#1 Pavement Distress - Cracking

ACE XP
POLYMER FIBER

Aramid Pavement Solutions
Good, Better, Best & Test

ARMI
INTERLAYER

SURFACE TECH™

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Balanced Mix Design Solutions

Asphalt pavements need to be stiff enough to minimize rutting, but resilient enough to bend without breaking to prevent cracking. The trend over the last 20 years has been one-sided — fixing the ruts at the expense of the cracks. Many in the industry have begun to recognize the need for a "balanced approach" to developing pavement designs that will perform well in resisting both rutting and cracking.

There are seven key existing performance or index tests for asphalt cracking (see Table 1). These tests vary in complexity and cost, and as a result, the asphalt industry has not traditionally performed cracking performance tests on every project. As a result, not many owner agencies truly know how their current mix designs are performing to resist cracking.

For rut testing, the Hamburg Wheel Tracker (HWT) test (AASHTO T324) tends to be the most widely used method. However, many agencies and specifiers, including DOTs, are moving toward adopting performance-based specifications where both mix designs and daily production will need to meet certain minimums in both cracking and rutting parameters in order to be considered.

Table 1. *Seven existing cracking tests selected by NCHRP 9-57 and IDEAL-CT*

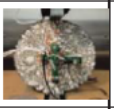
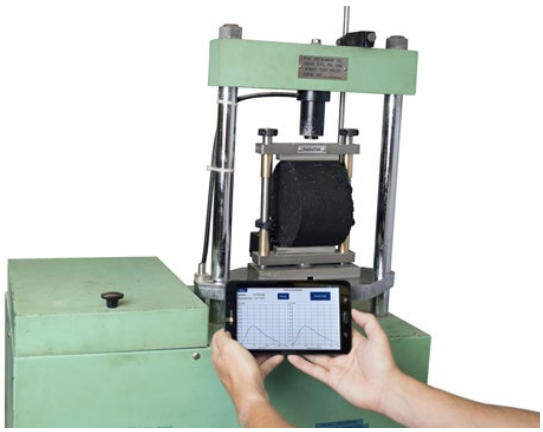
Cracking tests		Test limitations and equipment cost
DCT		• Specimen prep: 3 cuts, 1 notch, and 2 holes • Instrumentation: glue 2 studs, mount 1 clip gauge • Equipment cost: $50,000
SCB-AASHTO TP105		• Specimen prep: 3 cuts and 1 notch • Instrumentation: glue 3 studs, mount 1 extensometer + 1 clip gauge • Testing: 30 min. • Equipment cost: $50,000
SCB-Louisiana transportation research center		• Specimen prep: 9 cuts and 3 notches • Testing: around 30 min. • Equipment cost: less than $10,000
SCB-Illinois		• Specimen prep: 3 cuts and 1 notch • Equipment cost: $10,000-$18,000
IDT-CST		• Specimen prep: 2 cuts • Instrumentation: Glue 8 studs, mount 4 extensometers • Testing: 1-2 hours • Equipment cost: more than $50,000
OT		• Specimen prep: 4 cuts, glue specimen to bottom plates • Testing: 30 min. - 3 hr. • Equipment cost: $40-50,000
BBF		• Specimen prep: large slab, 4 cuts • Instrumentation: glue 1 stud and mount 1 linear variable differential transformer • Specimen testing: 1 hour to days • Equipment cost: more than $100,000
IDEAL-CT		• **No cutting, notching, drilling, gluing, or instrumentation** • **Test completion within 1 min.** • **Repeatable (or low variability) with COV<25 percent** • **Practical for routine uses in Departments of Transportation (DOTs) and contractors' laboratories** • **Low cost test equipment (<$10,000)** • **Sensitive to asphalt mix composition** • **Cracking performance related**

Figure 1. Hamburg Wheel Tracker (HWT) Test

Balance mix design depends on an easy, low cost and accurate way to measure crack resistance. A new and promising cracking test has recently been developed by Dr. Fujie Zhou and his colleagues at the Texas A&M Transportation Institute. The Indirect Tensile Cracking Test at Intermediate Temperature (IDEAL-CT) [ASTM D8225] is a reduced cost method that provides consistent results to predict field performance in cracking. This test, along with HWT, can be used daily to ensure that asphalt mixes meet both rutting and cracking performance criteria in a balanced manner.

Figure 2. IDEAL-CT at Intermediate Temperature



In the above testing, ***Surface Tech's Aramid Pavement Solutions*** show a range of improvement in both Rutting and Cracking performance depending on the amount added to the design mix.

#1 Pavement Distress - Cracking

Improving Performance is a Choice

The first step in improving the performance of asphalt pavements is knowing the performance of the existing asphalt mix designs in both the HWT and IDEAL-CT performance tests as mentioned above. Because most problems today are cracking problems, it makes sense to focus on improving the crack resistance of existing asphalt mix designs. Running IDEAL-CT to define the crack index of common various mix designs quickly teach an owner which mix designs are more crack resistant than others. Importantly, improvement can be gained by discontinuing use of poor performing mix designs or finding a way to make local materials perform better.

Table 2. *Thresholds for IDEAL-CT Mixture Performance Tests.*

Test	Mix Type	Minimum CT Index	Set By
IDEAL-CT (ASTM D8225)	Dense-Graded	65	Dr. Fujie Zhou 2018
	Superpave	105	
	SMA	145	
	RCRI (ARMI™)	650	Surface Tech 2019

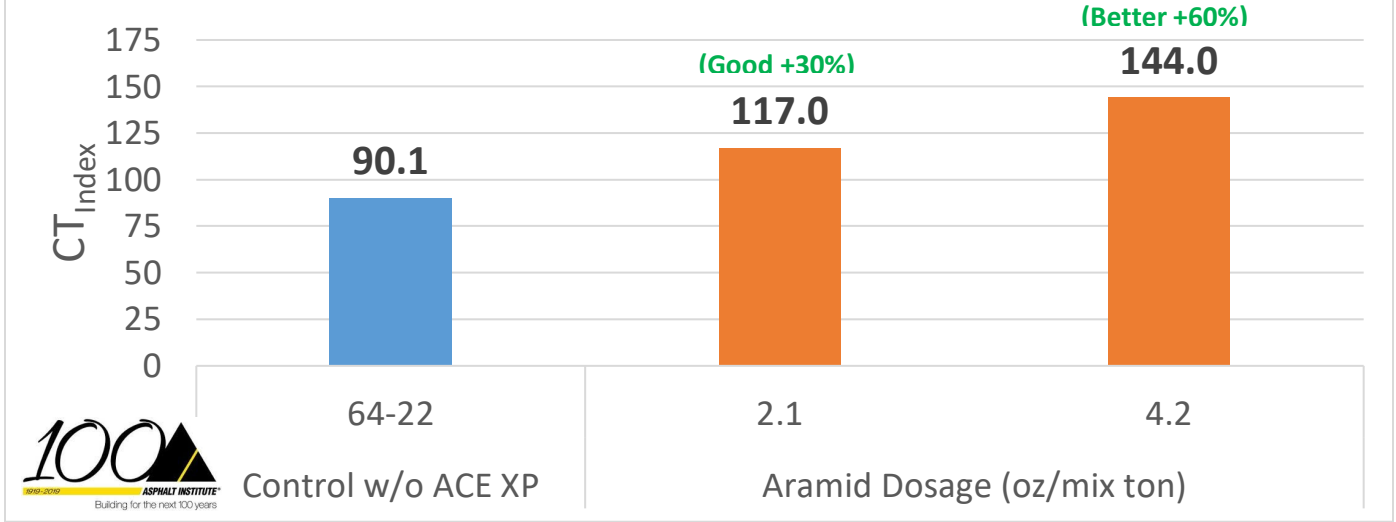
Notice the minimum thresholds listed above do not call out minimum RAP/RAS % or asphalt binder content. Both of these parameters will lower or raise a CT Index value depending on how much is used in the mix design. The results of IDEAL-CT can be compared to actual field performance, and the CT Index adjusted accordingly to achieve better crack performance.

For example, if a dense grade mix design shows a CT Index value of 65, and the in-place performance shows cracks completely returning in 3 years, which is not desirable, then the CT Index value should be raised incrementally by the % of desired performance increase. So, if the desired field performance in this example was 5 years, the CT Index should be raised by 67% or a new CT Index value of 108.

Adding Aramid Fiber to Increase IDEAL-CT and Crack Resistance

In the example above, it may seem like the only option might be to stop using the dense grade mix which yielded the CT Index of 65. However, using one of ***Surface Tech's Aramid Pavement Solutions*** such as ACE XP Polymer Fiber™ is one solution to improve crack performance without abandoning the lower performing mix designs.

Table 3. Typical Lab Mixed IDEAL-CT Index Values for a Medium Volume Dense Grade Mix (No RAP, 5.4% AC) and ACE XP (No RAP, 5.4% AC) Dosed Mixtures (oz)



#1 Pavement Distress - Cracking

Balance the New IDEAL-CT Mix Design for Rutting

The Hamburg Wheel (HWT) Test typically sets a limit of ½" (12.5mm) of rut depth along with a minimum number of cycles for a given PG binder grade. It is important to check the improved IDEAL-CT mix design created above in the HWT to ensure the mix design stills performs as required for the given use.

Table 4. *Thresholds for HWT Mixture Performance Tests.*

Test	PG Binder Grade	Rut Depth	Cycles to Failure
Hamburg Wheel (HWT) Test (AASHTO T324)	PG 64-22	12.5 mm	10,000
	PG 70-22	12.5 mm	15,000
	PG 76-22	12.5 mm	20,000
	RCRI (ARMI™)	12.5 mm	5,000

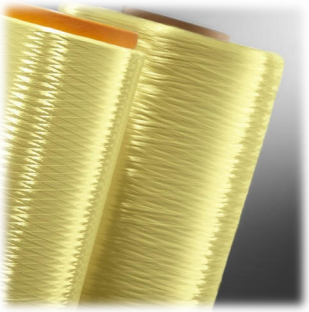
Typically, when using one of ***Surface Tech's Aramid Pavement Solutions*** to improve the IDEAL-CT, the HWT results will also improve or at least remain in a desired range of performance. For example, testing shows that ACE XP Polymer Fiber™ will improve both rutting and cracking performance by 30% to 50% with adding only 3.4 ounces to every ton of plant mix. Thus, by using the ACE XP Polymer Fiber™ to improve cracking typically provides a safety factor of moving the "balanced mix design" too far and creating a rutting problem.

What is XP Polymer Fiber™

ACE XP Polymer Fiber™ is a true achievement in additive technology to enhance asphalt concrete performance.

The first product in ***Surface Tech's Aramid Pavement Solutions*** collection is ACE XP Polymer Fiber™ (AXP). When AXP is added to asphalt pavement it extends the service life by dramatically improving the asphalt's resistance to cracking and rutting (distresses that may cause premature failure).

To create ACE XP Polymer Fiber™, high-strength man-made "***ar***omatic poly***amid***e" or ***Aramid*** Fibers are bundled and coated with Sasobit® wax to create an asphalt concrete additive that is simple to mix with any WMA or HMA through a drum and or batch asphalt operation. The 3-dimensional reinforcement throughout the asphalt layer increases the asphalt's resistance to cracking, rutting, and fatigue while providing improved ESAL (Equivalent Single Axel Load) capacity through improved modulus.



Aramid Fiber
(2.1 to 4.2 ounces/ton)

Sasobit® Wax
(1.3 to 2.6 ounces/ton)

ACE XP Polymer Fiber™
(3.4 to 6.8 ounces/ton)

#1 Pavement Distress - Cracking

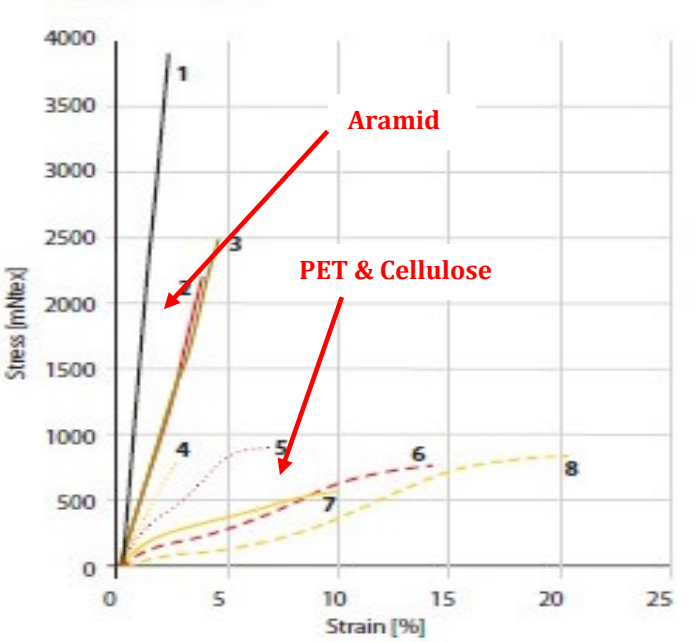
ACE XP Polymer Fiber™ is engineered for performance.

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 polymer fiber boasting high tensile strengths over 400,000 psi (5 x steel), a superior stress/strain relationship, and decomposition temperatures of 932°F (well above asphalt mixing temperatures of 400°F). Both ¾" long and 1.5" long fiber lengths are available for superior long-term performance.

Table 5. ACE XP Polymer Fiber™ Specifications

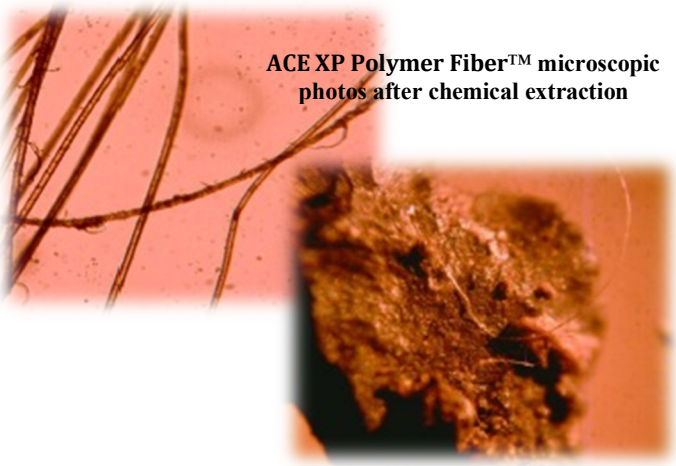
Material Property	Measure
Material	Para-Aramid Fiber (50-52% by weight)
Form	Filament Yarn
Tensile Strength	> 2.758 (GPa)
Elongation at Break	< 4.4 (%)
Modulus	> 95 (GPa)
Specific Gravity	1.44-1.45 (g/cm³)
Decomposition Temperature	> 800 (˚F)
Treatment Type	Sasobit® Wax (48-50% by weight)
Treatment Melting Temperature	> 170 (˚F)
Length	¾" & 1.5" +/-0.05 (inch)
Appearance/Handling	Free Flowing Coated Fiber Bundles (visual)

Figure3. Aramid Stress/Strain Curves

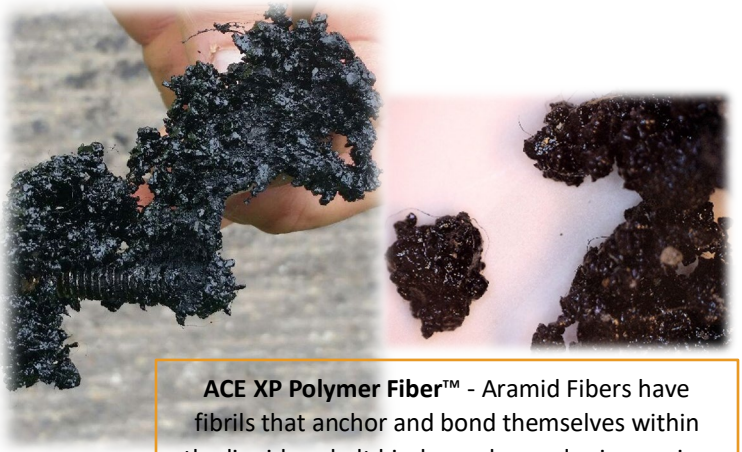


How does ACE XP Polymer Fiber™ reinforce asphalt concrete?

3.4 oz. / ton (1x Dose) to 6.8 oz. / ton (2x Dose) of ACE XP Polymer Fiber™ is mixed into WMA or HMA, the Sasobit® wax melts at approximately 170°F, releasing millions of Aramid Fibers uniformly throughout each ton of asphalt concrete. Aramid is a unique polymer fiber that has hair-like fibrils which root tenaciously in the liquid asphalt binder and bond to small granules and aggregates. Through the combination of high tensile strength, strength at low strain, and "fiber anchoring" ACE XP Polymer Fiber™ delivers reinforcement to asphalt concrete and enhances the strength and durability of the finished asphalt concrete mix.



ACE XP Polymer Fiber™ microscopic photos after chemical extraction



ACE XP Polymer Fiber™ - Aramid Fibers have fibrils that anchor and bond themselves within the liquid asphalt binder and granules increasing the tensile strength of the mix.

#1 Pavement Distress - Cracking

What is ARMI™

Surface Tech's ARMI™ product is used in conjunction with an Optimized Asphalt Mix Design to create a superior Reflective Crack Relief Interlayer (RCRI).

The second product in ***Surface Tech's Aramid Pavement Solutions*** collection is called ARMI™. The Aramid Reinforced Mix Interlayer (ARMI™) takes asphalt pavement crack resistance to the next level, providing a permanent plant produced and paver laid 1" thick asphalt interlayer.

The standard ARMI™ product will drastically reduce both bottom up and top down crack penetration through the 1" thick interlayer providing unparalleled crack resistance.

ARMI PLUS is further modified to achieve the crack resistance specific to the owner's performance needs and expectations.

Both ARMI™ and ARMI PLUS are engineered with a special asphalt mix design and liquid binder (reinforced with ACE XP Polymer Fiber) which is hot-mixed and hot-laid to stay in place even though the surface course above is replaced 1 or 2 times during the life of the interlayer.

Combining both ***Surface Tech's Aramid Pavement Solutions*** together and adding ACE XP Polymer Fiber™ to reinforce the surface course over ARMI™ will provide the most crack resistant ***system*** on the market today reducing costly maintenance over the life of the pavement.

ARMI™ is engineered to provide superior crack resistance by balancing rutting performance with impressive cracking performance of both the IDEAL-CT and Bending Beam Fatigue Tests as shown below:

Table 6. *Thresholds for ARMI™ Performance Tests.*

Purpose	Performance Test	Method	Test Temp	Criteria
Rutting	Hamburg Wheel Tracker passes to 1/2" (12.5mm) rutting	AASHTO T324	40, 45, or 50C	5,000 passes
	or			
	AMPT Flow Number	AASHTO T378	45, 50, or 55C	60
Reflective Cracking	Indirect Tensile Cracking Test (IDEAL-CT)	ASTM D8225	13, 20, or 25C	650 index
	or			
	Repeated Flexural Beam Fatigue	AASHTO T321	10, 15, or 20C	20,000 cycles

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Performance by Controlling Mix Design

ARMI™ is engineered to provide unparalleled performance by controlling the mix design including the gradation, PG asphalt binder type and content, volumetrics and in-place density as shown in ***Table 7***. In addition, the amount of ACE XP Polymer Fiber can vary to achieve the performance shown in ***Table 6*** above, this approach ensures that ARMI™ can be made in all parts of the country using readily available aggregate and PG asphalt binder sources.

The resulting in-place ARMI™ product will be semi-impermeable reducing water penetration to the subgrade below. By reducing the water infiltration to the subgrade ARMI™ will enhance the long-term structural performance of the pavement system.

As part of the ARMI™ system, Surface Tech provides the producer with a mix design using their raw material sources to meet the HWT and IDEAL-CT test performance shown in ***Table 6*** before production. In addition, Surface Tech provides plant mix HWT and IDEAL-CT validation once the project starts.

Table 7. *Standard Job Mix Range for ARMI™ Design*

Gradation	
Sieve	**% Passing**
3/8 inch (9.5 mm)	100
No. 4 (4.75 mm)	80-100
No. 8 (2.36 mm)	60 – 85
No. 16 (1.18 mm)	40 – 70
No. 30 (600 mm)	25 – 55
No. 50 (300 mm)	15 – 35
No. 100 (150 mm)	8-20
No. 200 (75 mm)	6-14
Asphalt Content	
7 to 10%	
Volumetrics	
% air voids at 50 gyrations using Superpave Gyratory Compactor (SCG)	0.5 to 2.5%
Mineral Aggregate (VMA)	16% minimum
In-Place Density	
96-98% of G_{mm} (maximum)	

Protecting the ARMI™ Investment

ARMI™ alone is not the complete solution. The interlayer must be covered by a high-quality overlay with an ACE XP Polymer Fiber™ reinforced binder that meets the 98% reliability for that climatic region that can absorb some of the movement to provide a pavement system approach. For example, ARMI™ may absorb 80% of the strain while the surface will need to absorb the remaining 20% of the strain. In addition, ARMI™ has an added benefit of a structural modulus at about half (typical structural coefficient of 0.20) that of regular HMA providing added structure to the pavement.

The ACE XP Polymer Fiber™ reinforced overlay brings ***Surface Tech's Aramid Pavement Solution*** together and serves to protect the ARMI™ investment. The minimum overlay thickness is shown in ***Table 8*** below and has been developed based on 20-year Equivalent Single Axial Loads (ESAL).

Table 8. *Minimum HMA Overlay Thickness Needed to Protect ARMI™*

Traffic Load, millions of 20-year ESALs	Minimum Overlay Thickness Required to Protect the RCRI
< 3	1.5"
3 to10	2.5"
10 to 30	3.0"
> 30	3.5"

#1 Pavement Distress - Cracking

Good, Better, Best Approach to Solving Cracking Problems

A single solution to cracking is not practical due to the variability of asphalt mixes across the United States. However, once the IDEAL-CT Index is understood and accepted, owners and engineers can start solving their unique cracking problems with data driven solutions.

By combining the use ***Surface Tech's Aramid Pavement Solutions*** ranging from the 3.4 oz. / ton to 6.8 oz. /ton of ACE XP Polymer Fiber™ for reinforced overlays to incorporating ARMI™ on the tough problems, Surface Tech provides owners and engineers a choice on how they solve their cracking problems.

Table 9. *IDEAL-CT Comparisons – Good, Better, Best, Very Best Performance*

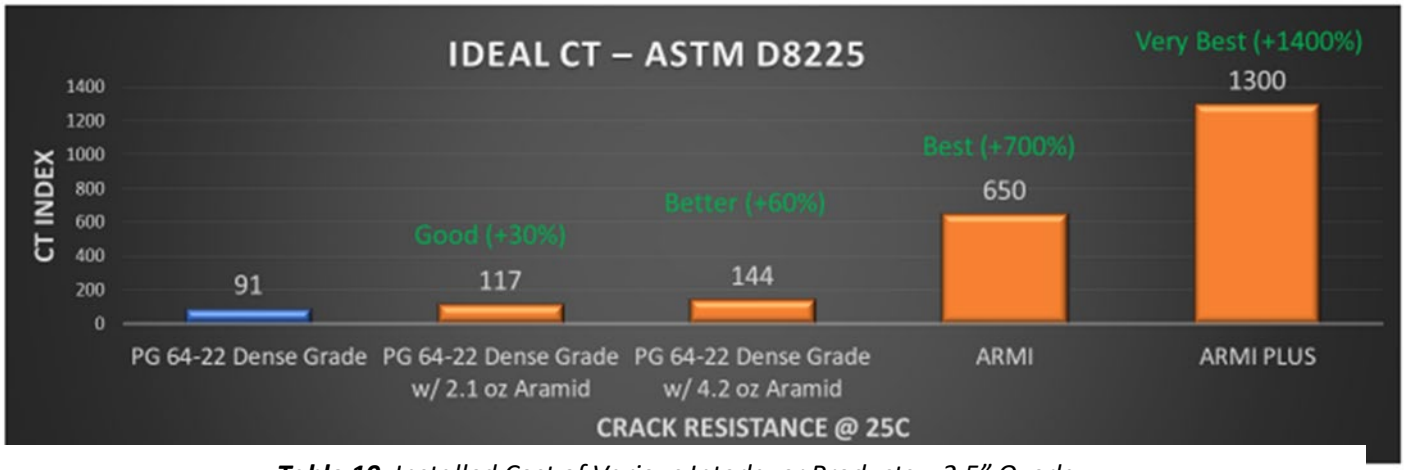
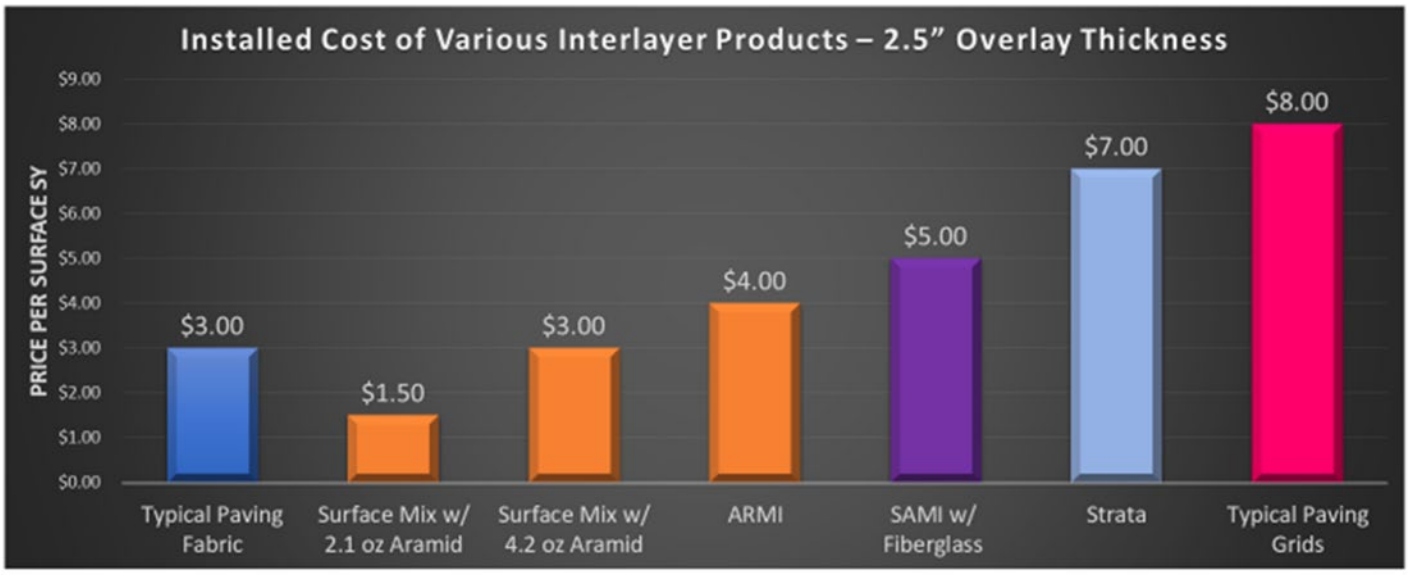


Table 10. *Installed Cost of Various Interlayer Products – 2.5" Overlay*



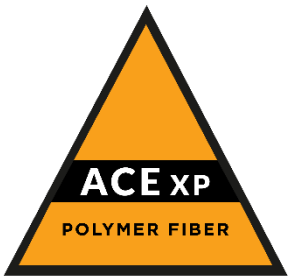
Good, Better, Best Cost Comparisons

#1 Pavement Distress - Cracking

Pulling it All Together – Suggested Usage Table

The following recommendations have taken Surface Tech years of lab and field testing to develop. Using IDEAL-CT Index to identify the needed crack resistance for overlay performance on varying existing crack conditions allows for the use of all ***Surface Tech's Aramid Pavement Solutions*** and provides the owner a choice.

Surface Tech's Aramid Pavement Solutions - Use Recommendations (ACE XP™ and ARMI™ – 38mm lengths)			
20-Year Design EASL's, Millions	**< 4.5" Overlays (Consider Existing Cracking Conditions)**		
	Moderate Cracking Overlay Solution (IDEAL CT = +80)	**Moderate to Severe Cracking Overlay Solution (IDEAL CT = +110)**	**Very Severe Cracking to Jointed PCC Overlay Solution (IDEAL CT = +650)**
< 1	PG64-22* + 2.1 oz./ton Aramid Polymer Fiber	PG64-22 + 4.2 oz./ton Aramid Polymer Fiber	1" - ARMI Interlayer + min. 1.5" PG64-22 Surface & 2.1 oz./ton Aramid Polymer Fiber
1 to < 3	PG64-22 + 2.1 oz./ton Aramid Polymer Fiber	PG64-22 + 4.2 oz./ton Aramid Polymer Fiber	1" - ARMI Interlayer + min. 1.5" PG64-22 Surface & 2.1 oz./ton Aramid Polymer Fiber
3 to <10	PG64-22 + 2.1 oz./ton Aramid Polymer Fiber	PG64-22 + 4.2 oz./ton Aramid Polymer Fiber	1" - ARMI Interlayer + min. 2.5" PG64-22 Surface & 2.1 oz./ton Aramid Polymer Fiber
10 to <30	PG64-22 + 2.1 oz./ton Aramid Polymer Fiber	PG64-22 + 4.2 oz./ton Aramid Polymer Fiber	1" - ARMI Interlayer + min. 3.0" PG64-22 Surface & 2.1 oz./ton Aramid Polymer Fiber
30>	PG64-22 + 4.2 oz./ton Aramid Polymer Fiber	PG64-22 + 4.2 oz./ton Aramid Polymer Fiber	1" - ARMI Interlayer + min. 3.5" PG64-22 Surface & 2.1 oz./ton Aramid Polymer Fiber
*Note: The recommended binder selection should meet 98% reliability for that climatic region, without the need for Polymer Modification.			



Aramid Pavement Solutions
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SURFACE TECH™

#1 Pavement Distress - Cracking

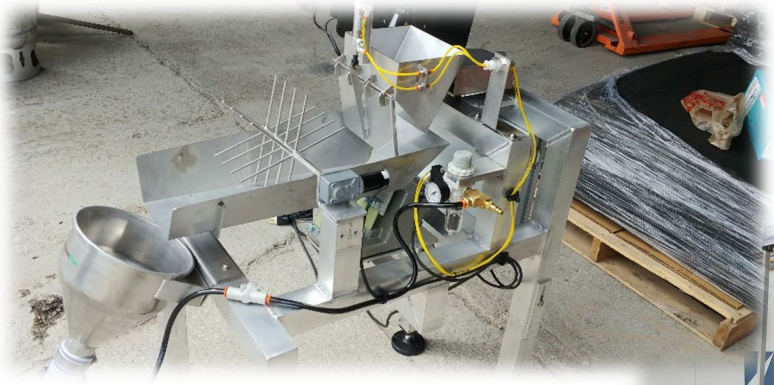
Are Surface Tech's Aramid Pavement Solutions easy to produce and lay?

Absolutely! ACE XP Polymer Fiber™ or ARMI™ Aramid are easily added by a simple-to-operate Line-Vac® Compressed Air Delivery System or the Automated Micro Doser MD3+. Both ACE XP Polymer Fiber™ and ARMI™ Aramid are engineered with controlled amounts of both Aramid and a fully soluble Sasobit® Wax. The wax melts at 170° F, releasing millions of individual aramid fibers throughout the aggregate and Recycled Asphalt Pavement (RAP) prior to the injection of the liquid asphalt binder. The addition of 3.4 to 6.8 ounces per ton of asphalt will not change the asphalt volumetrics or require any change to the job mix formula (JMF).

Installation Assurance?

Surface Tech partners with the producer on every project to provide a robust QA/QC program. Asphalt producers choose the option best fits the job to achieve consistent and compliant blending at their plants.

- Full Service – Provided by a Trained and Certified QA/QC Technicians
- Do-it-Yourself (DIY) – Self Perform after Training & Certification is Obtained



The Micro Doser MD3+ is used to weigh out the proper ACE XP Polymer Fiber™ dosage and then transport it to the RAP Collar at a Drum Plant or Weigh Hopper at a Batch Plant

The MD3+ Mini delivers ACE XP Polymer Fiber™ continuously to either the Drum Plant through the RAP Collar or Weigh Hopper at a Batch Plant

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Both QA/QC Methods ensure ACE XP Polymer Fiber™ or ARMI™ is well dispersed in the Asphalt Mix

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