OVERVIEW OF FIBER-REINFORCED CONCRETE BRIDGE DECKS

AUTHORS

Armen Amirkhanian, Assistant Professor
Civil, Construction, and Environmental Engineering
University of Alabama

Jeffery Roesler, Professor
Civil and Environmental Engineering
University of Illinois, Urbana-Champaign

Introduction

Limited guidance is currently available on design and testing of fiber-reinforced concrete (FRC) for bridge decks and overlays. A review of past studies by Alhassan and Ashur (2012) found reductions in bridge deck cracking with the addition of macrofibers (see Figure 1).

At sufficiently high dosages (e.g., 1.0% by volume), macrofibers can significantly increase the post-cracking structural capacity of a bridge deck in a similar fashion to reinforcing bars. However, current practice does not consider the increased structural capacity from macrofiber reinforcement in the design process. Nevertheless, multiple states have required bridge decks with macrofibers to be constructed in order to reduce deck cracking.

Commonly used fibers for FRC bridge decks are steel and polyolefin (synthetic) macrofibers, which provide structural capacity compared to microfibers, which are primarily used for plastic shrinkage cracking control. Bridge deck overlays are a more common application of FRC as opposed to an entire bridge deck constructed from FRC.

While ultra-high performance concrete (UHPC) that typically includes higher volume fractions of fiber is beginning to see use on bridge decks, its application is not discussed in this tech brief, as it is a fundamentally different material than the portland cement concrete (PCC) mixtures typically used for bridge decks.

Fiber Dosage Rates

FRC materials for bridge decks and overlays do not have a uniformly applied dosage rate. Macrofiber content varies depending on the material, shape, texture, aspect ratio, field application, and desired performance. Typical ranges used in past bridge deck applications are between 3 to 8 lb/yd³ for polyolefin fibers and 20 to 90 lb/yd³ for steel fibers, or corresponding to volume percentages between 0.2% to 1%.

Jerod Gross

Figure 1. Synthetic macrofibers for FRC

National Concrete Pavement Technology Center
2711 South Loop Drive, Suite 4700
Ames, IA 50010-8664
cptechcenter.org

Director, Peter Taylor
515-294-3230 / ptaylor@iastate.edu

National Concrete Pavement Technology Center
Tech Center
IOWA STATE UNIVERSITY
Institute for Transportation

Many states require the macrofiber dosage to be determined from a residual strength test, similar to specifications for FRC pavement overlays. A residual strength test provides an assessment of the fiber's ability to resist pullout from the concrete matrix, slow crack growth, and absorb fracture energy.

The two most commonly specified tests are ASTM C1399 and ASTM C1609. The ASTM C1399 test utilizes a steel plate underneath a flexural beam, which is removed after the peak load is reached. The subsequent load-deflection of the beam without the steel plate is measured, and an average residual strength (ARS) value is calculated. However, ASTM C1399 is not a preferred performance test for FRC materials for bridge decks and overlays.

ASTM C1609 is currently the recommended performance test to evaluate FRC materials for bridge decks, deck overlays, and pavement overlays (ACI Committee 544 2018). The ASTM C1609 method requires a closed-loop testing system to execute and provides several performance measures of the combined concrete-macrofiber interaction (see Figure 2).

From ASTM C1609, the residual strength (f_{150}^{D}) and the equivalent flexural strength ratio ($R_{T,150}^{D}$) are calculated from the monotonic load-deflection curve of a flexural beam specimen until 1/8 in. deflection is reached.

Field Implementation

Significant experimentation with FRC bridge decks and overlays across the US has occurred during the past few decades (Maggenti et al. 2013, Newhook and Mufti 1996). FRC overlays of bridge decks with steel or synthetic macrofibers are more common than constructing the entire deck with FRC.

The details of individual projects vary significantly because of local materials, engineering expertise, and lack of formal design procedures for FRC bridge decks and overlays. Several state departments of transportation (DOTs) have led the implementation of FRC decks, with California being the most progressive in mandating that all bridge decks, regardless of type, incorporate macrofibers.

A synopsis of experiences from a variety of states that have applied FRC to bridge decks and overlays follows, in chronological order:

- **Ohio 1992:** Bridge deck overlay containing steel fibers used at a dosage of 0.8% by volume on US 30 without significant cracking noted during the analysis period.
- **South Dakota 1994:** Polyolefin macrofibers added to the mixture at a dosage of 25 lb/yd^3 (1.7% by volume). After two years, 44 cracks were measured with only 12 of the cracks having widths greater than 0.007 in.
- **Illinois 2006–2007:** A number of the bridge structures on the Dan Ryan Expressway in Chicago overlaid with a microsilica concrete that contained polypropylene macrofibers with a specified amount of 3 lb/yd^3.
- **California 2007:** Polyolefin macrofibers added at a dosage of 3 lb/yd^3 with a shrinkage-reducing admixture (SRA) dosage ranging from 0.75 to 1.5 gal/yd^3 to the Pit River Bridge. After five years, the deck had little cracking and cores taken at the crack locations revealed that the cracks were quickly arrested at the surface. The companion section without SRAs or fibers had significant cracking within 6 weeks of opening.
- **Illinois 2010:** Bridge over the EJ&E railroad along Irving Park Road in Chicago overlaid with and without glass macrofibers. Fibers were dosed at 2.4 lb/yd^3. The overlay was examined one year later, and no cracking was observed in the fibrous section while hairline cracking was observed in the section without fibers.
- **Minnesota 2018:** St. Paul High Bridge underwent a deck overlay project that used FRC with a macrofiber dosage of 5 lb/yd^3 and was opened to traffic in December 2018 (see Figure 3).

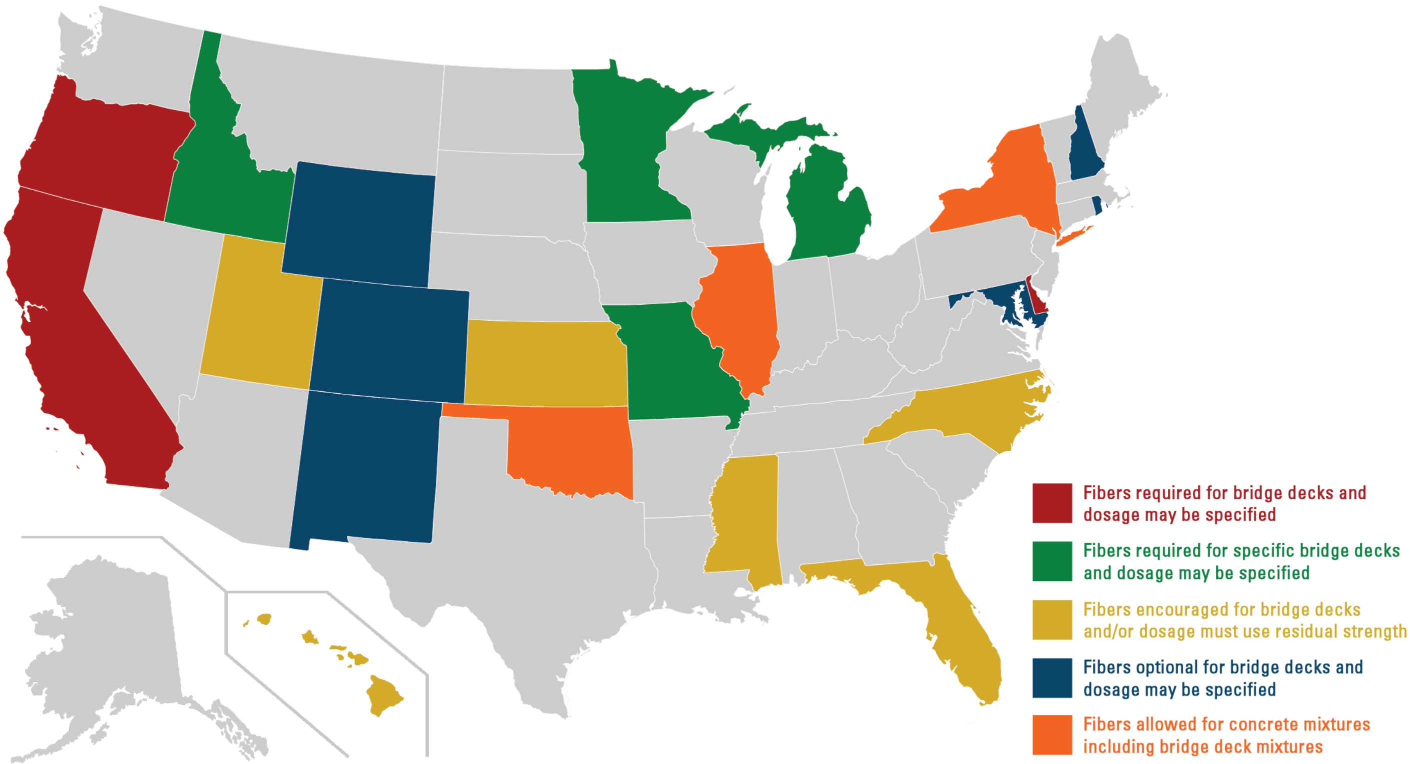
Figure 2. ASTM C1609 beam test for FRC materials

Figure 3. High Bridge in St. Paul, Minnesota, where macrofibers were used on the deck at 5.0 lb/yd^3 dosage

Specifications

Twenty-one states have specification language outlining the use of FRC for bridge deck and overlay applications as shown in Figure 4.

Of these 22 states, eight require the fiber dosage to be determined from either ASTM C1399 or ASTM C1609 performance tests of a flexural beam. Furthermore, eight states specify minimum dosages that are independent of any specified residual strength or manufacturer-recommended dosages.



Map only shows states that have explicitly incorporated language on fiber reinforcement into their standards and specifications manuals. Iowa is not highlighted because its specification only applies to a single county. Additionally, the map does not reflect states that currently have an inventory of fiber-reinforced bridge decks or states that routinely approve FRC mixtures for bridge deck applications unless those states also explicitly incorporate language on fiber reinforcement into their standards and specifications manuals.

Figure 4. State DOTs that incorporate fiber reinforcement into their specifications or special provisions

Examples of the specification language related to bridge decks and overlays with macrofibers from various states:

California (§ 51-1.02B): Concrete for concrete bridge decks must contain polymer fibers. Each cubic yard of concrete must contain at least 1 pound of microfibers and at least 3 pounds of macrofibers.

Florida (Dev. Spec. 346-FRC): [Fiber dosages must] Produce an Average Residual Strength (ARS) of no less than 215 psi from a test set of 5 beams in accordance with ASTM C1399.

Illinois (QPL of Synthetic Fibers): The synthetic fiber shall be a monofilament or bundled monofilament with a minimum length of 1.0 in. (25 mm) and a maximum length of 2 1/2 in. (63 mm), and shall have a maximum aspect ratio (length divided by the equivalent diameter of the fiber) of 150. The quantity of synthetic fiber(s) added to the concrete mixture shall be sufficient to have a residual strength ratio ($R_{150,3}$) of 20.0 percent according to Illinois Modified ASTM C1609. The maximum dosage rate shall not exceed 5.0 lb/cu yd (3.0 kg/cu m), unless the manufacturer can demonstrate through a field demonstration that the concrete mixture will be workable and fiber clumping is not a problem as determined by the Engineer.

Mississippi (§ 711.04.2): The dosage rate shall be such that the average residual strength ratio ($R_{150,3.0}$) of fiber reinforced concrete beams is a minimum of 20.0 percent when the beams are tested in accordance with ASTM C1609.

Oregon (§ 02001.31(g)): Use synthetic fiber reinforcing from the QPL [Qualified Product List] 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.

Summary

Researchers and DOTs have experimented with fiber reinforcement in bridge decks and deck overlays for nearly four decades. The most common objective for implementing fiber reinforcement in bridge decks and overlays is to reduce cracking and crack widths from load, material, and environmental deformations.

For state DOTs that have experimented with macrofibers, nearly all of the published studies showed improvements in performance with respect to crack control.

Typical macrofiber dosages have ranged from 3 to 8 lb/yd³ for synthetic and 20 to 90 lb/yd³ for steel fibers. Fewer than half of the states have specification language to implement fiber-reinforced concrete to bridge decks and overlays. Even fewer of these states use performance-based specifications to determine the macrofiber dosage rate.

Due to the wide range of fiber types and geometries, the recommended performance test is ASTM C1609, as this standard test method links the required macrofiber volume fraction and concrete mixture with the specified FRC residual strength (f_{150}^{D}).

References

ACI Committee 544. 2018. *Guide to Design with Fiber-Reinforced Concrete*. 544.4R-18. American Concrete Institute, Farmington Hills, MI.

Alhassan, M. A. and S. A. Ashur. 2012. *Superiority & Constructability of Fibrous Additives for Bridge Deck Overlays*. Illinois Center for Transportation, University of Illinois at Urbana-Champaign, IL.

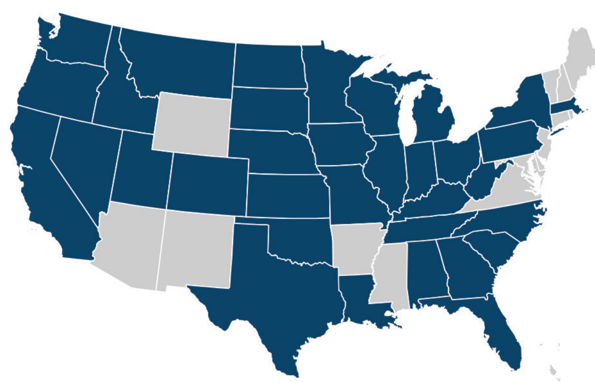
Maggenti, R., C. Knapp, and S. Fereira. 2013. Controlling Shrinkage Cracking. *Concrete International*, Vol. 35, No. 7, pp. 36–41.

Newhook, J. P. and A. A. Mufti. 1996. A Reinforcing Steel-Free Concrete Deck Slab for the Salmon River Bridge. *Concrete International*, Vol. 18, No. 6, pp. 30–34.

Technology Transfer Concrete Consortium

The goal of the Technology Transfer Concrete Consortium (TTCC) Transportation Pooled Fund TPF-5(313) is to help state departments of transportation (DOTs) design and build longer life concrete pavements that result in a higher level of user satisfaction for the public. One of the strategies for achieving longer life pavements is to use innovative materials and construction optimization technologies and practices.

Thirty-four states currently participate in the TTCC: Alabama, California, Colorado, Florida, Georgia, Idaho, Illinois, Indiana, Iowa (lead state), Kansas, Kentucky, Louisiana, Massachusetts, Michigan, Minnesota, Missouri, Montana, Nebraska, Nevada, New York, North Carolina, North Dakota, Ohio, Oklahoma, Oregon, Pennsylvania, South Carolina, South Dakota, Tennessee, Texas, Utah, Washington, West Virginia, and Wisconsin



About the National Concrete Pavement Technology Center

The mission of the National Concrete Pavement Technology Center is to unite key transportation stakeholders around the central goal of advancing concrete pavement technology through research, tech transfer, and technology implementation.