



WHEN PERFORMANCE MATTERS

Technical Brief

Advanced Aramid Fiber Technology for Asphalt

Testing By:

**Advanced Asphalt Technologies
Asphalt Institute
HiTech Asphalt Solutions
Ingios Geotechnics
Texas Transportation Institute
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 the Fiber Reinforced Asphalt Concrete (FRAC) when reinforced by ACE Fiber. The testing performed and summarized on the following pages was 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 Test (Lab)*
- ▲ *APLT – Static Creep (Field)*
- ▲ *APLT – Dynamic Modulus (Field)*
- ▲ *Chemical Extraction Test (Lab)*
- ▲ *Aramid State Dispersion Ratio Test – ADSR Test (Lab)*

HIGH PERFORMANCE FIBER REINFORCED ASPHALT CONCRETE (FRAC)

Contact Jen-Hill Construction Materials 800-452-4435

Lab Testing Summary

Lab Test Description	ACE Fiber™ Results
Lab - TTI Overlay Tester <i>Thermal/Reflective Cracking</i>	+140%
Lab - DC(T) Test <i>Low Temperature Fracture Energy</i>	+21%
Lab - IDT Strength Test <i>Low Temperature Strength @ Critical Crack Temperature</i>	+10%
Lab - IDT Creep Compliance Test <i>Determine Low Temperature Critical Cracking Value (Bottom PG Number)</i>	-4.3° C (-1 PG – Bottom Number)
Lab - Hamburg Rut Test <i>Determine Rut Resistance of Various Asphalt Mixes (Top PG Number)</i>	PG64-22 (w/ ACE) = PG70-22 (+1 PG – Top Number)
Lab - Hamburg Rut Test <i>Determine Rut Resistance of Various Asphalt Mixes (Top PG Number)</i>	PG70-22 (w/ ACE) = PG76-22 (+1 PG – Top Number)

Field Testing Summary

Field Test Description	ACE Fiber™ Results
Field – APLT (Automated Plate Load Test) Static Creep <i>Measure Plastic Deformation of In-Place Asphalt (Rut)</i>	+121% Rebound Ratio
Field – APLT (Automated Plate Load Test) Elastic Modulus <i>Measure Elastic Modulus of In-Place Asphalt w/ ACE Fiber</i>	+200%
Field – APLT (Automated Plate Load Test) <i>SN Layer Coefficient, a_1 Back Calculate SN Layer Coefficient, a_1 using Measured Elastic Modulus</i>	+43%
Field – APLT (Automated Plate Load Test) <i>ESAL Prediction Using AASHTO 93 Calculate Increase ESAL Capacity of In-Place Asphalt w/ ACE Fiber</i>	+500%

Aramid Mix & Dispersion Lab Validation

Lab Test Description	ACE Fiber™ Results
Lab – Aramid Chemical Extraction Test (AI) <i>Measure the amount of Aramid Fibers in each Sample & Ton</i>	2.8 to 7.4 oz./ton
Lab – Aramid Chemical Extraction Test (AAT) <i>Measure the amount of Aramid Fibers in each Sample & Ton</i>	2.3 to 2.4 oz./ton
Lab – Aramid Dispersion State Ratio – ADSR (AI) <i>Classify the dispersion of the recovered Aramid Fibers from Extraction</i>	84.3%
Lab – Aramid Dispersion State Ratio – ADSR (AAT) <i>Classify the dispersion of the recovered Aramid Fibers from Extraction</i>	86.2%

The Overlay Tester

Developed by Texas Transportation Institute

Performed by Hitech Asphalt Solutions



Test Summary:

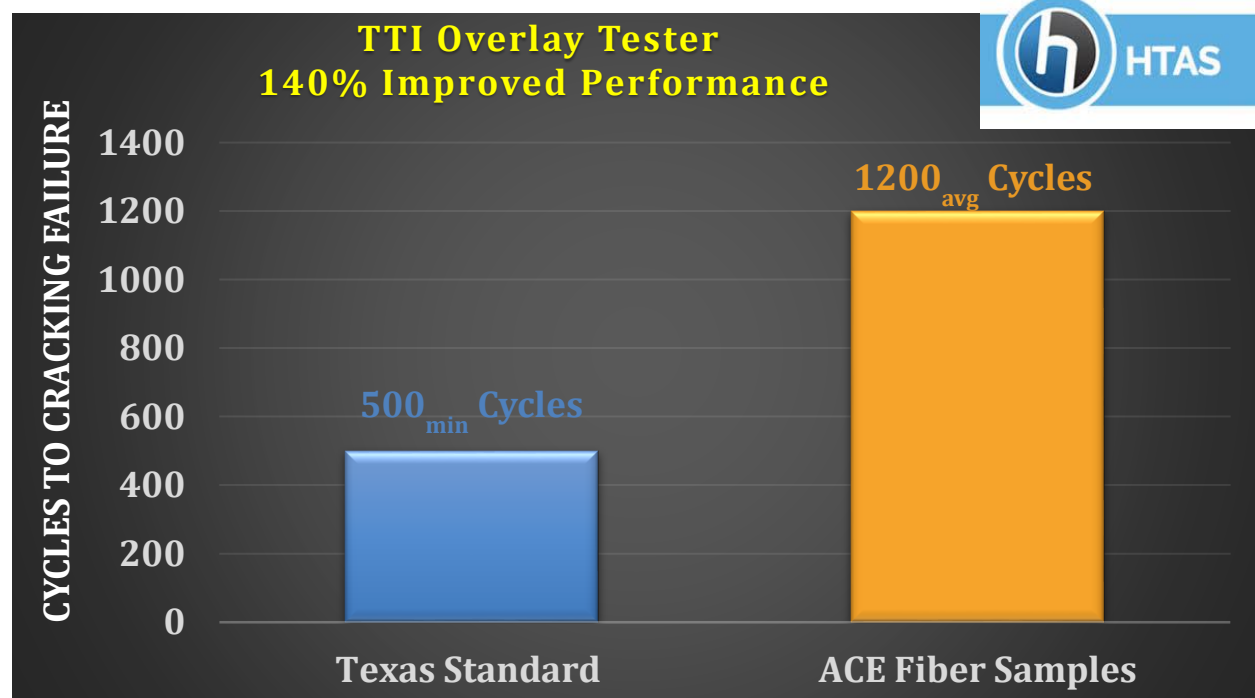
In this test one plate is locked and the other cycles back and forth a distance of 0.025 inches, with 5 second opening and 5 second closing, which **simulates a HMA overlay over a thermally active crack or joint**. The number of complete cycles of the crack to reach the surface is recorded.



Results:

In 2014 HiTech 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. This 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 HTAS Table 1 below.

HTAS Table 1



The DC(T) Test

The Disk Shaped Compact Tension Test

Performed by Western New England University

Test Summary:

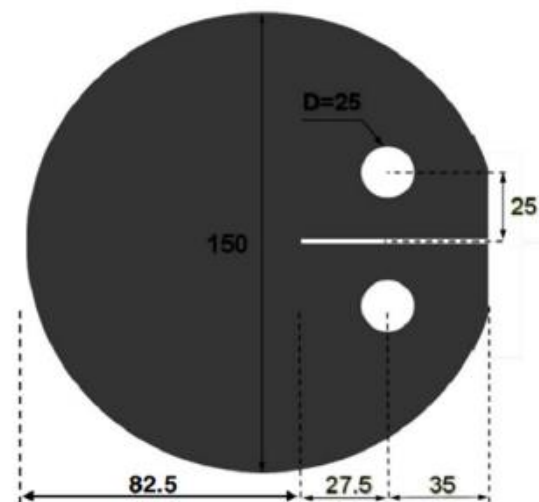
Disk-shaped Compact Tension test [DC(T)] was conducted in accordance with ASTM D7313-07 to assess the fracture resistance of asphalt mixtures. DC(T) tests were performed in the materials laboratory at University of Illinois. Figure 1 shows DC(T) testing setup and figure 2 show the sample dimensions.

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. 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.

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.



WNEU Figure 1

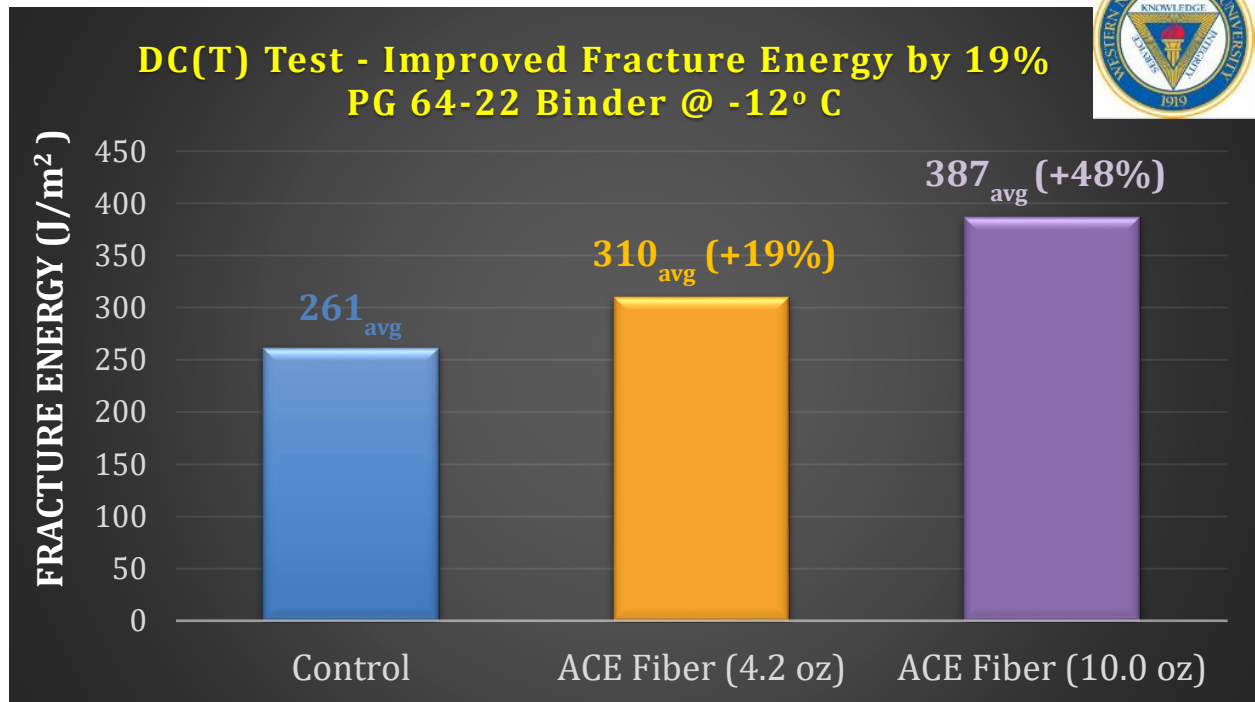


WNEU Figure 2

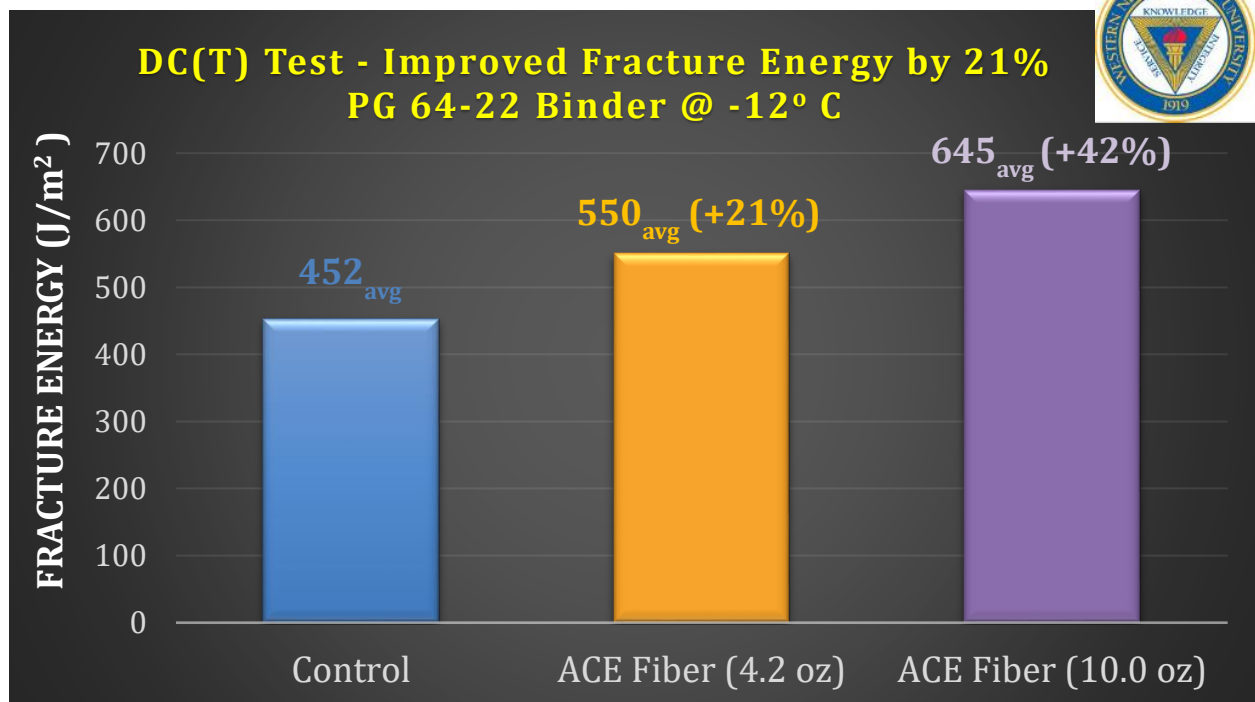
Results:

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 WNEU Table 1 and Table 2 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 due to 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. First being July of 2016 and second being November of 2016. The goal was to test a higher quality mix the second time around and see the results.*

WNEU Table 1 - July 2016



WNEU Table 2 - November 2016



The (IDT) Test

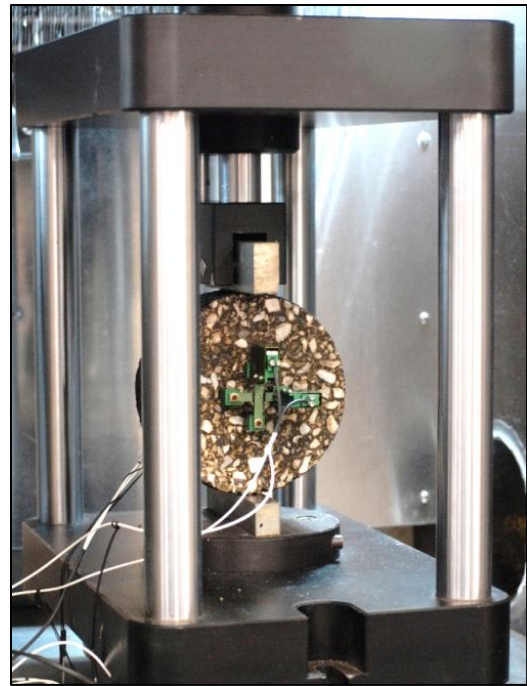
The Indirect Tensile & Compliance Test

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 (AI/AAT Figure 1) and a vertical constant load was applied and indirect displacement was measured for 300 s.



AI/AAT Figure 1

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.

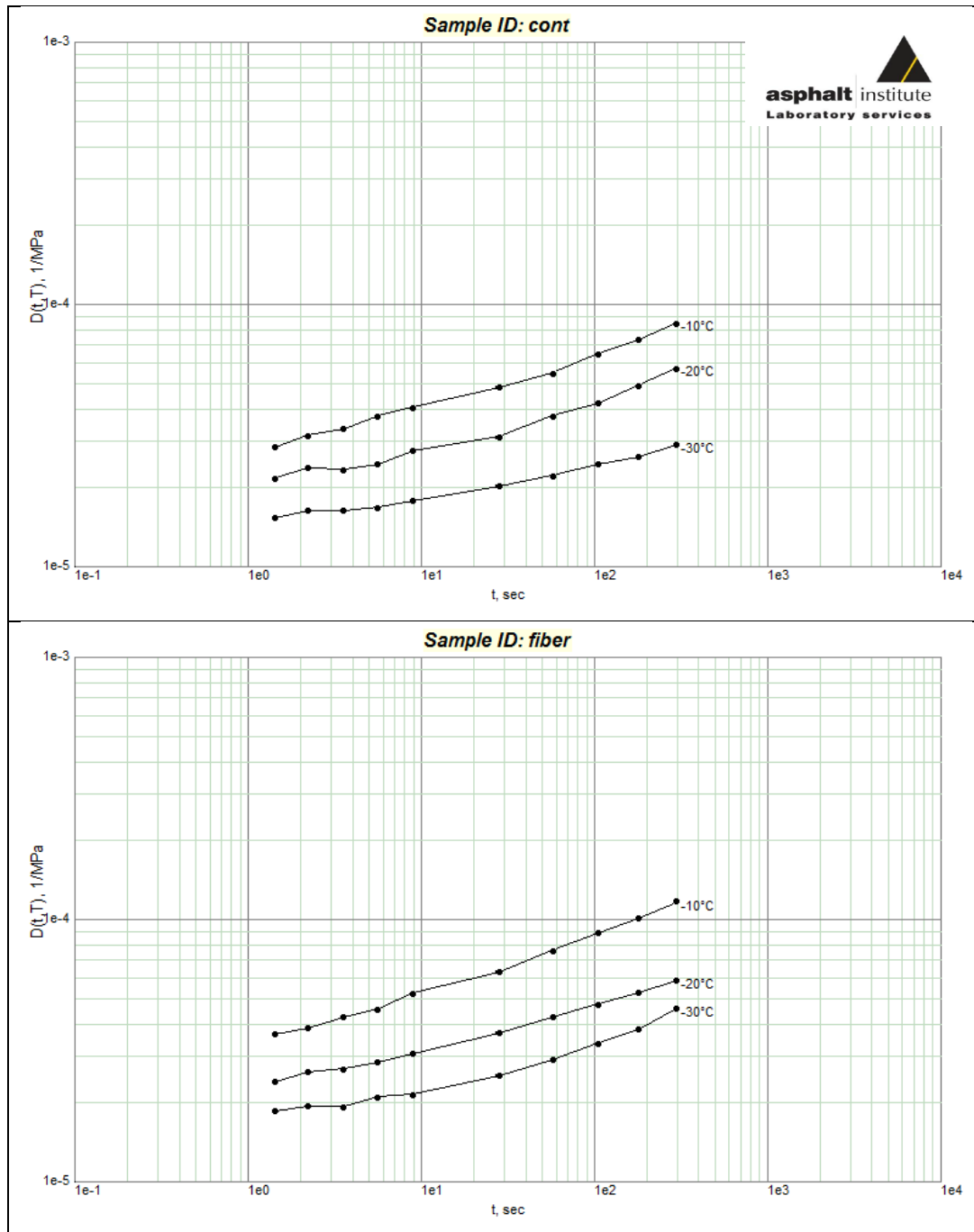
Results:

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), AI/AAT Figure 2, to form a shifted compliance curve, AI/AAT Figure 3. 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 AI/AAT Figure 4 for Advances Asphalt Technologies.

The (IDT) Test

Isotherms from Compliance Testing

Performed by Advanced Asphalt Technologies
And Asphalt Institute

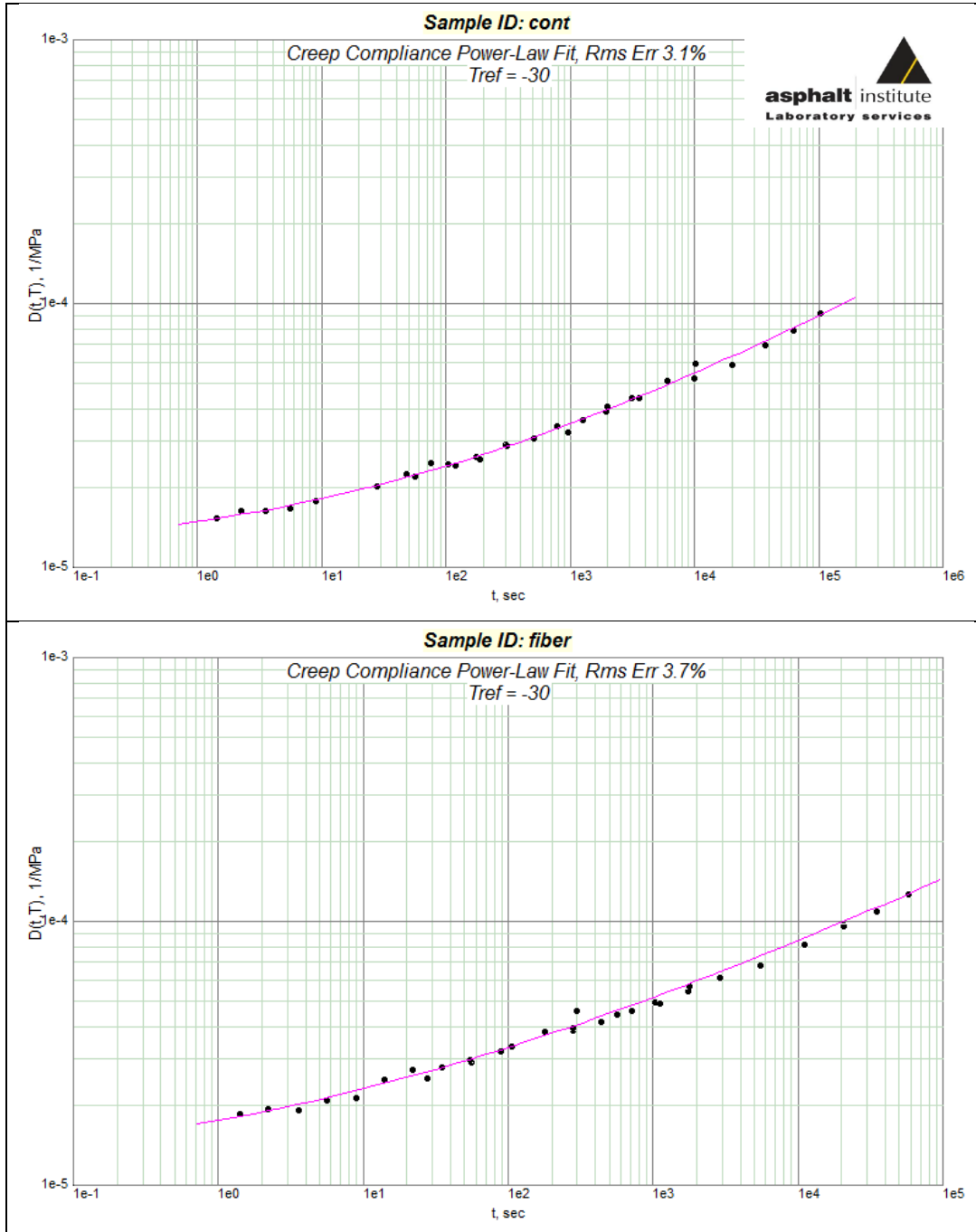


AI/AAT Figure 2
Isotherms from Compliance Testing of the Control and ACE Fiber Samples

The (IDT) Test

Shifted Compliance Curves (to determine time temperature shift)

Performed by Advanced Asphalt Technologies
And Asphalt Institute



AI/AAT Figure 3
Shifted Compliance Curves (to determine time temperature shift) of the
Control and ACE Fiber Samples

The (IDT) Test

Estimated Thermal Stress & Critical Cracking Temperature

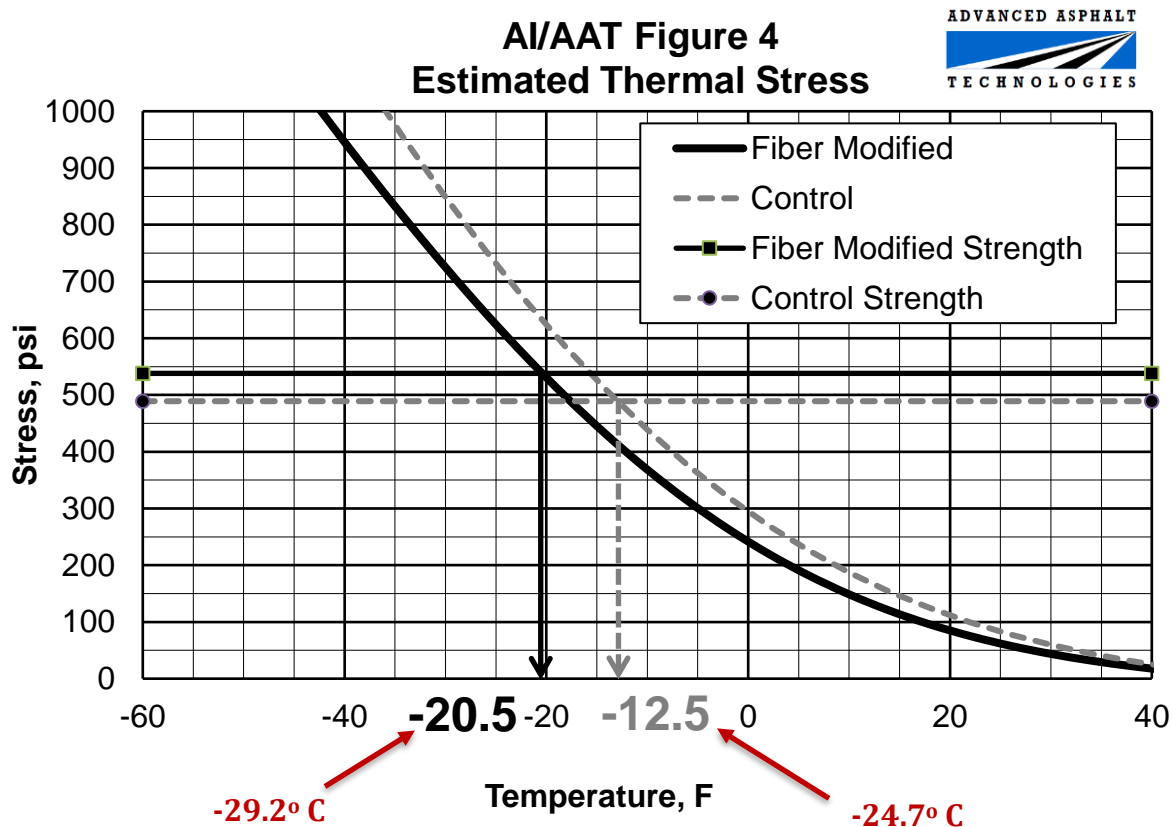
Performed by **Advanced Asphalt Technologies**
And **Asphalt Institute**

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.

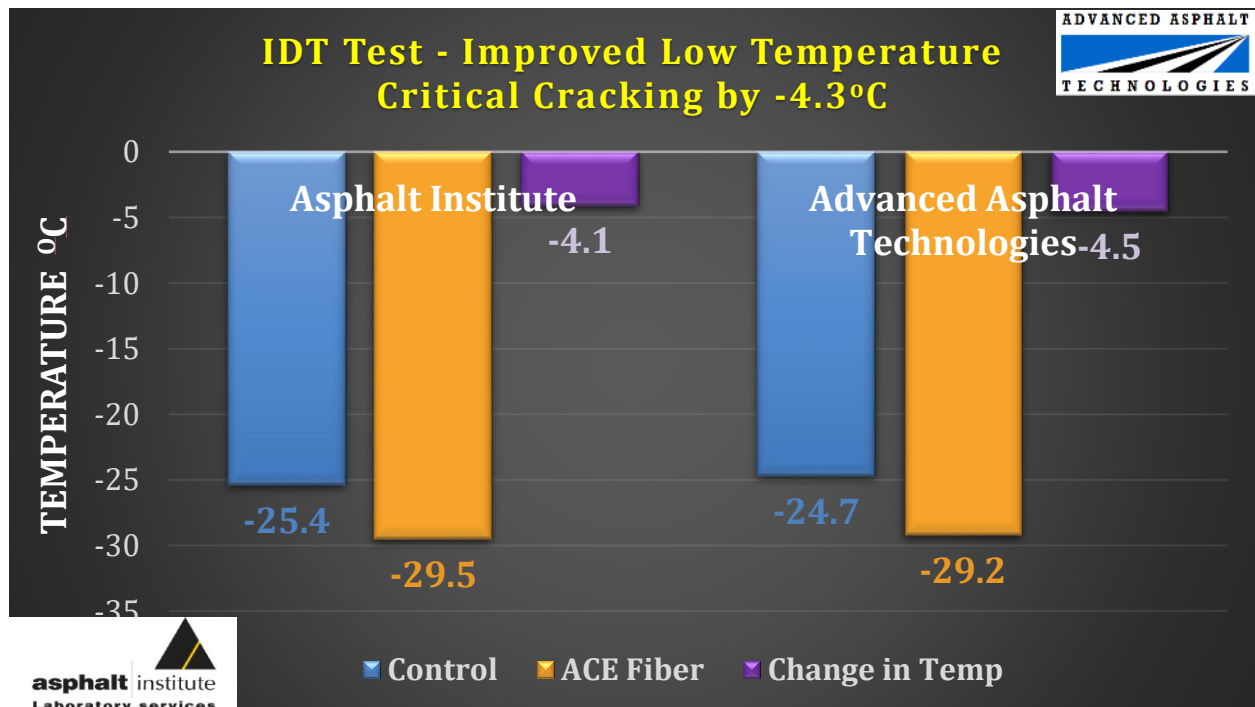
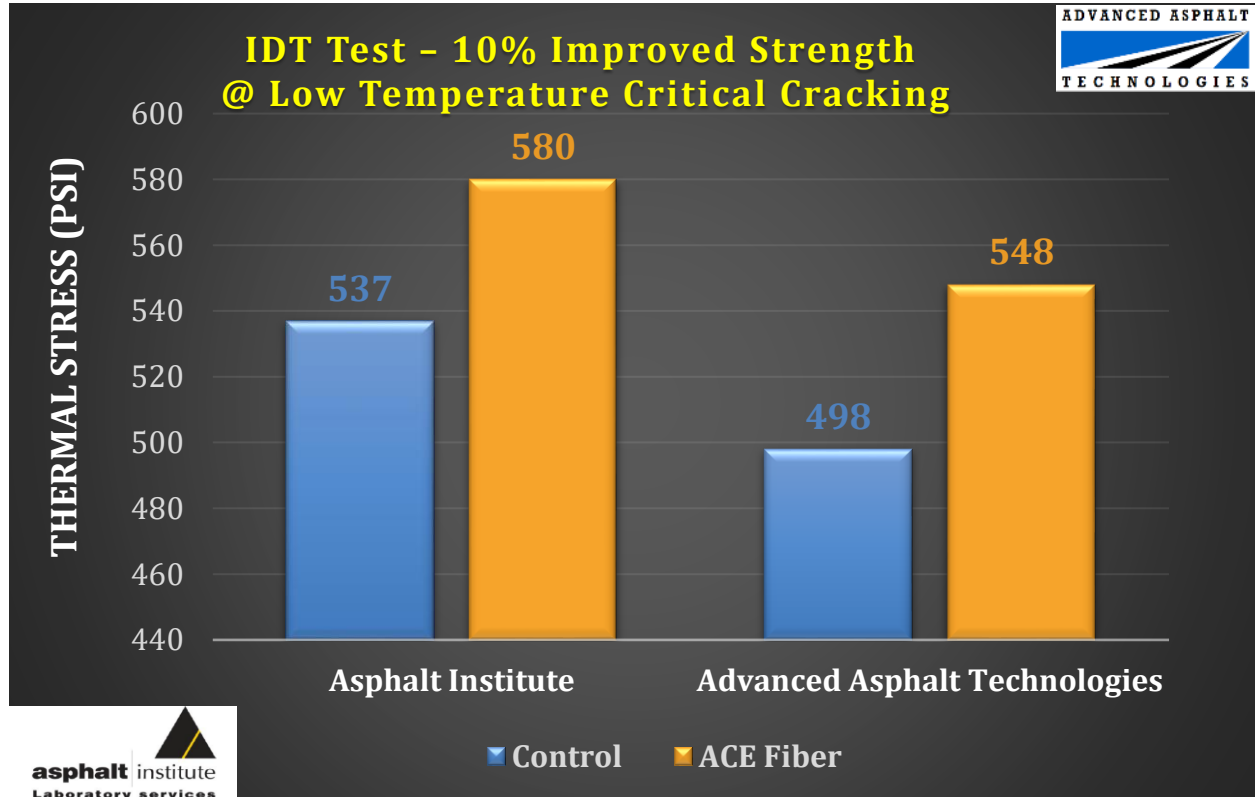
This finding could lead to a cracking improvement of mixtures containing Reclaimed Asphalt Pavement (RAP) or Reclaimed Asphalt Shingles (RAS).



The (IDT) Test Summary

The Indirect Tensile & Compliance Test

Performed by Advanced Asphalt Technologies
And Asphalt Institute



Hamburg Wheel Tracking Test

TxDOT Test Method 242F

Performed by Texas Transportation Institute
And HiTech Asphalt Solutions

Test Summary:

The Hamburg Wheel Tracking Test is run under water a water bath capable of controlling the test temperature within $\pm 2^\circ\text{C}$ (4°F) over a range of 25 to 70°C (77 to 158°F). The steel wheel with 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 $705 \pm 22\text{ N}$ ($158 \pm 5\text{ lbs.}$). 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).

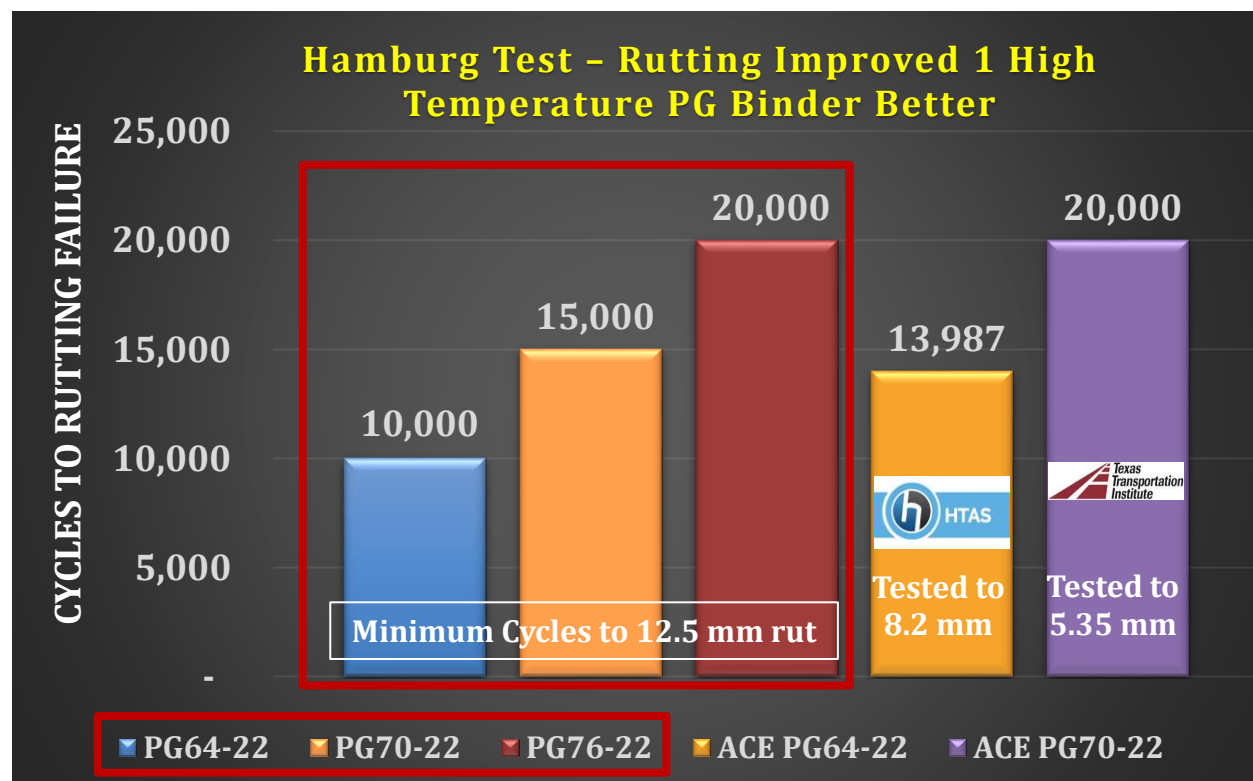
The rut depth induced by the steel wheel is automatically measured during the test. The test is run until the **rut depth** exceeds 12.5mm (0.50 inches). Test apparatus is shown TTI/HTAS Figure 1.



TTI/HTAS Figure 1

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).



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.

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.



Ingios Figure 1

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. of ACE fiber reinforced AC surface course layer, 4.5 in. of ACE fiber reinforced AC base course layer, 8 in. of dense graded aggregate base layer, Type 2 geogrid, and subgrade.

Results:

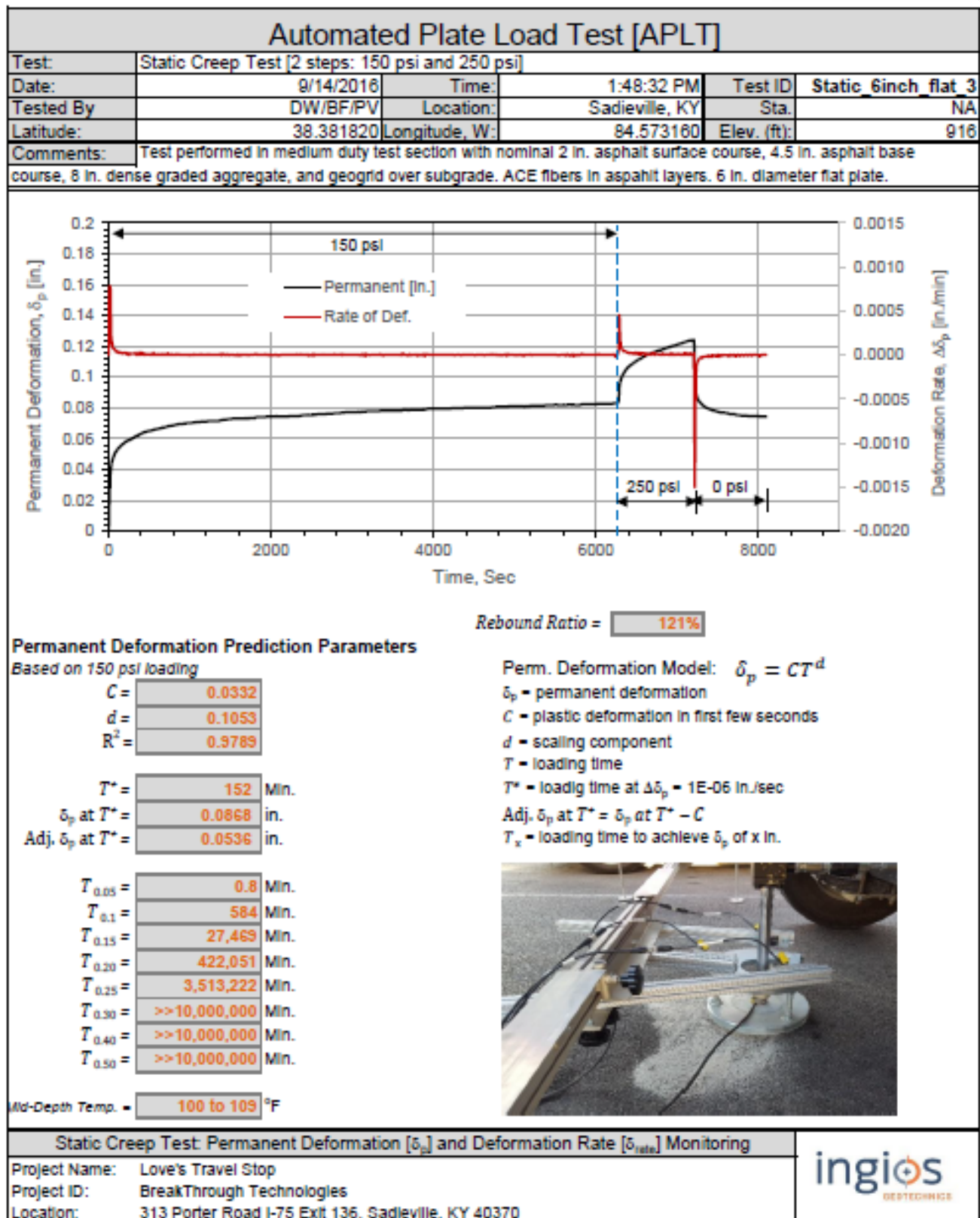
Static creep test results showed that permanent deformation (δ_p) at the end the static creep test with applied contract stress of 150 psi averaged about 0.14 in. Forecasting power models show that at all three test locations the number of loading cycles to achieve 0.5 inch permanent deformation (i.e., 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 15,000 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

Performed by Ingios Geotechnics, Inc.



The (APLT) Dynamic Modulus Test

The Automated Plate Load Test

Performed by Ingios Geotechnics, Inc.



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Results:

The in-situ backcalculated and temperature corrected fiber reinforced AC layer moduli (E'_{AC}) values averaged about 1.32 million ksi for 70 psi cyclic stress and loading frequency of 1.59 Hz.

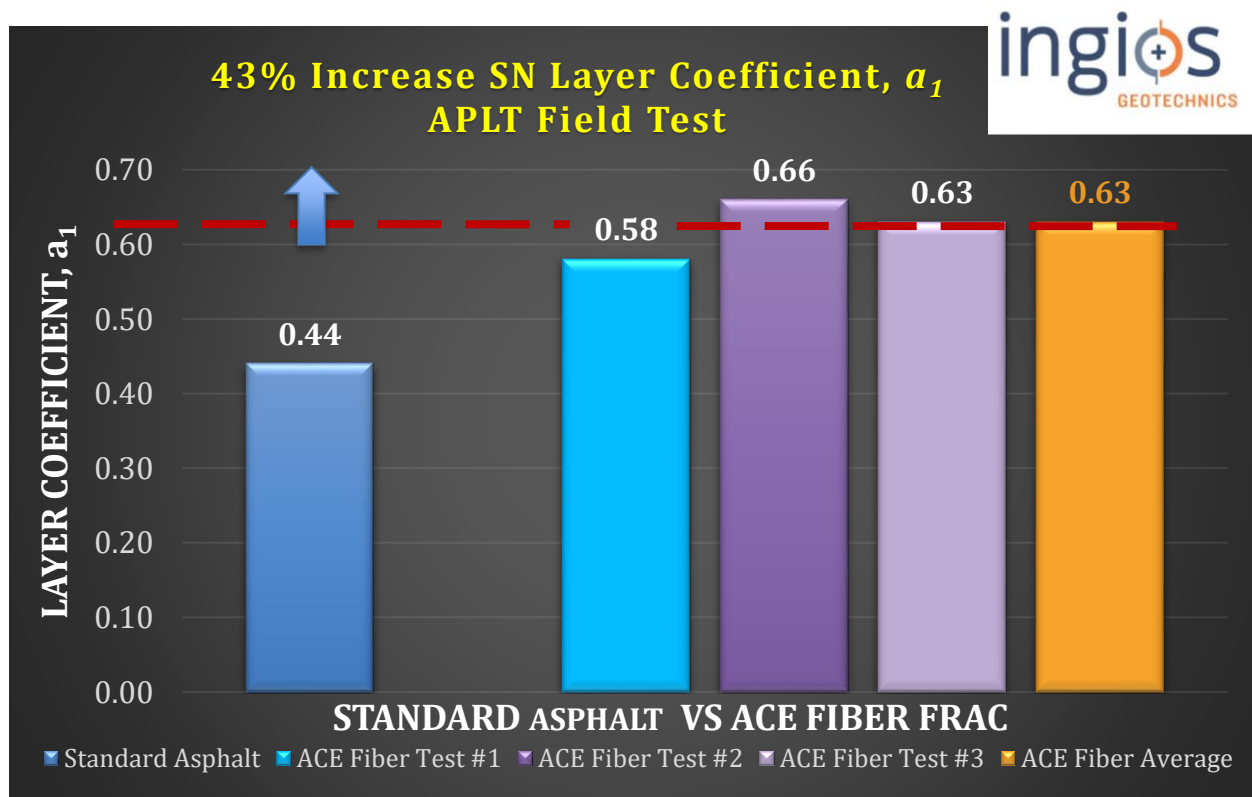
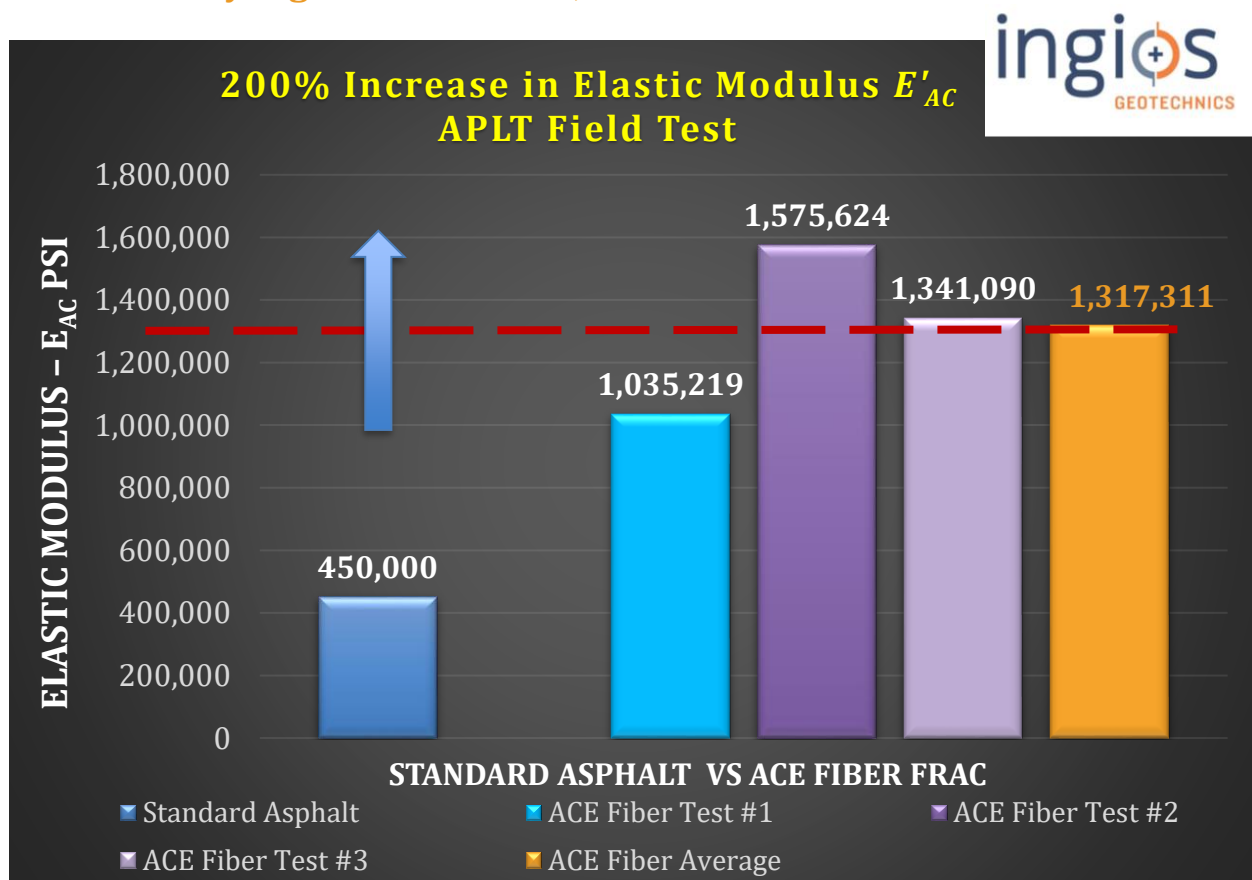
ESAL calculations were performed using the measured subgrade M_R values as well as assuming a 50% reduction in the M_R values to account for future saturation. Results and analysis from three test points produced an average structural layer coefficient for the fiber reinforced AC layer (a_1) of 0.63 and an average of 67.5 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 11.2 million.

ESAL calculations showed that compared to an unreinforced AC layer case ($a_1 = 0.44$), the ACE fiber reinforced AC layer ($a_1 = 0.63$) increased the average number of ESALs by about 6 times.

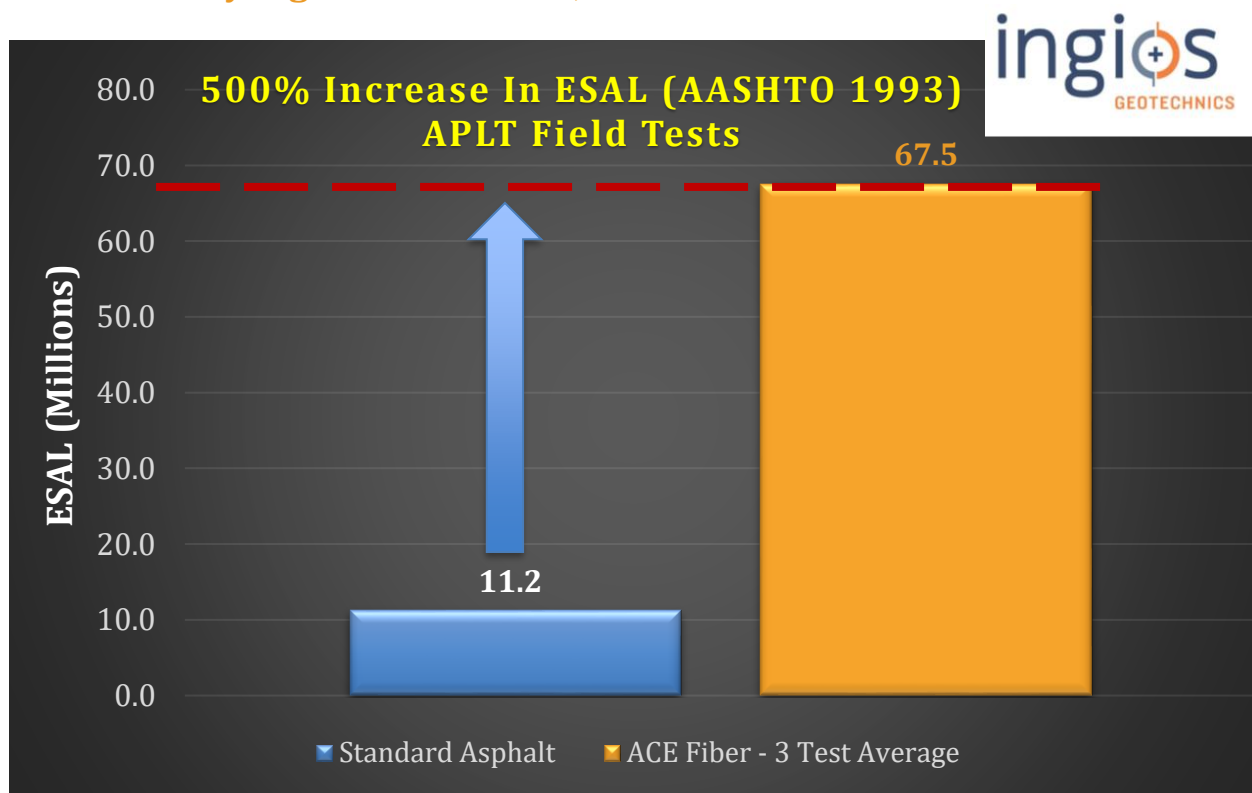
The (APLT) Dynamic Modulus Test

Performed by Ingios Geotechnics, Inc.



The (APLT) Dynamic Modulus Test

Performed by Ingios Geotechnics, Inc.



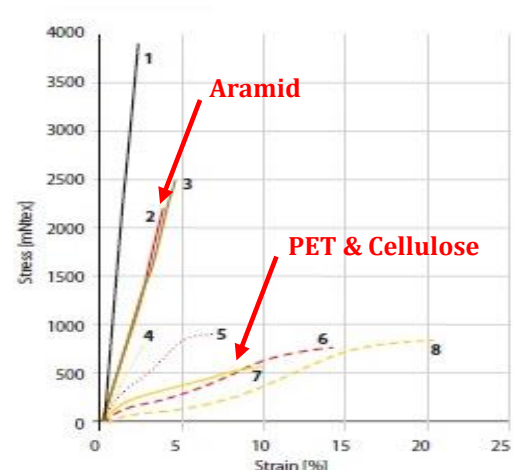
ACE Fiber™ is engineered for performance.

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 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/cm ³)	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



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.



AI/AAT Figure 1

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 1 Below.

Table 1 - ACE Fiber Extraction Test Results per ASTM D2172

ACE Fiber Sample	Test Lab	% Extracted Fibers (%)	Weight of Fibers (oz./ton)
ACE Fiber Sample 1	AAT	.007	2.3
ACE Fiber Sample 2	AAT	.007	2.4
ACE Fiber Sample 3	AI	.014	4.5
ACE Fiber Sample 4	AI	.009	2.9
Average:		.009	3.0

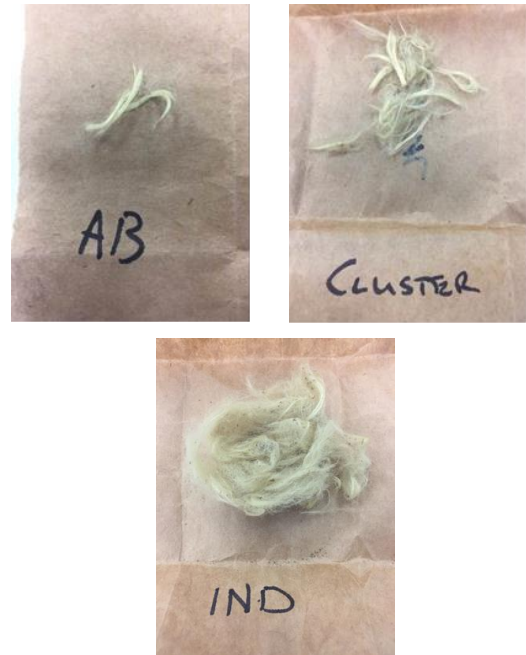
ADSR Test of Aramid Fibers

Aramid Dispersion State Ratio

Performed by Advanced Asphalt Technologies
And Asphalt Institute

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AI/AAT Figure 1

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. Non-the-less, Table 2 shows the dispersion description and % weights of each dispersion state of the sample with the bundle state being the worst case where the fiber does not disperse, followed by the agitated bundle, cluster, and individual fibers (indicates best dispersion).

Table 2 - ACE Fiber ADSR Classification

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