Fiber Reinforced Overlays

Dr. Armen Amirkhanian, P.E.
About Me

• B.S. Ceramic and Material Science Engineering
  – Clemson University

• 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$^3$ ~ 0.38% by $V_f$
  – Polypropylene 4 kg/m$^3$ ~ 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
WHERE LEGENDS ARE MADE
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 \( f_{e,3} = 140 + 0.015 (x - 4000) \) 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
  – ASTM 1609-10 (2012)
  – JCI-SF4 (1983)

• RESIDUAL STRENGTH
Flexure Test Method
ASTM C1609-12 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)
Fiber-Reinforced Concrete Pavement Design

• Use existing concrete pavement design thickness methods (AASHTO, PCA, FAA, MEPDG, 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

- \( f_{150} = 150 \text{ psi (for example)} \)
- \( \text{MOR} = 600 \text{ psi} \)
# 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></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type of Overlay Road</strong></td>
<td>Local Road/Street</td>
</tr>
<tr>
<td><strong>Millions of ESALS in Design Life</strong></td>
<td>0.01 to 5.0 million ESALS</td>
</tr>
<tr>
<td><strong>Asphalt Pre-Condition</strong></td>
<td>Fair</td>
</tr>
<tr>
<td>*refer to Tech Report to example estimates of asphalt pre-condition</td>
<td></td>
</tr>
<tr>
<td><strong>Desired New Concrete Thickness</strong></td>
<td>4.5 to 6 inch PCC thickness</td>
</tr>
<tr>
<td><strong>Remaining HMA Thickness after Milling</strong></td>
<td>3 to 4.5 inches HMA remaining</td>
</tr>
<tr>
<td><strong>Overlay Slab Size</strong></td>
<td>6ft joint spacing</td>
</tr>
<tr>
<td><strong>Desired Performance Enhancements</strong></td>
<td>basic FRC overlay</td>
</tr>
<tr>
<td><em>(this will generate a higher residual strength, but not included in effective flexural strength)</em></td>
<td></td>
</tr>
</tbody>
</table>

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

| Plain Unreinforced Concrete Flexural Strength *(MOR)* | 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.

![Graph showing MOR vs. Mid-span deflection](image)
FRC Overlay Design Example

- 4 million ESALs
- Asphalt: moderate
- 3” remains after milling
- Overlay: 4.5-6”
- 6ft joint spacing
- MOR 600 psi

No Fibers

5.75” Thick

$f_{eff} = 725$ psi

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

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

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)
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)
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/yd³ 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 macrofibers
- 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)
FRC Bridge Decks With No Rebar

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

From: Newhook and Mufti 1996
FRC Bridge Decks With No Rebar

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

From: Forta Corporation
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 project? NO