Performance Benefits of Fiber-reinforced Thin Concrete Pavement and Overlays

MnDOT Contract No. 1003325; Work Order 56

TAP MEETING # 1

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UMD

NRRA
National Road Research Alliance
Strategic Implementation Through Cooperative Pavement Research

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Research Group

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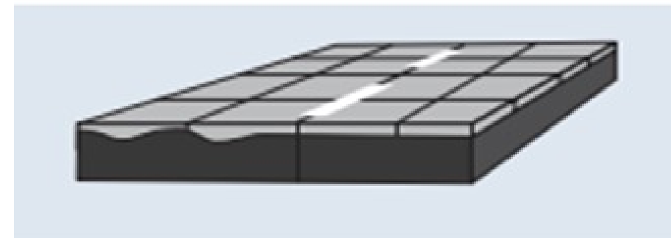
Thin Concrete Pavement/ Overlay

Thin conc. Pavement

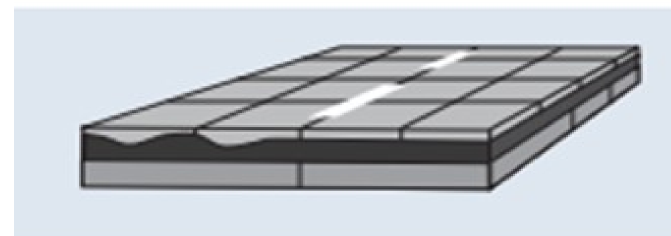
Over agg. base

Thickness: 3 to 6 inches

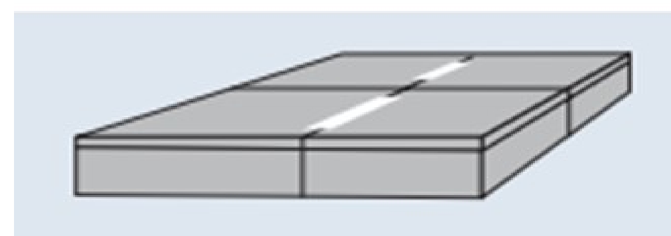
Thin conc. Overlays



Over asphalt



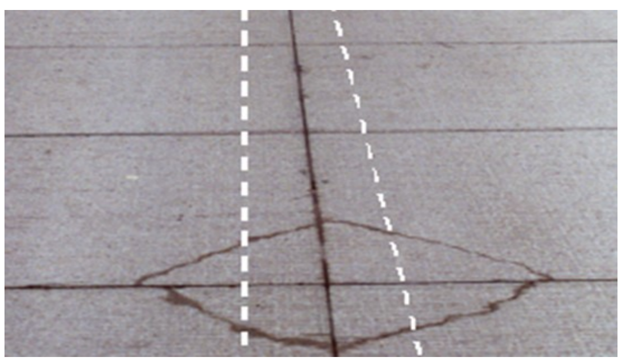
Over composite



Over concrete

Distresses

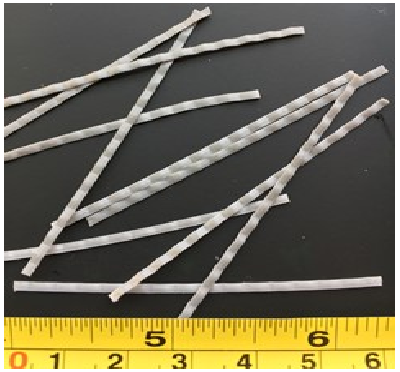
Cracks



Joint faulting

Slab migration

Use of Fibers



Many concrete overlays were constructed with structural fiber reinforced concrete

Observed benefits:

1. Reduce cracking/ crack propagation

2. Increased load transfer efficiency
   - reduced faulting

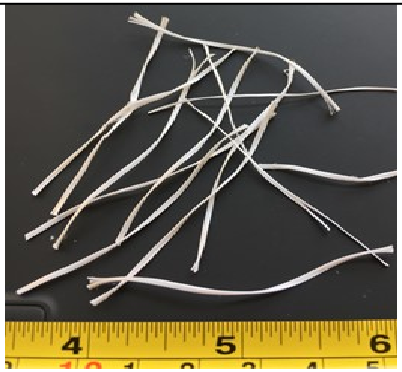
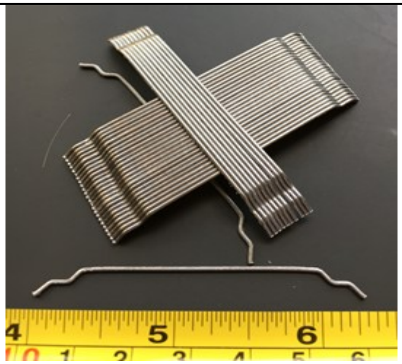
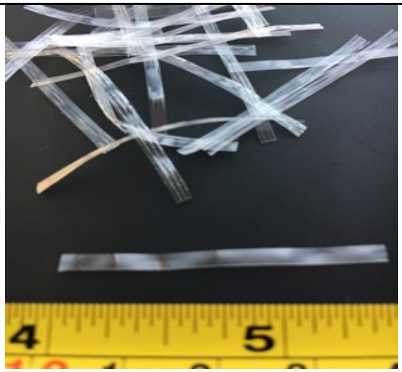
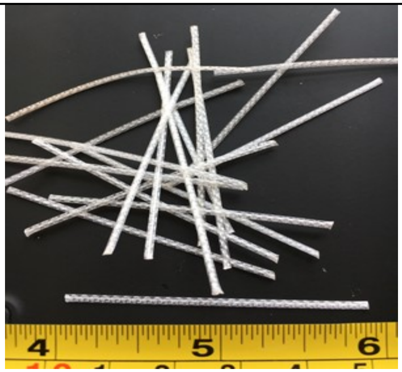
3. Reduced slab migration

Quantification of the benefits ??

Research Objectives

Determining contribution of fibers in:

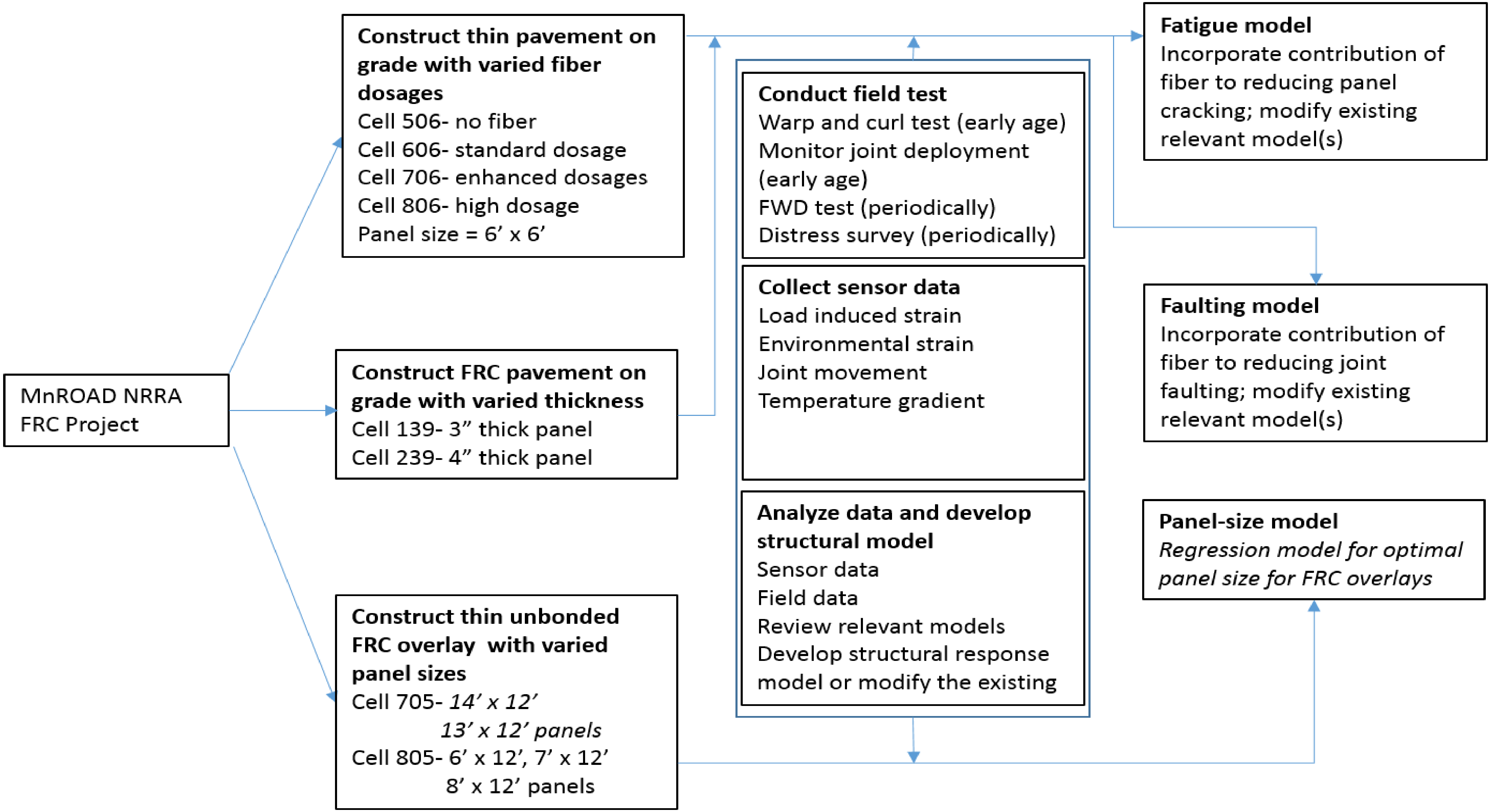
- reducing panel fatigue cracking
- mitigating joint faulting
- Increasing panel size

Research Methodology

Cell number	Length (ft)	Pavement/ overlay Type	Underlying layer (constr. year)	Type of concrete/ fiber dosage*	Panel size W ft x L ft	Panel thickness (inch)
506	144	Thin pavement on grade	11 in. class 5Q aggregate base (2017)	Plain concrete	6 x 6	5; 6*
606*	138			FRC/ standard		
706				FRC/ enhanced		
806				FRC/ high		
139	270	Ultra-thin Pavement on grade	6 in. class 5 aggregate base (2017)	FRC/ enhanced	6 x 6	3
239	273	Thin Pavement on grade			6 x 6	4
705	144	Thin unbonded overlay	Concrete (1993)	FRC/ standard	Driving: 14 x 12 Passing: 13 x 12	5
805	124				Driving: 6 x 12 and 8 x 12 Passing: 6 x 12 and 7 x 12	5

Research Methodology



Tasks

Tasks	Schedule
Task 1: Literature review	2017 Nov to 2018 February
Task 2: Annual cell performance report	2018 Aug to 2018 October: Year 1 2019 Aug to 2019 October: Year 2 2020 Aug to 2020 October: Year 3
Task 3: Contribution of fibers in reducing panel fatigue cracking	2019 Jan to 2019 Dec
Task 4: Contribution of fibers in mitigating joint faulting	2019 May to 2020 April
Task 5: Optimal panel size for FRC overlays	2019 Aug to 2020 July
Task 6 and 7: Final report	April 2020 to 2020 October

Task Descriptions (Tasks 1 and 2)

Tasks	Schedule
Task 1: Literature review	Draft report submitted; Findings will be discussed shortly
Task 2: Annual cell performance report	Annual performance and distress data will be analyzed to understand the influence of fibers The observed trends will be used in Task 4,5 and 6.

Tasks 3 Descriptions

Tasks	Schedule
Task 3: Contribution of fibers in reducing panel fatigue cracking	**2019 Jan to 2019 Dec**

Based on the strain measured at the MnROAD sections –

- Investigate the applicability of the existing structural models (e.g., BCOA-ME, New Design procedure for unbonded conc. Overlay (Dr. Khazanovich and Dr. Vandenbossche's study)

- Adjust/ modify the relevant models to incorporate the fibers contribution as a function of fiber properties (e.g., modulus of rupture, residual strength, joint performance (or stiffness) gain)

Tasks 3 Descriptions

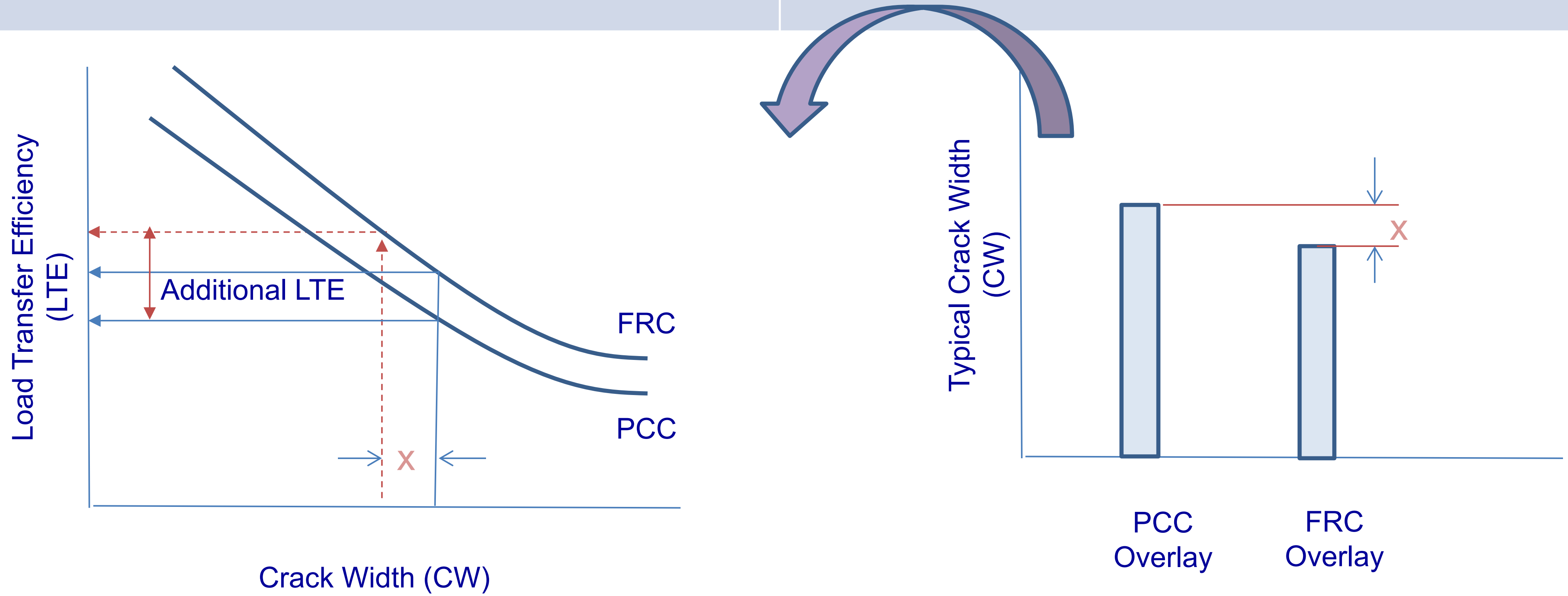
Tasks	Schedule
Task 3: Contribution of fibers in reducing panel fatigue cracking	**2019 Jan to 2019 Dec**

Based on the performance and distress of the MnROAD and other similar projects –

- Develop incremental fatigue damage procedure (similar to AASHTO-ME); critical stress and strain are function of fiber property, joint stiffness, effective slab length, etc., which will vary with crack width = function of seasonal tempr.

Tasks 4 Descriptions

Tasks	Schedule
Task 4: Contribution of fibers in mitigating joint faulting	2019 May to 2020 April



Tasks 4 Descriptions

Tasks	Schedule
Task 4: Contribution of fibers in mitigating joint faulting	**2019 May to 2020 April**

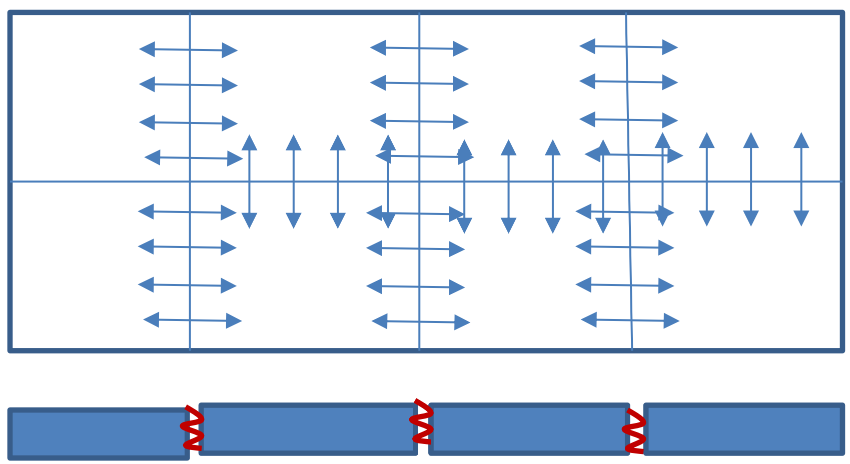
Based on the FWD and crack width movement data –

- Study the load transfer behavior of FRC (existing lab study)
- Consider creep issue or plastic elongation of fibers
- Verify the load transfer behavior of FRC sections with the FWD data
- Adjust/ modify the relevant models to incorporate the fibers contribution as a function of fiber properties (e.g., modulus of rupture, residual strength, joint performance gain)
- To consider the seasonal crack width movement, incremental damage approached will be adopted

Tasks 5 Descriptions

Tasks	Schedule
Task 5: Determine optimal panel size	2019 Aug to 2020 July

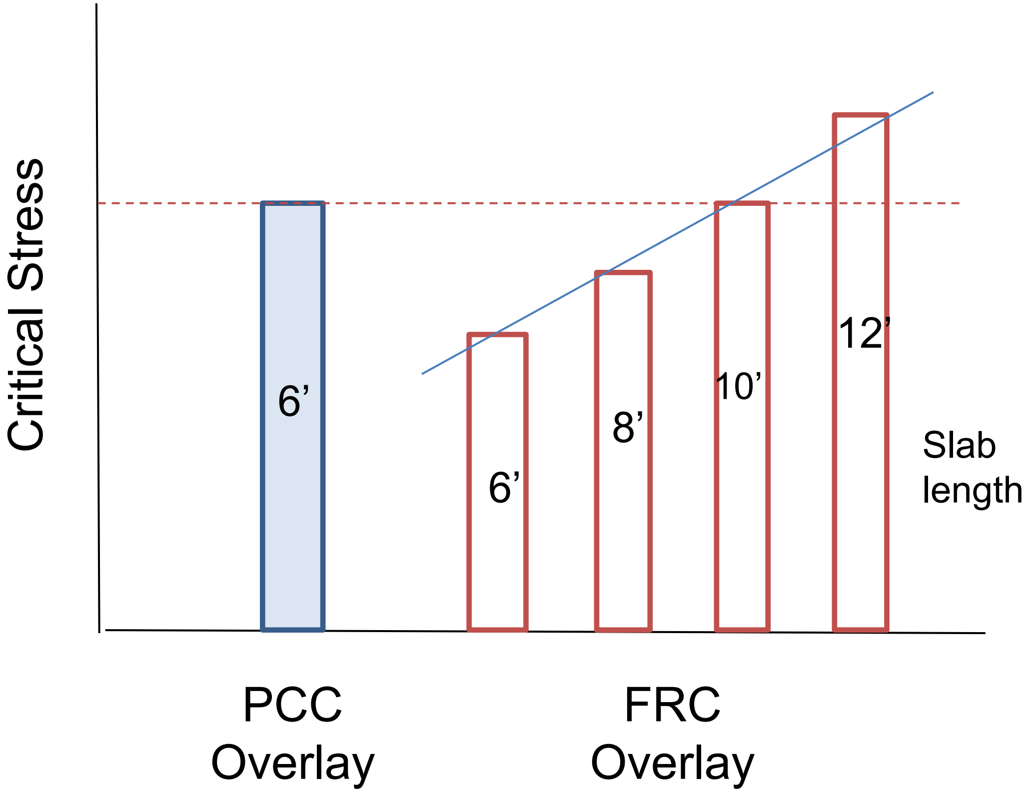
FRC slabs

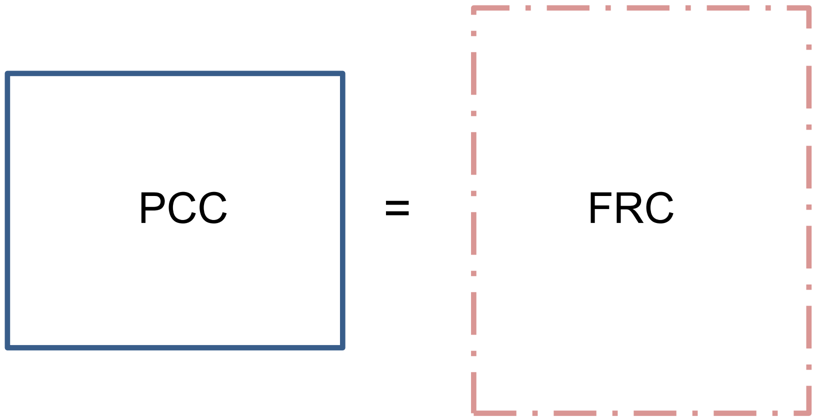


Through FEM analysis

Tasks 5 Descriptions

Tasks	Schedule
Task 5: Determine optimal panel size	**2019 Aug to 2020 July**





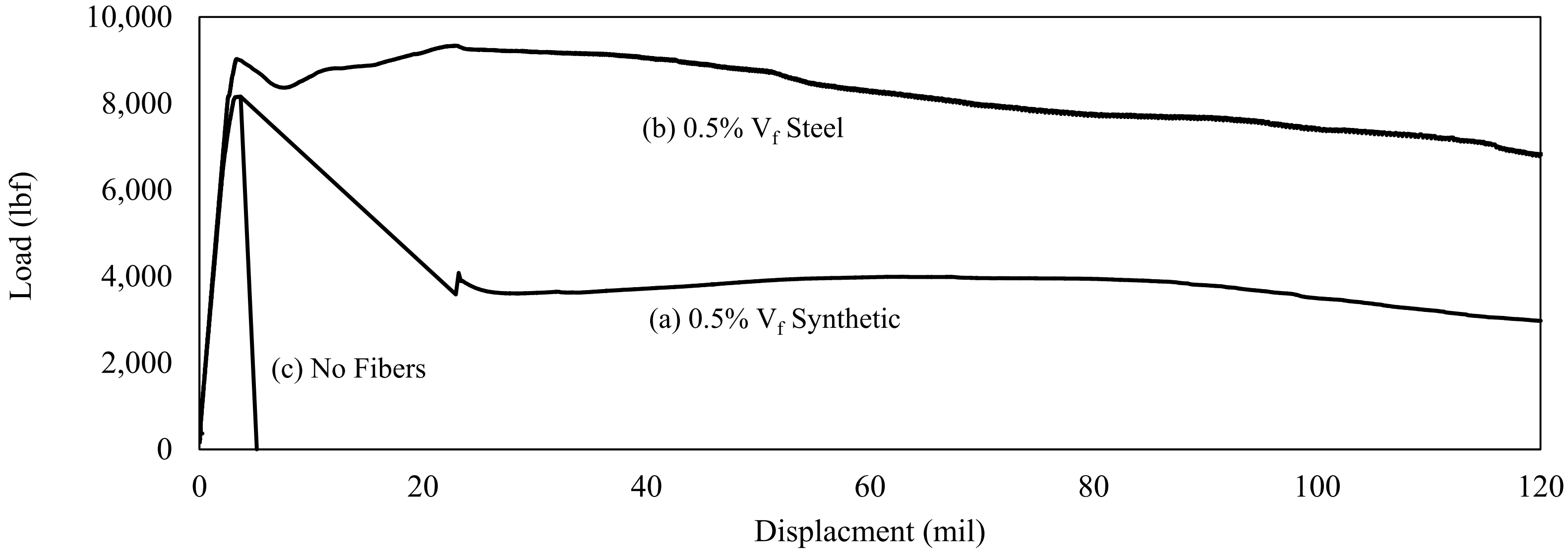
Tasks 5 Descriptions

Tasks	Schedule
Task 5: Determine optimal panel size	**2019 Aug to 2020 July**

Based on the performance and distress of the Cells 139, 239, 705 and 805 and FEM analysis findings-

Optimal slab size = f(fiber property, underlying layer properties, temperature change in the region, etc.)

Task 1 Findings



Fibers

Materials (ASTM C1116)

Type I: steel
Type II: glass
Type III: synthetic
Type IV: natural fibers

Stiffness/ dia.

Micro/ non-structural
Macro/ structural

Geometry/texture

Straight
Crimped
Hooked end
….
….

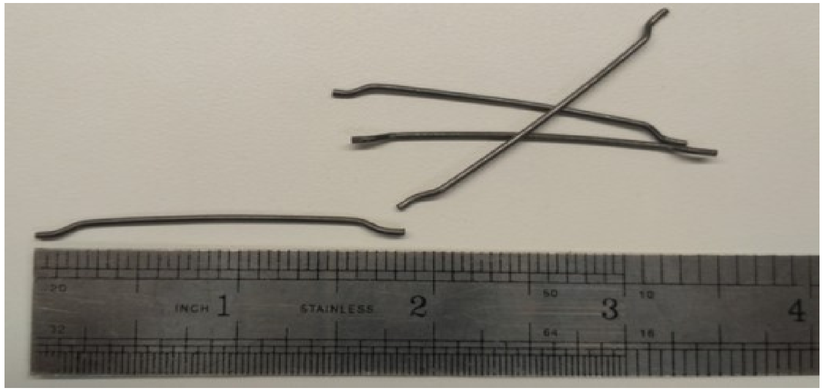
FRC: Fresh Conc. Properties

Steel

Typical volume fraction: 0.25% to 1.5%

Slump: 1 to 4 in. lower compared to PCC

Fiber balling: When aspect ratio >100



Synthetic

Typical volume fraction: 0.25% to 1.5%

Slump: Usually drops

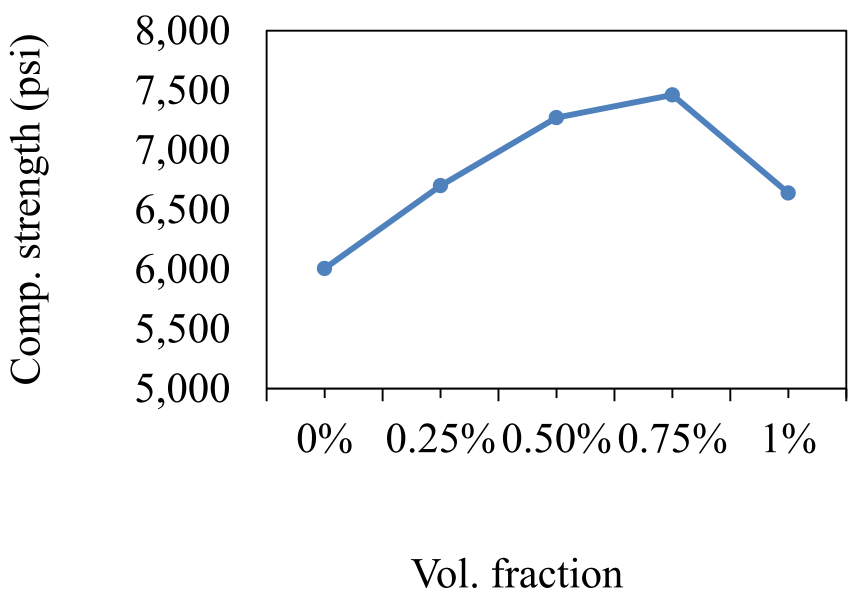
Fiber balling: When aspect ratio >100
$V_f > 1\%$

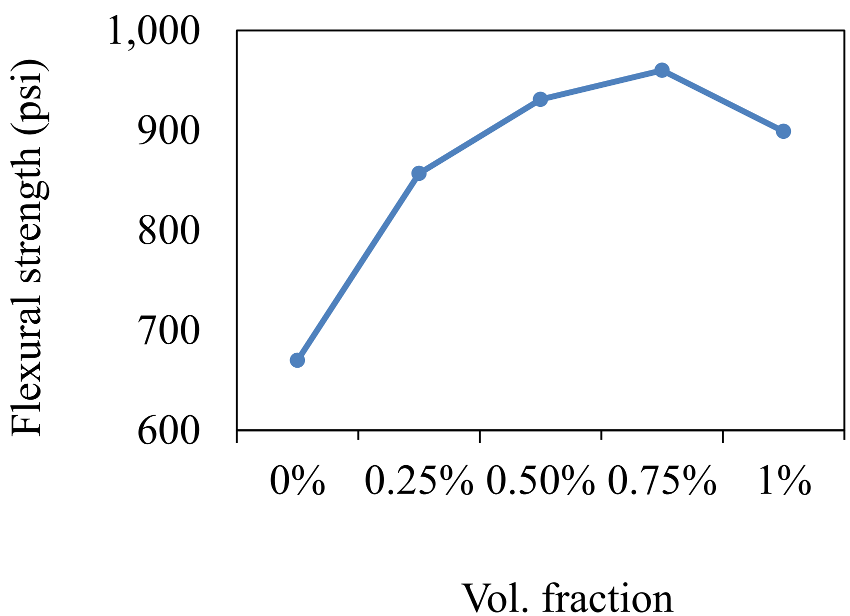
Steel FRC: Hardened Conc. Properties

Comp. strength: 0% to 25% increase

Flexural strength: 0 to 50% (@1.5% volume fraction)

Direct tensile strength: 40% more compared to PCC





After Mahadik & Kamane, 2014

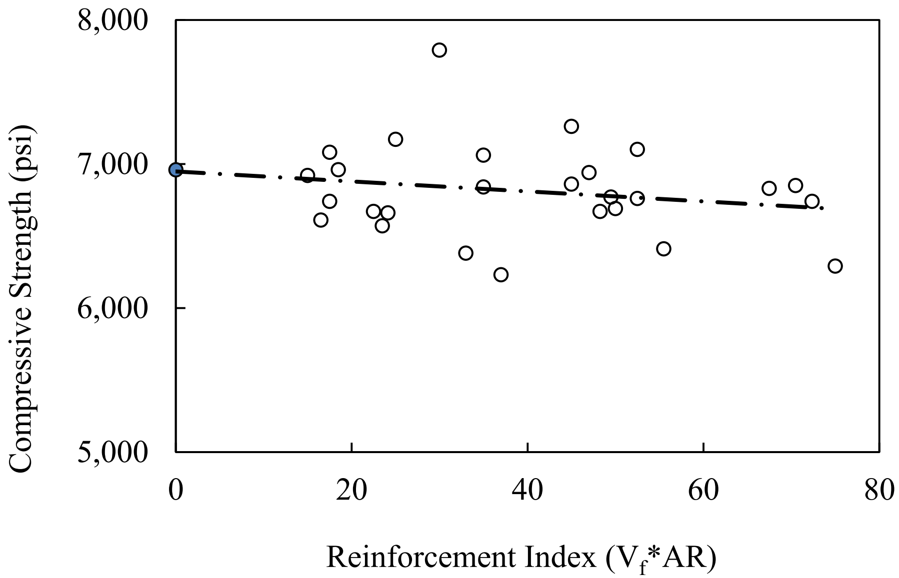
Syn. FRC: Hardened Conc. Properties

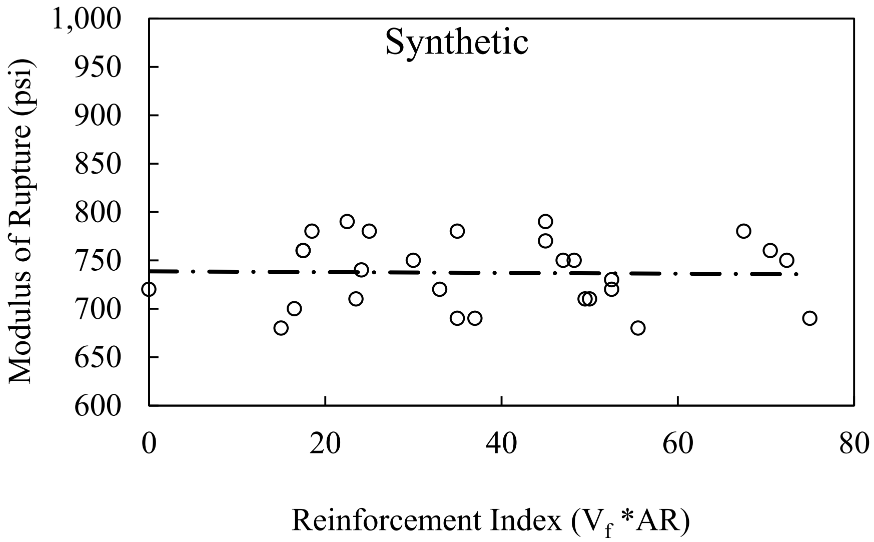
Comp strength: Little improvement; ductile failure of cylinders

Flexural strength: No improvement

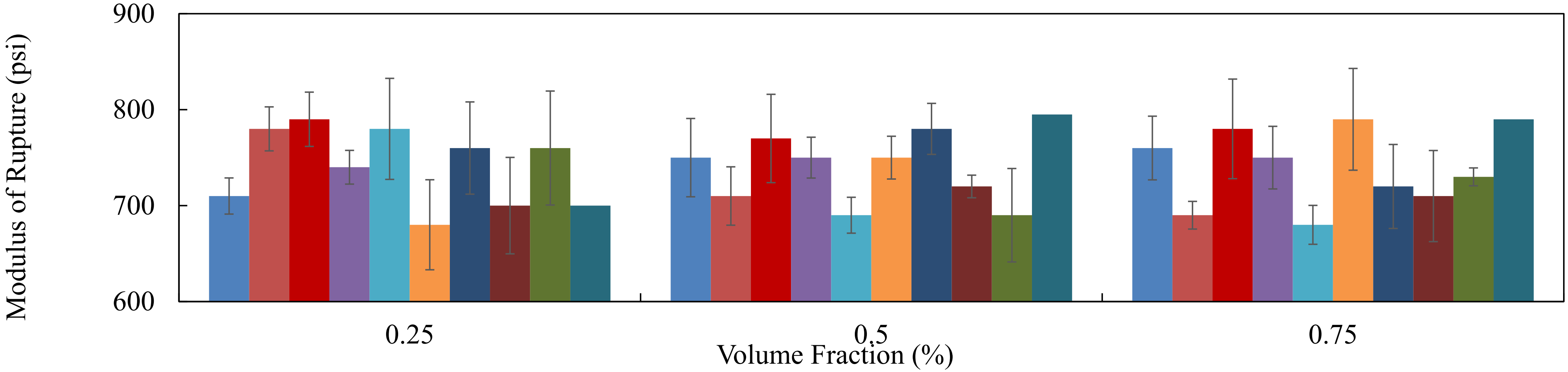
Toughness/ Residual strength: Significant improvement

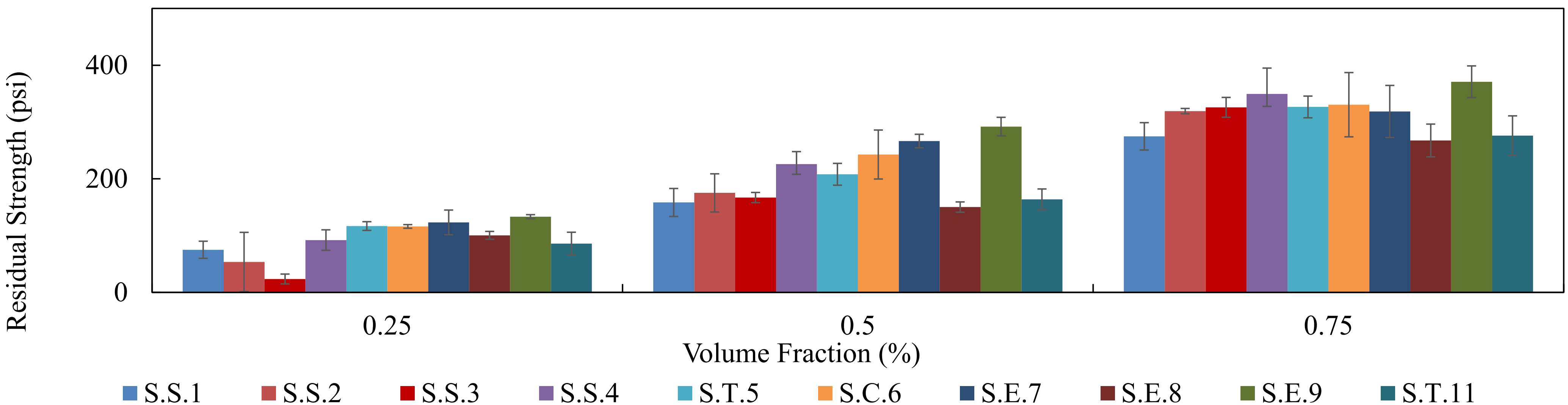
Load transfer efficiency (LTE): Significant improvement



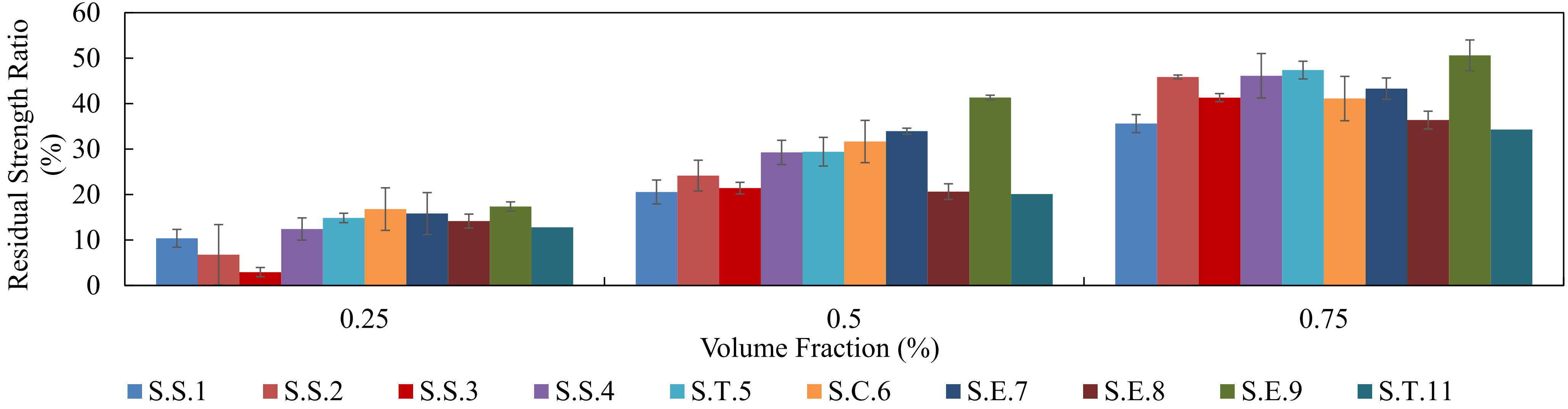


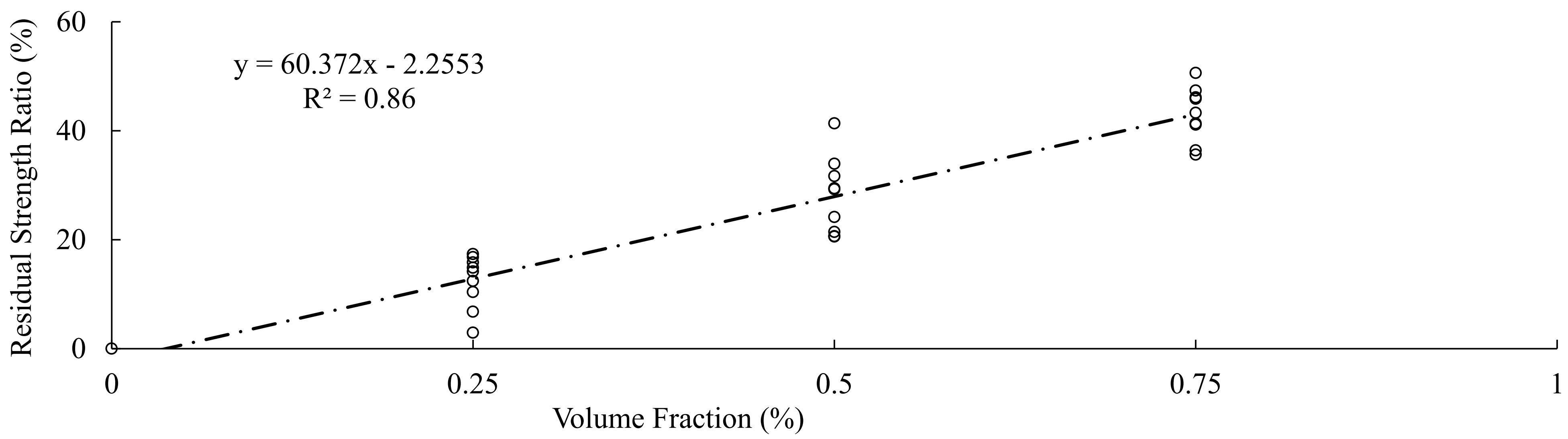
Syn. FRC: Hardened Conc. Properties



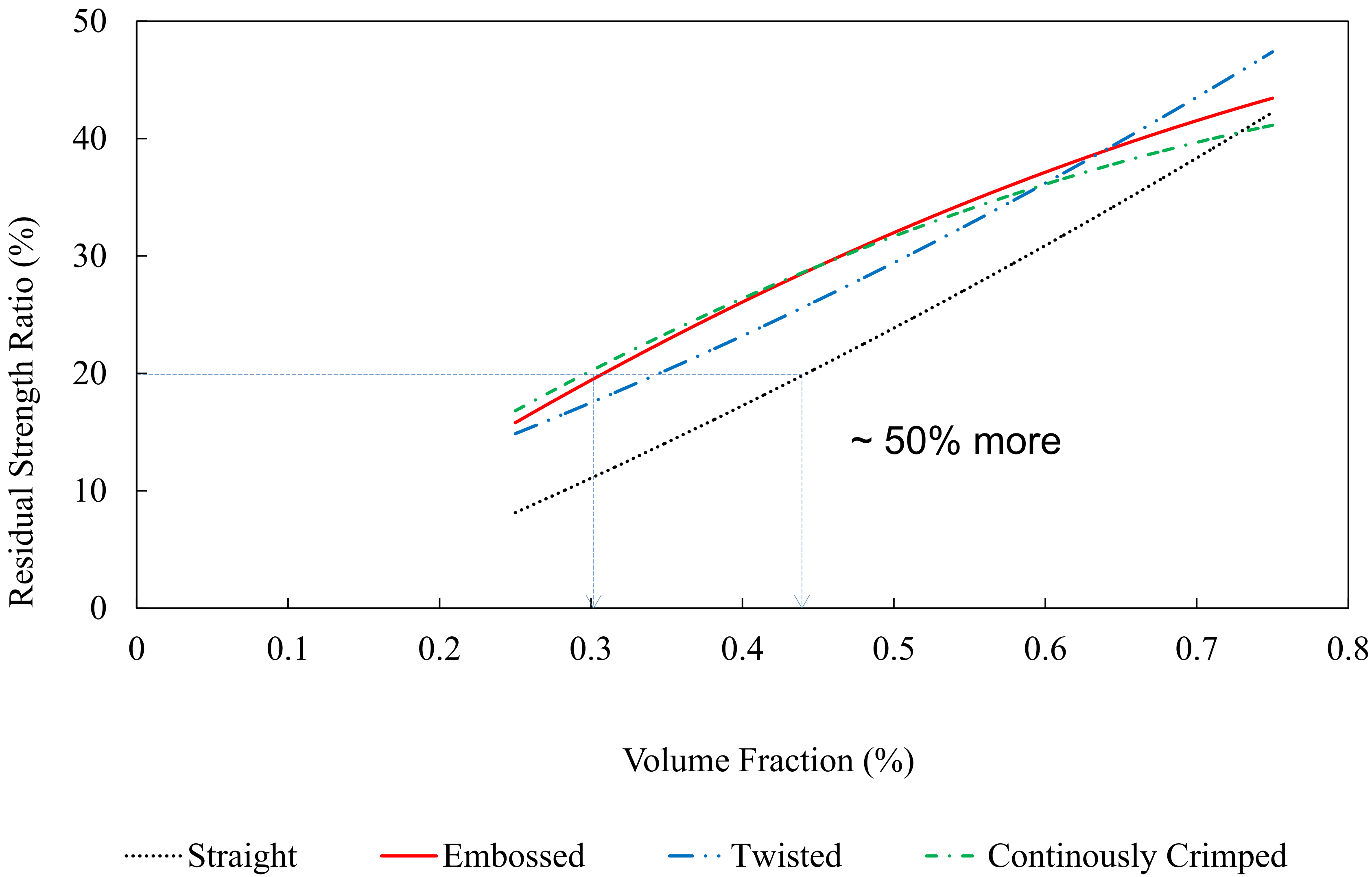


Syn. FRC: Hardened Conc. Properties

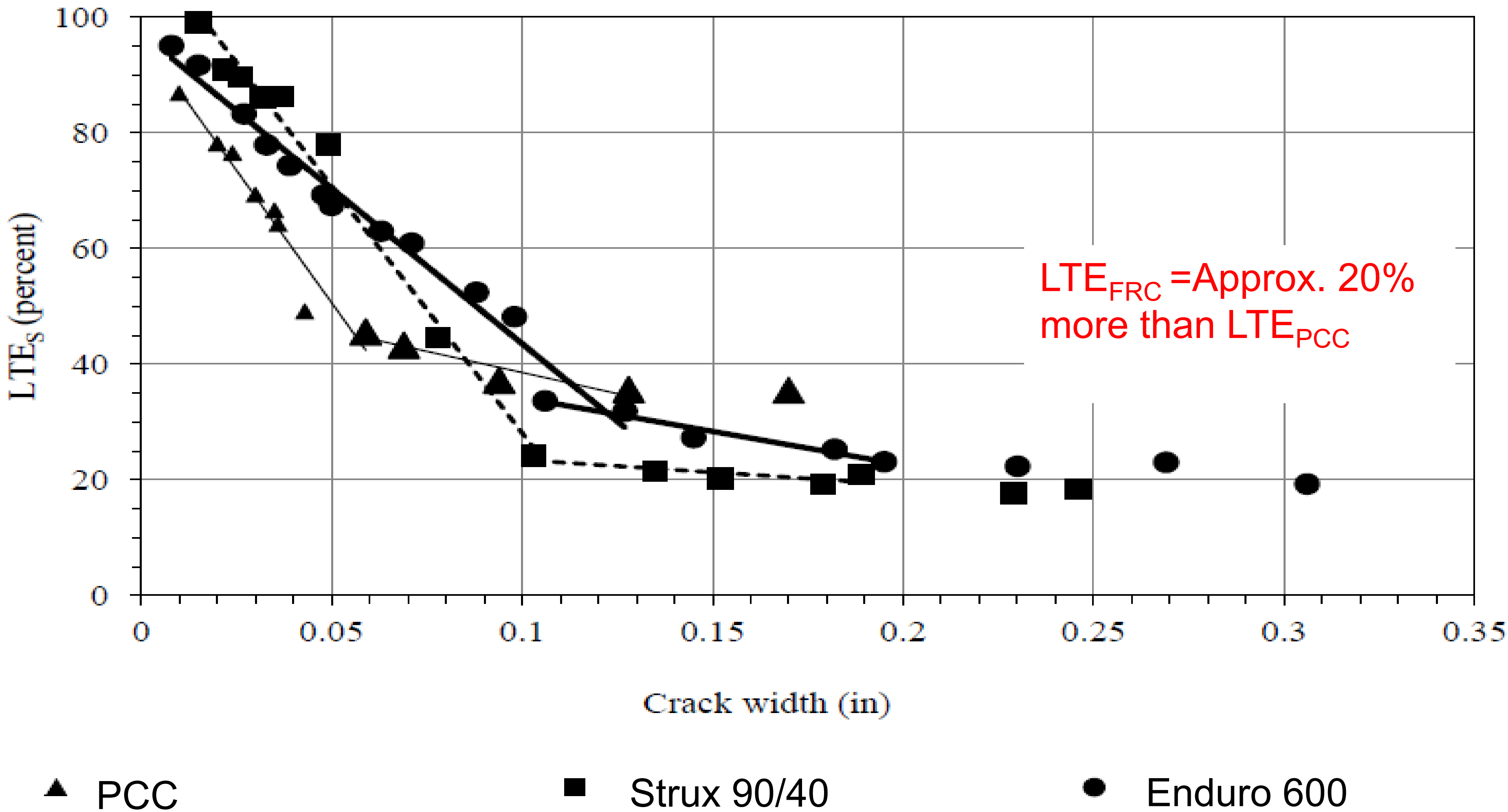




Syn. FRC: Hardened Conc. Properties



Syn. FRC: Hardened Conc. Properties



Barman and Vandenbossche, 2014.

Syn. FRC: Hardened Conc. Properties

Pictures of Enduro 600 fibers after fatiguing with 10 million load cycles.

FRC in Existing Conc. Overlays

State	Number of Projects	Projects using Steel fibers		Projects using Synthetic fibers		Synthetic Fiber Dosage Distribution (%)	
		%	Dosage lb/yd^3	%	Dosage lb/yd^3	3 lb/yd^3	Other lb/yd^3
Georgia	6	0	N/A	100	3	100	0
Illinois	19	6	80	94	3, 4, 7.5	11	89
Kansas	8	0	N/A	100	3	88	12
Minnesota	11	0	N/A	100	3, 6.5, 25	36	64
South Carolina	3	0	N/A	100	3	100	0
Virginia	3	28	50, 75	72	3, 20, 25, 0.9	17	83
Total	**50**	6	N/A	94	--	51	49

FRC projects in other States

State	Project details	Year of Const.	Traffic (ADT)	Overlay Thickness, Inches	Fiber type and dosage (lb/yd^3)	Distress data
Pennsylvania	Intersection of State Route (SR)-133 and SR-100, Chester County	1988	36,079	4	Polypropylene, 3	N/A
Texas	Intersections on LP-250 at Wadley Road, Holiday Hill Road and Midland Drive, Midland	2005	26,650	3	Polypropylene, 3	A mid slab and corner cracks were observed after one or two years of construction which could be due to the heavy traffic and wheel path adjacent to the longitudinal joint.
Texas	Intersection of LP-250 at Midkiff Road and Garfield Road, Midland	2001	25,000	3	Polypropylene, 3	N/A
New York	Intersection at Waldon Avenue and Central Avenue, near Buffalo	2002	12,250	4	Polypropylene fibers, N/A	Corner cracks along the free longitudinal joints were found.
New York	NY-408 and SH -622, Rochester	2002	9,350	4	Polypropylene fibers, N/A	Corner cracks along the free longitudinal joints were found.
Michigan	Patterson Avenue, from 44th Street to 36th Street, Kentwood	2006	31,891	4	fibrillated polypropylene, 1.5	The overall performance of the project found good; however, there are few distress due to improper alignment of edge of existing asphalt layer and the joint between the white topping and full depth widening.

Approved list of Fibers

Illinois

Source	Fiber Trade Name	Length (inch)	Aspect ratio, specific gravity, modulus of elasticity (ksi),tensile strength (ksi)
General Resource Technology	Advantage structural fiber	1.5 or 2	100, 0.91, N/A, 70
Propex	Fibermesh 650	Graded	96.5, 0.91, N/A, 70
ABC Polymer Industries	Tuf-Max DOT™	1.5 or 2	N/A, 0.91, 800, 70
BASF Corporation	MasterFiber® MAC Matrix	2.1	70, 0.91, N/A, 85
The Eucild Chemical Company	Tuf-Strand SF™	2	74, 0.92, 1380, 87-94
Forta Corporation	FORTA-FERRO®	1.5 or 2.25	N/A, 0.91, N/A, 83-90
GCP Applied Technology	Strux® 90/40	1.55	90, 0.92, 1378,90

Approved list of Fibers

Georgia

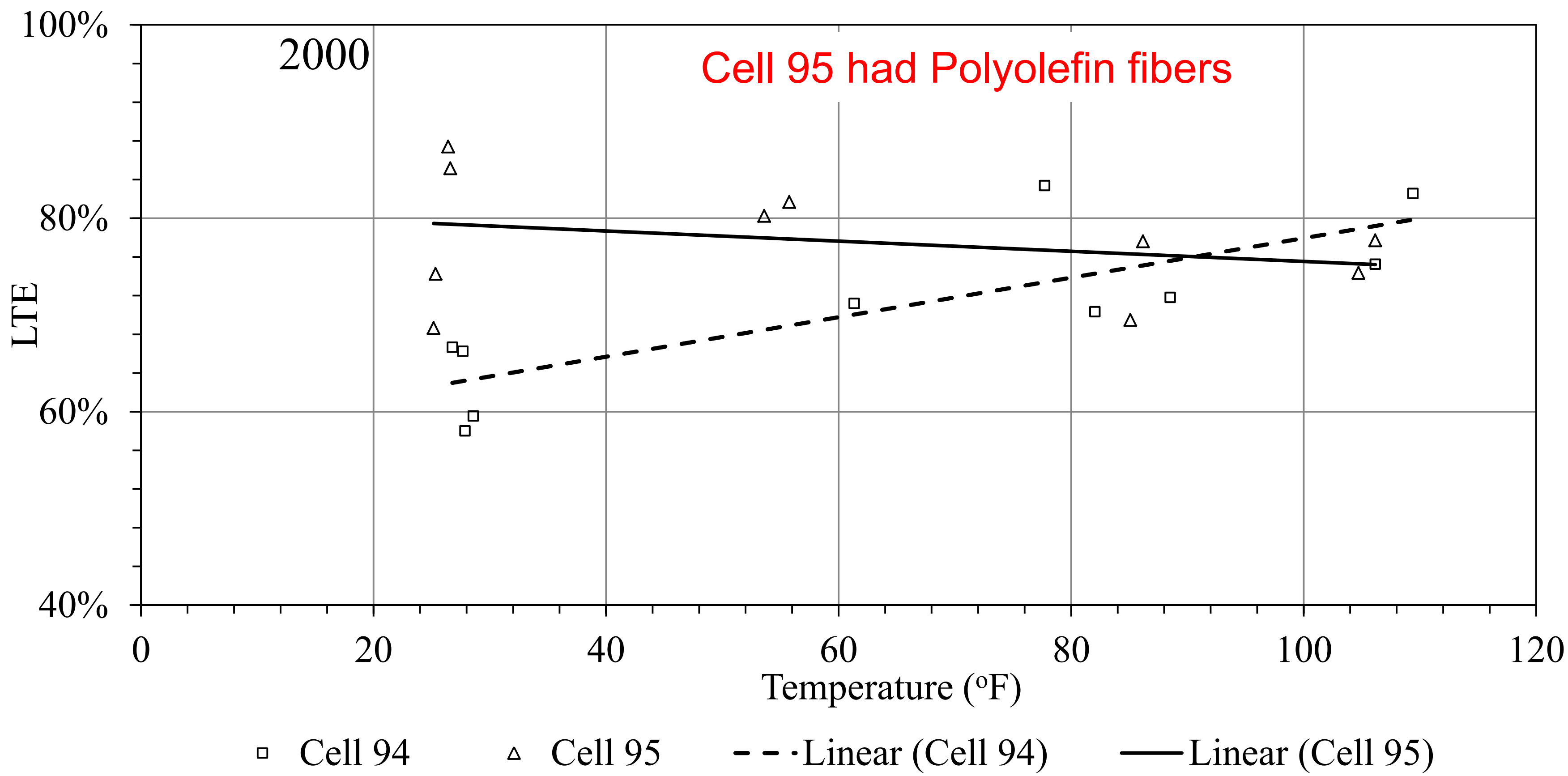
Source	Fiber trade name	Length (inch)	Aspect ratio, specific gravity, modulus of elasticity (ksi),tensile strength (ksi)
ABC Polymer Industries	(i)Tuf-Max DOT™ (ii) Performance Plus DOT™	1.5 or 2.0	(i) 74, 0.91, 800, 70 (ii) N/A, 0.91, 800, N/A
BASF Corporation	(i) MasterFiber® MAC 100 (ii) MasterFiber® MAC Matrix	(i) 1.5 (ii) 2.1	(i) 59, 0.91, N/A, N/A (ii) 70, 0.91, N/A, 85
Elasto Plastic Concrete	Bar chip 48 (BC48)™	1.89	N/A, 0.90-0.92, 1450, 93
The Euclid Chemical Corporation	Tuf-Strand SF™	2	74, 0.92, 1380, 87-94
Forta Corporation	FORTA-FERRO®	1.5 or 2.25	N/A, 0.91, N/A, 83-90
Propex Operation Co., LLC	NOVOMESH® 950	1.8-varies	N/A, 0.91, N/A, N/A
W.R. Grace	Strux® 90/40	1.55	90, 0.92, 1378,90

Performance of Existing FRC Overlays

Illinois

Performance of Existing FRC Overlays

Minnesota



Performance of Existing FRC Overlays

Minnesota

– Cell 96, No cracked panels, joint deterioration (too many fibers)

Burnham, 2015

Performance of Existing FRC Overlays

Minnesota

Localized distress in Cell 162, (b) concrete broken to replace the slab (Burnham & Andersen, 2015).

Performance of Existing FRC Overlays

South Carolina

Fibers holding shattered slab pieces

Performance of Existing FRC Overlays

Missouri

- US 60: A bonded concrete overlay project (1999)
- polypropylene fibers - 3 lb/yd^{3}; 4 inches thick and included 3 ft x 3 ft and 4ft x 4 ft panel sizes
- Fibers did not reduce panel cracking but did reduce crack widths and joint degradation. No faulting was observed on this project and may be related to the use of fibers.

General Performance Summary

State	Performance summary
Georgia	No information available
Illinois	Reduced slab migration, joint separation, faulting and increased ride quality
Kansas	Less faulting, spalling and panel cracks
Minnesota	Increased LTE in old cells; no strong conclusions on new cells
Missouri	Restricted faulting, reduced crack width and joint degradation
South Carolina	Increased service life
Virginia	Fibers exhibited good resiliency in minimizing cracking and crack width

Questions?

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