TRANSPORTATION LEARNING NETWORK

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Welcome!

Fiber-Reinforced Concrete for Structure Components (MPC 17-342)

Admad Ghadban, Nadim Wehbe & Micah Underberg

Our partners: Mountain-Plains Consortium Region 8 · Montana MDT Department of Transportation · NDDOT North Dakota Department of Transportation · South Dakota DOT Connecting South Dakota and the Nation · Wyoming Transportation Department

South Dakota State University SDSU

Outline

- Problem Description
- Objectives
- Literature Review & DOT Interviews
- Methodology
- Experimental Results
- Conclusions
- Recommendations

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Problem Description

Concrete Deterioration → Poor Performance → Reduced Life Expectancy

Low Tensile Strength of Concrete → Crack Formation & Propagation → Moisture and Chloride Penetration → Steel Corrosion → Loss of Structural Capacity

Fiber-Reinforced Concrete → Enhanced Tensile Strength → Better Crack Resistance

Limited Implementations of FRC by SDDOT → Lack of up-to-date Information about FRC → Need for Further Research

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Objectives

- Identify best practices for design and construction of FRC
- Assess potential application, performance, costs, benefits and drawbacks of FRC
- Develop guidance for design, material selection, construction, testing, and application of FRC in South Dakota

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Literature Review & DOT Interviews

- Fiber catalog
- Fibers can significantly decrease the consistency of concrete
- Higher paste content can increase slump and reduce crack width for FRC
- Fiber balling can be reduced by choosing fibers with low aspect ratios and increasing paste volume & mixing time
- The effect of fibers on the compressive strength of FRC is inconsistent
- Improved impact and freeze-thaw resistance
- No significant effect on permeability
- Better abrasion resistance with macro fibers

Literature Review & DOT Interviews

- Steel fibers could produce hazardous surfaces
- Field testing is mainly conducted through surface inspection and bond strength test
- FRC experiences smaller cracks with increased density
- Effect of fiber type and dosage is not sufficiently studied
- Cost is doubled or sometimes even tripled
- SDDOT has no current specifications
- Brief specifications from Georgia DOT, Texas DOT, Illinois DOT, and Washington DOT
- Design, preparation, mixing, testing, and finishing of FRC is similar to conventional concrete except as detailed by the guideline

Methodology

- Fiber selection:

Fiber	Strux 90/40	Fibermesh 650	TUF-STRAND SF	FORTA-FERRO	Dramix 5D
Manufacturer	W.R. Grace	Propex Fibermesh	Euclid Chemical Company	Forta Corporation	Bekaert
Fiber Class	Synthetic	Synthetic	Synthetic	Synthetic	Steel
Length (in)	1.55	1.5 - 1.75 blend	2.0	2.25 - 1.5 blend	2.4
Equivalent Diameter (in)	0.017	0.016 - 0.018	0.027	0.028, 0.019	0.04
Aspect Ratio*	90	96.5	74	79.5	65
Specific Gravity	0.92	0.91	0.92	0.91	7.85
Tensile Strength (ksi)	90	89	87 - 94	83 - 96	333.5
Modulus of Elasticity (ksi)	1378	1088	1380	690	30,000
Recommended Dosage Rate (lb/yd3)	3 - 12	3 minimum	3 - 20	3 - 30	25 minimum
Manufacturer Recommended Applications	Overlays, Slab-on-grade, Pavements, Composite steel floor decks	Overlays, Slab-on-grade, Pavements, Composite metal decks	Toppings, Slab-on-grade, Pavements, Thin walled pre-cast	Bridge decks, Industrial floors, Pre-cast products, Shotcrete	Bridges, Structural floors, Foundation slabs
Cost ($/lb)	6.00 **	5.00 **	6.00 **	5.00 **	1.19

Methodology

- Mix design:
  - ➢ 0.38 w/c
  - ➢ 21 mixes

Material	Proportion
Type I/II Cement	524 lb/yd3
Class F Fly Ash	131 lb/yd3
Quartzite Coarse Aggregate	1620 lb/yd3
Natural Sand	1300 lb/yd3
Water	250 lb/yd3
Daravair M	0.62 oz/cwt
WRDA 82	3.6 oz/cwt

Fiber	Dosage 1	Dosage 2	Dosage 3	Dosage 4
Strux 90/40	3 lb/yd3 (0.21 %)	5 lb/yd3 (0.34 %)	8 lb/yd3 (0.55 %)	10 lb/yd3 (0.69 %)
Fibermesh 650	3 lb/yd3 (0.21 %)	5 lb/yd3 (0.35 %)	8 lb/yd3 (0.56 %)	10 lb/yd3 (0.69 %)
TUF-STRAND SF	3 lb/yd3 (0.21 %)	5 lb/yd3 (0.34 %)	8 lb/yd3 (0.55 %)	10 lb/yd3 (0.69 %)
FORTA-FERRO	3 lb/yd3 (0.21 %)	5 lb/yd3 (0.35 %)	8 lb/yd3 (0.56 %)	10 lb/yd3 (0.69 %)
Dramix 5D	25 lb/yd3 (0.20 %)	45 lb/yd3 (0.36 %)	65 lb/yd3 (0.53 %)	85 lb/yd3 (0.69 %)

Methodology

- Mixing:
  - ➢ Additional 5 min of mixing time

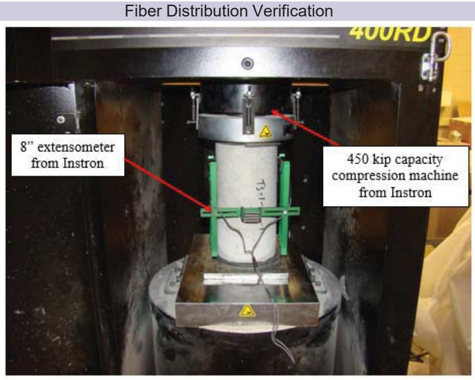
Methodology

- Consolidation:
  - ➢ All specimens were subjected to internal vibration

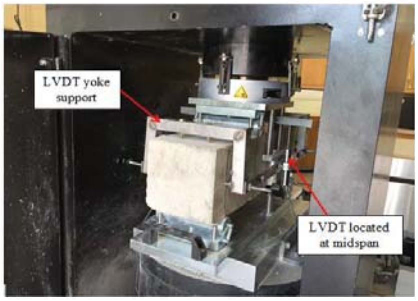
Methodology

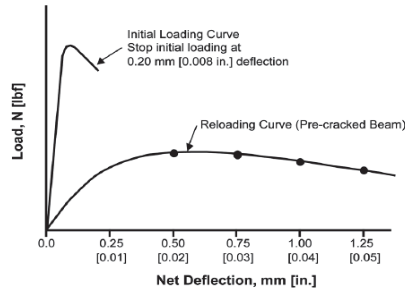
- Adopted tests:

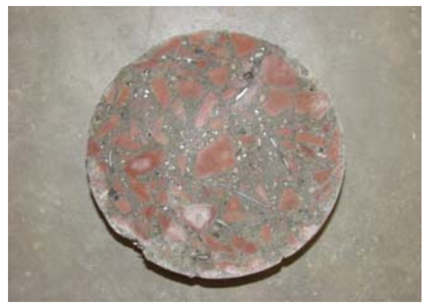
Type of Test	Test Name	Standard/Source
Fresh Concrete	Density (Unit Weight)	ASTM C138
	Slump of Hydraulic-Cement Concrete	ASTM C143
	Air Content of Freshly Mixed Concrete by the Pressure Method	ASTM C231
	Temperature of Freshly Mixed Hydraulic-Cement Concrete	ASTM C1064
Hardened Concrete	Compressive Strength of Cylindrical Concrete Specimens	ASTM C39
	Average Residual-Strength of Fiber-Reinforced Concrete	ASTM C1399
	Flexural Performance of Fiber-Reinforced Concrete (Using Beam With Third-Point Loading)	ASTM C1609
	Drop-Weight Impact Test	ACI Comm. 544
	Fiber Distribution Verification	N/A



Methodology







Methodology

- Statistical analysis:
  - F-test using SAS to evaluate the significance of the effect of fiber type and dosage on the measured properties
    - ★ p-value<0.05 indicates statistical significance

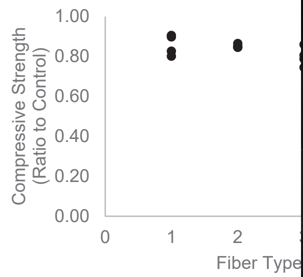
Experimental Results

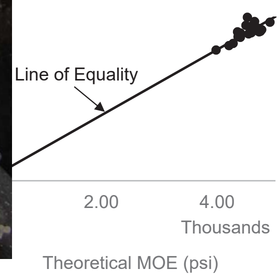
Statistical Analysis

	Fiber Type		Volume Fraction of Fibers	
	F-value	p-value	F-value	p-value
Fresh Air Content	0.93	0.4994	0.79	0.6271
Unit Weight	0.22	0.9195	0.89	0.5676
Slump	1.93	0.211	12.38	0.0017
Temperature	9.65	0.0056	0.68	0.704
Compressive Strength	1.83	0.2283	1.53	0.2948
Modulus of Elasticity	5.12	0.0301	2.09	0.1738
Toughness	1.19	0.3919	8.67	0.005
Equivalent Flexural Strength Ratio	9.3	0.0062	15.98	0.0008
Normalized Effective Modulus of Rupture	0.02	0.9985	2.87	0.0916
Average Residual Strength	2.22	0.1676	8.13	0.0061
Impact Test First Crack	0.71	0.6115	1.43	0.3263
Impact Test Failure	5.12	0.0301	7.18	0.0087

Fiber Type

- Compress

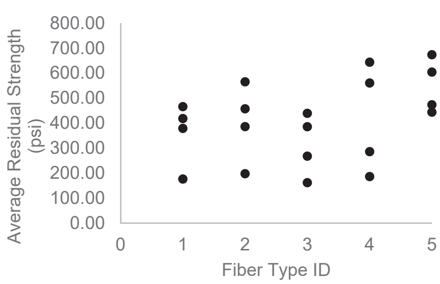


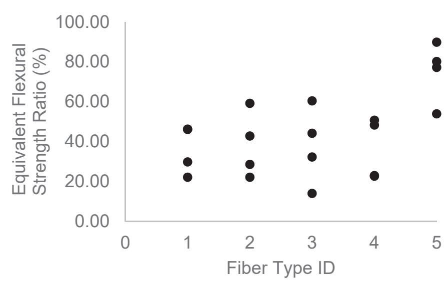


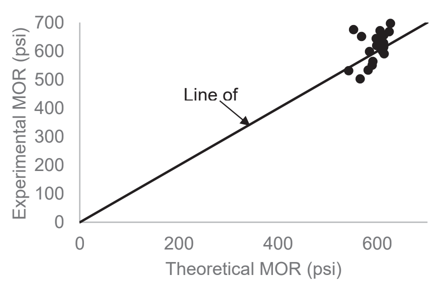
Fiber Type ID
1
2
3
4
5

Fiber Type

- Flexural Performance:



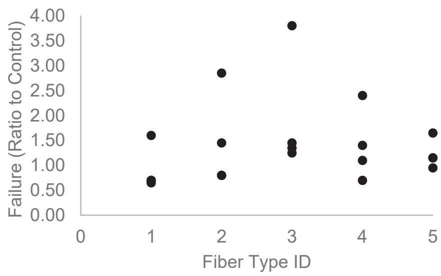


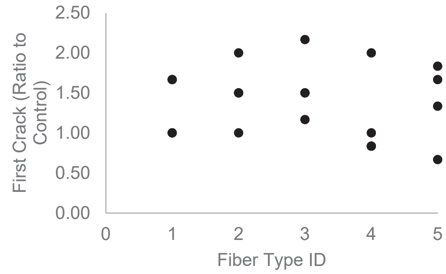


Fiber Type ID	Fiber Name
1	Strux 90/40
2	Fibermesh 650
3	TUF-STRAND SF
4	FORTA-FERRO
5	Dramix 5D

Fiber Type

- Impact Performance:





Fiber Type ID	Fiber Name
1	Strux 90/40
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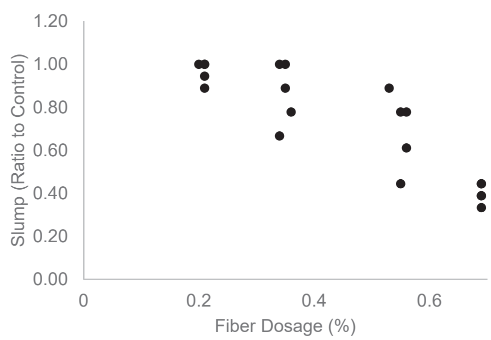
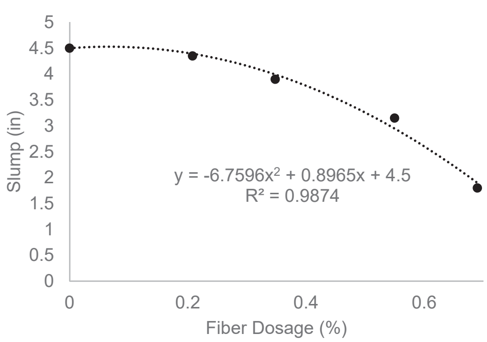
Fiber Dosage

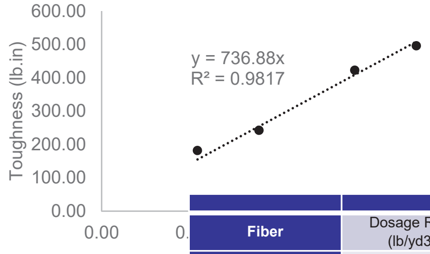
- Slump:

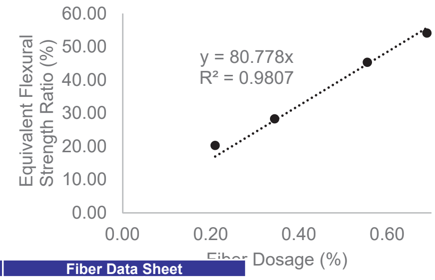




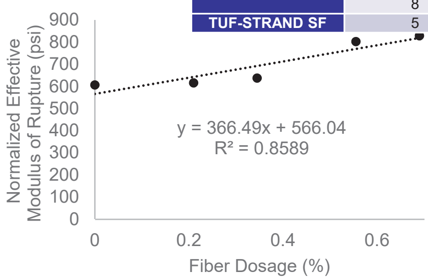
Fiber Dosage

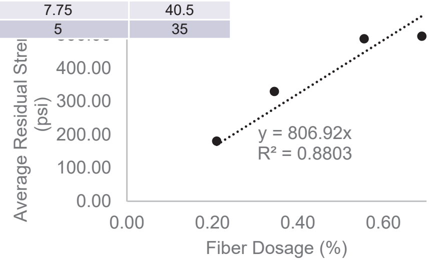
- Flexural Performance:





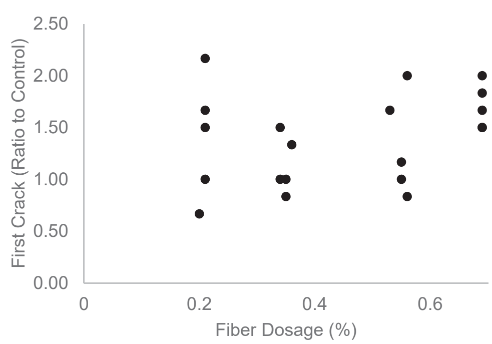
	Study Results		Fiber Data Sheet	
Fiber	Dosage Rate (lb/yd3)	Ratio (%)	Dosage Rate (lb/yd3)	Ratio (%)
Strux 90/40	3	22	3	20
	5	30	5	28.5
	8	46	7.75	40.5
TUF-STRAND SF	5	32	5	35

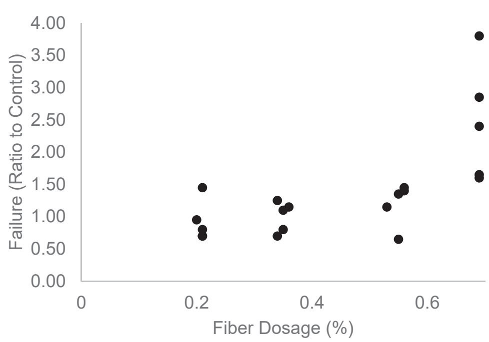




Fiber Dosage

- Impact Performance:





Conclusions

- The difference in results between the specimen replicates for each test can be very significant for FRC due to possible difference in fiber distribution and orientation among the specimens.
- Fibers have resulted in the reduction of compressive strength and modulus of elasticity of concrete by an average of 18 % and 13%, respectively.
- The type of synthetic fibers used in the concrete has no significant effect on any of the fresh and hardened concrete properties that were measured in this study.
- Steel FRC has superior flexural properties compared to synthetic FRC but it has the concern of being susceptible to corrosion. Since it is not directly exposed to deicer salt, Jersey barrier is one application where steel fibers could be used.
- Steel fibers are twice as expensive as synthetic fibers but they can perform better or at least as good as synthetic fibers at half the dosage rate.
- The most cost-effective synthetic fibers among the tested ones are Fibermesh 650 and FORTA-FERRO fibers.

Conclusions

- Slump decreases nonlinearly with the increase in fiber dosage.
- For synthetic FRC with fiber dosages between 0.21% and 0.69%, data showed that an increase of 0.1% in fiber dosage results in an average increase of:
  - 74 lb.in in toughness
  - 8% in equivalent flexural strength ratio
  - 37 psi in modulus of rupture
  - 81 psi in average residual strength
- Experimental results were in good agreement with available manufacturers’ claims.
- The adopted impact test gave inconclusive results due to its qualitative nature and due to the lack of specimen replicates.
- Saw-cut surfaces of FRC cylinders showed uniform fiber distribution and no fiber balling, indicating the adequacy of 5 minutes of additional mixing in laboratory mixes.

Recommendation (Design)

- Higher slump values, compared to PCC mixes, should be targeted for FRC mixes in order to compensate for the reduced workability of FRC mixes.
- Fine to coarse aggregate ratio should be increased in order to provide higher mortar content that is helpful in increasing workability, minimizing fiber balling, and reducing crack widths.
- Up to 20% and 15% reduction in compressive strength and modulus of elasticity, respectively, should be taken into consideration when designing FRC mixes.

Construction

- Manual consolidation should be completely avoided.
- FRC tining should be modified by either reducing the tining angle, turning the tining rake over, or grinding the tining grooves after hardening.
- A burlap drag or a broom should be used instead of a carpet drag in order to avoid pulling out fibers from the surface of the FRC.

Fiber Type and Dosage

- To minimize fiber balling, fibers with low aspect ratios should be used.
- Steel fibers should be avoided in components that would be exposed to chloride penetration.
- Among the tested synthetic fibers, FORTA-FERRO should be used due to its cost-effectiveness and low aspect ratio.

Future Research

- Instead of the empirical correlations that are usually obtained from experimental results which cannot be guaranteed to work under all circumstances due to limitations in the testing matrix, it is better to come up with theoretical correlations and then verify them against comprehensive experimental results obtained from very different mixes.
- The effect of other aspects of the mix design such as mortar content, w/c, coarse aggregate, and cementitious materials should be studied.
- Other, more informative, workability measurements such as rheology should be explored in order to better correlate fiber dosage to workability of FRC mixes.
- Effect of fiber type and dosage on impact performance of FRC structures should be studied using more reliable instrumental impact tests incorporating compressive and tension loading with variable strain rates.

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Transportation Learning Network Contact Information

TLN Help Desk
Office: (701) 231-1087
shannon.l.olson@ndsu.edu

Office: (701) 231-7766
susan.hendrickson@ndsu.edu

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