Fiber Reinforced Concrete Pavements: Real Research & Real Projects
Dan Biddle | November 30, 2017
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FRC – Fiber Reinforced Concrete – Pavements
FRC Pavements

- Pavement problems
- Pavement design
- Fiber options
- LTRC research
- Projects – normal joints
- Projects – extended joints
- Fiber option review
U.S. highway system clearly needs help. Pavement demands have grown while dollars have dwindled.
A concrete pavement joint is always a problem...a future repair just waiting to happen.

Michigan State Route 23 between Toledo and Ann Arbor
“The Great Horse Manure Crisis of 1894.” Pavement problems change with the times.
Court Avenue, Bellefontaine, Ohio 1891
“Artificial stone” pavement...125 years and counting.
Poor pavements are expensive for motorists:

- Faster vehicle wear & tear
- Reduced vehicle value
- Higher repair & maintenance costs
- Higher fuel consumption & tire wear
- Cost average driver $516 per year
When considering driver costs – concrete is the material of choice.

Heavy vehicles cause greater deflection on flexible pavements than on rigid pavements, causing up to 7% more fuel needed. And commercial truck traffic will grow over 70% in the next 15 years.
Joints are concrete pavement’s most vulnerable issue.

Reduction or elimination of pavement joints is an on-going goal.
FORTA® has a 15+ history of reducing joints in interior floor slabs. Next target... exterior pavements.
JRCP – Jointed Reinforced Concrete Pavement

- Long 30-60’ panels with mild steel reinforcement
- Load-transfer baskets at the joints
- Poor performance history – mid-panel faulting
- Essentially discontinued by 1990
JPCP – Jointed Plain Concrete Pavement

• Short unreinforced panels, 15 to 20’ long
• Load-transfer baskets at the joints
• Currently most economical pavement design
CRCP – Continuously Reinforced Concrete Pavement

• Continuous steel reinforcement
• No transverse joints
• Steel has no tensile or flexural responsibility – only to hold cracks tightly together: Let-it-crack philosophy
• Cracks occur at spacing of 2-8 ft., generally less than 0.02 in.
• Best ride – most expensive
Steel mat is labor-intensive and expensive in CRCP systems. And steel corrodes.
FRC pavement designs are dependent on dosage.

Higher dosage = more opportunities

1. Low dosage: 3-4 lbs. /cu. yd.
   - Add-on to conventional jointed design
   - Reduce cracking
   - Improve toughness
2. Medium dosage: 4-7 lbs./cu. yd.
   - Reduce cracking – improve toughness
   - Used in jointed designs
   - Consideration of longer joint spacing is valid
3. High dosage: 7.5+ lbs. /cu. yd.
   • Reduce crack width opening
   • Large improvement to toughness
   • Dramatic increase to joint spacing
   • Consider ‘joint-free’ pavement?
CFRCP – Continuously Fiber Reinforced Concrete Pavement

• Brainchild of Dr. John Kevern, Associate Professor of Civil Engineering, University of Missouri at Kansas City
• Same concept as CRCP – enough reinforcement to allow frequent tight cracks
• **BUT**...fibers must prove to hold cracks tight, i.e. < 0.02 in., under typical pavement conditions such as fatigue
A joint-free fiber-reinforced pavement would have many advantages...if toughness and fatigue can be qualified.

### Comparison of CRCP, JPCP, and CFRCP

<table>
<thead>
<tr>
<th>Pavement Type</th>
<th>Benefits</th>
<th>Shortcomings</th>
<th>Difference in cost</th>
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<tr>
<td>CRCP</td>
<td>• Smooth driving surface</td>
<td>• Labor intensive</td>
<td>• Added steel cost</td>
</tr>
<tr>
<td></td>
<td>• Fewer joint durability concerns</td>
<td>• Potential corrosion of steel leading to durability issues</td>
<td>• More labor cost</td>
</tr>
<tr>
<td>JPCP</td>
<td>• Less steel</td>
<td>• Joint maintenance</td>
<td>• Lower steel cost than CRCP</td>
</tr>
<tr>
<td></td>
<td>• Less labor intensive than CRCP</td>
<td></td>
<td>• Less labor cost than CRCP</td>
</tr>
<tr>
<td>CFRCP</td>
<td>• No steel</td>
<td></td>
<td>• Fiber cost comparable to steel cost of CRCP</td>
</tr>
<tr>
<td></td>
<td>• Smooth driving surface</td>
<td></td>
<td>• Less labor cost</td>
</tr>
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• June 2013
• Louisiana Transportation Research Center, Baton Rouge, LA
• Research arm of LA-DOT
• Conducted in cooperation with U.S. Department of Transportation, Federal Highway Administration
• Casting at LTRC with LA-DOT materials
• Testing at UMKC concrete laboratories
“Evaluation of the Fatigue and Toughness of Fiber Reinforced Concrete for use as a New Highway Pavement Design”

Dr. John Kevern, Associate Professor of Civil Engineering
University of Missouri – Kansas City

Dr. Tyson Rupnow, Associate Director of Research
Louisiana Department of Transportation
Concrete mix materials and proportions standard LA-DOT pavement:

- 400 lbs. Portland cement
- 100 lbs. Class C fly ash
- 1,900 lbs. #67 limestone
- 1,266 lbs. natural concrete sand
- 250 lbs. water
- W/C = 0.50
- 5-7% air
Four fibers at multiple dosages tested:

1. Polypropylene fibrillated 1 ½” @ 1.5, 3.0 and 4.5 lbs. /cu. yd.
2. Polypropylene macro 2 ¼” @ 4.5, 7.5, 10.5 and 15.0 lbs. /cu. yd.
3. Carbon sheath 4” @ 9.0, 21.0 and 30.5 lbs. /cu. yd.
4. Type I hooked-end steel 2” @ 85 lbs. /cu. yd.
Wide range of test parameters:

- Slump C-143
- Unit weight C-138
- Air content C-231
- 7-day compressive strength C-39
- 28-day compressive strength C-39
- Flexural strength C-78
- Toughness C-1609
- Fatigue at 90% and 70% stress levels
- Pre-cracked fatigue at 50% stress levels
Toughness ARS @ 0.03” deflection

Carbon, 21.0 lbs.
Macro syn., 10.5 lbs.
Steel, 85 lbs.
Macro syn., 15.0 lbs.
Macro syn., 7.5 lbs.
Macro syn., 4.5 lbs.
Carbon, 9.0 lbs.
Fibrillated, 4.5 lbs.
Carbon, 30.5 lbs.
Fibrillated, 1.5 lbs.
Fibrillated, 3.0 lbs.

Polypropylene macro fibers performed extremely well compared to much higher dosages of steel and carbon fibers.
Fatigue Testing

- Notched-beam method per University of Illinois protocol
- Beams tested at 90% and 70% ultimate flexural strength
Pre-cracked Fatigue Testing

- Fibers were overwhelming the ability to crack – some beams exceeded 10 million cycles
- Pre-cracked the notched beams per ASTM C-1399
- Performed until failure (< 100 lbs.) or 1 million cycles
Macro Synthetic Pre-cracked Fatigue @ 50% Stress Ratio:

• Showed remarkable changes to failure mode: from normal 4-stage failure to slower 2-stage failure
• When fibers at bottom began to fatigue and break, fibers at top absorbed load and postponed failure
• Both 10.5 and 15.0 lb. dosages > 85 lbs. steel fibers
Fracture face observations revealed:
  - Macro synthetic = gradual fatigue and failure
  - Steel = sudden and progressive failure
LTRC Conclusions:

• At stress ratios of 60% and less, CFRCP outperforms JPCP; **CFRCP will be thinner than JPCP.**
• **Macro synthetic fibers increase the fatigue performance better than steel fibers** at the correct dosage.
• Macro synthetic fibers in the range of **7.5 to 10.5 lbs. / cu. yd.** provides the greatest combination of fatigue, toughness, and pre-cracked fatigue performance.
• The use of fibers has an effect on the design thickness of pavements, **resulting in thinner pavements for low-stress, high-volume applications.**
LTRC – What’s next?

- Phase II: full-scale fatigue loading of macro synthetic fiber 220 ft. panels, Baton Rouge
- Soliciting pooled-funding from other DOT’s
- Searching for highway test section to compare CFRCP to JPCP and CRCP under same conditions
J.M. Smucker – Orrville, OH 2009-2014

- Over 10,000 cu. yds. of FRC Pavements in a 5-year period
- FORTA-FERRO® 2 ¼” @ 4.0 lbs./cu. yd.
- 6” thick pavement with 15’ panels
Fed-Ex Freight – Conley, GA

March 2011

- Converted from #3 bars @ 24” O.C.E.W mat
- FORTA-FERRO® 2 ¼” macro fiber @ 3.0 lbs./cu. yd.
- 7 ½” thick pavement, 15’ x 15’ panels
- 4,400 cu. yds., 5 acres of trailer truck pavement
Mineral Spring Street – Orrville, OH August 2012

- Converted from 4x4-W2.9xW2.9 WWF
- FORTA-FERRO® 2 ¼” macro fiber @ 4.0 lbs./cu. yd.
- 9” thick pavement, 14.5’ panels, 2,700’ long
Old Dominion Freight – Phoenix, AZ  December 2014

• Large freight-transfer hub, truck pavement, parking, and dock slabs
• 18,000 cu. yds., conventional joint spacing, no load-transfer baskets
• FORTA-FERRO® 2 ¼” macro fiber @ 5.0 lbs./cu. yd.
Murphy Tractor – Zelienople, PA  October 2015

- 330,000 sq. ft. of pavement and parking for largest John Deere dealer in W. Pennsylvania
- 7,000 cu. yds., 7” thick, 15’ x 15’ jointed panels, no load-transfer baskets
- FORTA-FERRO® 2 ¼” macro fiber @ 4.0 lbs./cu. yd.
Atlanta Bonded Warehouse – Kennesaw, GA  2003

• Tractor trailer guard-house pavement pad, over 150 trucks/day
• 40’ x 70’ x 6” joint-free panel on poor substrate
• FORTA-FERRO® macro fiber @ 7.5 lbs./cu. yd.
Aldi Paving – Springfield, OH          October 2012

- 70,000 sq. ft. of car-park and pavement
- Jointed panels increased from 12’x12’ to 40’x40’, saving 7,000+ of sawcutting and joint filler
- FORTA-FERRO® macro fiber @ 7.5 lbs./cu. yd.
McMaster Carr Paving – Douglasville, GA      November 2014

• 300,000 sq. ft. of tractor trailer pavement for large distribution center
• Joints increased from 12’-15’ to 30’ or more, reducing joints and filler by > 50%
• FORTA-FERRO® macro fiber @ 7.5 lbs./cu. yd.
Terrapin Trail – Orrville, OH  September 2015

- City residential development street
- 29’ wide street, 9” thick
- Joints extended from 15’ to 30’, load transfer baskets only at center-line joint
- FORTA-FERRO® macro fiber @ 5.0 lbs./cu. yd.
Current Pavement Design Issues:

• Joint deterioration is a major problem
• Steel corrosion is a major problem
• Pavement smoothness caused by curling is a major problem
• Durability and longevity are major problems
Macro Fiber Options:

1. Low dosage 3-4 lbs. = alternate to temperature steel, reduced cracking, normal joint spacing

2. Medium dosage 5.0-7.5 lbs. = alternate to temperature steel, added toughness, longer joint spacing

3. High dosage 9.0 lbs. = considerable fatigue improvement, improvement to ride-ability, goal of joint-free pavements
Smooth, durable, cost-effective, reduced-joint pavements are available today.

Macro synthetic fibers provide the key to the pavement of the future.

- September 2011
- Residential driveway, W. Pennsylvania
- 155’ long x 10’ wide x 5” thick
- No joints – and no cracks
To learn more about FRC Pavements......