Laboratory Fatigue Evaluation of Continuously Fiber Reinforced Concrete Pavement

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Outline

- Background
- Objectives
- Results
- Preliminary cost benefit analysis
- Recommendation

Background

- CRCP
  - Well performing smooth pavement
  - Joint free
  - Expensive
- JPCP
  - Performs “well”
  - Sawn joints with dowel baskets for load transfer
  - Joints can deteriorate prematurely
  - Significantly less cost than CRCP

Background

- FRC
  - Crackless industrial floors
  - Highway use has dwindled
  - Fiber market is now robust with many types, shapes, and applications
  - Can we create a new pavement type?
  - How will it perform?
- CFRCP – Continuously fiber reinforced concrete pavement

Background

Pavement type	Benefits	Shortcomings	Difference in cost
CRCP	-Smooth driving surface -Fewer joint durability concerns	-Labor intensive -Potential corrosion of steel leading to durability issues	-Added steel cost -More labor cost
JPCP	-Less steel -Less labor intensive than CRCP	-Joint maintenance	-Lower steel cost than CRCP -Less labor cost than CRCP
CFRCP	-No steel -Smooth driving surface		-Fiber cost comparable to steel cost of CRCP -Less labor cost

Objectives

- Characterize the fresh and hardened properties of CFRCP concrete
- Determine comparative fatigue resistance of different fibers, differing fiber blends and dosage rates
- Recommendations for future research, including full scale loading and possible field implementation sites

Laboratory Testing

- Fresh properties
  - Slump, air content and unit weight
- Hardened properties
  - Compressive strength (7 & 28 days), splitting tensile strength, MOE and Poisson's ratio, flexural strength, post crack flexural behavior, cyclic crack propagation in notched beam specimens

Concrete Mix Design

- Air content – 5-7%
- Slump - 5±2 inches
- Total cementitous = 500 pcy
  - 20% class C fly ash
- w/cm – 0.50
- Coarse aggregate
  - #67 limestone
- Fine aggregate
  - Concrete sand

Concrete Mix Design

Coarse Aggr. (lb/yd^3)	Fine Aggr. (lb/yd^3)	Water (lb/yd^3)	Polypropylene Macro Fibers (lb/yd^3)	Carbon Fibers (lb/yd^3)	Steel Fibers (lb/yd^3)	Polypropylene Fibrillated Fibers (lb/yd^3)
1938	1290	250				
1911	1267	250				1.5
1907	1268	250				3.0
1899	1270	250				4.5
1895	1274	250	4.5			
1894	1267	250	7.5			
1900	1253	250	10.5			
1888	1252	250	15.0			
1895	1274	250		9.0		
1890	1259	250		21.0		
1883	1251	250		30.5		
1888	1266	250			85	

Fibers

- Polypropylene fibrillated fiber
  - 0.1, 0.2, and 0.3 percent
  - 1.5, 3.0, and 4.5 pcy
- Polypropylene macro fiber
  - Twisted bundle fiber
  - 0.3, 0.5, 0.7, and 1.0 percent
  - 4.5, 7.5, 10.5, and 15.0 pcy

Fibers

- Carbon fiber
  - Large number of carbon fibers held together with a nylon mesh
  - 0.1, 0.7, and 1.02 percent
  - 9.0, 21.0, and 30.5 pcy
- Steel fiber
  - 0.9 percent or 85 pcy

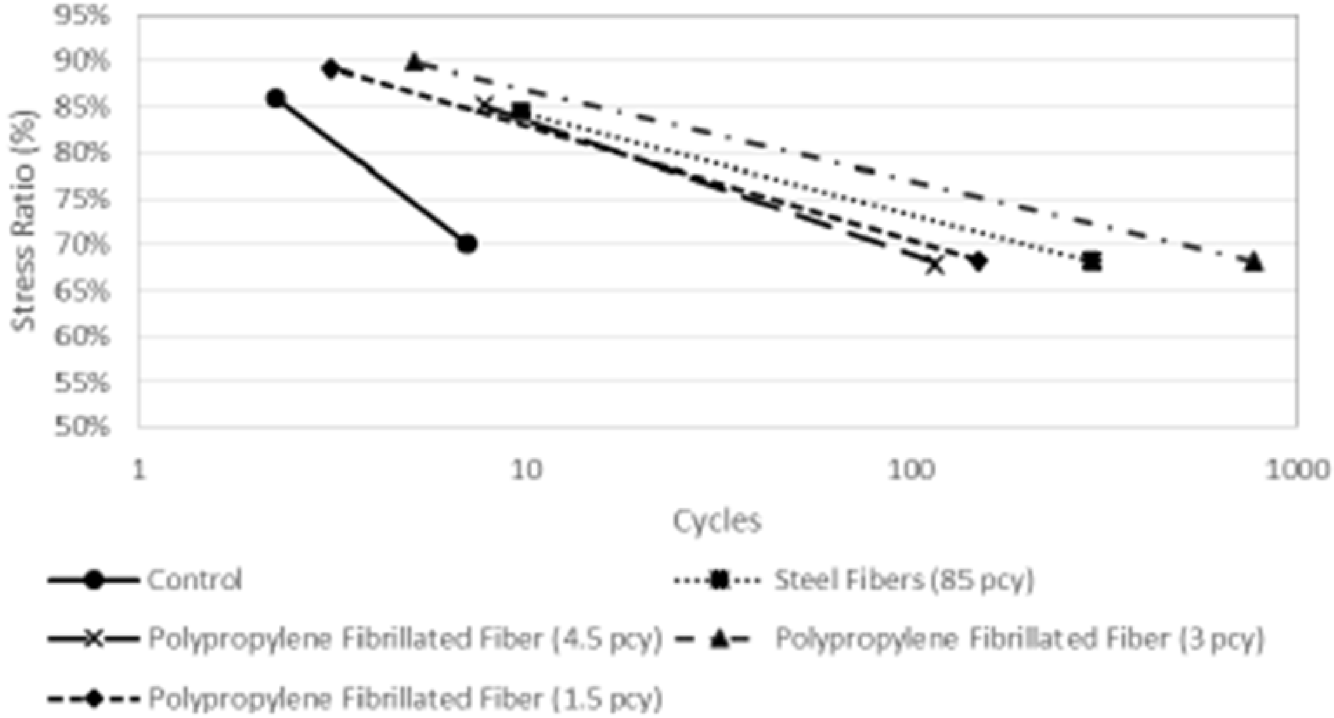
Fiber Properties

Fiber Type	Specific Gravity	Length (in.)	Tensile Strength (ksi)
Polypropylene Fibrillated	0.91	1.50	83-96
Polypropylene Macro	0.91	2.25	83-96
Carbon	1.70	4.00	600
Steel	7.85	2.00	152

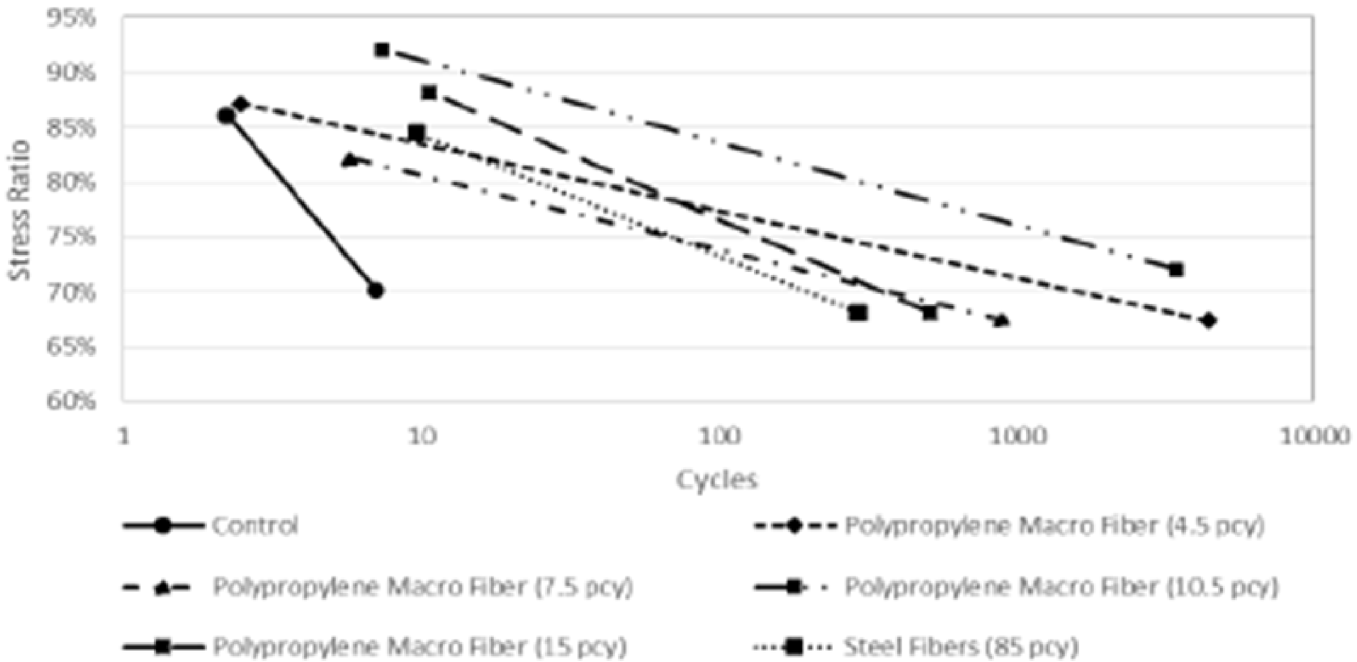
Results

Fiber Type	Fiber Dosage (pcy) (% volume)	Slump (in.)	Unit Weight (lb/ft³)	7 Day Compressive Strength, psi (COV)	28 Day Compressive Strength, psi (COV)	Flexural Strength, psi (COV)
Control	-	5.00	145	4,540 (2.2)	6,230 (1.4)	770 (10.7)
Polypropylene	1.5 (0.1%)	5.75	142	3,800 (1.7)	5,060 (1.0)	770 (7.0)
Fibrillated	3.0 (0.2%)	3.50	145	4,790 (0.5)	6,290 (1.9)	765 (6.0)
Fiber	4.5 (0.3%)	1.75	146	5,340 (9.0)	7,420 (1.4)	815 (8.3)
Polypropylene	4.5 (0.3%)	2.25	145	5,080 (18)	6,540 (2.6)	780 (8.1)
Macro Fiber	7.5 (0.5%)	0.75	147	5,450 (1.1)	7,030 (3.9)	760 (7.7)
	10.5 (0.7%)	1.00	148	5,550 (2.1)	7,090 (2.5)	760 (5.1)
	15.0 (1.0%)	0.25	147	4,920 (2.0)	5,850 (3.9)	785 (8.9)
Carbon Fiber	9.0 (0.3%)	0.75	144	5,130 (3.3)	6,310 (5.4)	820 (2.8)
	21.0 (0.7%)	0.50	145	5,030 (6.4)	6,630 (6.6)	885 (4.2)
	30.5 (1.0%)	0.25	145	5,720 (10.0)	6,340 (5.8)	865 (8.7)
Steel Fiber	85.0 (0.9%)	4.00	147	4,610 (2.7)	5,880 (1.6)	805 (9.1)

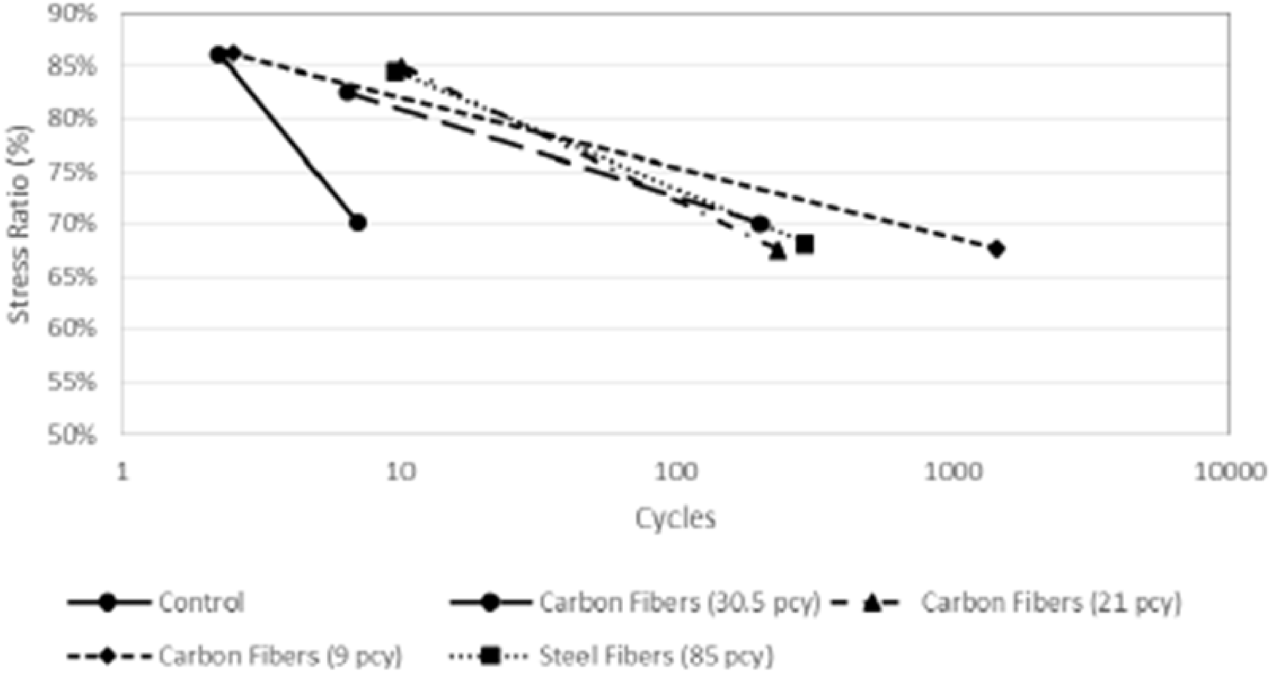
Results – Fatigue Testing



Results – Fatigue Testing



Results – Fatigue Testing



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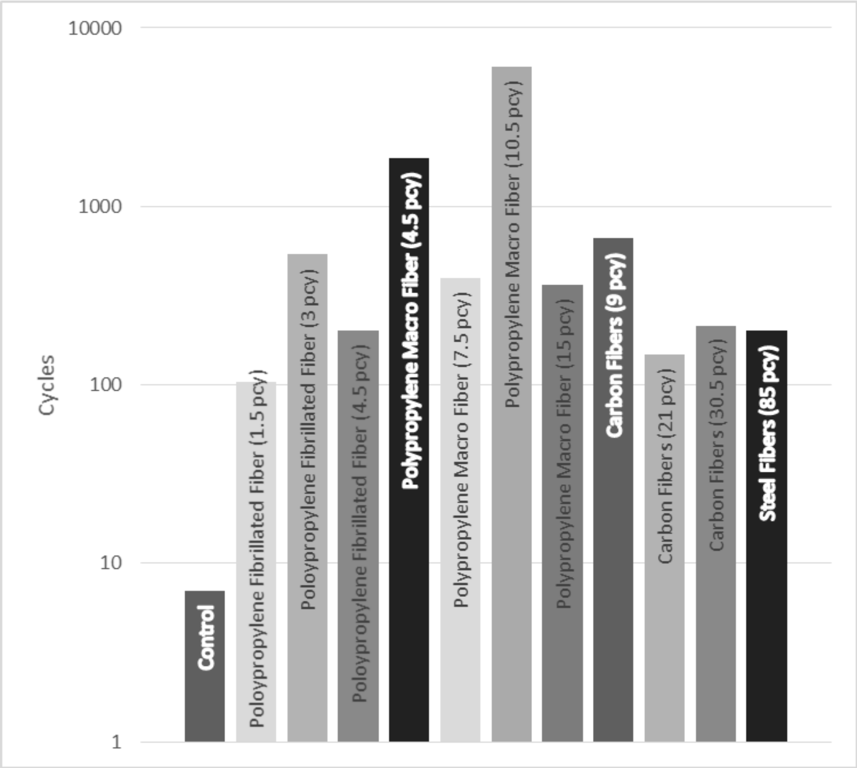
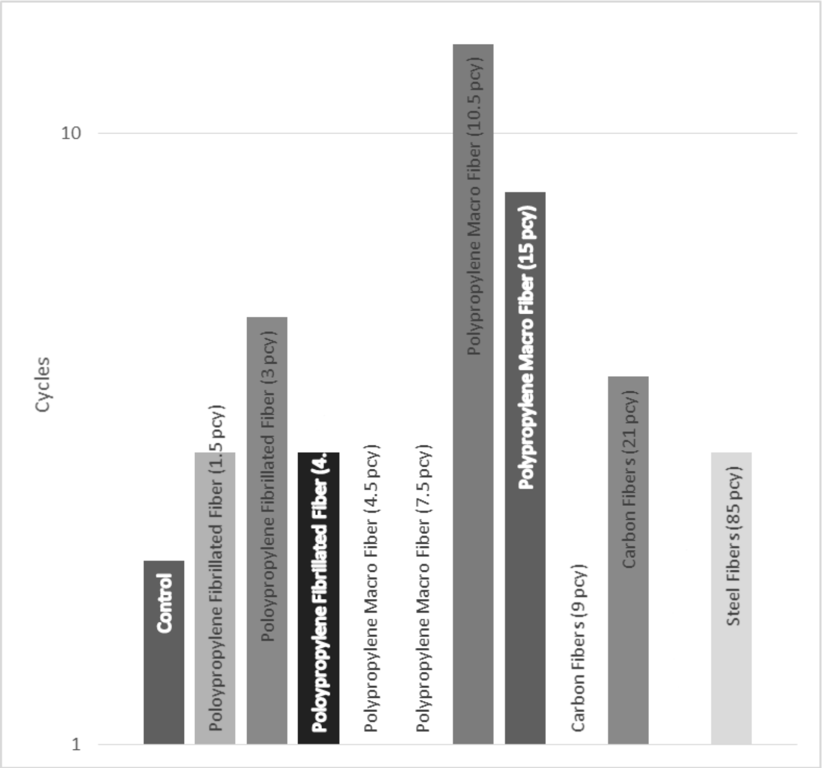
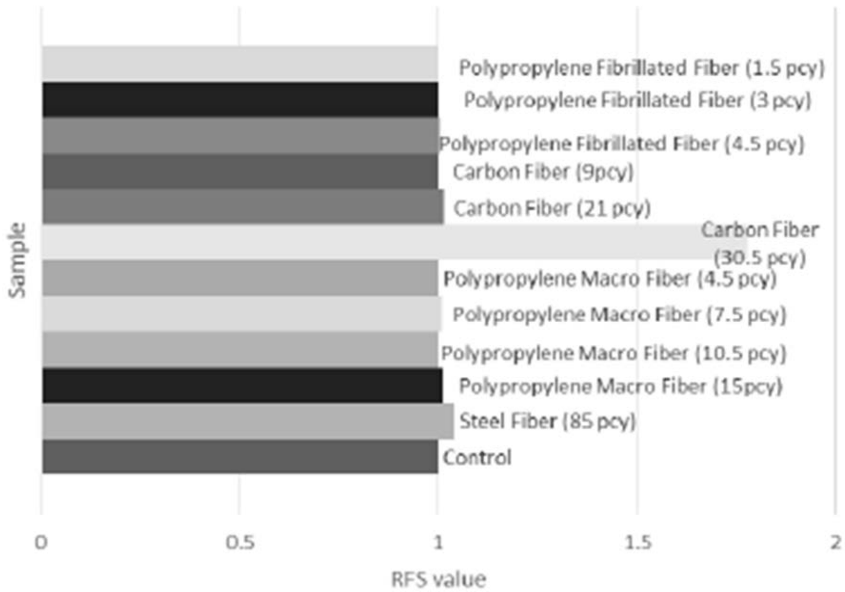


70% Stress Ratio

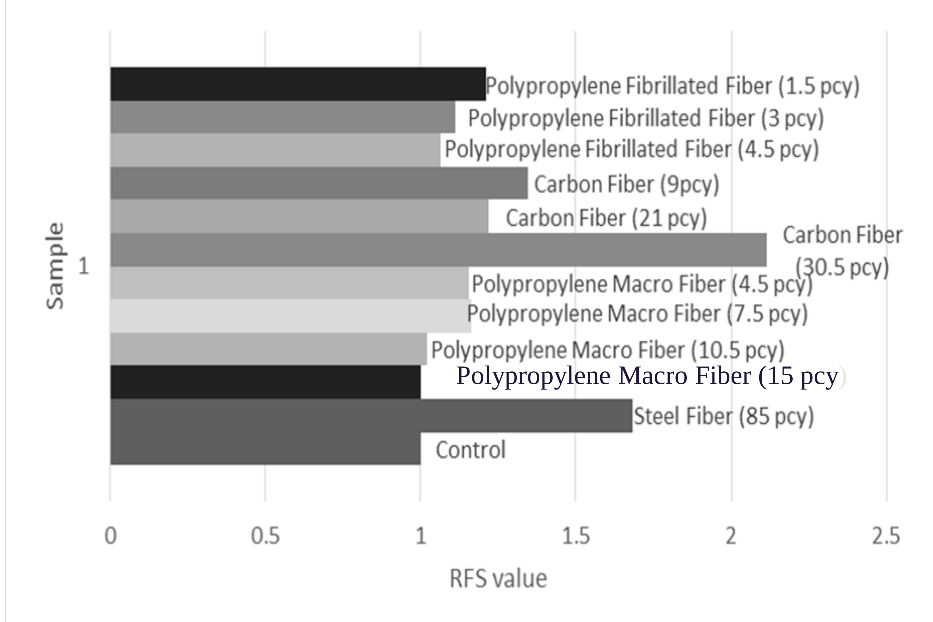


90% Stress Ratio

Results – Fatigue Testing

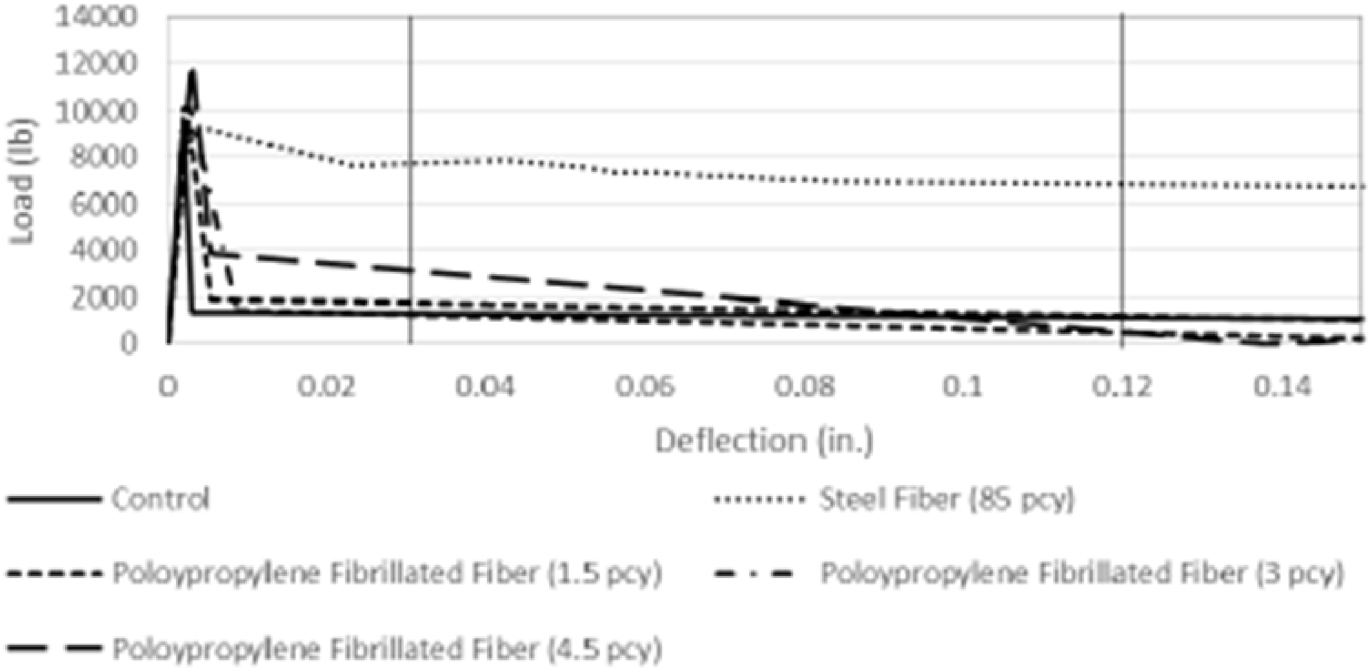


90% Stress Ratio

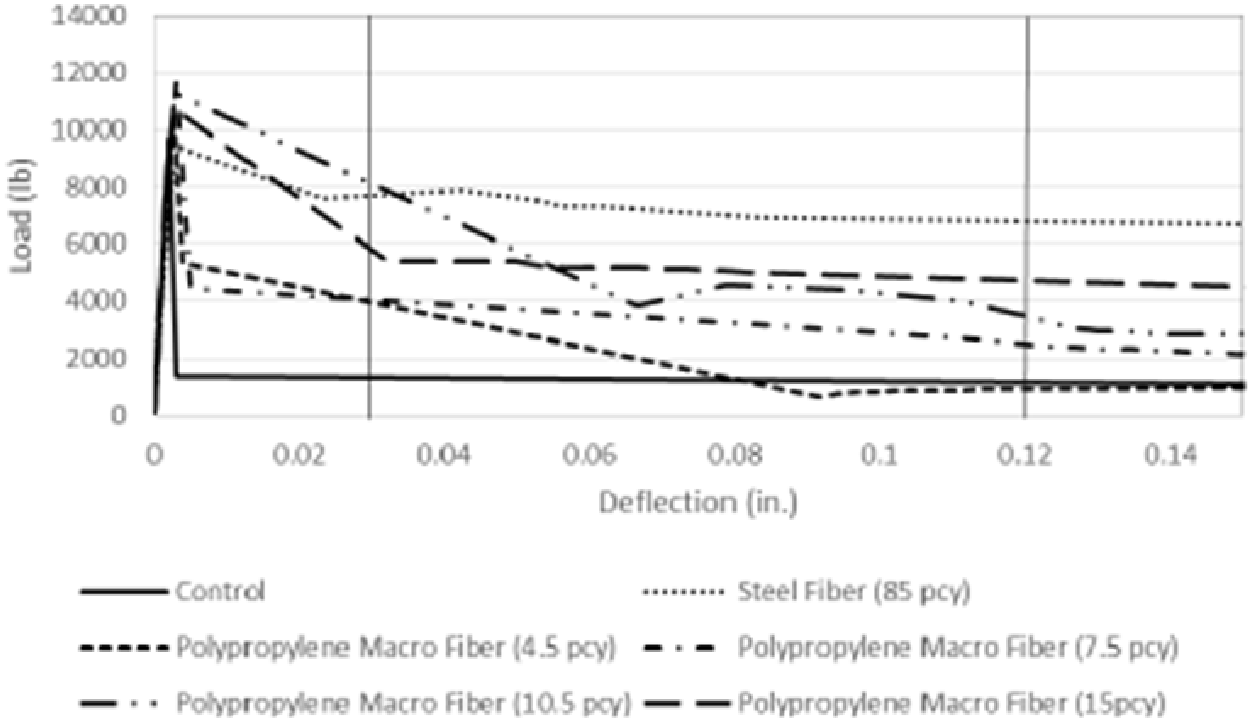


70% Stress Ratio

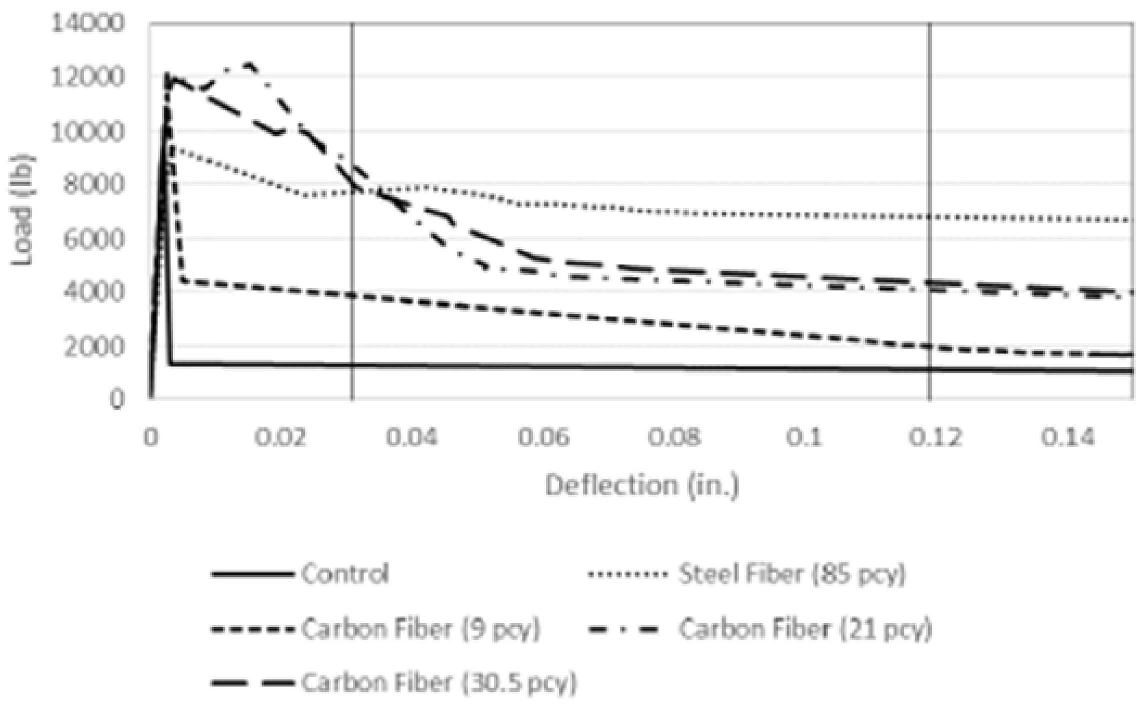
Results – Toughness Testing



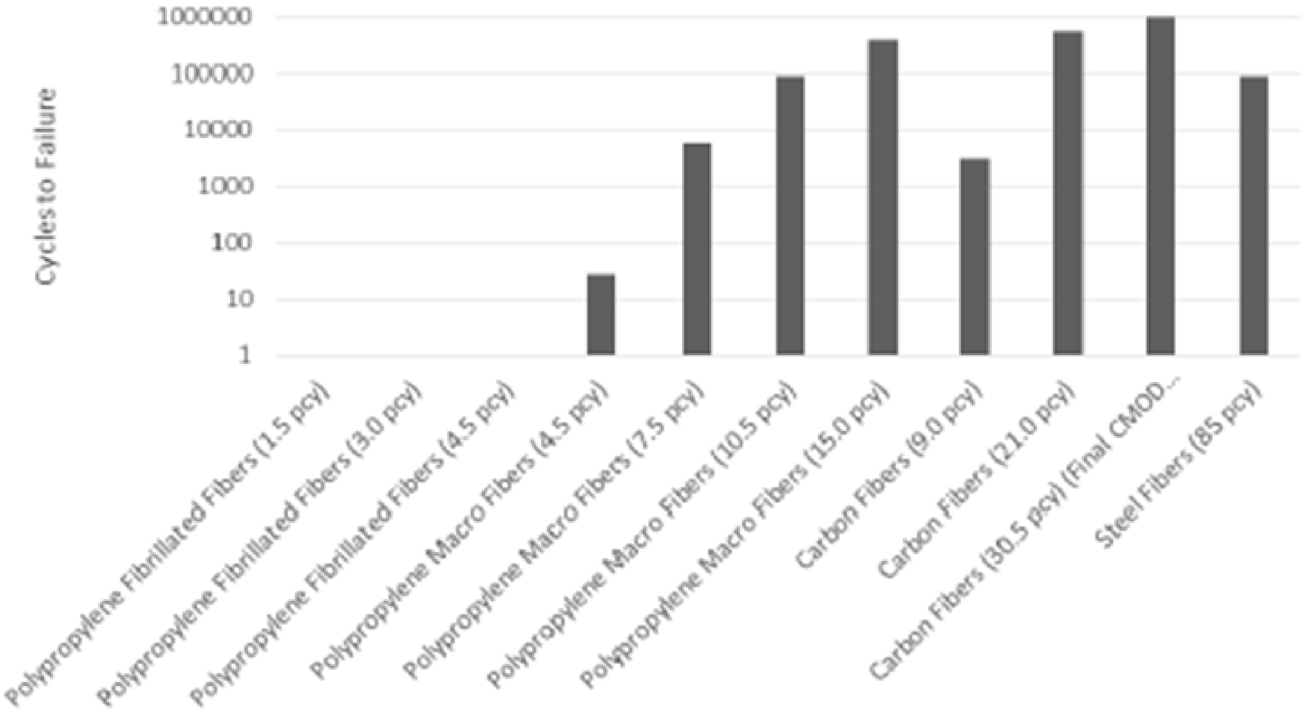
Results – Toughness Testing



Results – Toughness Testing



Results – Pre-cracked Fatigue



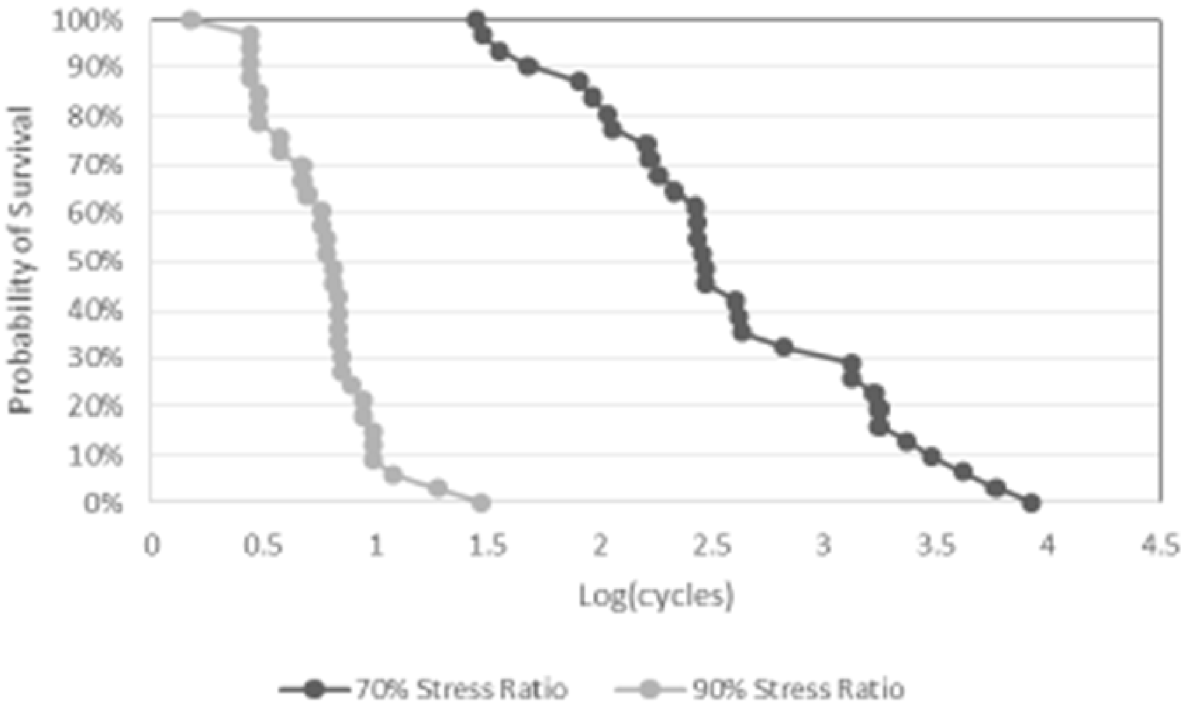
Results - Pavement Design

- Fatigue only data used
- McCall form analysis was completed

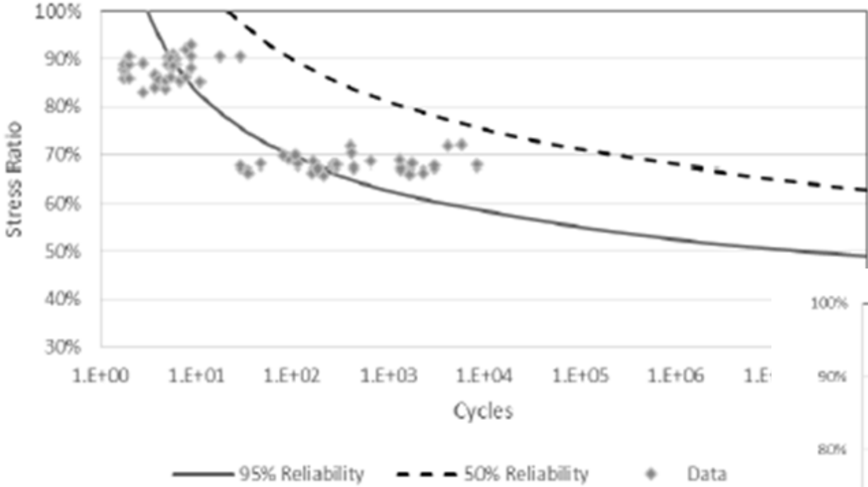
$$\log N = \left[\frac{-SR^{-\alpha}\log(1-P)}{\beta}\right]^{\gamma}$$

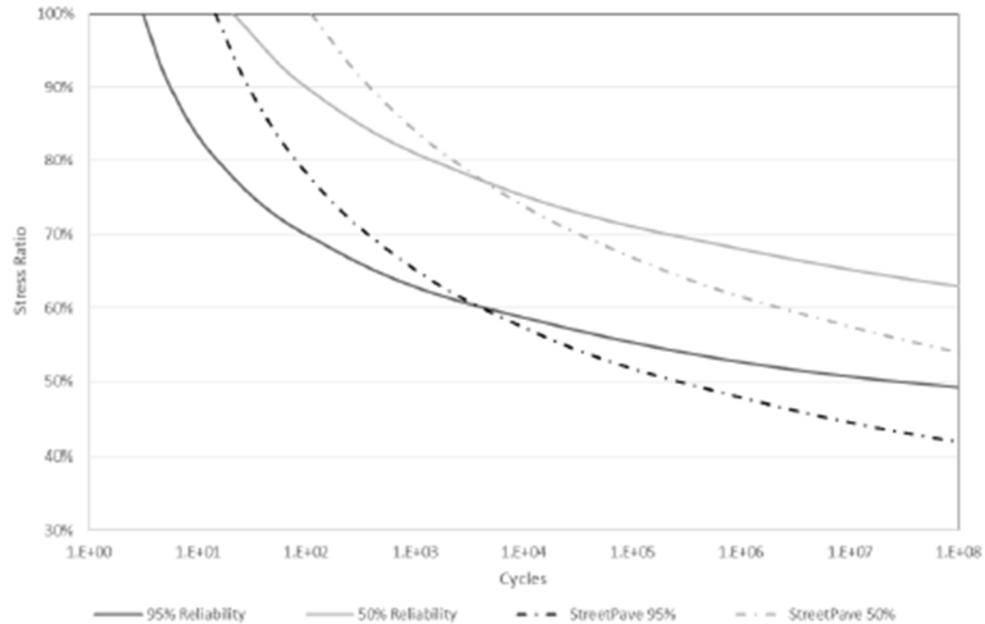
- Where N = # cycles, SR = stress ratio, P = probability of failure and α, γ, β are model coefficients

Results – Pavement Design



Results - Pavement Design





Conclusions

- Fibers improve fatigue performance
- Carbon fibers increase performance when dosed above 21 pcy compared to steel
- Polypropylene fibrillated and macro fibers increase fatigue performance when dosed correctly
- Fiber reinforcement can inhibit performance compared to steel when overdosed, but not below that of plain concrete

Conclusions

- Toughness testing showed that tensile strength and dosage rate were critical for ductility
- Fibers with increased tensile strengths had a greater residual load carrying capacity AND carried greater loads at larger deflections
- Pre-cracked fatigue testing showed that the length of the fiber is also crucial to the performance

Recommendations

- Construction of full scale testing sections
  - Give a greater understanding of how fiber reinforcement improves performance
- Laboratory testing to create a more accurate pavement design curve
- Highway test section to determine if CFRCP will eliminate the need for joints and perform the same as CRCP

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