Understanding Fiber-Reinforced Asphalt Concrete: Mechanisms and Applications

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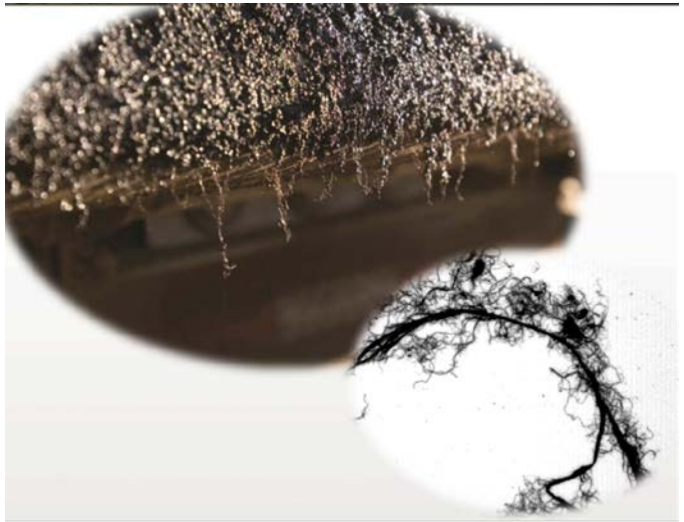


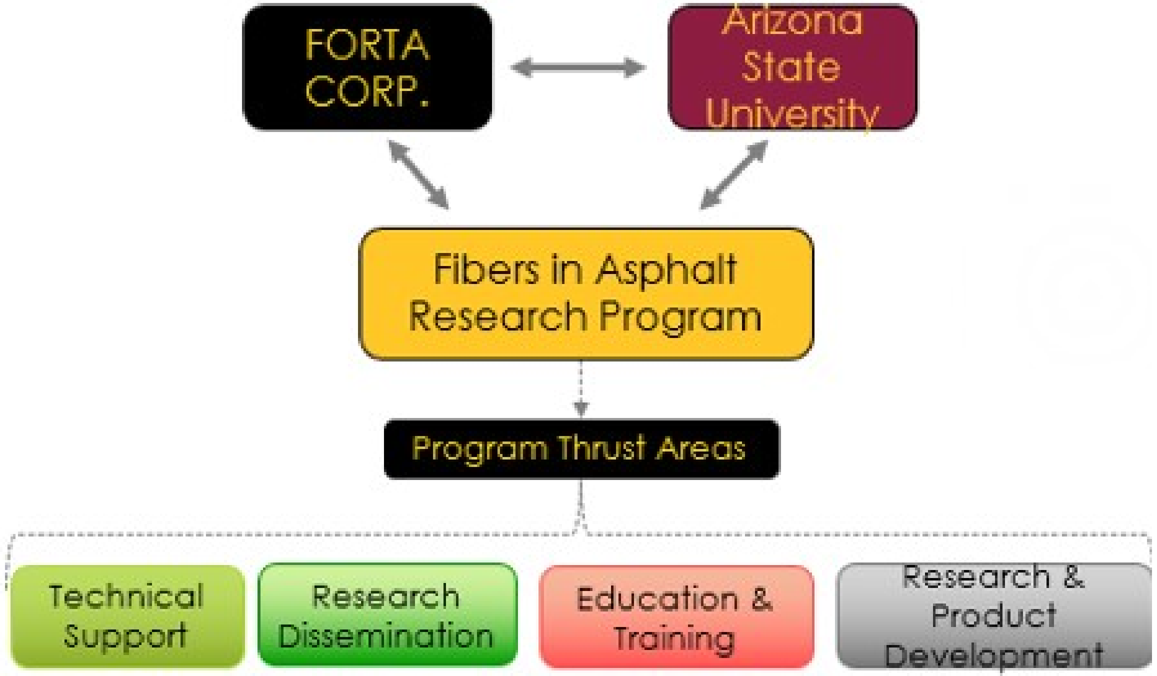
Outline

- Fibers Reinforcement Mechanism
- Fibers in Asphalt Mixtures
  - Overview of Aramid Fibers
  - Field Performance of FRAC
- Advancing the Knowledge of Fiber Reinforced Asphalt Concrete
  - State of Fiber
  - Asphalt mix composition
  - Laboratory Test Protocols

Fibers Research and Development

- 1. Understanding the interaction of Fibers in the Asphalt Mix Design process.
- 2. Understanding the basic, fundamental mechanisms of fiber state that may govern their mechanical response.
- 3. Refining and developing laboratory test procedures that could fairly represent and characterize fiber reinforcement performance

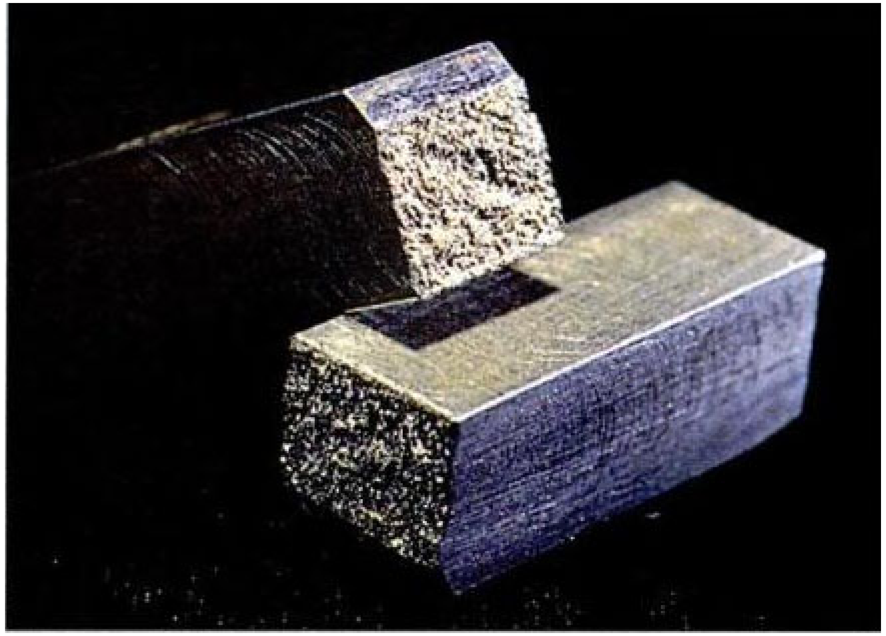
Research Program Since 2006

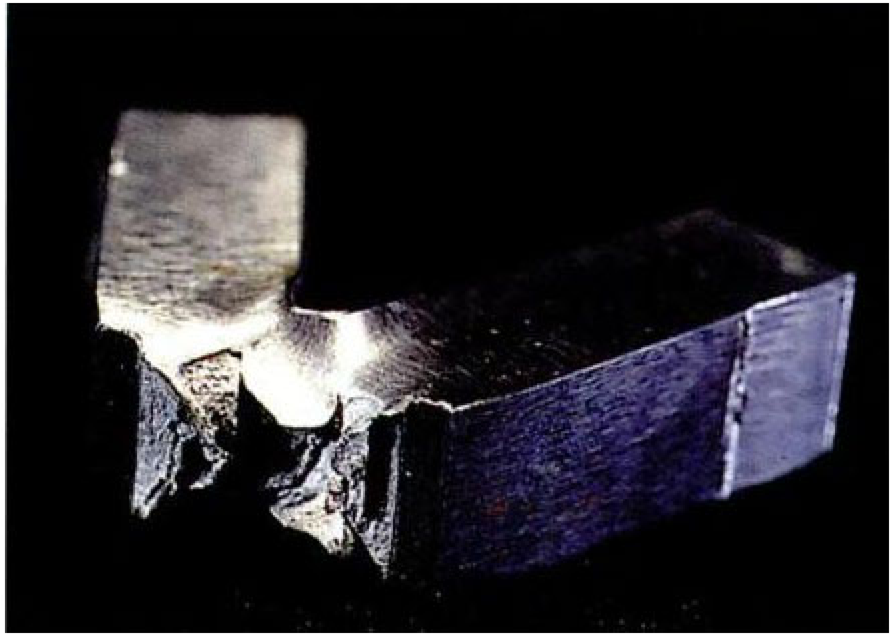


Fiber Reinforcement Mechanism

Mechanical Benefits

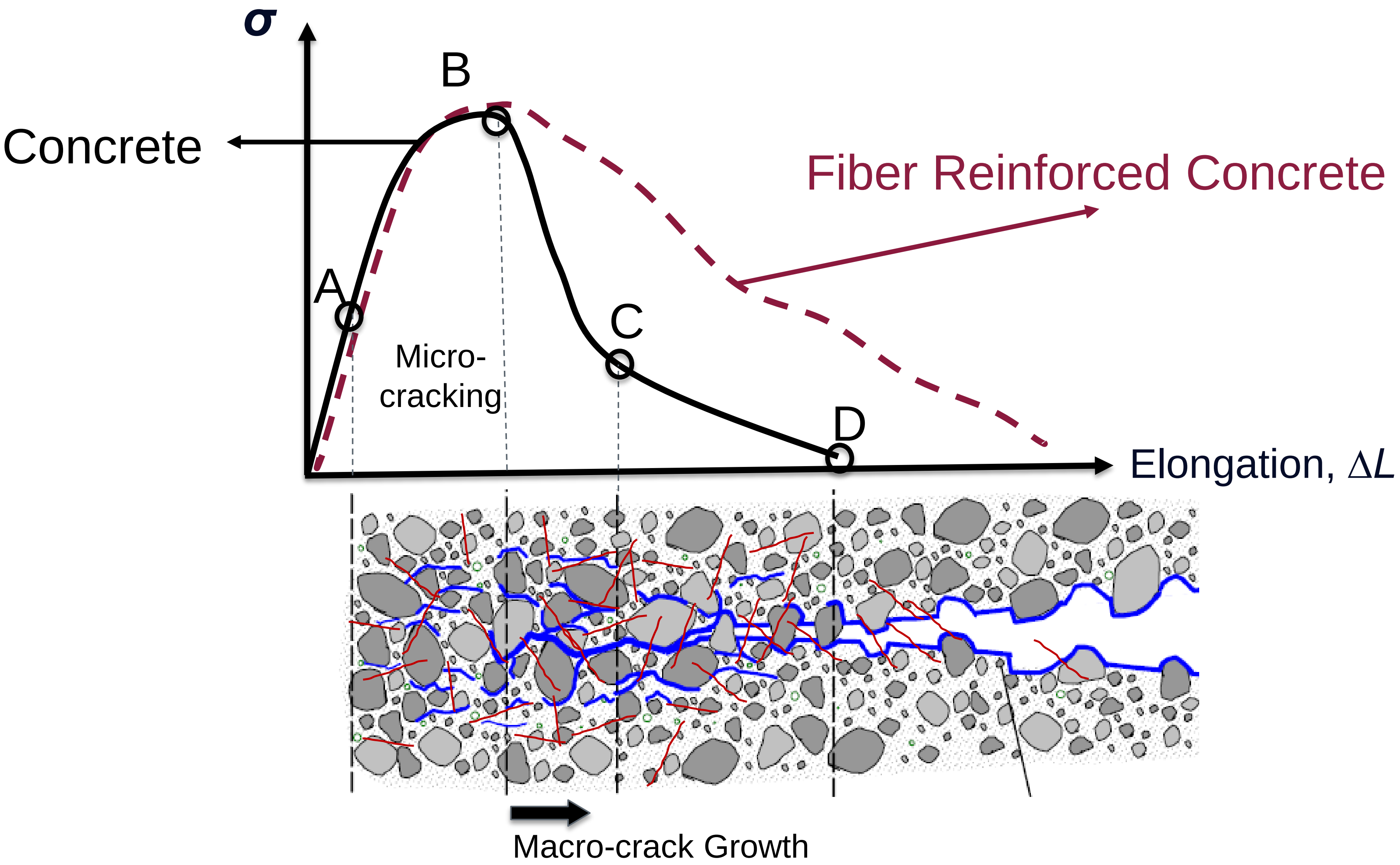
- Toughness is the ability of a material to absorb energy and plastically deform without fracture
- Resistance of material to fracture when it is stressed



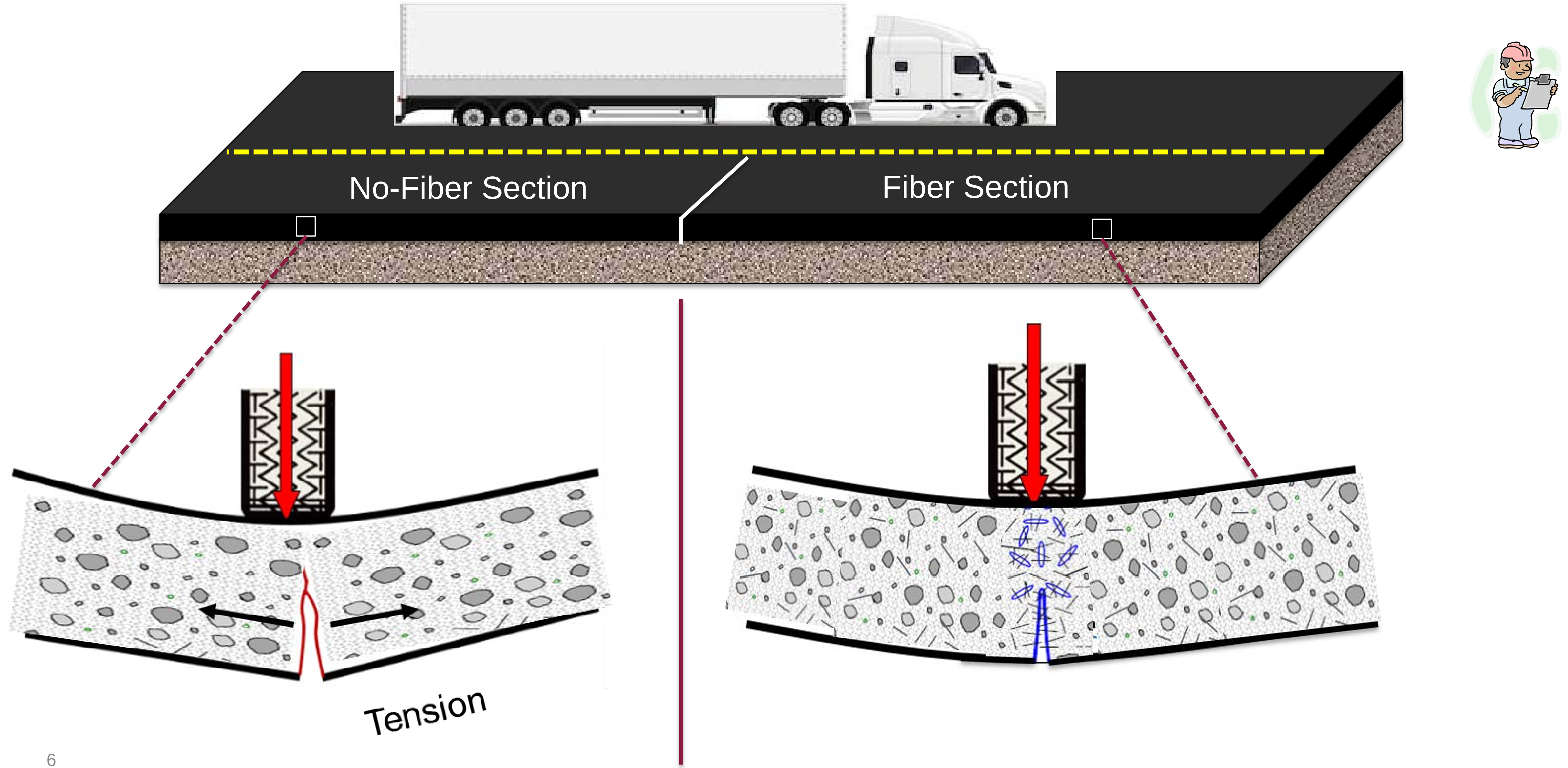


Fiber Reinforcement Mechanism

Crack Controlling Mechanism

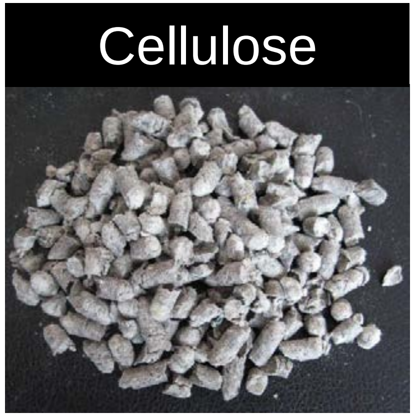


How can fibers help reinforce asphalt pavements?



Types of Fibers used in Asphalt Mixtures

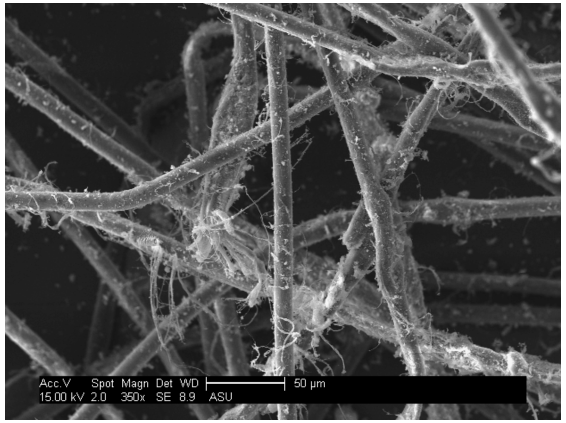
- Natural
  - Cotton, cellulose, coconut, bamboo
- Non-Synthetic
  - Glass, carbon, mineral (rock wool, asbestos)
- Synthetic
  - Polypropylene, nylon polyester, aramid

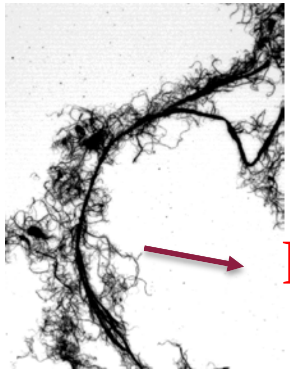


Why Aramid Fibers in Asphalt Mix?

a. Physical Properties *(ASTM D8395)*

- ➢ Stable at high temperatures (> 425 ºC)
- ➢ High Linear Density (>3200 dtex)
- ➢ Surface Morphology →





Fibrils

b. Mechanical Properties *(ASTM D8395)*

- ➢ High tensile strength (> 2700 MPa)

c. Favorable cost

- ➢ *Used at very low dosage (0.006% by Weight of Asphalt Mix)* → *No Mix Design Changes*

Field Performance of FRAC

Summary of Pavement Condition Index Survey

Location	Route	Section	Avg. PCI Rating	When measured?
Lackawanna County, PA	I-81	Control	79 (Satisfactory)	3 years after service
Lancaster PA, Franklin Road	SR 3036		69 (Fair)	4 years after service
Erie, PA	SR 4016		64 (Fair)	3 years after service
PA	Glen David Drive		64 (Fair)	NA
S Fayette Township, PA	Palomino Drive		54 (Poor)	NA
Wexford, PA	Stonewood Drive		57 (Fair)	NA
Costa Mesa, CA	Paularino Avenue		84 (Satisfactory)	NA
Lackawanna County, PA	I-81	Fiber	94 (Good)	3 years after service
Lancaster PA, Franklin Road	SR 3036		94 (Good)	4 years after service
Erie, PA	SR 4016		71 (Satisfactory)	3 years after service
PA	Glen David Drive		84 (Satisfactory)	NA
S Fayette Township, PA	Palomino Drive		76 (Satisfactory)	NA
Wexford, PA	Stonewood Drive		70 (Satisfactory)	NA
Costa Mesa, CA	Paularino Avenue		94 (Good)	NA

Field Performance of FRAC

I-81 -Lackawanna County, PA

- Two 1.5 miles (2.4 km) long sections of fiber and non-fiber 2” (50 mm) overlay was placed in 2013.
- Data were collected according to the PennDOT, Automated Pavement Condition Survey Field Manual and analyzed using ASTM D6433

Distress	Severity	Unit	Quantity					
			Fiber Sections			Control Sections		
			1830	1840	1850	1814	1820	1824
Rutting	Low	sqft	26.4	0.0	105.6	184.8	396.0	132.0
Fatigue Cracking	Low	sqft	0.0	32.8	0.0	119.3	994.0	1617.0
Transverse Cracking	Low	ft	10.7	0.0	2.4	10.8	13.4	4.5
Edge Deterioration	Low	ft	332.5	114.5	48.5	212.6	0.0	130.6
Patching	Low	sqft	326.3	15.2	0.0	113.8	0.0	0.0
2015 PCI			**91.0**	**94.0**	**95.0**	**90.0**	**77.0**	**70.0**
			94, Good			***79, Satisfactory***		
2017 PCI			***82, Satisfactory***			***65, Fair***		

Field Performance of FRAC

New York DOT's answer to reflective cracking of composite pavements

Solutions

- Transverse joint repair 6'wide 6" deep remove & replace with HMA
- Fabrics
- SAMI stress absorbing membrane interlayer
- Usual pavement repairs
- Increase overlay thickness

The outcome

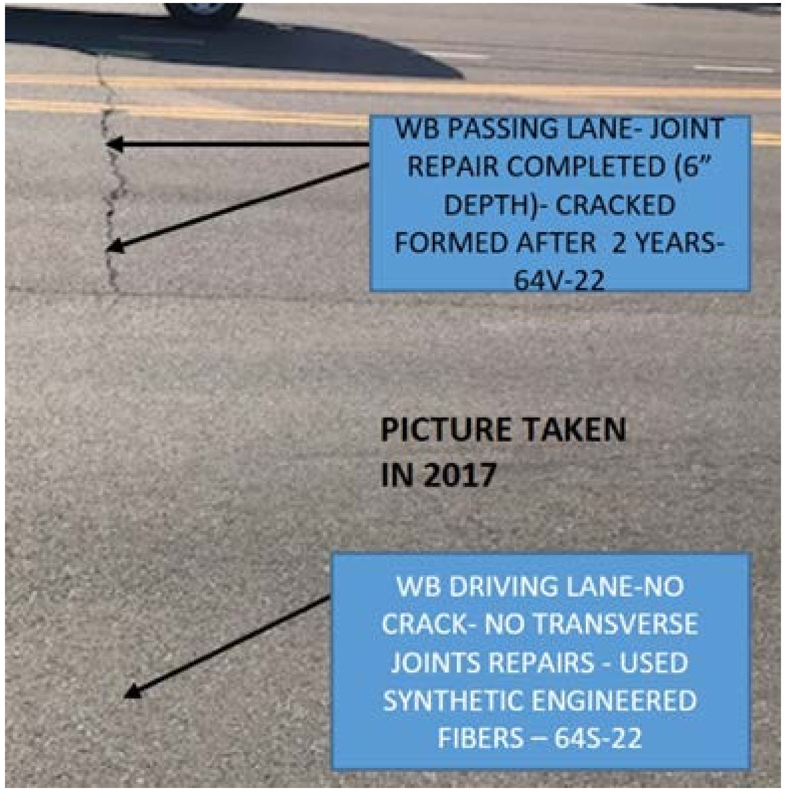
- None of the repair strategies were successful
- Reflective Cracking within the first year
- Crack sealing at year 2

Field Performance of FRAC

New York DOT's answer to reflective cracking of composite pavements

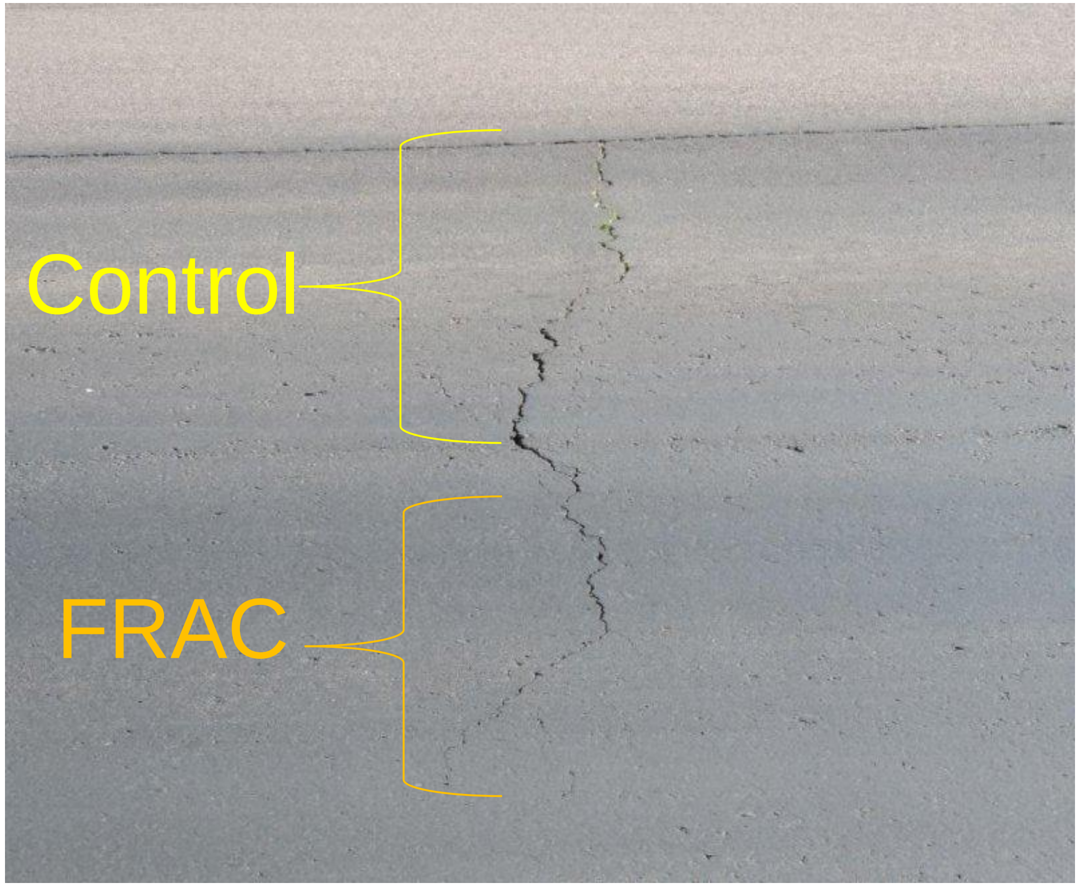
- Several test sections with and without poly-aramid fibers were implemented by New York DOT to study the potential benefits of fibers in improving the pavement performance to reflective cracking.

Location	Route	Year	Project Type	Outcome
Marcy in Region 2, NY	SR 291	2014	1.5"single course	delayed the reflection cracks by 1 to 2 years
Scottsville Rd, NY (Rochester airport, Region 4)	SR 383	2015	2" overlay in WB Ln with >80% traffic loading	No visible crack was observed after two years of assessment
Greigsville, Region 4, NY	SR 63	2016	2" overlay in a Heavy volume traffic section	The number of lane joints issue significantly reduced as of the year 2020



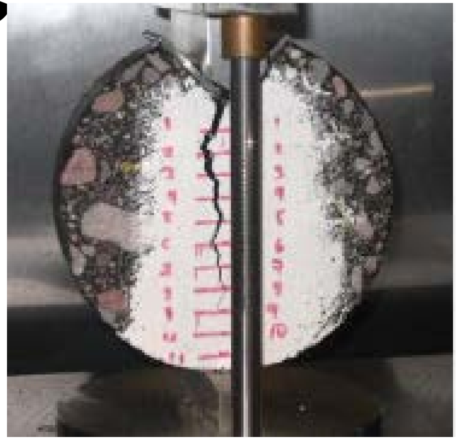
Field Performance of FRAC

City of Tempe- Evergreen Drive 2008

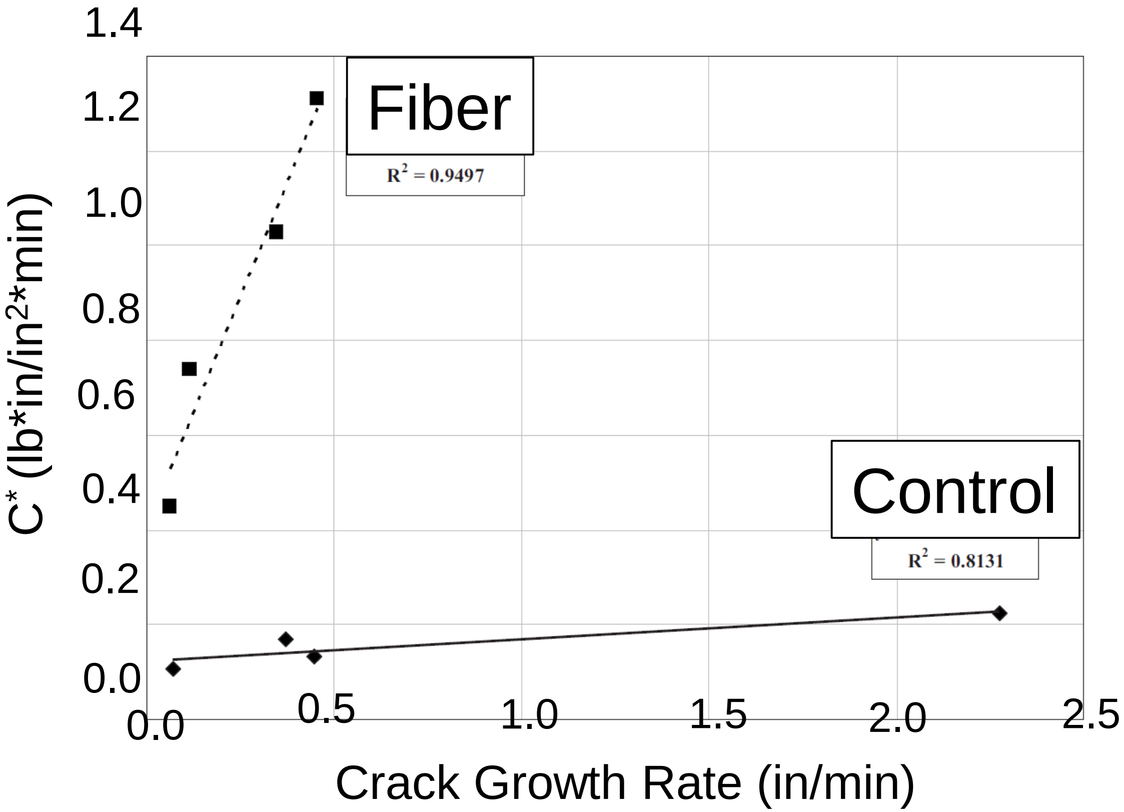


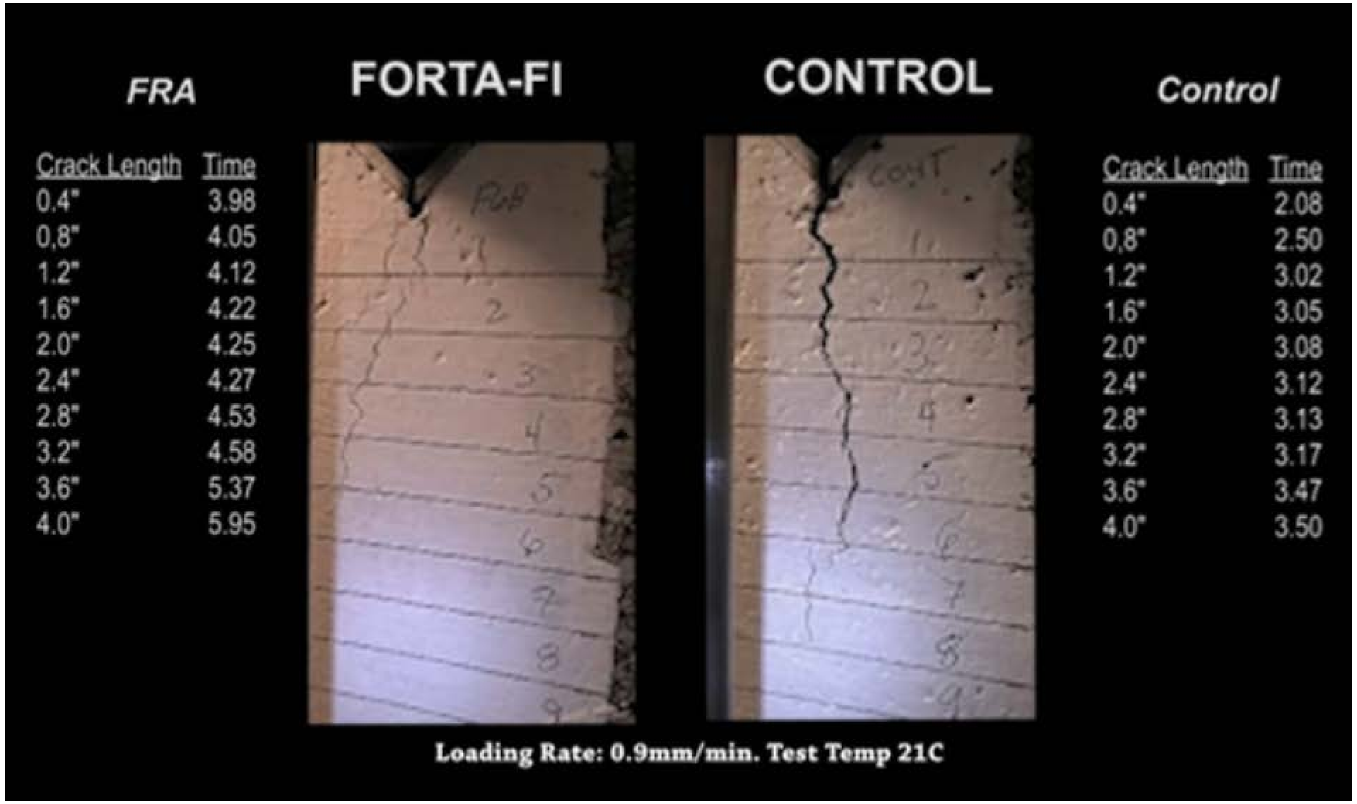
Fracture Test Performance of FRAC

C Test Result* *(Stempihar 2013, Ph.D.)*



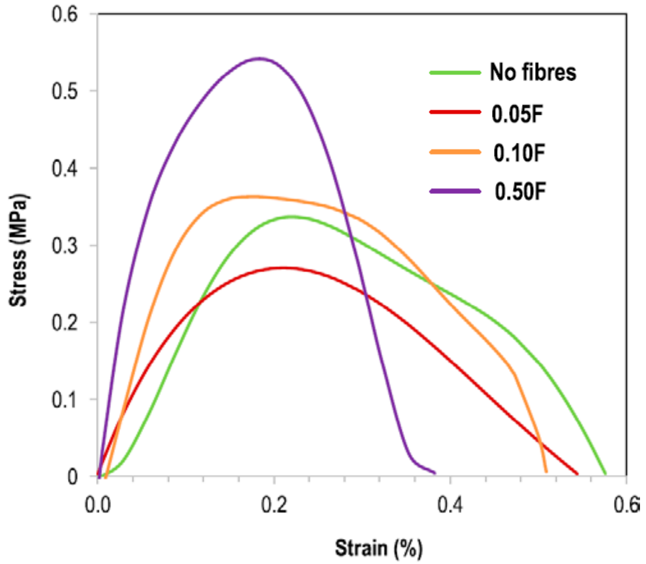
Kaloush, K. E., Biligiri, K. P., Zeiada, W. A., Rodezno, M. C., & Reed, J. X. (2010). Evaluation of fiber-reinforced asphalt mixtures using advanced material characterization tests. Journal of Testing and Evaluation, 38(4), 1.

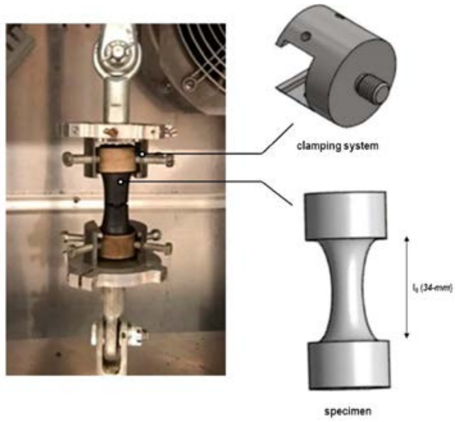




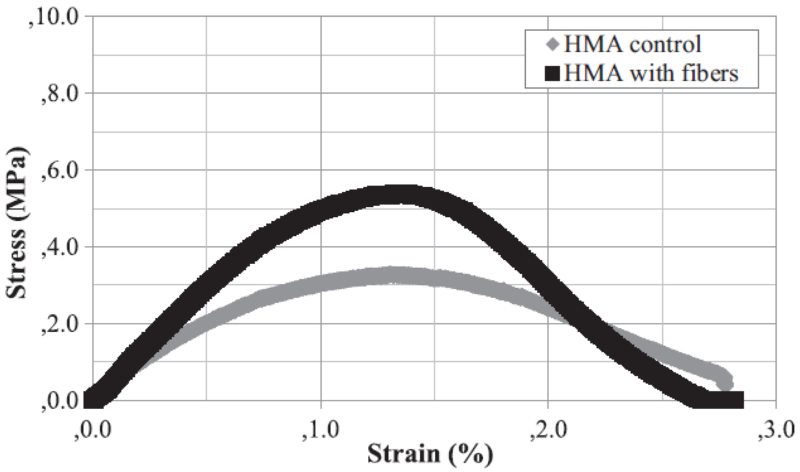
Have always results been positive?

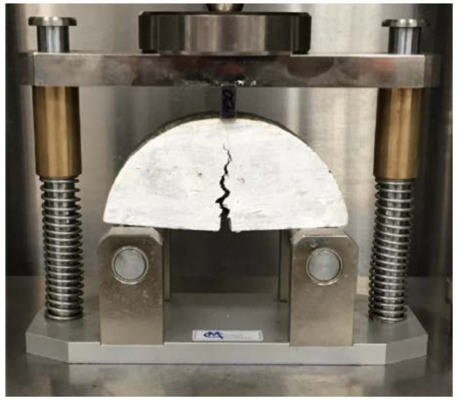
Apostolidis et al. (2019)



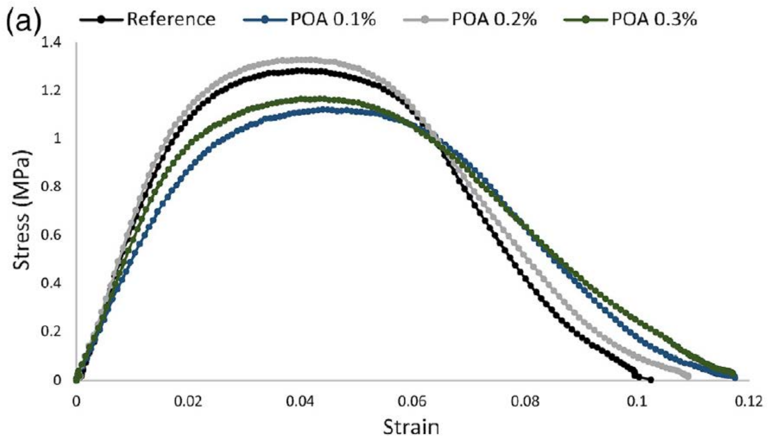


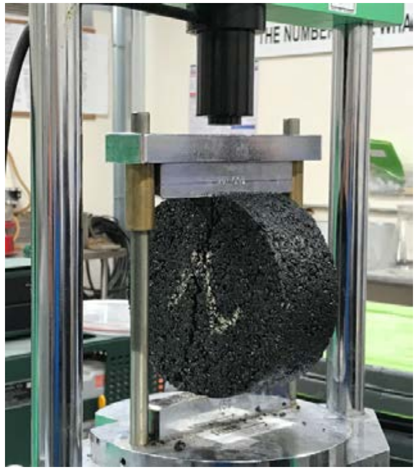
Klinsky et al. (2018)

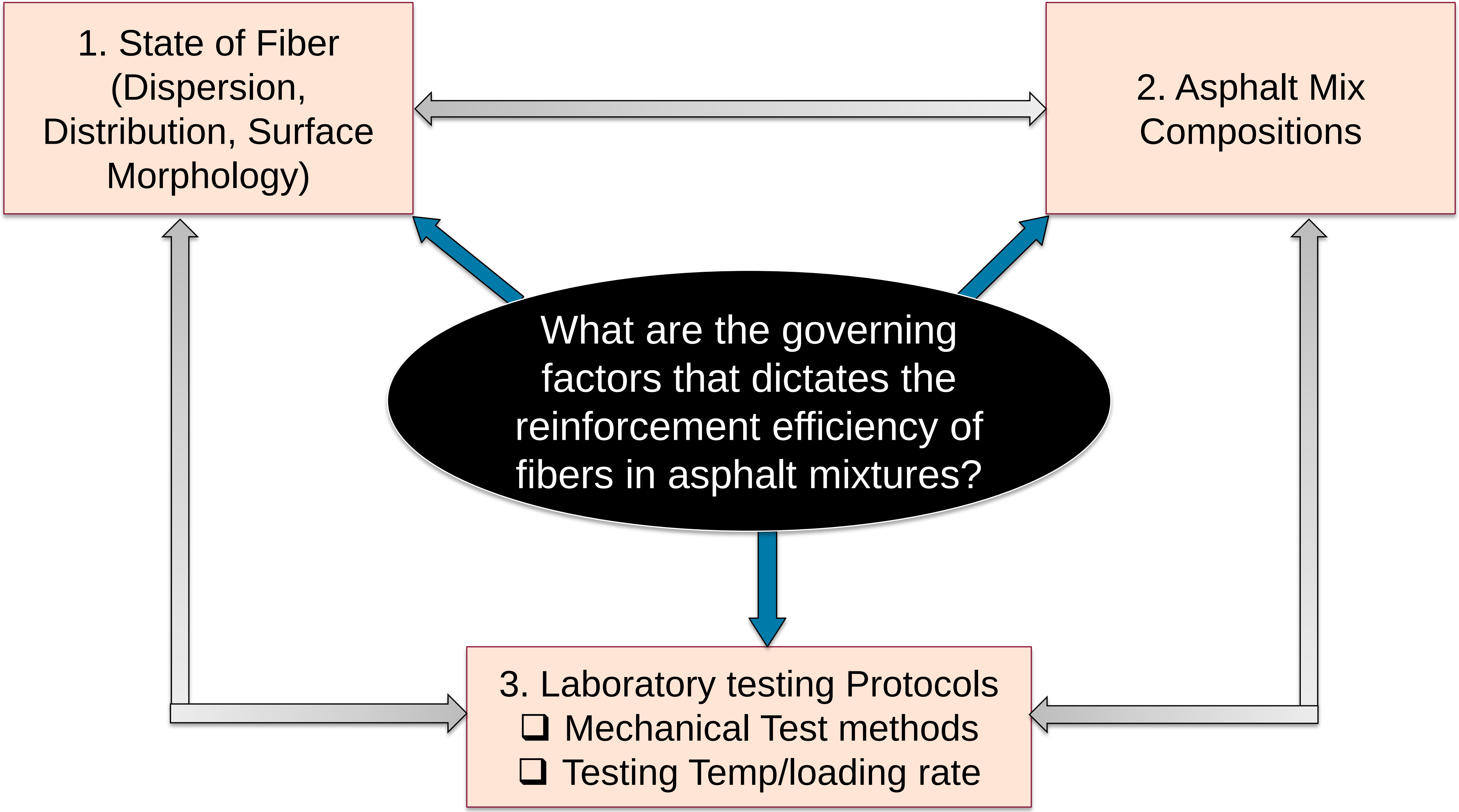




Slebi-Acevedo et al. (2020)

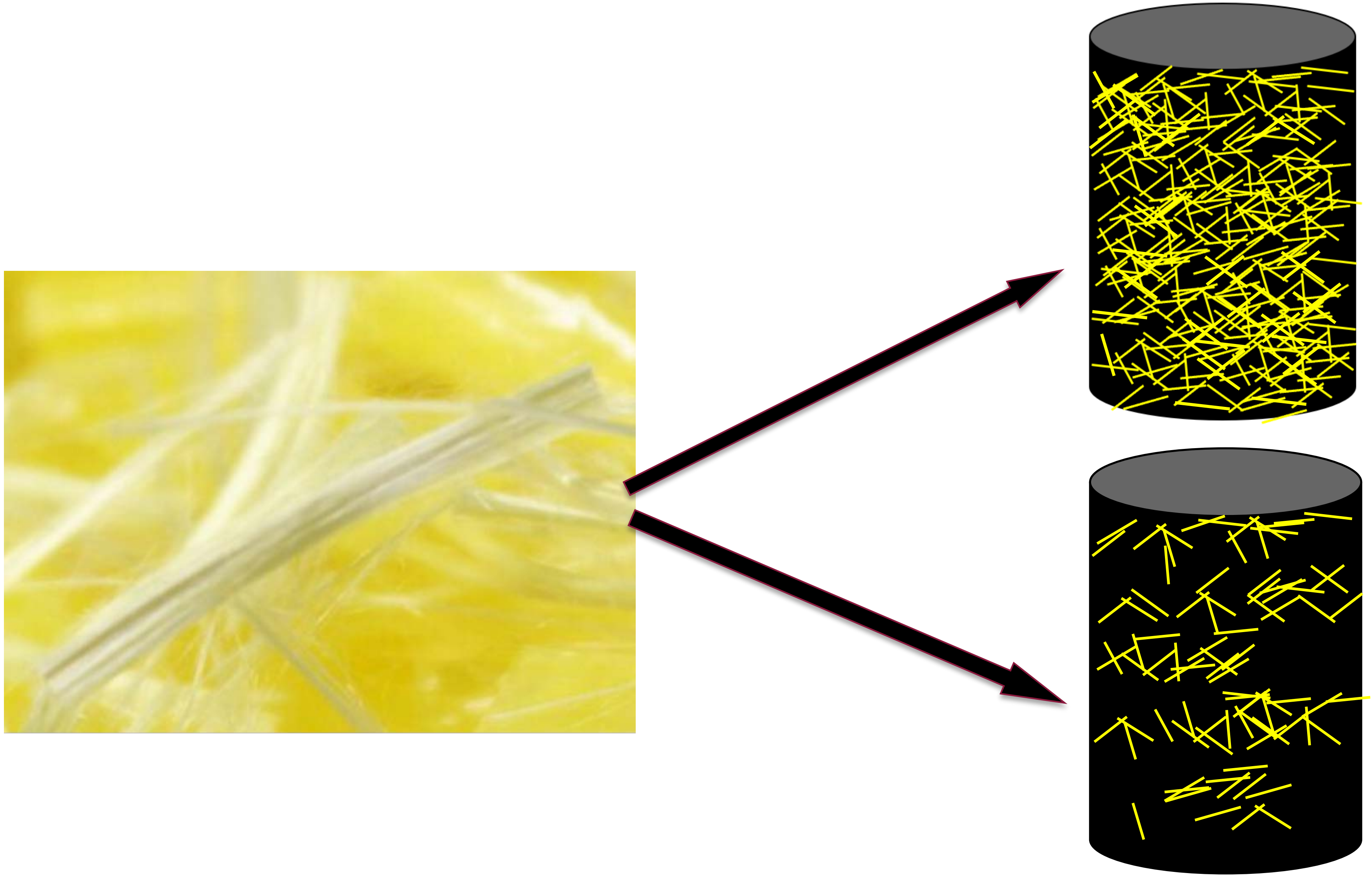





1. State of Fiber (Dispersion, Distribution, Surface Morphology)
2. Asphalt Mix Compositions
What are the governing factors that dictates the reinforcement efficiency of fibers in asphalt mixtures?
3. Laboratory testing Protocols
❑ Mechanical Test methods
❑ Testing Temp/loading rate

1. State of Fiber (Dispersion and Distribution)

ASU Laboratory Studies



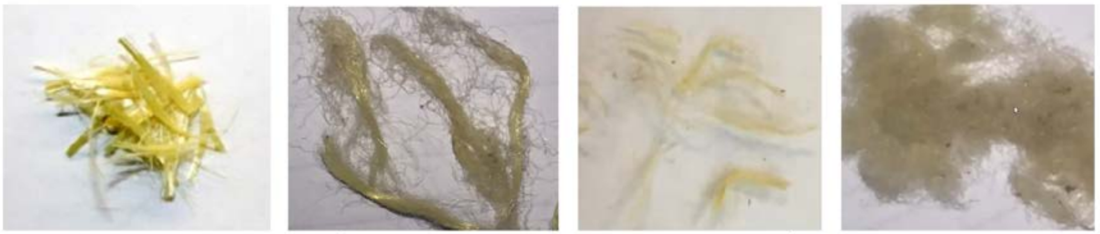
- ✓ Highly dispersed and distributed fibers in the asphalt mix.
- ✓ Low Fiber dispersion and distribution in the Asphalt Mix.

1. State of Fiber (Dispersion and Distribution)

ASU Laboratory Studies

- Aramid Dispersion State Ratio
  - Amount of extracted aramid fibers in the individual state compared to the total aramid extracted (in percent)

Bundle | Agitated Bundle | Cluster | Individual



Undesirable ⟷ Most Desirable

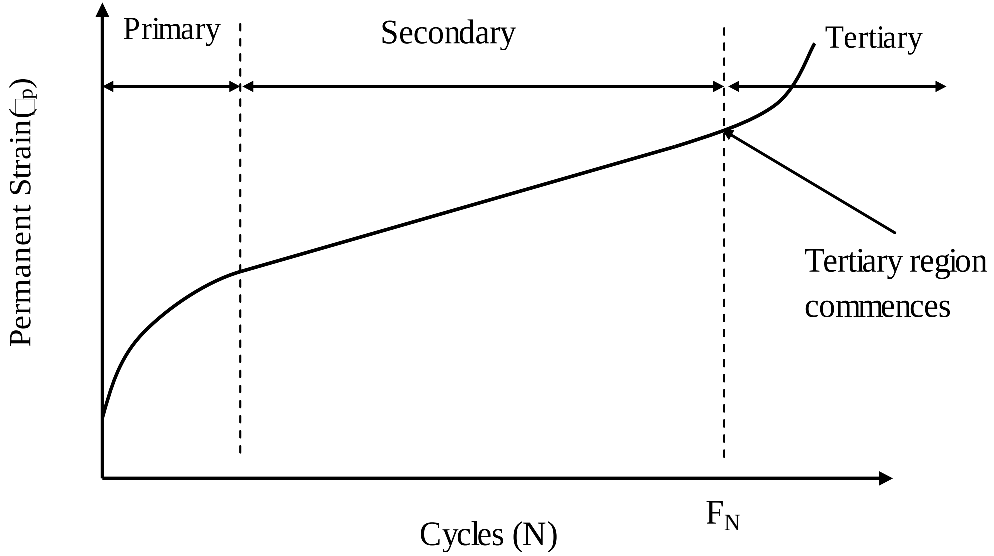
1. State of Fiber (Dispersion and Distribution)

ASU Laboratory Studies

- ❑ A total of three field prepared mixtures were obtained; one control mix and fiber reinforced asphalt mixes.

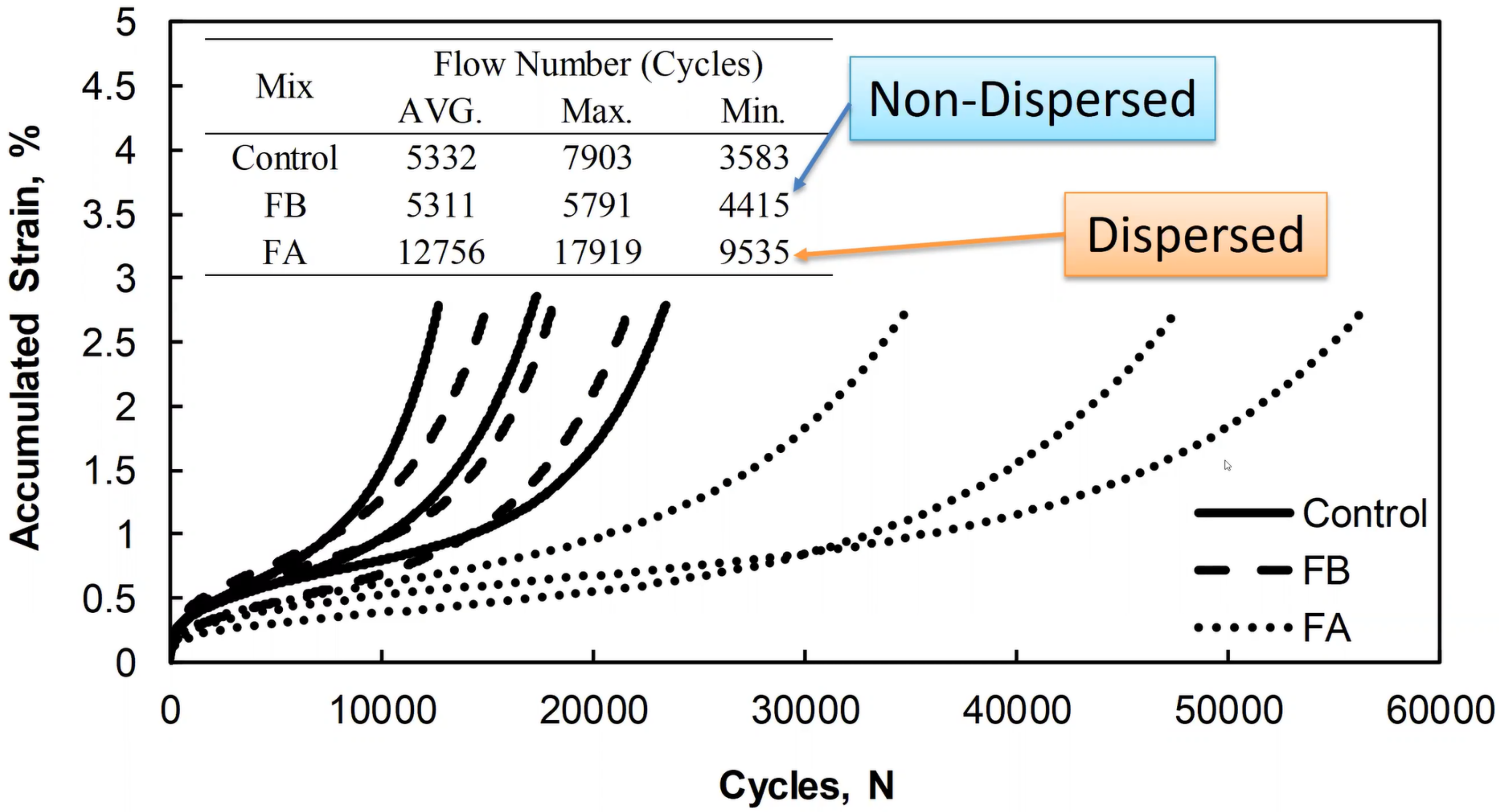
Mix Information	
Mix Type	12.5 mm Marshal
Binder Type	PG 70-10
Asphalt Binder Content (%)	5.2%
Fiber Type	Synthetic Aramid
Fiber Length & Dosage	19 mm & 0.006%

- ❑ Fiber extraction recovery
- ❑ Flow Number Test (AASHTO T378)



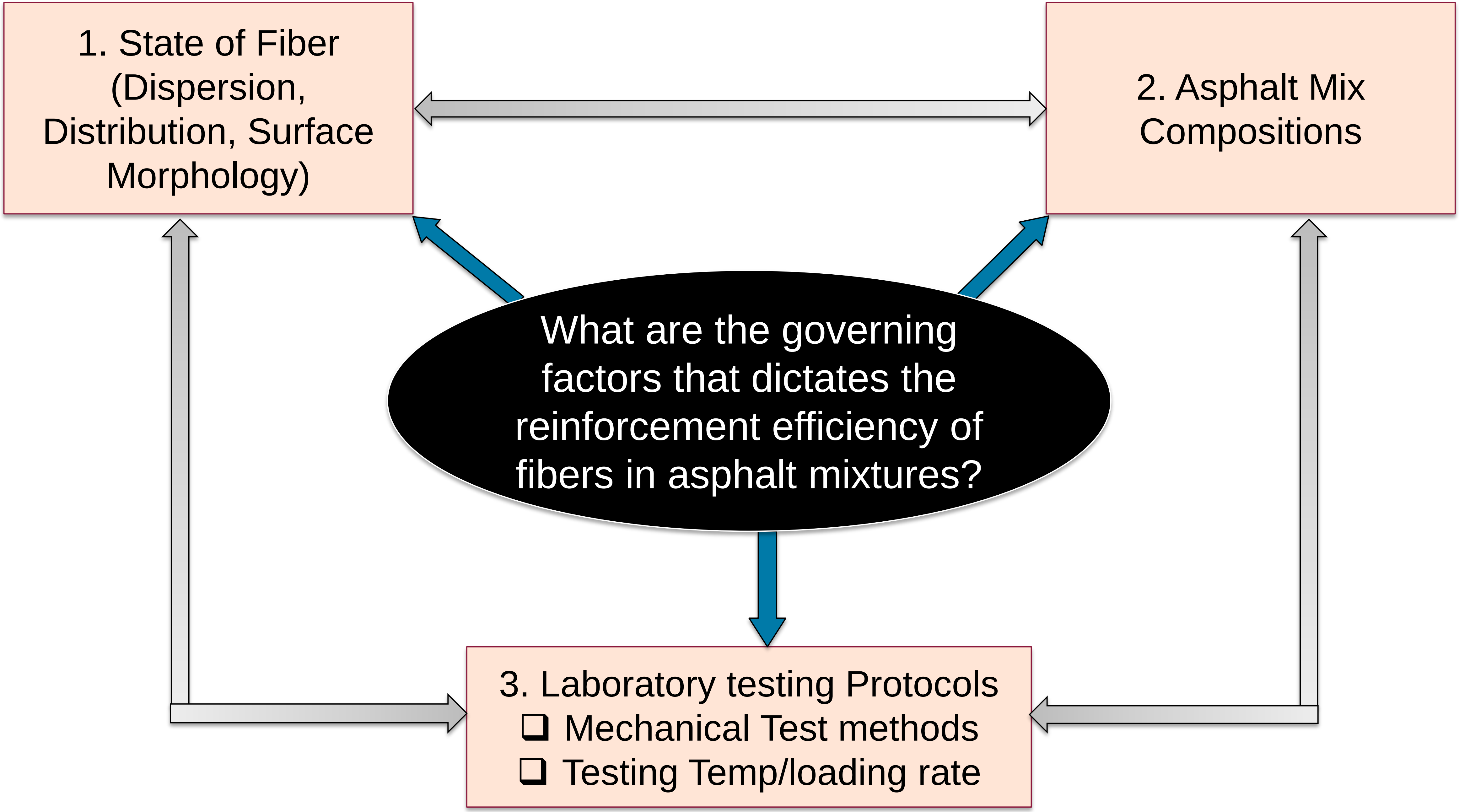
1. State of Fiber (Dispersion and Distribution)

ASU Laboratory Studies



Mix	Flow Number (Cycles)		
	AVG.	Max.	Min.
Control	5332	7903	3583
FB	5311	5791	4415
FA	12756	17919	9535

Noorvand, H., et al. (2018). Effect of synthetic fiber state on mechanical performance of fiber reinforced asphalt concrete. Transportation Research Record, 2672(28), 42-51.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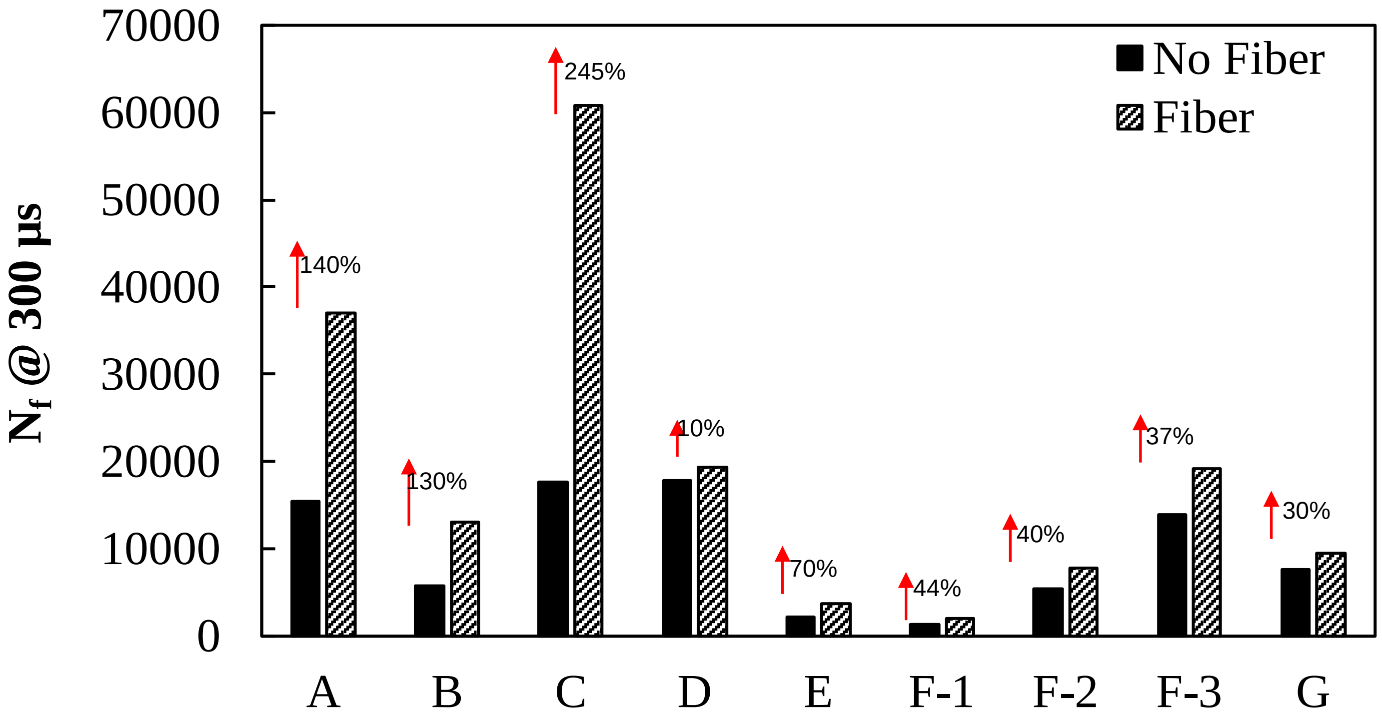
2. Asphalt Mix Composition

ASU Laboratory Studies

- Uniaxial Fatigue Test (AASHTO TP107) was performed on lab prepared Fiber and no fiber specimens with various mix designs.
- For all the fiber specimens, poly-aramid fiber blends were used at 0.05% and ¾” (19 mm) long.

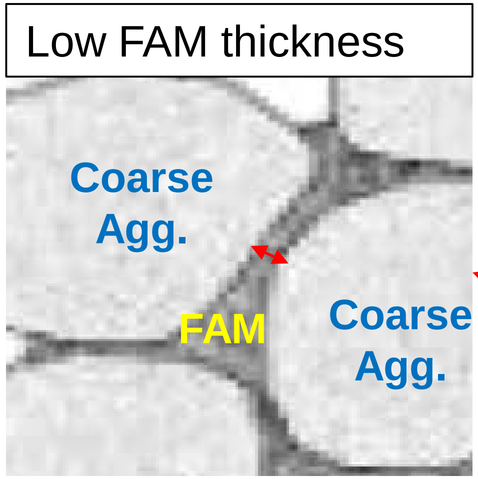


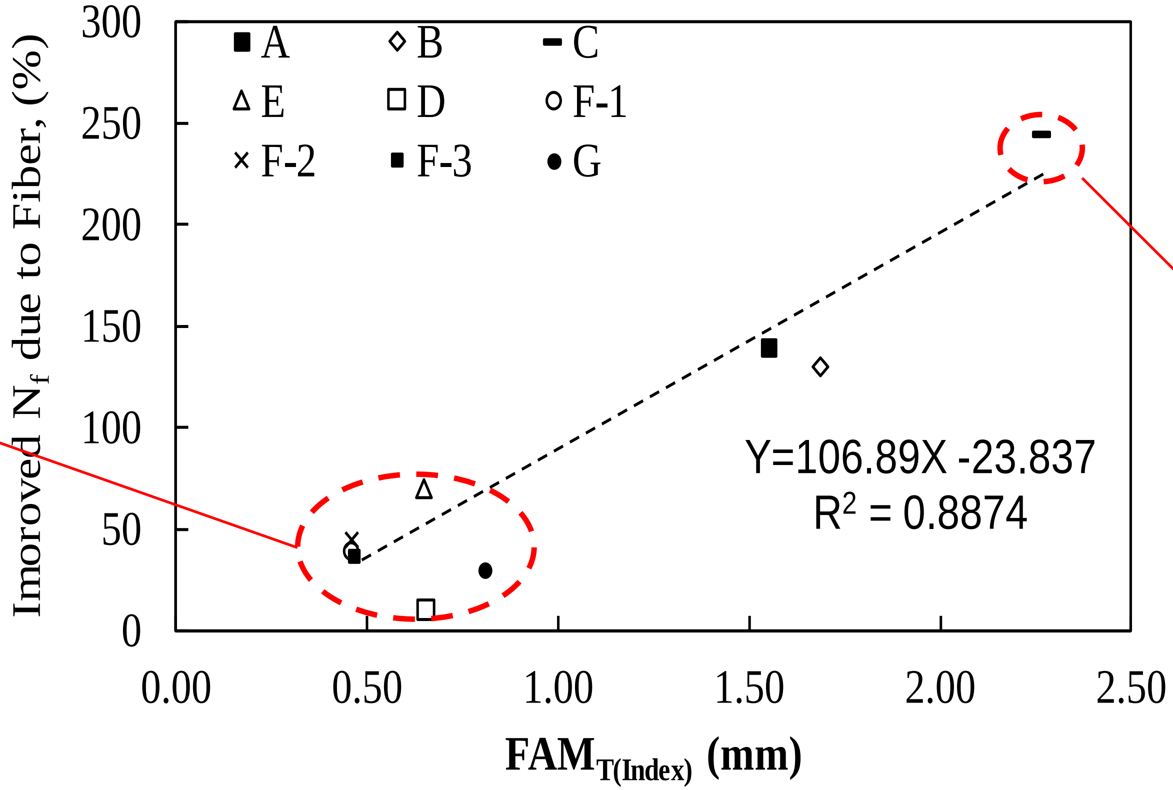
- To evaluate the reinforcement efficiency of fibers in asphalt concrete based on compositions of asphalt mixtures.

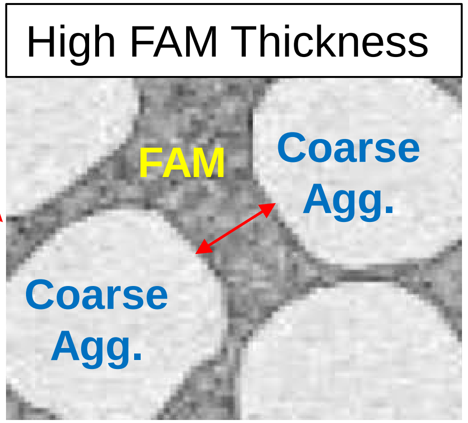
2. Asphalt Mix Composition

ASU Laboratory Studies

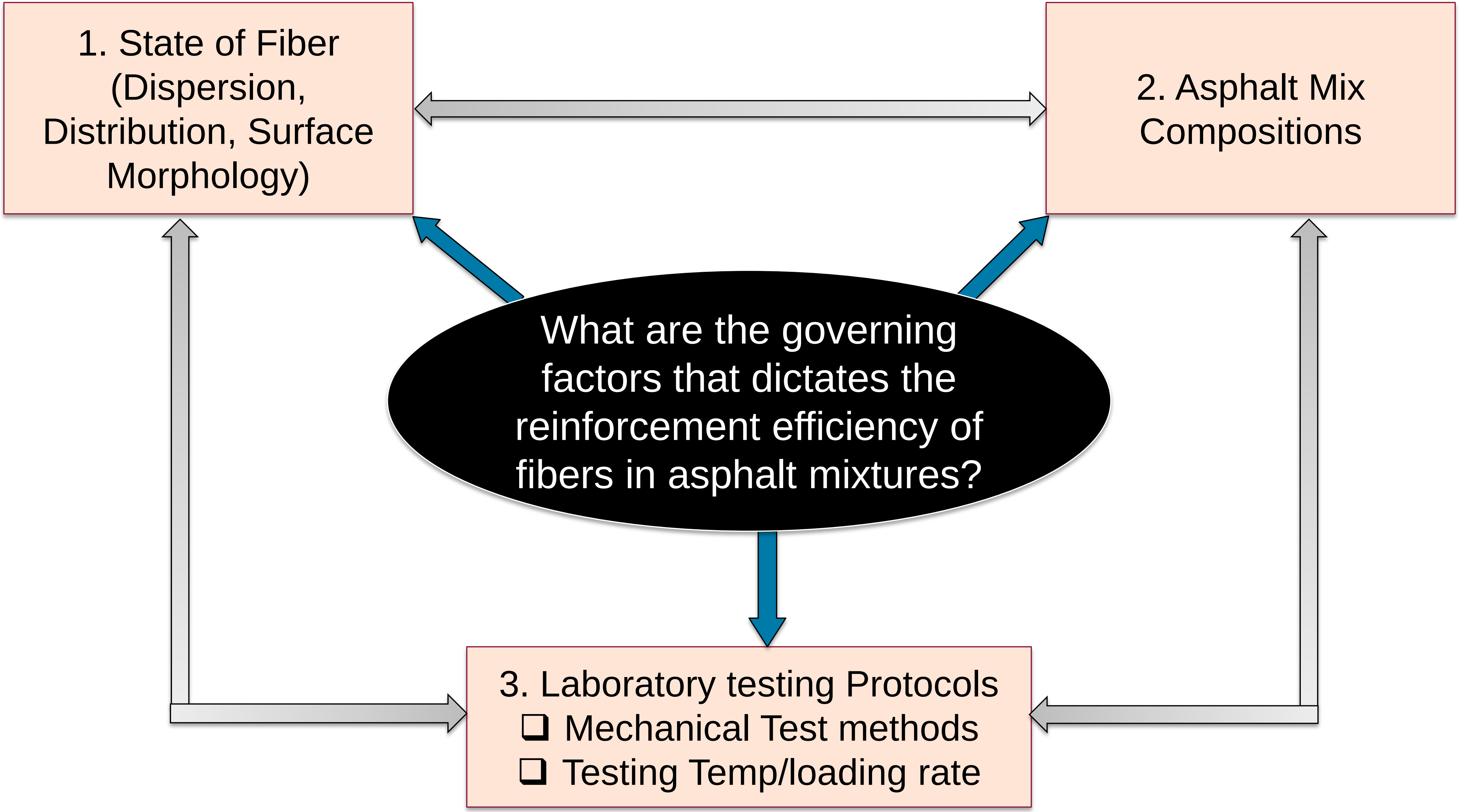
- There is a connection between the fiber reinforcement efficiency in improving fatigue life and gradation.







The Bailey Method $$FAM_{T(Index)} = \frac{V_{FAM}}{SA_{CA}}$$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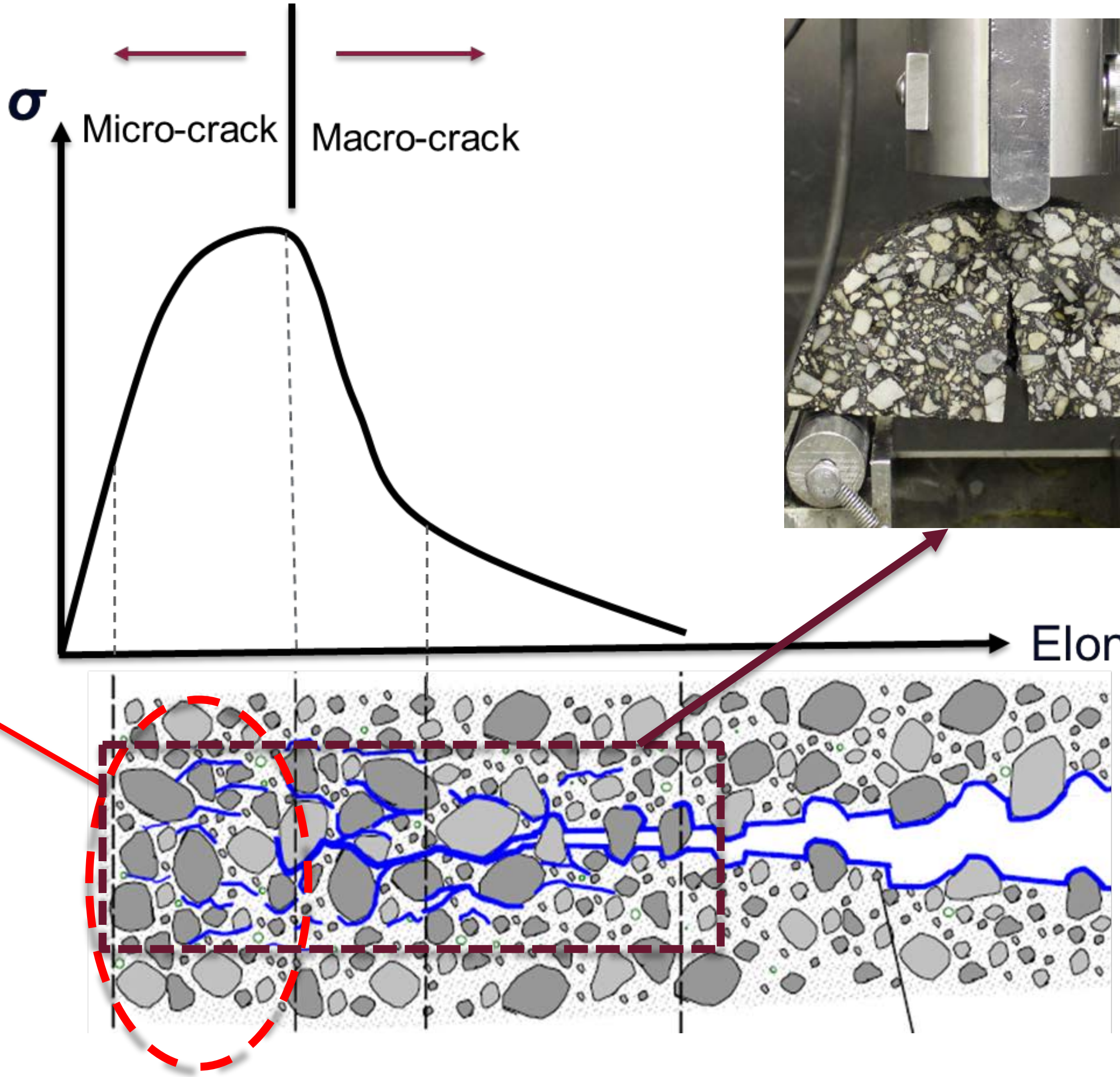
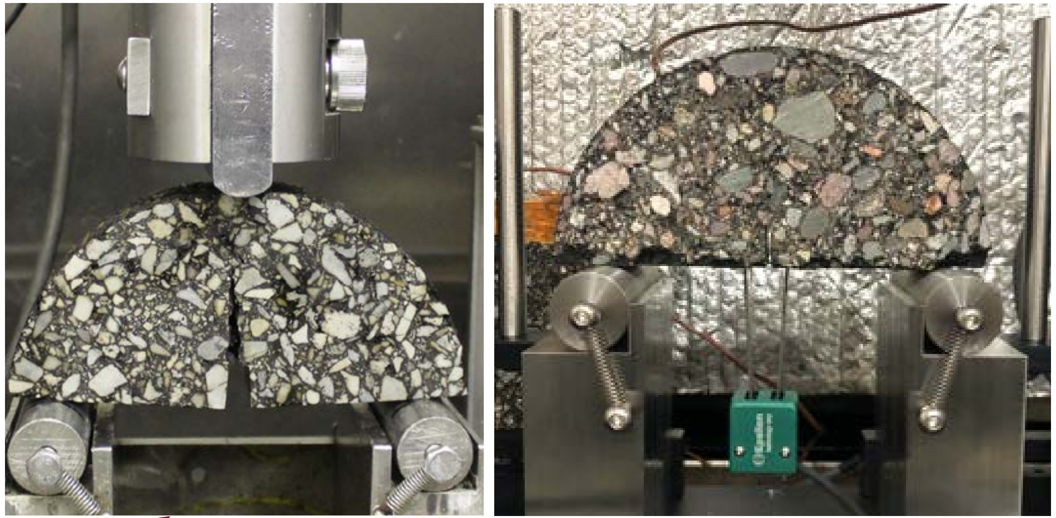
3. Laboratory Testing Protocols

ASU Laboratory Studies

Cyclic Fatigue Test

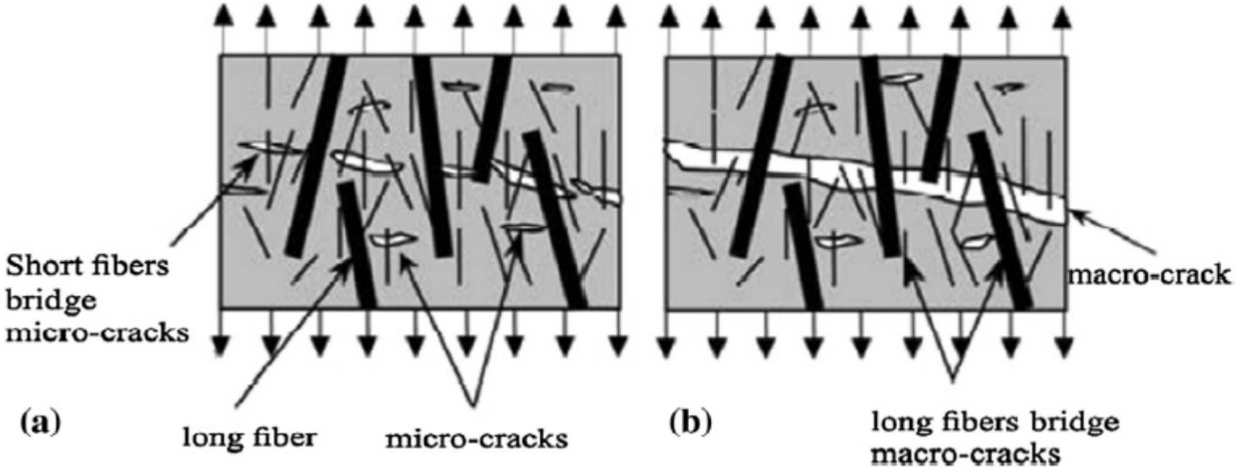


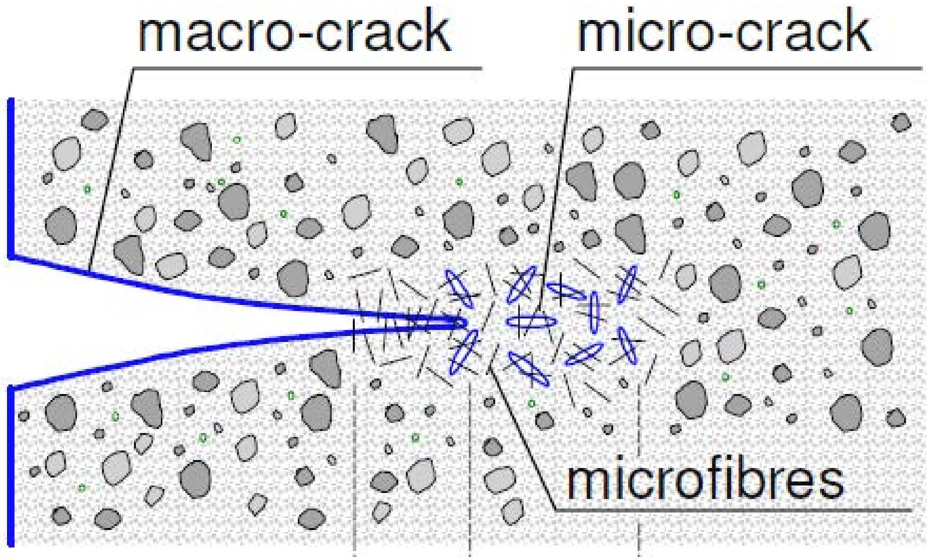
Monotonic Testing



3. Laboratory Testing Protocols

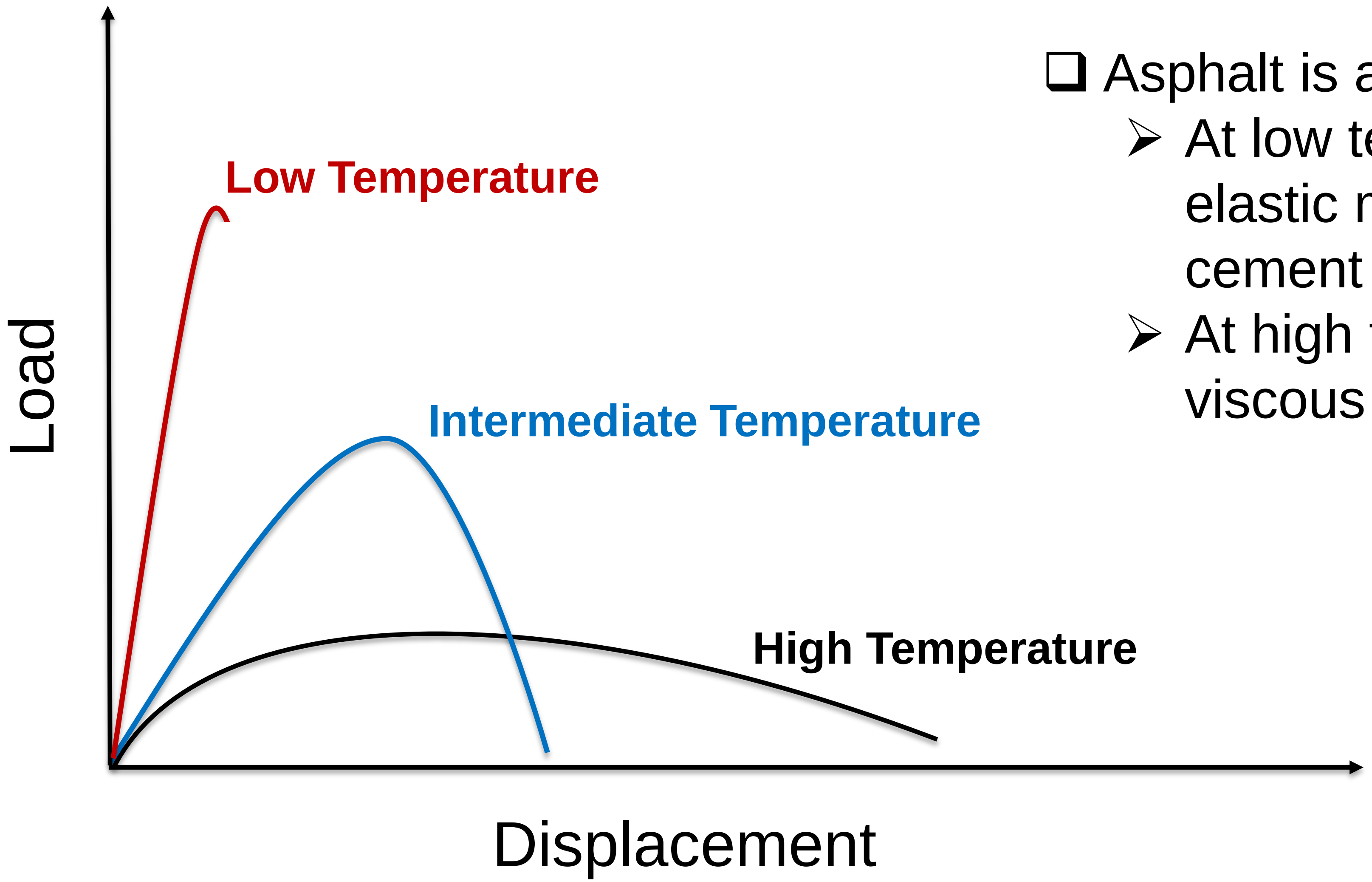
ASU Laboratory Studies





3. Laboratory Testing Protocols

ASU Laboratory Studies



- ❑ Asphalt is a viscoelastic material:
  - ➢ At low temperature it is an elastic material (Portland cement concrete)
  - ➢ At high temperature it is a viscous material (fluid, polymer)

3. Laboratory Testing Protocols (Fiber Optimization)

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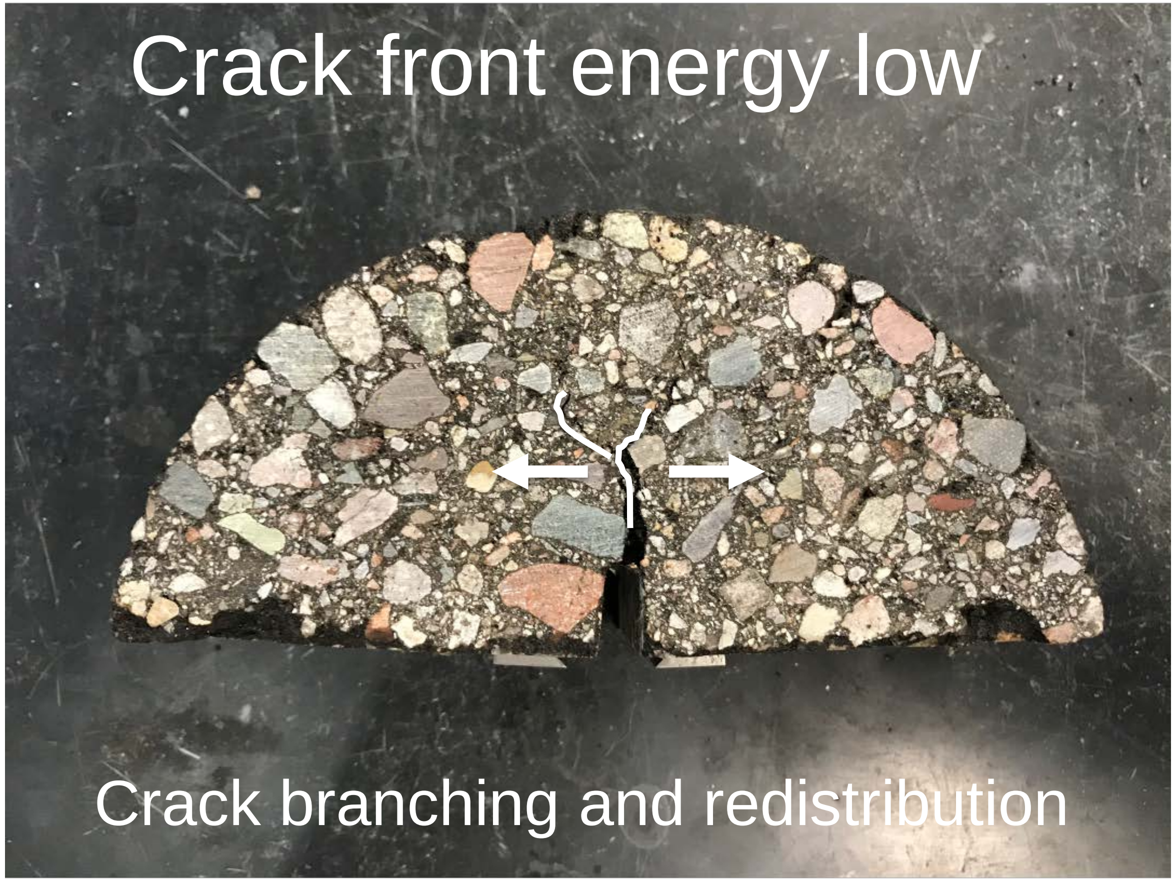
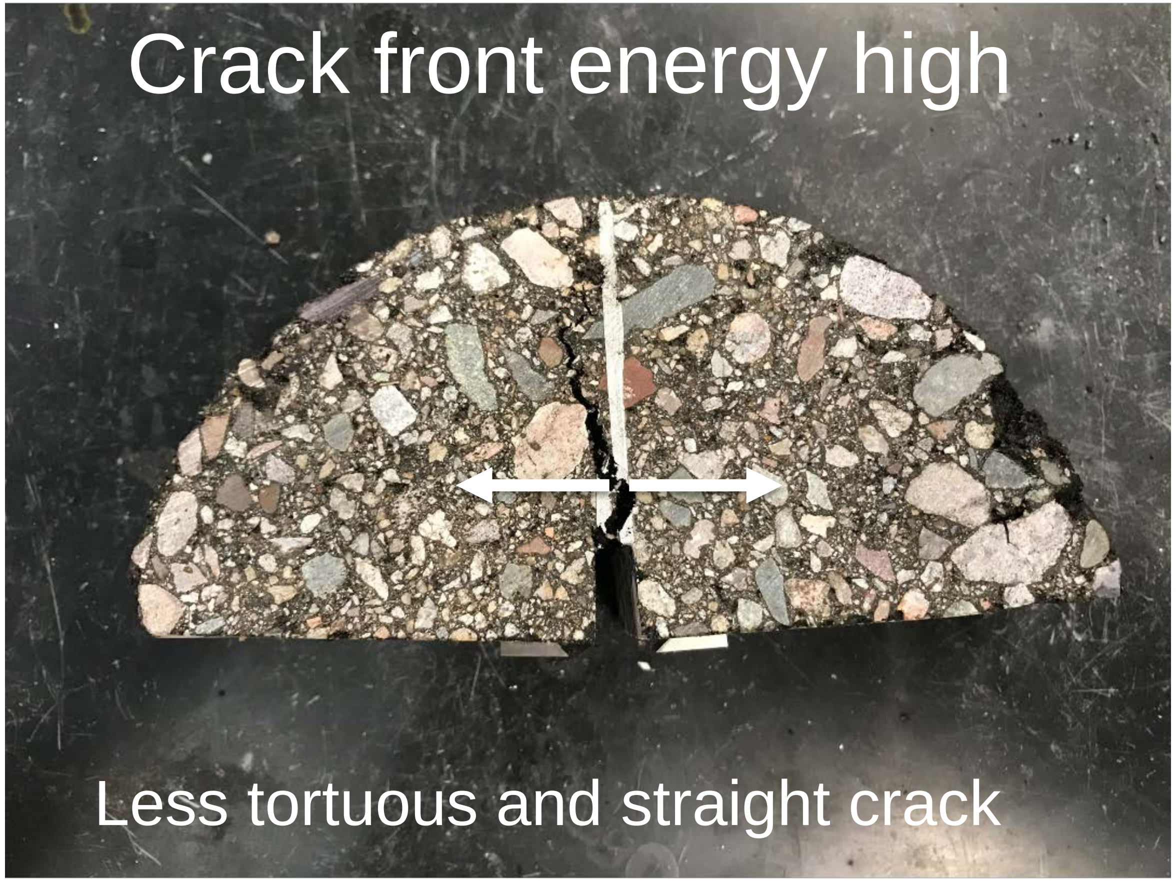


Higher temperatures
Lower rates of loading or CMOD
Lower stiffness mixes



Lower temperatures
Higher rates of loading or CMOD
Higher stiffness mixes

Conclusion

- Aramid Fibers can be used to improve the mechanical performance of asphalt mixtures.

- Studies generally demonstrate positive benefits of FRAC.
  - There have been evidence from the field performance of poly-aramid fiber blends in asphalt mixtures.
  - ASU lab studies have shown improvement in the fatigue life and rutting resistance of asphalt mixtures from the addition of poly-aramid fiber blends.

Conclusion

- However, due to the limitations and difficulties of some laboratory testing procedures in simulating field conditions, there have also been inconsistent reports and experience with respect to efficiency of fibers.

- Key factors in understanding the basic, fundamental underlying mechanisms that govern the overall mechanical response of FRAC mixtures.
  - State of Fibers
  - Asphalt mix compositions
  - Lab test protocol

Thank You!

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