Fiber Reinforced Overlays

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2020 ICPA Workshop
About Me

• B.S. Ceramic and Material Science Engineering  
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• M.S., PhD Civil Engineering  
  – University of Illinois Urbana-Champaign

• Post-Doc @ Oregon State

• Assistant Professor at The University of Alabama
• Registered Professional Engineer in four states
Outline

• Past and Myths
• Review of National Specifications
• How do I specify and design?
• Real life projects
• Canada
Acknowledgements

- TTCC/Fiber-Reinforced Concrete Project
- National Concrete Consortium
- National Concrete Pavement Technology Center
- Snyder and Associates, Inc.
- “Fiber Reinforced Concrete for Pavement Overlays” Technical Advisory Committee
- Drs. Jeffery Roesler, Amanda Bordelon, and Alex Brand
Fiber Reinforcement
(defined by ASTM C1116)

- Fiber Materials:
  - Type I: Steel FRC
  - Type II: Glass FRC (alkali-resistant only)
  - Type III: Synthetic FRC (moisture and alkali-resistant)
  - Type IV: Natural FRC (moisture and alkali-resistant)

- May be specified either volume or weight basis
  - Steel 30 kg/m$^3 \sim 0.38\%$ by $V_f$
  - Polypropylene 4 kg/m$^3 \sim 0.44\%$ $V_f$
What have been past FRC challenges?

- Several premature slab failures in field (Rollings 1993)
  - Excessive slab sizes (1.5\*L to 2.0\*L) with higher paste contents (shrinkage) and too thin
  - Slab curling
  - Larger crack widths (dominant joints)

- Dosage amount and type of fiber chosen on “experience”
  - Various fiber types, shapes, and materials

- Structural Design benefit was *NOT effectively standardized in past*
Mythbusters

• Fibers do not
  – Increase compressive strength
  – Increase flexural strength
  – Increase tensile strength

• Fibers do
  – Increase toughness
Rust

• Will I have corrosion with steel fibers?
  – Yes
  – No
  – Generally limited to surface exposed fibers
  – Extensive literature review performed by Marcos-Meson et al. 2018
Specifications

• Widely vary state to state
  – Volume fraction
  – Weight dosage
  – Residual strength
Example Specifications: Oregon

Use synthetic fiber reinforcing from the QPL and according to Section 02045 in all bridge deck and silica fume overlay concrete. Use synthetic fiber reinforcing according to the manufacturer’s recommendations at the rate designated on the QPL. **Fiber packaging is not allowed in the mixed concrete.**
Example Specifications: Oregon
Example Specifications: Delaware

...concrete for decks require the use of nonferrous reinforcement fibers at a rate of 1.5 pounds per cubic yard.
Example Specifications: Utah

- Use 4 lb/yd$^3$ of concrete mix
- Provide a minimum flexural strength ratio ($R_{e,3}$) of 25 percent when tested according to ASTM C 1609.
Example Specifications: Kansas

• Provide fibers, which when tested using the procedure described in subsection 1722.4b., result in a minimum equivalent flexural strength ($f_{e,3}$) of:
  • Minimum required $f_{e,3} = 140 + .015 (x - 4000)$ psi
  • In the above equation, $(x)$ is the average concrete compressive strength as defined in subsection 1722.4b.(2)(c).

• Provide fibers, which when tested using the procedure described in subsection 1722.4b., result in a minimum strength ratio ($R_{e,3}$) of 25%.
Example Specifications: Missouri

The steel fiber dosage rate shall be 80 pounds per cubic yard of concrete.
How to specify fibers in concrete?

• Comparison of Flexure Strength Tests
  – ASTM 1018
  – ASTM C1399
  – ASTM C1550
  – JCI-SF4 (1983)

• RESIDUAL STRENGTH

Note 1—Residual strength is not a true stress but an engineering stress computed using simple engineering bending theory for linear elastic materials and gross (uncracked) section properties.
New Change

The fixtures specified in Test Method C78 are suitable with the qualification that supporting rollers shall be able to rotate on their axes and shall not be placed in grooves or have other restraints that prevent their free rotation.

The supporting rollers shall be able to rotate on their axes throughout the duration of a test and shall conform with Practice C1812/C1812M.


Flexure Test Method
ASTM C1609-19 and JCI-SF4

Beams: 6 in x 6 in (15x15cm)
Span (L): 18 in (45cm)
L/150 = 0.12 in (3 mm)
## Flexural and Residual Strength Values*

<table>
<thead>
<tr>
<th>Material</th>
<th>Flexural Strength MOR (psi [MPa])</th>
<th>$f_{150}$ (psi [MPa])</th>
<th>$R_{150}$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plain Concrete</td>
<td>686 [4.73]</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>0.32% Synthetic</td>
<td>680 [4.69]</td>
<td>126 [0.87]</td>
<td>18.0</td>
</tr>
<tr>
<td>0.48% Synthetic</td>
<td>699 [4.82]</td>
<td>225 [1.55]</td>
<td>32.0</td>
</tr>
<tr>
<td>0.35% Hook Steel</td>
<td>679 [4.68]</td>
<td>234 [1.61]</td>
<td>34.5</td>
</tr>
<tr>
<td>0.50% Crimp Steel</td>
<td>766 [5.28]</td>
<td>184 [1.27]</td>
<td>24.0</td>
</tr>
</tbody>
</table>

*Actual values measuring according to ASTM C1609-07 (different roller assembly)

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Fiber-Reinforced Concrete Pavement Design

• Use existing concrete pavement design thickness methods (AASHTO, FAA, PavementDesigner, AASHTO Pavement ME)
  – MOR = plain concrete flexural strength

• Modified flexural strength (MOR’)
  – include benefit of fibers ($f_{150}$) = residual strength

• Input MOR’ for concrete strength
Modified Strength Equations

- \( \text{MOR}' = (\text{MOR} + f_{150}) \)
  - \( \text{MOR} \) = plain concrete flexural strength
  - \( f_{150} \) = residual strength
  - \( \text{MOR}' \) = effective flexural strength of FRC

- \( f_{150} = 150 \text{ psi} \) (for example)
- \( \text{MOR} = 600 \text{ psi} \)

Altoubat et al. (2007)
Bordelon and Roesler (2012)
## Residual Strength Estimator for Fiber-Reinforced Concrete Overlays

**Instructions:** Run an overlay design software to determine the design inputs. Select design choices from the drop-down menus below to narrow down the recommended performance requirement of FRC for the proposed overlay pavement. Determine the effective flexural strength to input into overlay design software instead of design concrete flexural strength. Prepare specifications to achieve design residual strength of FRC material.

<table>
<thead>
<tr>
<th>Design Input Choices</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of Overlay Road</td>
<td>Local Road/Street</td>
</tr>
<tr>
<td>Millions of ESALS in Design Life</td>
<td>0.01 to 5.0 million ESALS</td>
</tr>
<tr>
<td>Asphalt Pre-Condition*</td>
<td>Fair</td>
</tr>
<tr>
<td>Desired New Concrete Thickness</td>
<td>4.5 to 6 inch PCC thickness</td>
</tr>
<tr>
<td>Remaining HMA Thickness after Milling</td>
<td>3 to 4.5 inches HMA remaining</td>
</tr>
<tr>
<td>Overlay Slab Size</td>
<td>6ft joint spacing</td>
</tr>
<tr>
<td>Desired Performance Enhancements</td>
<td>basic FRC overlay</td>
</tr>
</tbody>
</table>

*refer to Tech Report to example estimates of asphalt pre-condition

Plain Unreinforced Concrete Flexural Strength (MOR) based on 28 day Four Point Bending (ASTM C78 or ASTM C1609)

- 550 psi
Excel Calculator

**Recommended Residual Strength ($f_{150}$)**
Use value within this range for the Material Specification:

125 to 175 psi (target value from ASTM C1609 test results of FRC)

**Effective Flexural Strength ($f_{eff}$)**
Replace the MOR from the Pavement Design Software with this value:

650 psi

NOTE: Actual fiber dosage rates are dependent on fiber type, fiber dimensions, concrete mixing/placement technique, cement content and fiber content or volume fraction. The intended fiber and dosage rate should be verified by ASTM C1609 test method. These recommended values are based off of previous field and laboratory testing of fibers used in concrete overlay pavements. Refer to the Tech Guide or Tech Report for more details.
FRC Overlay Design Example

PavementDesigner

TRAFFIC

- Project Type: Street Overlay
- Design Life: 15 years
- Traffic Growth Rate: 2% per year

GODAL

- Reliability: 90%
- % of Slabs Crack at End of Design Life: 15%

CALCULATED TRAFFIC RESULTS

- Avg Truck/Day in Design Lane over the Design Life: 86
- Total Trucks in Design Lane over the Design Life: 315,321

AXLE LOAD (kips)

<table>
<thead>
<tr>
<th>Single</th>
<th>Tandem</th>
<th>Trifem</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>25</td>
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<tr>
<td>45</td>
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<td>50</td>
<td>86</td>
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<tr>
<td>102</td>
<td>102</td>
<td>90</td>
</tr>
</tbody>
</table>

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FRC Overlay Design Example

PavementDesigner

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FRC Overlay Design Example

• No Fibers
  – 5.75” Thickness

• Fibers (150 psi residual strength)
  – 4.75” Thickness

So what is the fiber dosage???
Dosages

• Need test data to establish dosage
  – Every fiber is different

• Minimum dosages often specified
  – Residual strength is most important factor!!!
Decatur, IL: Intersection US 36 and Oakland Avenue (1998)

9cm inlay of a milled 15cm HMA surface, 0.9-1.2m wide panels

34% panels cracked
Patching
Rough w/ migration

2012
Decatur, IL: Intersection US 36 and Oakland Avenue (1998)

9cm inlay of a milled 15cm HMA surface, 0.9-1.2m wide panels

34% panels cracked
Patching
Rough w/ migration

2012
Chicago, IL: Western Avenue Bus Pads (2003)

- Project consisted of a number of stops along Western Avenue (5 were surveyed) 10ft x 100ft sections, 3.3ft x 4ft joint spacing
- 4-in thick inlay, high fiber dosage of 7.5 to 8.5 lb/yd³
- Considered a bonded/unbonded hybrid project, as the conditions of the underlying layer varied project to project
Kane County, IL: North Lorang Road (2004)

- 4.25-4.5” thick concrete overlay of 3-3.5” of HMA over aggregate base
- 4 lb/yd$^3$ synthetic macro-fibers
- Square 5 ft x 5 ft panels
- Project built to serve a quarry: average of 30 trucks/day (peak of 280/day)
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Mundelein, IL: Schank Avenue (2005)

- 4-in. concrete overlay of a composite pavement (2.25 to 6.5-in. HMA over 4.75 to 9.25-in. PCC)
- Square 4ft x 4ft panels
- 4 lb/yd$^3$ synthetic macro-fibers
- High truck traffic volume (no data available, but comparable to Lorang Road and more general traffic)
Mundelein, IL: Schank Avenue (2005)

- 4-in. concrete overlay of a composite pavement (2.25 to 6.5-in. HMA over 4.75 to 9.25-in. PCC)
- Square 4ft x 4ft panels
- 4 lb/yd$^3$ synthetic macro-fibers
- High truck traffic volume (no data available, but comparable to Lorang Road and more general traffic)
Mundelein, IL: Schank Avenue (2005)

- 4-in. concrete overlay of a composite pavement (2.25 to 6.5-in. HMA over 4.75 to 9.25-in. PCC)
- Square 4ft x 4ft panels
- 4 lb/yd$^3$ synthetic macro-fibers
- High truck traffic volume (no data available, but comparable to Lorang Road and more general traffic)
ACPA Concrete Overlay Explorer

The National Concrete Overlay Explorer

Instructions

1263 items

640 results out of 1263 cannot be plotted.

Concrete Overlay Type
1. Bonded on Concrete
   15. Unbonded Concrete Resurfacing of Asphalt Pavement (Conventional Whitetopping)

Application
- Highway
- Street/Road
- Airport
- NA

State
- AB
- AL
- AR
- AZ

Overlay Thickness (in.)
- 1 - 1
- 2 - 3
- 3 - 4

Year Constructed
- 1900 - 1905
- 1910 - 1915
- 1915 - 1920
- 1920 - 1925

Project Size (SF)
- 0 - 5000
- 50000 - 100000
- 100000 - 150000
- 150000 - 300000

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FRC Bridge Decks With No Rebar

• 1995: Canada (Newhook and Mufti 1996)
  – 9 lbs/yd$^3$ synthetic fibers
  – No reinforcing bars
  – 8” thick deck
FRC Bridge Decks With No Rebar

• 1995: Canada (Newhook and Mufti 1996)
  – 9 lbs/yd$^3$ synthetic fibers
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MACRO-Fiber Reinforcement Benefits for Concrete Pavements

• Maintain crack/joint widths
• Non-uniform support condition
• Tie *longitudinal*/transverse contraction joints
  – *Avoid slab migration*
• Reduce deterioration rates after initial cracking
  – slab deflect ↑ and displace more easily
  – Thin concrete overlays deteriorate more rapidly under traffic
• Should I use fibers on every concrete pavement projects? **NO**