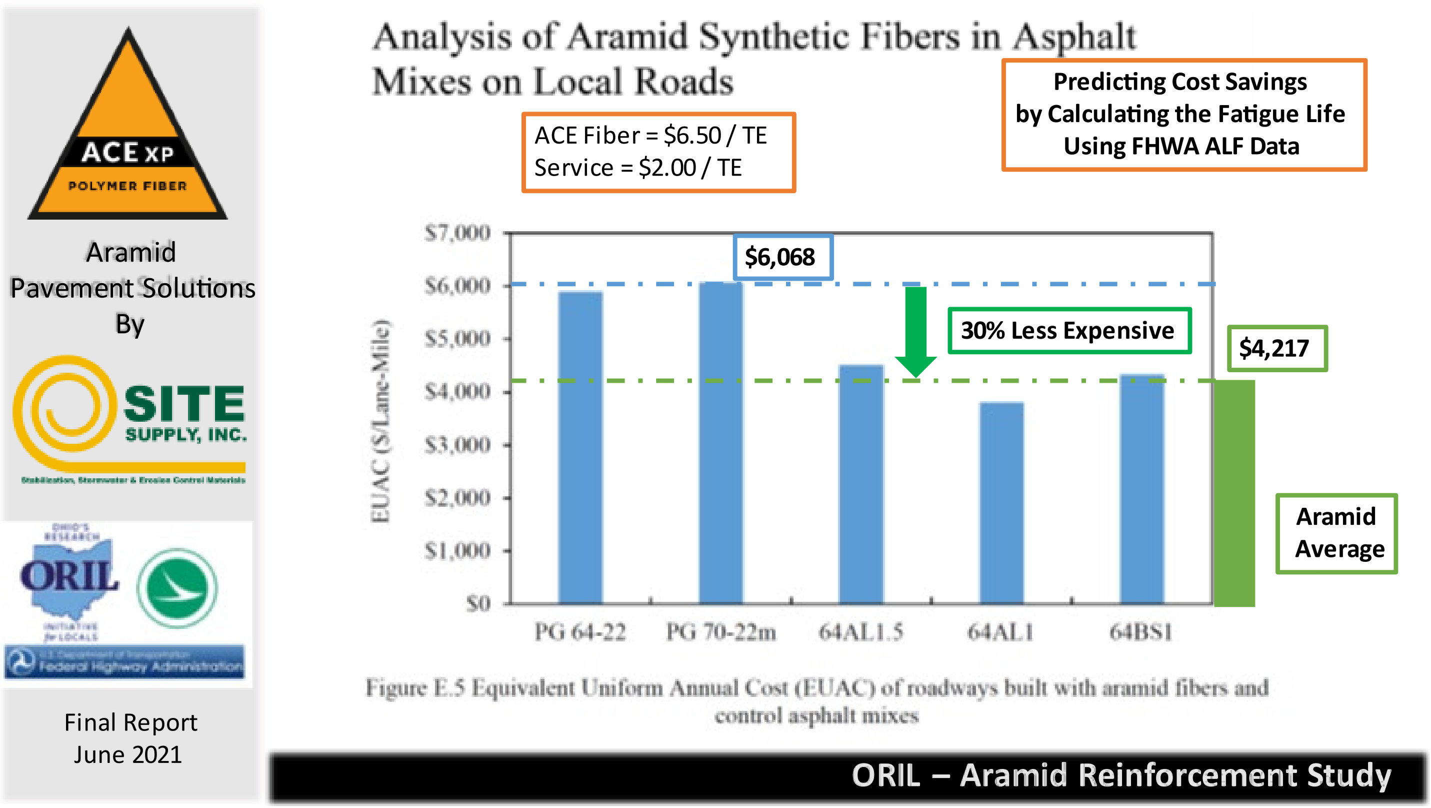
Table E.3 Equivalent Uniform Annual Cost (EUAC) of roadways built with aramid fibers and control asphalt mixes

	Average Nf Increase	Service Life in Year	Initial Cost of Overlay per Lane-Mile	EUAC (Yearly Cost) per Lane-Mile
PG 64-22	-	9.0	$43,853	$5,898
PG 70-22M	17%	10.5	$51,322	$6,068
64AL1.5	72%	15.5	$51,333	$4,512
64AL1	104%	18.4	$48,840	$3,806
64BS1	65%	14.9	$47,813	$4,332

Average $4,217

ORIL – Aramid Reinforcement Study

Table 34 (Continued) – Predicting Service Life by Calculating the Fatigue Life Using FHWA ALF Data – Summary & Results



Falling Weight Deflectometer (FWD) Testing

Evaluate the in-place Modulus of Various Roadways

Performed by S&ME

Figure 34– Location Map for FWD Testing on KY US31

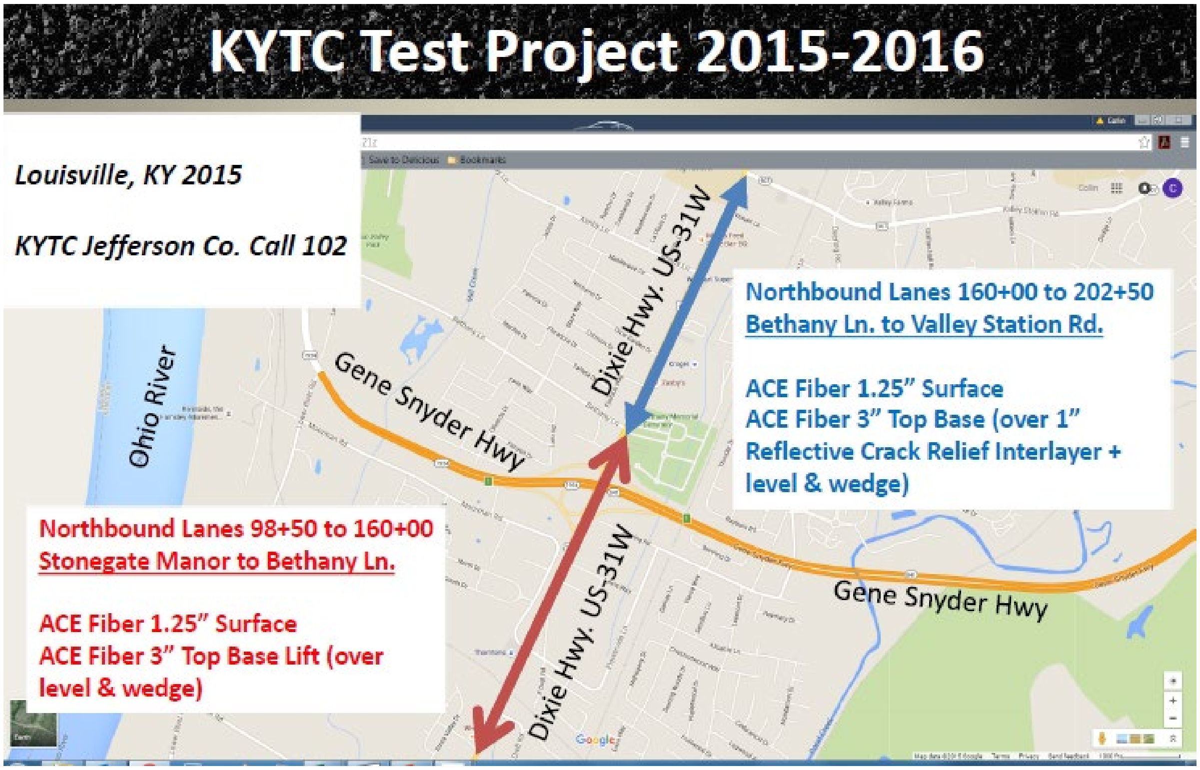


Figure 35– Pictures of Crack Performance on KY US31

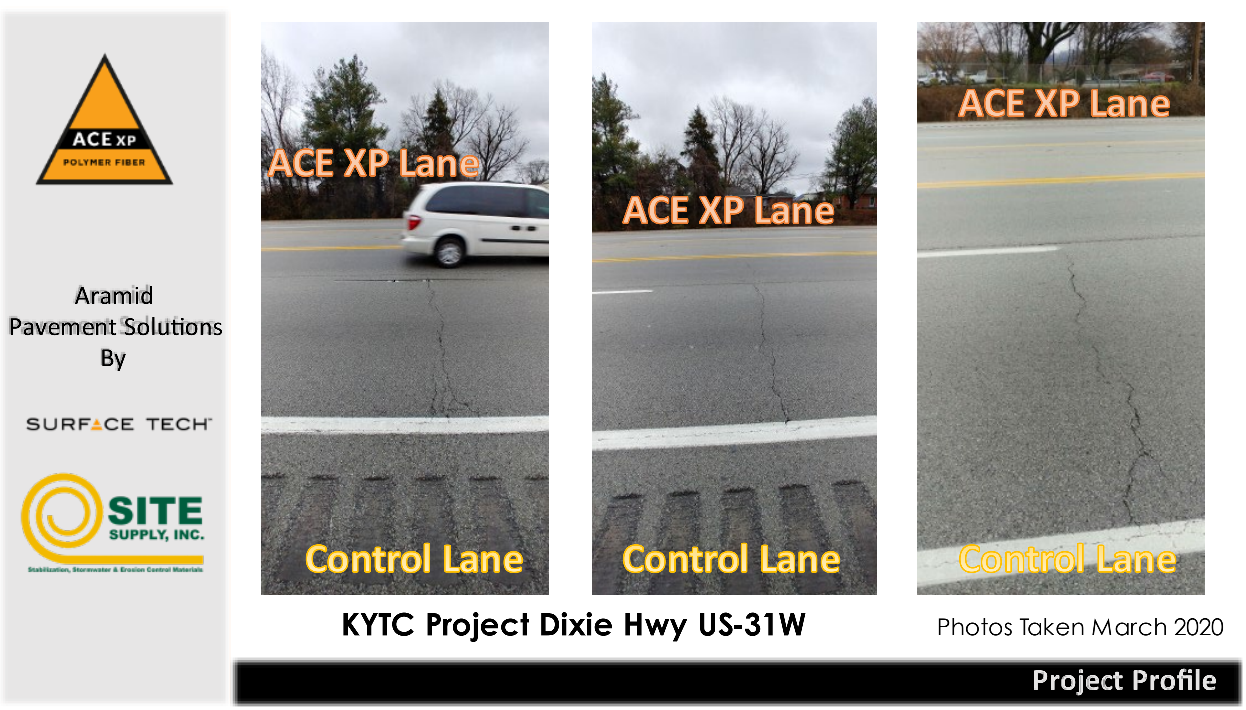


Figure 36 – FWD Data from KY US31

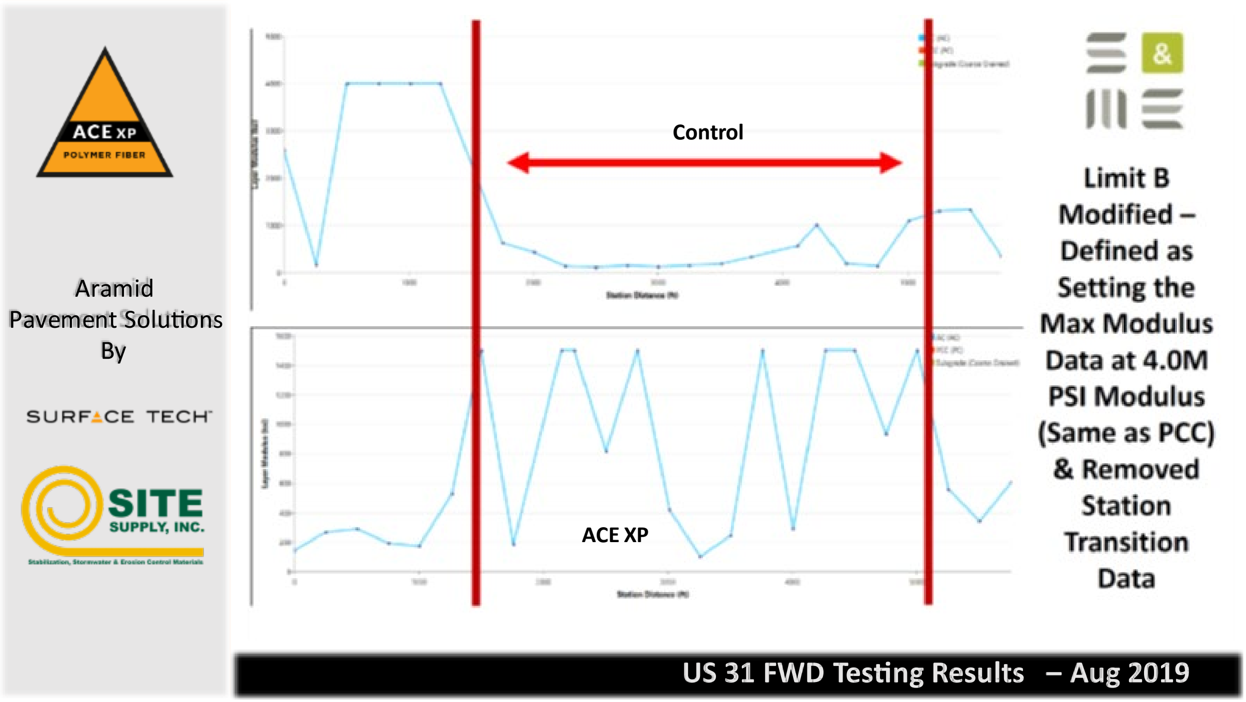


Table 37 – FWD Data from KY US31

Aramid Pavement Solutions By

SURFACE TECH

SITE SUPPLY, INC.

Table 2-8 Asphalt Concrete Layer Modulus – Limit B Modified

Tested Section	Location	Minimum Pavement Modulus psi	Maximum Pavement Modulus psi	Average Pavement Modulus psi	Standard Deviation psi
NB	Dixie Hwy	100,000	4,000,000	1,847,500	1,554,319
SB	Dixie Hwy	100,000	4,000,000	351,333	292,982

+425%

Limit B Modified – Defined as Setting the Max Modulus Data at 4.0M PSI Modulus (Same as PCC) & Removed Station Transition Data

US 31 FWD Testing Results – Aug 2019

Falling Weight Deflectometer (FWD) Testing

Evaluate the in-place Modulus of Various Roadways

Performed by S&ME

Figure 38– Location Map for FWD Testing on Man O' War Blvd, Lexington KY

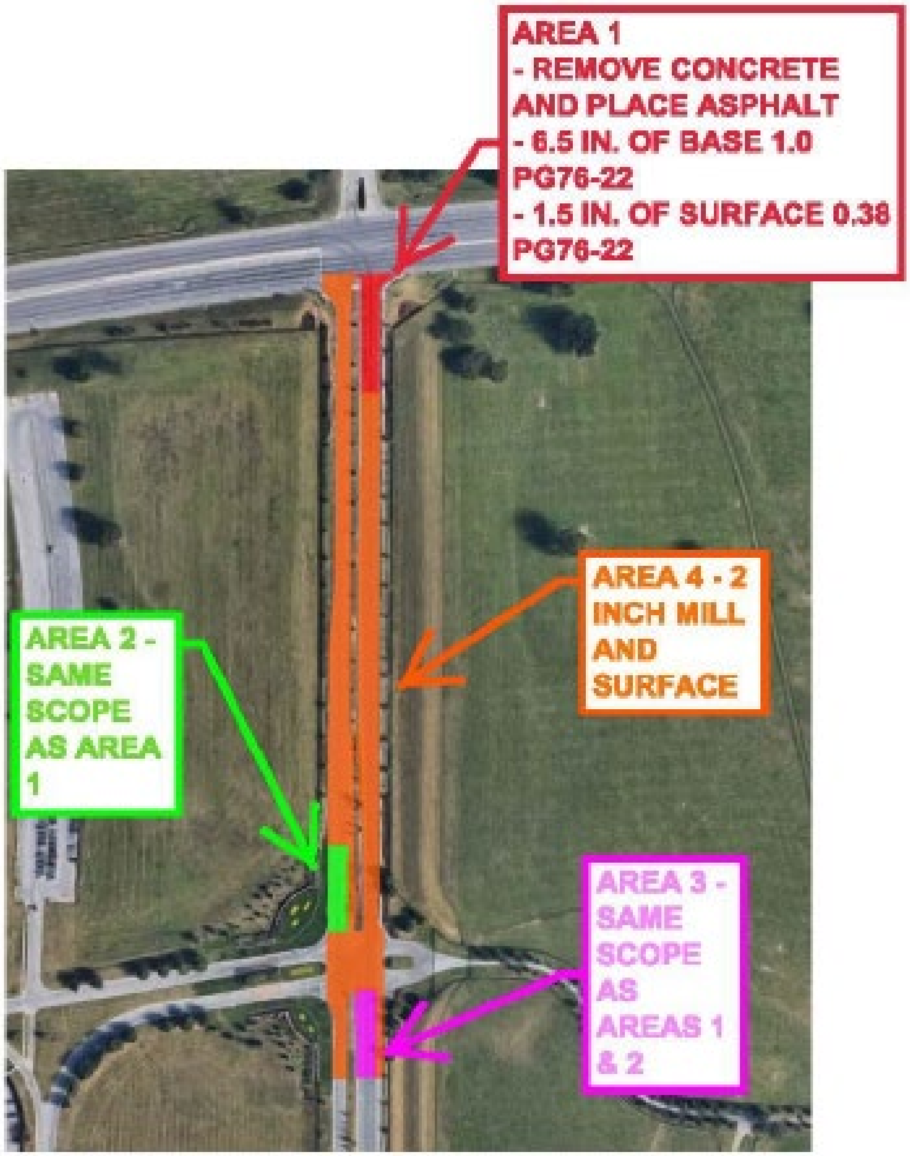


Table 36 – Backcalculated HMA moduli for NB Purple, Orange & Red Sections

Aramid Pavement Solutions By

SURFACE TECH

SITE SUPPLY, INC.

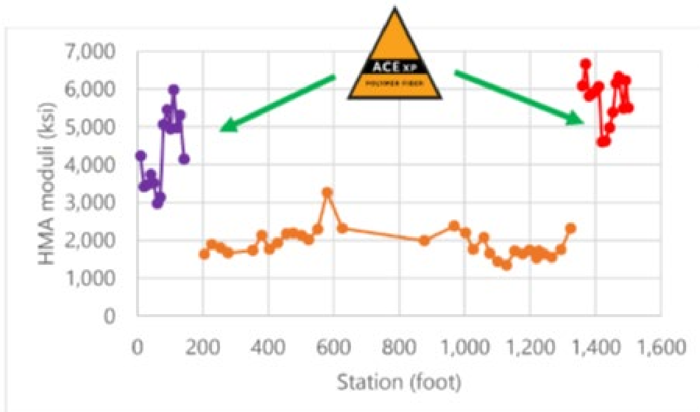


Figure 2-1: Backcalculated HMA moduli for NB Purple, Orange, and Red sections.

Man O'War FWD Testing Results – February 2022

Table 36 (Continued) – Backcalculated HMA moduli for NB Purple, Orange & Red Sections

Aramid Pavement Solutions By

SURFACE TECH

SITE SUPPLY, INC.

Table 2-1: Pavement layers backcalculated moduli.

Tested Section	Statistical parameter	HMA layer modulus (ksi)	DGA layer moduli (ksi)	Reinforced subgrade modulus (ksi)
Purple (NB)	Average (ksi)	4,308	60.7	32.6
	Minimum (ksi)	2,969	33.6	26.9
	Maximum (ksi)	5,977	98.4	38.0
	Standard deviation (ksi)	968	21.4	4.0
	COV (%)	22.5	35.2	12.3
	Included/Eliminated drops		14/1	
Orange (NB)	Average (ksi)	1,915	63.4	30.6
	Minimum (ksi)	1,337	34.9	23
	Maximum (ksi)	3,264	99.2	39.1
	Standard deviation (ksi)	372	21.6	3.4
	COV (%)	19.4	34.1	10.9
	Included/Eliminated drops		32/14	
Red (NB)	Average (ksi)	5,712	61.6	24.3
	Minimum (ksi)	4,597	37.8	20.4
	Maximum (ksi)	6,655	91.1	27.3
	Standard deviation (ksi)	612	11.9	1.9
	COV (%)	10.7	19.4	7.6
	Included/Eliminated drops		15/2	

+ 183 %

+ 204 %

Man O'War FWD Testing Results – February 2022

Table 37 – Backcalculated HMA moduli for SB Orange & Green Sections

Aramid Pavement Solutions By SURFACE TECH

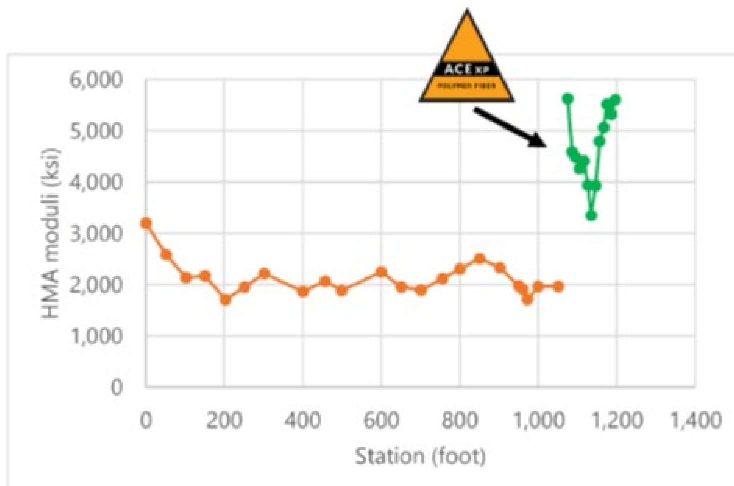


Figure 2-2: Backcalculated HMA moduli for SB Orange and Green sections.

Man O'War FWD Testing Results – February 2022

Table 37 (Continued) – Backcalculated HMA moduli for SB Orange & Green Sections

Aramid Pavement Solutions By SURFACE TECH

Table 2-1: Pavement layers backcalculated moduli.

Tested Section	Statistical parameter	HMA layer modulus (ksi)	DGA layer moduli (ksi)	Reinforced subgrade modulus (ksi)
Orange (SB)	Average (ksi)	2,120	75.0	28.1
	Minimum (ksi)	1,707	34.3	13.6
	Maximum (ksi)	3,198	99.5	35.4
	Standard deviation (ksi)	332	13.5	5.0
	COV (%)	15.6	18.0	17.7
	Included/Eliminated drops	22/3		
Green (SB)	Average (ksi)	4,685	59.1	29.9
	Minimum (ksi)	3,346	33.5	22
	Maximum (ksi)	5,627	72.0	36.8
	Standard deviation (ksi)	720	12.3	3.6
	COV (%)	15.4	20.8	12.0
	Included/Eliminated drops	13/0		

+ 176 %

In Place Modulus Testing has resulted in improved Modulus in all Locations Tested from 2016 through 2022. Minimum improvement of 150% was recorded as the average at 2 Loves Stores and the Maximum of 425% on the US-31 KYTC Project.

Man O'War FWD Testing Results – February 2022

On-going Crack Counts

Evaluate pavement cracking over time - ACE XP vs Control

Performed by Site Supply, Developed & Reviewed by The BATT Lab

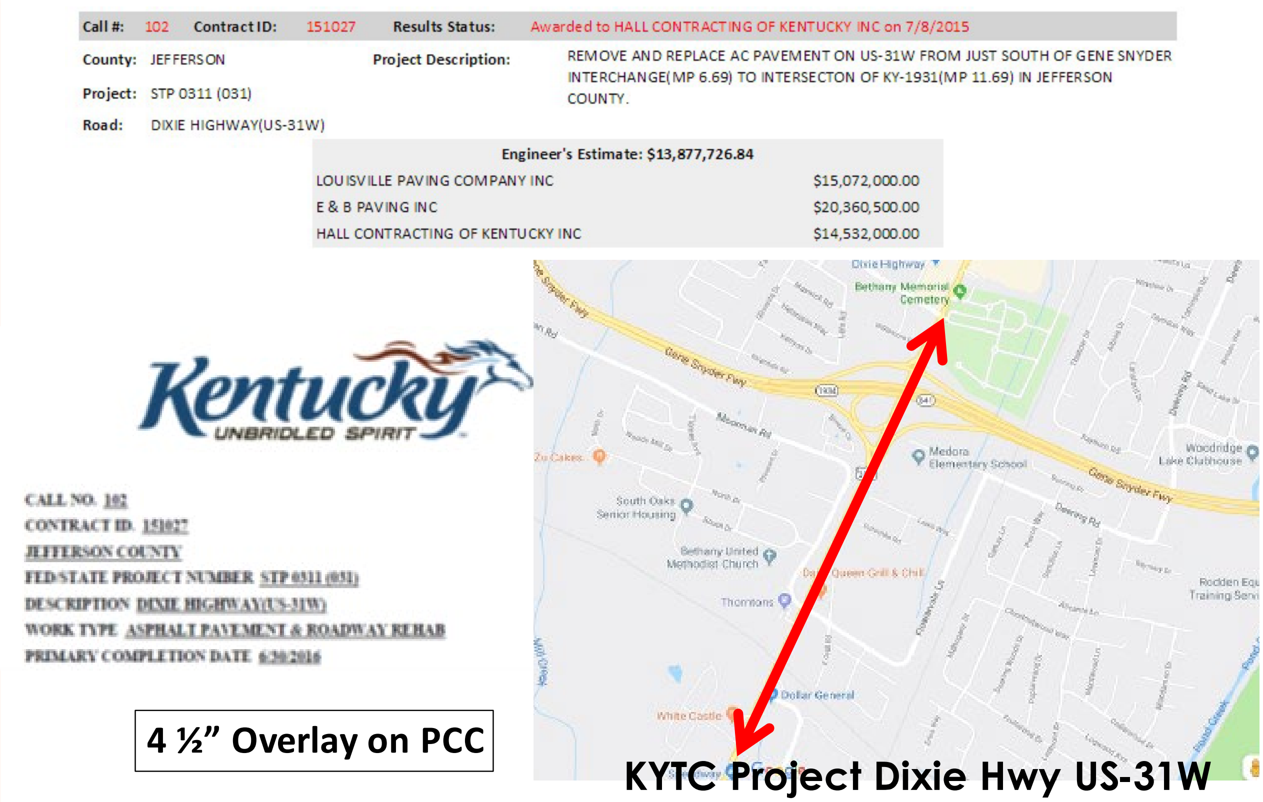


Figure 39– Crack counting system developed by The BATT Lab and performed each year since 2018 by Site Supply on the section of US31 below. NB lanes are ACE XP Reinforced

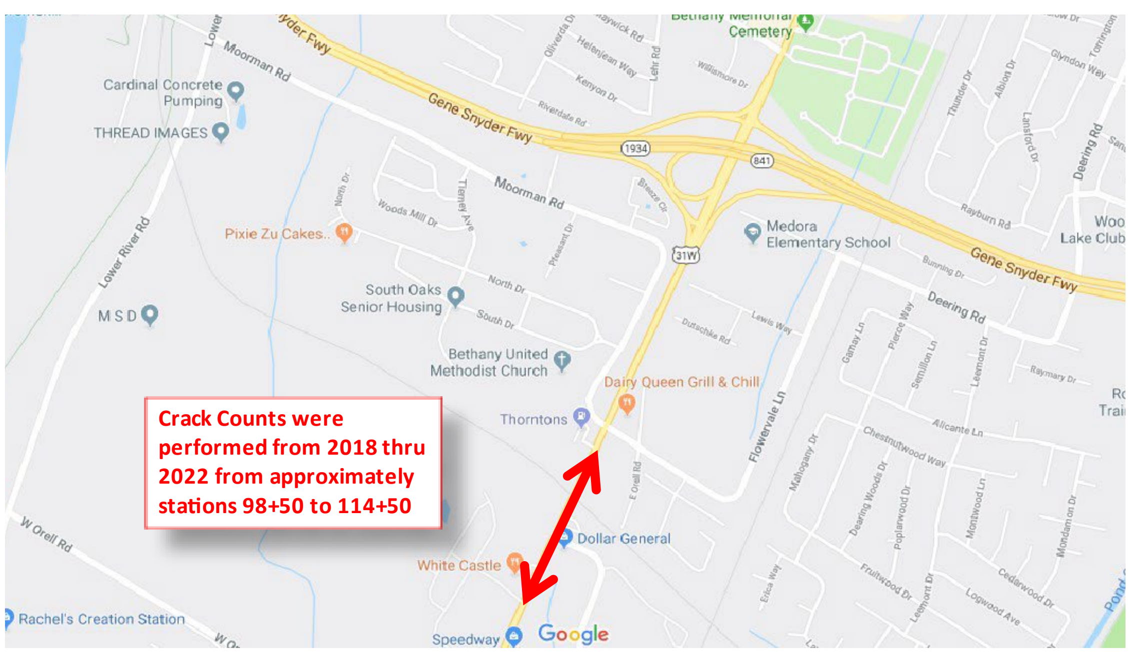


Figure 40 – Photos taken in 2020 of the crack development of both the NB lanes (Control) and the SB lanes (ACE XP Reinforced).

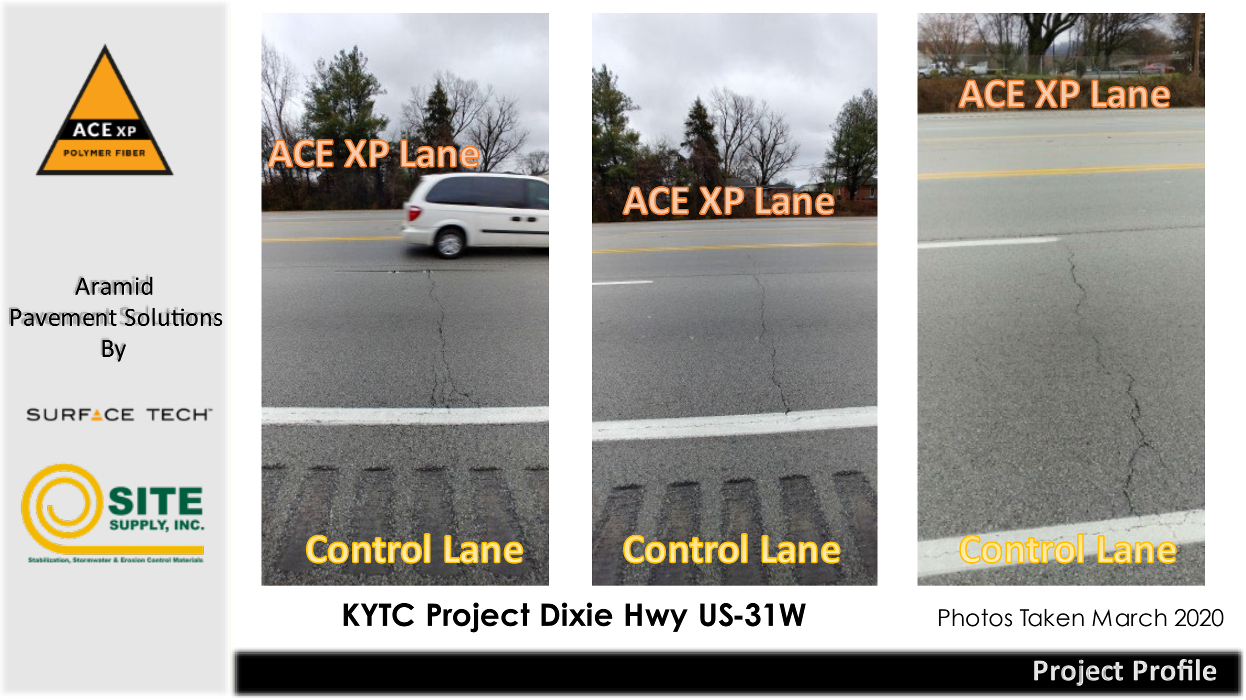
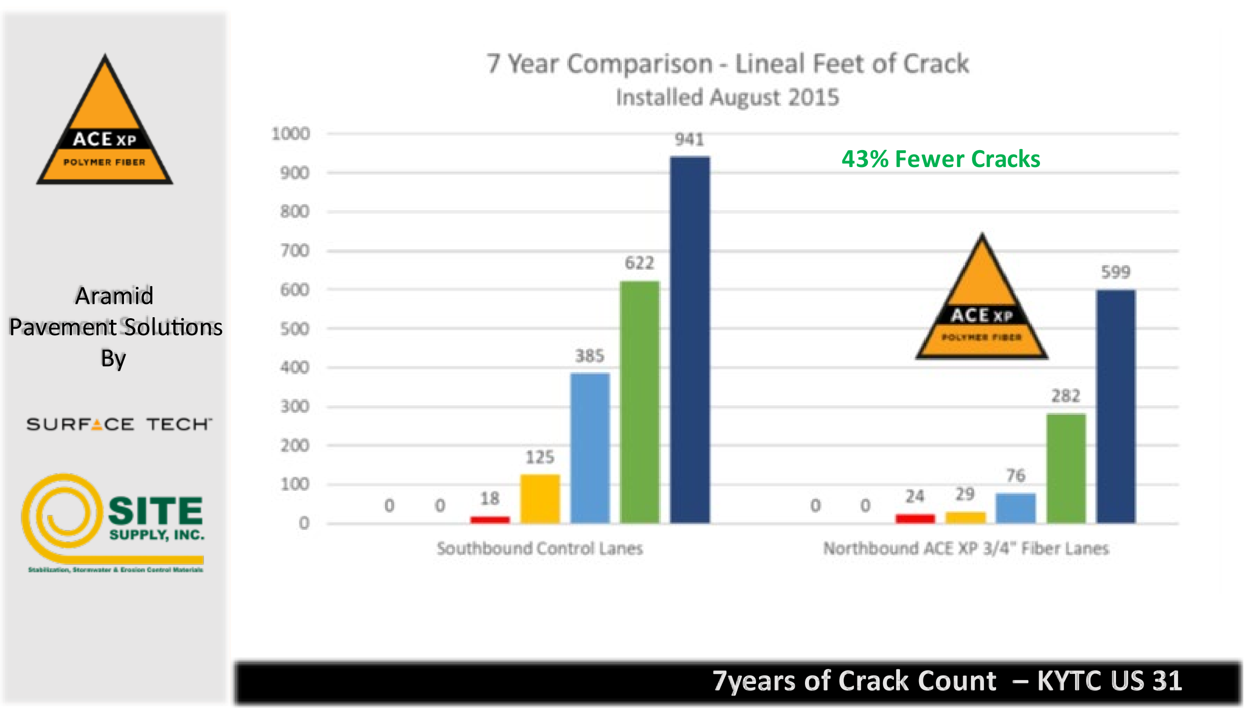


Table 39 – ACE XP reinforced NB lanes show 43% fewer cracks after 7 years as compared to the NB lanes (Control)



On-going Crack Counts

Evaluate pavement cracking over time - ACE XP vs Control

Performed by Site Supply, Developed & Reviewed by The BATT Lab

Figure 41 – Project Profile – City of Plainfield, Indiana ACE XP Reinforced PG76-22 vs Control PG76-22 (No ACE XP)

Aramid Pavement Solutions By SURFACE TECH

ACE XP Polymer Fiber - Overlay

Owner: City of Plainfield, Indiana

Project: Stafford Road– 2” Mill & Overlay

Producer: Milestone

Description: ACE XP Polymer Fiber + PG7622
- City wanted to control cracking

Date Installed: Fall 2018

Date Pictures Taken: March 2019

Project Profile

Figure 38 – Pictures taken in spring of 2019, just months or one winter after the pavement was installed in 2018

Aramid Pavement Solutions By SURFACE TECH

Stafford Road, City of Plainfield, Indiana
Week Ending 3/16/19

Project Profile

Table 40 – SCB/IFIT cracking testing run by the Heritage Group on field cores taken during installation

Aramid Pavement Solutions By SURFACE TECH

SITE SUPPLY, INC.

Table 6. IFIT Results for PPFC Cores

Field Core IFIT: Control Mix from 6/29					
Specimen	6/29 core 3A	6/29 core 3B	6/29 core 4A	6/29 core 4B	Daily Average
Air voids (%)	8.3	8.3	7.9	7.9	8.1
Fracture Energy (0.1 J/m2)	2028.6	2039.1	1727.5	1779.1	1893.6
Strength (0.1 psi)	60.7	65.2	61.1	61.1	62.0
Slope (.01)	-2.00	-2.49	-2.11	-2.25	-2.21
Flexibility Index (.01)	10.14	8.19	8.19	7.91	8.61
Field Core IFIT: Fiber Mix from 6/27					
Specimen	6/27 WB Core #3A	6/27 WB Core #3B	6/27 WB Core #4A	6/27 WB Core #4B	
Air voids (%)	11.0	11.0	11.2	11.2	11.1
Fracture Energy (0.1 J/m2)	1959.2	2083.0	1876.2	2570.0	2122.1
Strength (0.1 psi)	47.2	51.7	49.7	49.2	49.5
Slope (.01)	-1.15	-1.50	-1.45	-0.89	-1.25
Flexibility Index (.01)	17.04	13.89	12.94	28.88	18.19
Field Core IFIT: Fiber Mix from 6/28					
Specimen	6/28 EB Core #3A	6/28 EB Core #3B	6/28 EB Core #4A	6/28 EB Core #4B	
Air voids (%)	7.9	7.9	7.6	7.6	7.8
Fracture Energy (0.1 J/m2)	2621.4	2125.6	2370.7	2238.6	2339.1
Strength (0.1 psi)	70.8	59.5	65.1	72.7	67.0
Slope (.01)	-2.10	-1.63	-1.85	-1.98	-1.89
Flexibility Index (.01)	12.48	13.04	12.81	11.31	12.41

Heritage Research Group

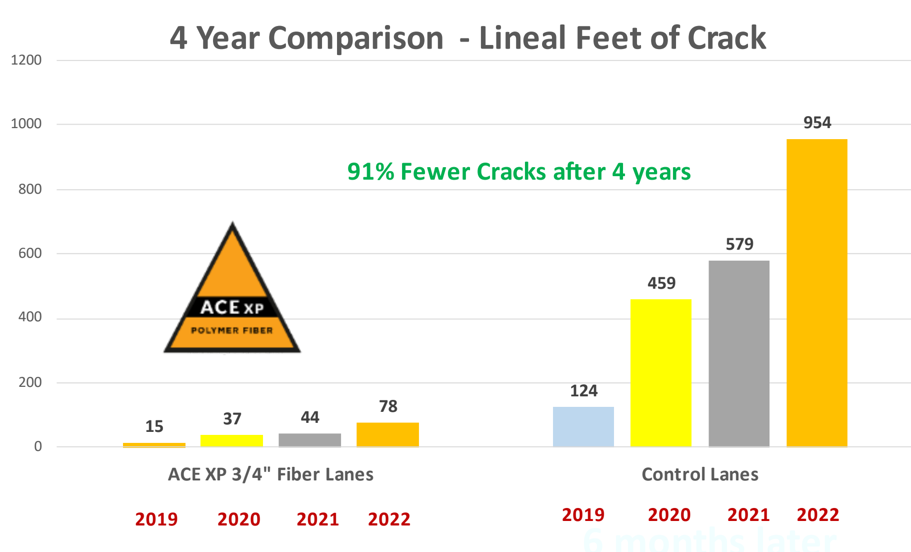
Field Samples showed 44% to 111% improvement in IFIT Flexibility Factor

Project Profile – Stafford Rd – Plainfield, IN

Table 41 – ACE XP reinforced lanes showing 91% fewer cracks after 4 years of observation

Aramid Pavement Solutions By SURFACE TECH

SITE SUPPLY, INC.



Stafford Road - Plainfield, Indiana Case Study

Aramid Reinforcement Study

Evaluate alternative materials for is use in modifying asphalt mixtures

Performed by Texas A&M Transportation Institute (TTI)

ACE XP POLYMER FIBER

Aramid Pavement Solutions By SURFACE TECH

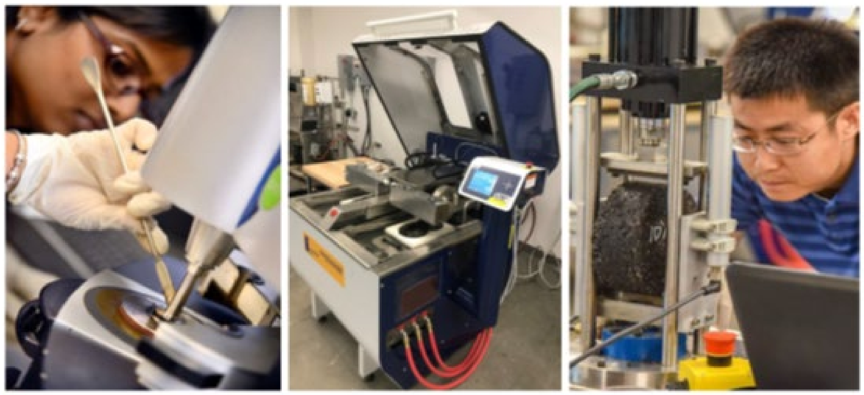
Texas A&M Transportation Institute

Authors:
Pravat Karki, Ph.D., P.E. (PI)
Fujie Zhou, Ph.D., P.E. (Co-PI)
Tito Nyamuhokya, Ph.D., P.E.

Development of a Laboratory Testing Protocol to Evaluate Alternative Materials for Use in Modifying Asphalt Binders and Alternative Materials for Use in Modifying Asphalt Mixtures

Submitted to:
STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION

Submitted by:
TEXAS A&M TRANSPORTATION INSTITUTE



FDOT – Aramid Reinforcement Study

Figure 42 – Mix Design Gradation and AC Content used for the testing (No RAP)

ACE XP POLYMER FIBER

Aramid Pavement Solutions By SURFACE TECH

Texas A&M Transportation Institute

Authors:
Pravat Karki, Ph.D., P.E. (PI)
Fujie Zhou, Ph.D., P.E. (Co-PI)
Tito Nyamuhokya, Ph.D., P.E.

Terms:
- AAB = Alternative Asphalt Binder
- AAM = Alternative Asphalt Mixture
- BIO = Bio-Rejuvenator
- RET = Reactive Ethylene Terpolymer

Terms:
- FMA = Fiber-Modified Asphalt
- PMA = Polymer Modified Asphalt
- SBS = Styrene Butadiene Styrene
- SB = Styrene Butadiene

Table 4-1. Control Mixture Gradation Verification Results

Sieve No.	Sieve Size (mm)	JMF	Washed Sieve Analysis Gradation	Difference
¾"	19.0	100.0	100	+0.0
½"	12.5	100.0	100	+0.0
3/8"	9.5	88.0	87.4	-0.6
#4	4.75	64.0	62.7	-1.3
#8	2.36	43.0	42.9	-0.1
#16	1.19	31.0	31.1	+0.1
#30	0.60	21.0	21.5	+0.5
#50	0.30	16.0	16.3	+0.3
#100	0.15	8.0	8.0	+0.0
#200	0.075	4.2	4.6	+0.4

AC Content = 5.1% **RAP Content = 0%**

FDOT – Aramid Reinforcement Study

Figure 43 – Asphalt Mixture performance tests run in this study

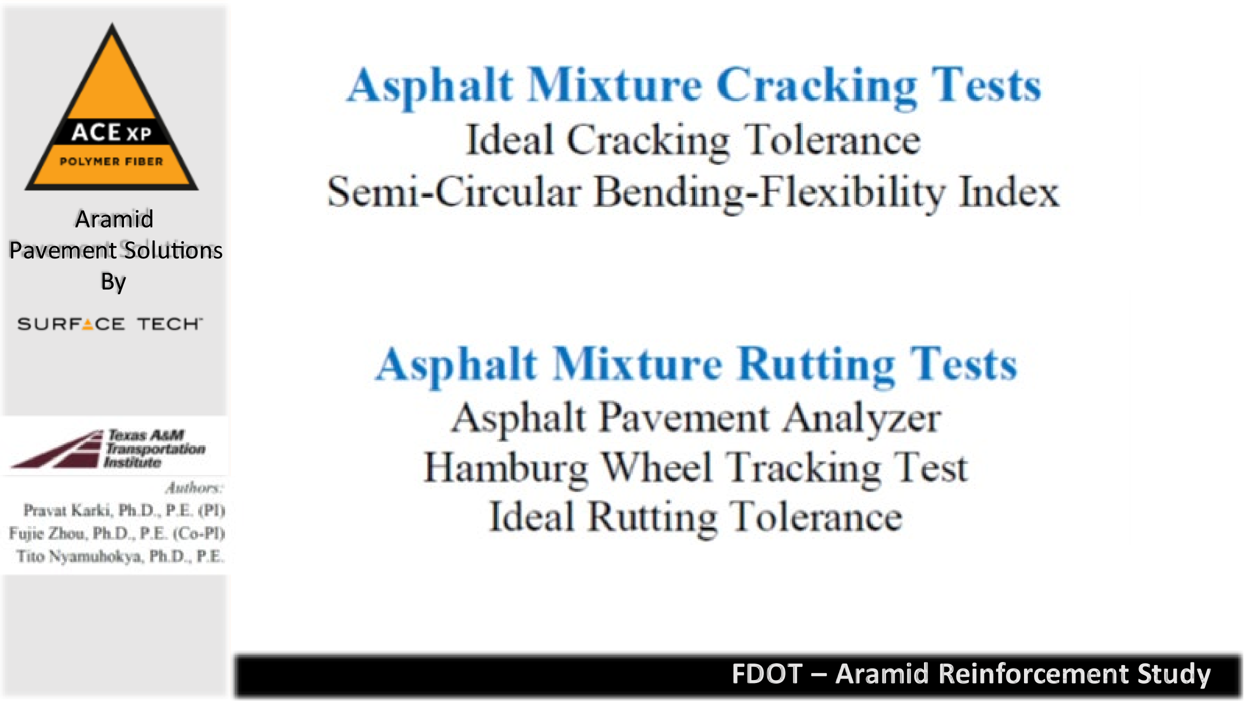


Table 42 – IDEAL CT shows PG76-22 reinforced with ACE XP polymer fiber with a 39.6% improvement in crack resistance compared to PG76-22 without fiber, while Forta-fi showed a -25.8% performance

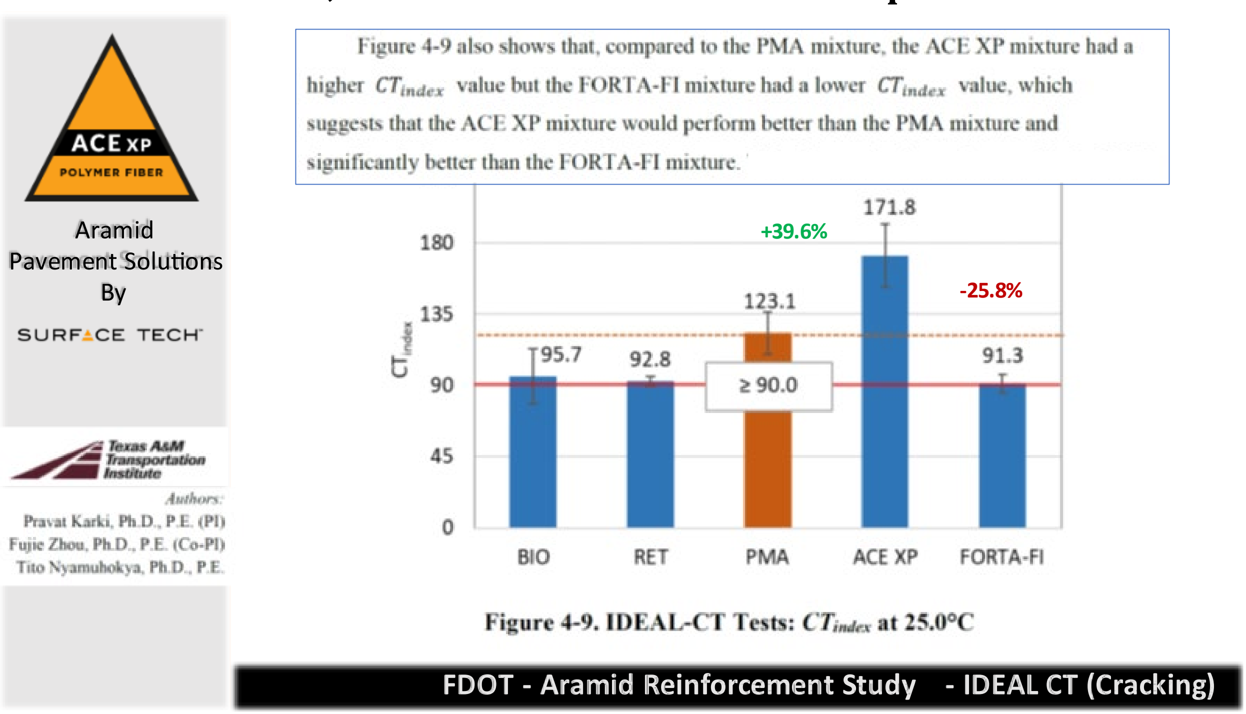


Table 43 – SCB-FI shows PG76-22 reinforced with ACE XP polymer fiber with equal performance in crack resistance compared to PG76-22 without fiber, while Forta-fi shows a -19.1% performance

ACE XP POLYMER FIBER

Aramid Pavement Solutions By SURFACE TECH

Texas A&M Transportation Institute

Authors:
Pravat Karki, Ph.D., P.E. (PI)
Fujie Zhou, Ph.D., P.E. (Co-PI)
Tito Nyamuhokya, Ph.D., P.E.

Figure 4-11 also shows that the ACE XP mixture had almost equivalent FI values while the FORTA-FI mixture had slightly lower FI values, meaning the ACE XP mixture would perform as good as the PMA mixture while the FORTA-FI mixture would perform only slightly inferior to the PMA mixture.

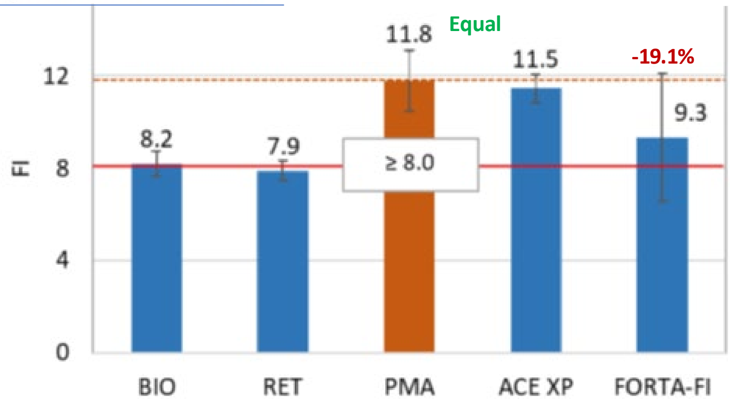


Figure 4-11. SCB-FI Tests: *FI* at 25.0°C

FDOT - Aramid Reinforcement Study - SCB-FI (Cracking)

Table 44 – APA Rut Test shows PG76-22 reinforced with ACE XP polymer fiber with equal performance to PG76-22 without fiber, as well as Forta-fi (These are very stiff mixes to begin with – Aramid Fiber will not help much)

ACE XP POLYMER FIBER

Aramid Pavement Solutions By SURFACE TECH

Texas A&M Transportation Institute

Authors:
Pravat Karki, Ph.D., P.E. (PI)
Fujie Zhou, Ph.D., P.E. (Co-PI)
Tito Nyamuhokya, Ph.D., P.E.

To synopsize, the APA test results suggest that both AMA mixtures (the BIO and the RET mixtures) would perform generally better than the FMA mixtures (ACE XP and the FORTA-FI mixtures) and each of these mixtures would perform at least equivalent to the PMA mixture.

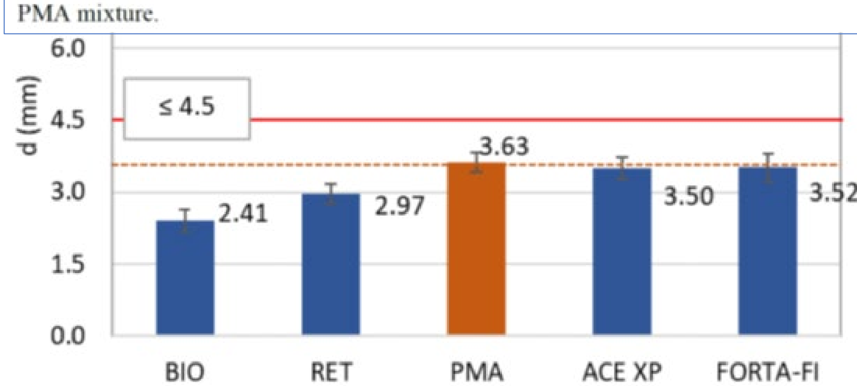


Figure 4-2. APA Tests: *d* at 8,000 cycles and 64.0°C

FDOT - Aramid Reinforcement Study - APA Rut (Rutting)

Table 45 – The Hamburg Wheels Tracker Rut Test shows close to equal performance across all tested.

(Mixtures performing within 1mm to each other are likely to perform similarly in the field)

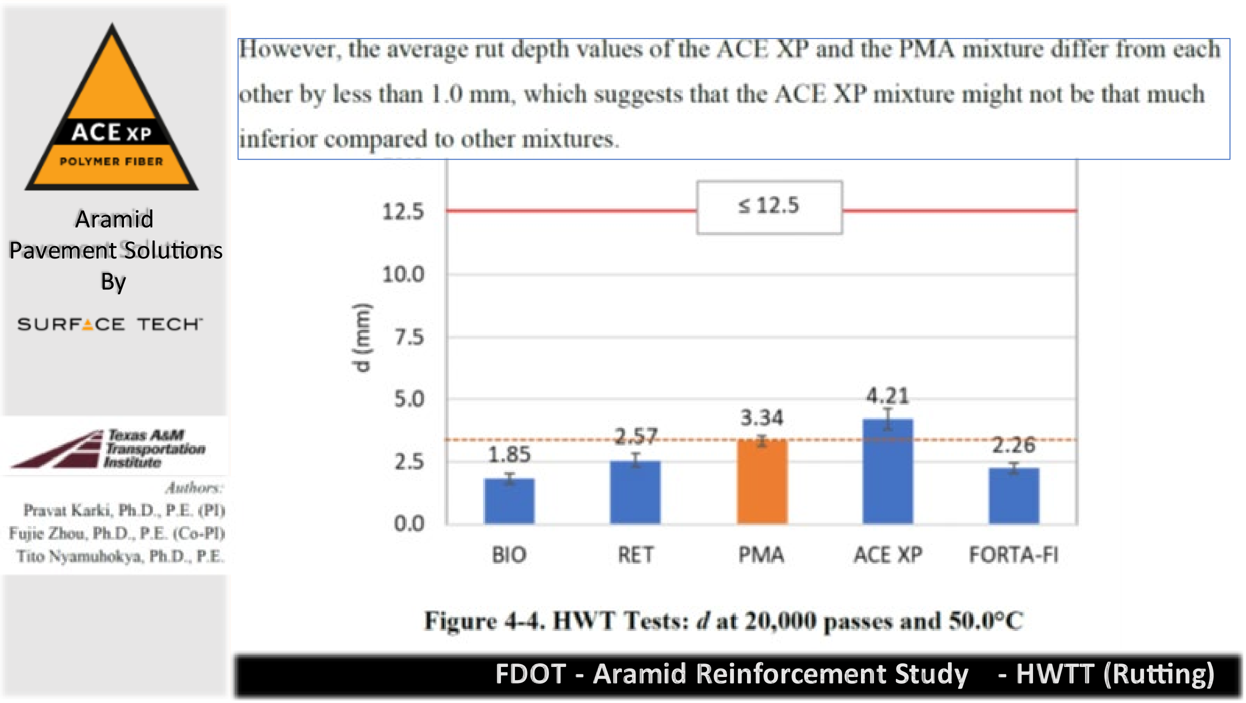
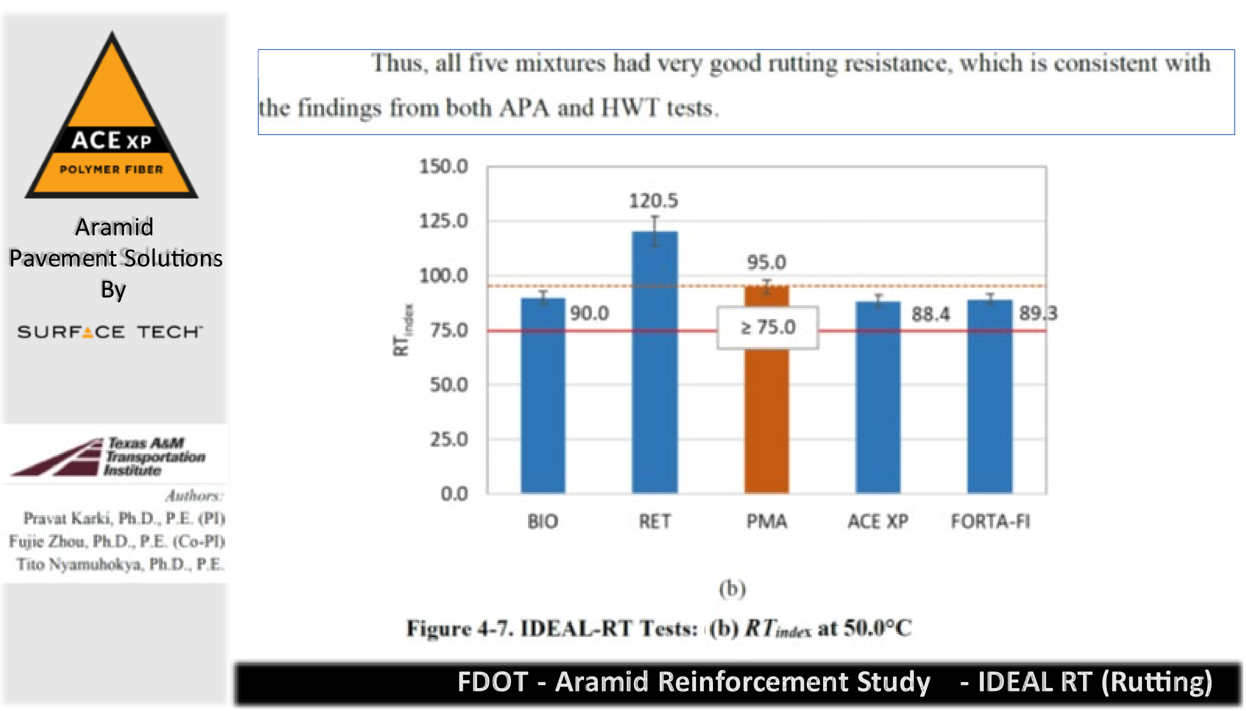


Table 46 – The IDEAL RT Rut Test shows very good rutting resistance across all mixtures, conforming results from APA and HWT



Aramid Reinforcement Study

Evaluate alternative materials for use is in modifying asphalt mixtures

Performed by Michigan Technological University (TRB Poster 2021)

The Laboratory Performance and Field Case Study of Asphalt Mixture with Sasobit Treated Aramid Fiber as Modifier

Dongdong Ge [a], Dongzhao Jin [a], Chaochao Liu [a], Junfeng Gao [a], Miao Yu [a], Lance Malburg [b], Zhanping You * [a]
[a] Michigan Technological University, [b] Dickinson County Road Commission

Introduction

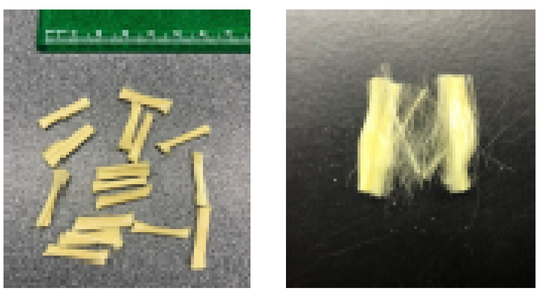
- The clumping of fiber in the asphalt binder restricted the application of fiber modified asphalt mixture using the wet process.
- The dry process is easy to operate, and the distribution of fiber in the mixture using the dry process is better.
- Sasobit treatment could reduce the production temperature, thus decrease the energy consumption and environmental pollution.

Materials and test methods

Materials

PG 58-34 asphalt binder

Property	Results	Specification
Rotational viscosity (135 °C) (Pa·S)	0.398	< 3.0
G*/sin δ (Unaged, 58 °C) (kPa)	1.542	> 1.0
G*/sin δ (RTFO aged, 58 °C) (kPa)	4.147	> 2.2
G*×sin δ (PAV aged, 16 °C) (kPa)	2346	<5000



Appearance of Sasobit treated aramid fiber

Sasobit treated aramid fiber

Properties	Results
Materials	Aramid Fiber (50-51% by weight)
Form	Filament Yarn
Length (inch)	0.75 ± 0.03
Diameter (inch)	0.1
Tensile Strength (GPa)	2.4-3.6
Modulus (GPa)	60-80
Elongation percentage at Break (%)	3.0-4.4
Specific gravity (g/cm³)	1.44 - 1.45
Decomposition Temperature (°C)	> 500
Treatment Properties	
Treatment Material	Sasobit® Wax (49-50% by weight)
Melting Temperature (°C)	> 77

Test methods

Hamburg Wheel Tracking Device

Disk-shaped Compact Tension test apparatus

UTM-100

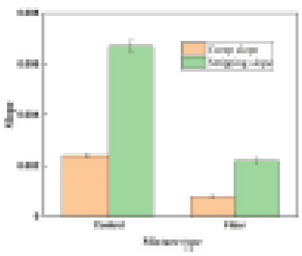
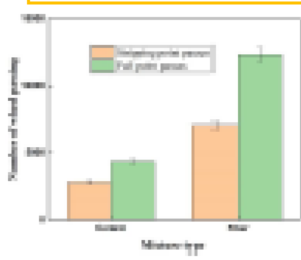
Figure 44 – Rutting, Cracking and Dynamic Modulus Data showing ACE XP mixture performing far superior to control

The Laboratory Performance and Field Case Study of Asphalt Mixture with Sasobit Treated Aramid Fiber as Modifier

Dongdong Ge [a], Dongzhao Jin [a], Chaochao Liu [a], Junfeng Gao [a], Miao Yu [a], Lance Malburg [b], Zhanping You * [a]
[a] Michigan Technological University, [b] Dickinson County Road Commission

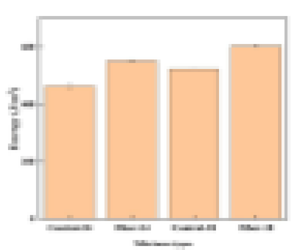
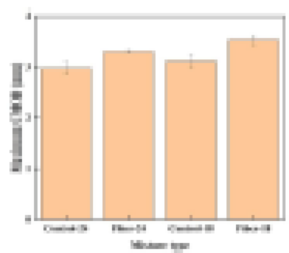
Analysis of test results

Rutting and moisture susceptibility

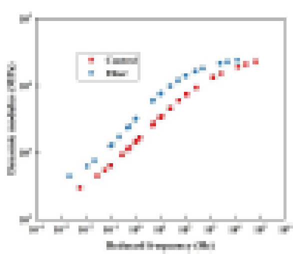
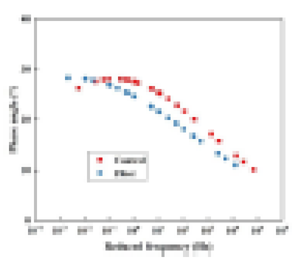
- The moisture damage in the asphalt mixture was restricted by the fiber addition.
- The rutting resistance of asphalt mixture was significantly improved after fiber modification.

Low temperature cracking resistance

- The improvement of fiber on the cracking property of the asphalt mixture was obvious even at the lower test temperature.
- Fiber modified asphalt mixture has better deformation ability at low temperatures.

Dynamic modulus

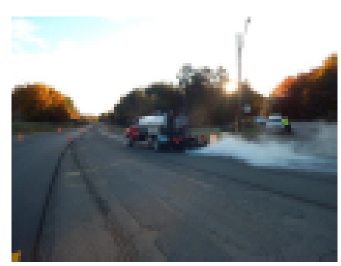
- The dynamic modulus of modified mixture was higher, at all test temperatures under different frequencies.
- The elastic property of the asphalt mixture was enhanced after fiber modification.

Field case study

Field construction

Milling of the surface layer

Surface cleanup



Emulsified asphalt application

Figure 45 – Conclusions of this Study

The Laboratory Performance and Field Case Study of Asphalt Mixture with Sasobit Treated Aramid Fiber as Modifier

Dongdong Ge [a], Dongzhao Jin [a], Chaochao Liu [a], Junfeng Gao [a], Miao Yu [a], Lance Malburg [b], Zhanping You * [a]
[a] Michigan Technological University, [b] Dickinson County Road Commission

Conclusions

- Fiber modification increased the rutting and moisture stability of the asphalt mixtures.
- The fracture energy and maximum CMOD of the control mixture increased after the fiber modification.
- The dynamic modulus of the asphalt mixture under different conditions was improved after fiber modification.
- The construction procedures of two types of asphalt mixtures in the field were displayed. The fiber modification significantly restricted the propagation of cracking in the asphalt mixture.

Acknowledgement: The work is carried out in cooperation with the Dickinson County Road Commission of Michigan.