CONCRETE PAVEMENT
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TechBrief

Evaluating the Use of Fiber-Reinforced Polymer Bars in Continuously Reinforced Concrete Pavement

This TechBrief discusses the potential use of fiber-reinforced polymer (FRP) bars in continuously reinforced concrete pavements (CRCP). Relative advantages and disadvantages of FRP bars are presented, and some specific considerations for the use of FRP bars in CRCP design and construction are described. This is followed by an overview of two recent experimental CRCP projects that have been constructed with FRP bars.

INTRODUCTION

Continuously reinforced concrete pavement designs (CRCP) are premium pavement designs that are often used on heavily-trafficked roadways and urban corridors. CRCP designs have no regularly spaced transverse joints but contain a significant amount of longitudinal steel reinforcement (typically 0.6 to 0.8 percent of the cross-sectional area). The high steel content both influences the development of transverse cracks within an acceptable spacing (about 3 to 6 ft [0.9 to 1.8 m]) and serves to hold them tightly together. CRCP offers a number of advantages over conventional jointed plain concrete pavement (JPCP), including low maintenance requirements, durability, smooth-riding surface, extended pavement life, and reduced life-cycle costs.

Although CRCP typically is an effective, long-lasting pavement design, it can develop performance problems when the aggregate-interlock load transfer at the transverse cracks is degraded. This occurs when the cracks become wider, which can be caused by large crack spacings, abrading of the aggregate faces, or rupturing of the longitudinal reinforcing steel. When coupled with poor base, subbase, or subgrade support and heavy truck loadings, these conditions can result in the deterioration of crack interfaces and punchouts.

The prevalence of wide cracks in CRCP has frequently been associated with ruptured steel and significant levels of corrosion (Zollinger et al. 1999). Because of that, there has been recent interest in identifying new reinforcing materials that can prevent or minimize corrosion-related issues in CRCP. Fiber-reinforced polymer (FRP) composite materials are one product being investigated for use in CRCP in place of traditional steel bars. FRP composites consist of a matrix of polymeric material (polyester, vinyl ester, or epoxy) that is reinforced by fibers of other reinforcing materials (typically glass, carbon, or graphite). Filler materials (such as calcium carbonate, clay, or hy-

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drated alumina) may also be added to improve specific properties of the composite or to lower its cost. Figure 1 shows a closeup of a glass fiber–reinforced polymer (GFRP) bar.

Advantages of FRP bars include not only their corrosion resistance, but also their high longitudinal strength, high fatigue endurance, and light weight. In addition, the electromagnetic transparency of FRP bars makes them suitable for use at toll collection booths where electromagnetic vehicle detectors are used (Walton and Bradberry 2005). Disadvantages of FRP bars include their high cost, low modulus of elasticity, and low shear strength.

Figure 1. Closeup of a glass fiber–reinforced bar.

GENERAL DESIGN CONSIDERATIONS FOR FRP IN CRCP

The following broad areas appear to be critical to CRCP performance: support conditions (base, subbase, and subgrade), concrete slab characteristics, and reinforcement details (Zollinger et al. 1999; Tayabji et al. 1999). The consideration of each of these elements as they pertain to the potential use of FRP bars is described in the following sections.

Base/Subbase/Subgrade Support Conditions

Although critical to all concrete pavement types, strong, uniform support conditions are particularly necessary in CRCP designs. The provision of better and more uniform support improves the design in two ways: 1) by reducing the slab thickness required, thereby reducing the cost of the required slab, and 2) by reducing the shearing stresses on the reinforcement, thereby decreasing the probability of a reinforcing bar failing in shear (which is particularly important for FRP-reinforced CRCP designs). When the subgrade has a California bearing ratio of 6 or less, stabilization should be included.

It is also important that an aggregate subbase with a minimum thickness of 6 in. (150 mm) be used to provide some drainage and frost protection of the pavement structural section. A permeable base directly under the slab is not necessary or desirable for CRCP (FHWA 2007) for two reasons:

- There are no transverse joints to allow infiltration of surface water.
- A permeable base allows infiltration of the fresh concrete into the voids of the permeable layer, thereby increasing the effective pavement thickness and decreasing the effectiveness of the reinforcing bars.

A stabilized base is generally recommended to help ensure strong uniform support (FHWA 2007). The best performance has been achieved by providing a dense-graded hot-mix asphalt (HMA) layer, 4 to 6 in. (100 to 150 mm) thick, over the granular subbase (FHWA 2007). Alternatively, a lean concrete base, 6 in. (150 mm) thick, with either a thin dense-graded HMA interlayer, a double application of wax-based curing compound, or an asphalt emulsion surface treatment may be used (Ayton and Haber 1997). The surface of the stabilized base should be relatively smooth to prevent a high level of mechanical bonding, which can contribute to undesirable diagonal cracking in the concrete slab. There should be no attempt to break the bond between the concrete slab and the HMA layer as some bond is needed to help develop the crack spacing at the desired intervals.

Concrete Slab Considerations

For most high-performance pavements, slab thicknesses for CRCP designs are between about 10 and 14 in. (250 to 355 mm). Additional slab thickness beyond the design thickness decreases the effective reinforcement content, which can lead to performance issues. This is a critical consideration for both steel- and FRP-reinforced CRCP.

In addition, there is a strong interaction between concrete strength, reinforcement content, and resultant crack spacings. All other factors held constant, higher concrete strengths produce longer crack spacings. An appropriate concrete strength should be determined for the FRP level of reinforcement and base restraint conditions and maintained at a consistent level throughout the construction process. The concrete itself must be well consolidated to promote good bond of the concrete to the reinforcement.

Reinforcement Details

Location of the FRP Reinforcement. The FRP should be designed with a minimum concrete cover, and with the bottom of the reinforcement being at or above the mid-depth of the slab. The minimum depth of cover (although not as critical as for steel reinforcement) should be 2 to 3 in. (51 to 76 mm). The performance of CRCP with steel reinforcement suggests the best performance has resulted when the reinforcement is placed at about one-third the slab depth (measured from the pavement surface). At this location the reinforcement is most effective in holding the cracks tightly together, thereby minimizing deflections and associated deterioration.

Amount of FRP-CRCP Reinforcement. The 1993 AASHTO Design Guide provides a procedure for the determination of steel reinforcement in CRCP based on three criteria: limiting the crack width to 0.04 in. (1 mm) or less; confining the crack spacing to between 3 and 8 ft (0.9 m to 2.4 m); and limiting the stress in the reinforcement to 75 percent of the yield strength (AASHTO 1993). However, the properties of FRP bars (particularly the elastic modulus) are such that, if they are placed at the same content level as conventional steel reinforcing, greater crack spacings and larger crack widths are produced (Choi and Chen 2005). One study suggests that the amount of FRP reinforcement required to produce similar crack patterns to companion steel-reinforced specimens in a fully restrained slab subjected to temperature and shrinkage deformations is three times the area of the steel reinforcement (Koenigsfeld and Myers 2003). For a given concrete coefficient of thermal expansion, several methods for controlling the crack spacings and widths are suggested, including increasing the amount of reinforcement, increasing the bond between the concrete and reinforcement, and increasing the friction between the slab and subbase (Choi and Chen 2005). Each of these methods is intended to increase the stress in the concrete needed to produce the desirable cracking pattern and crack widths.

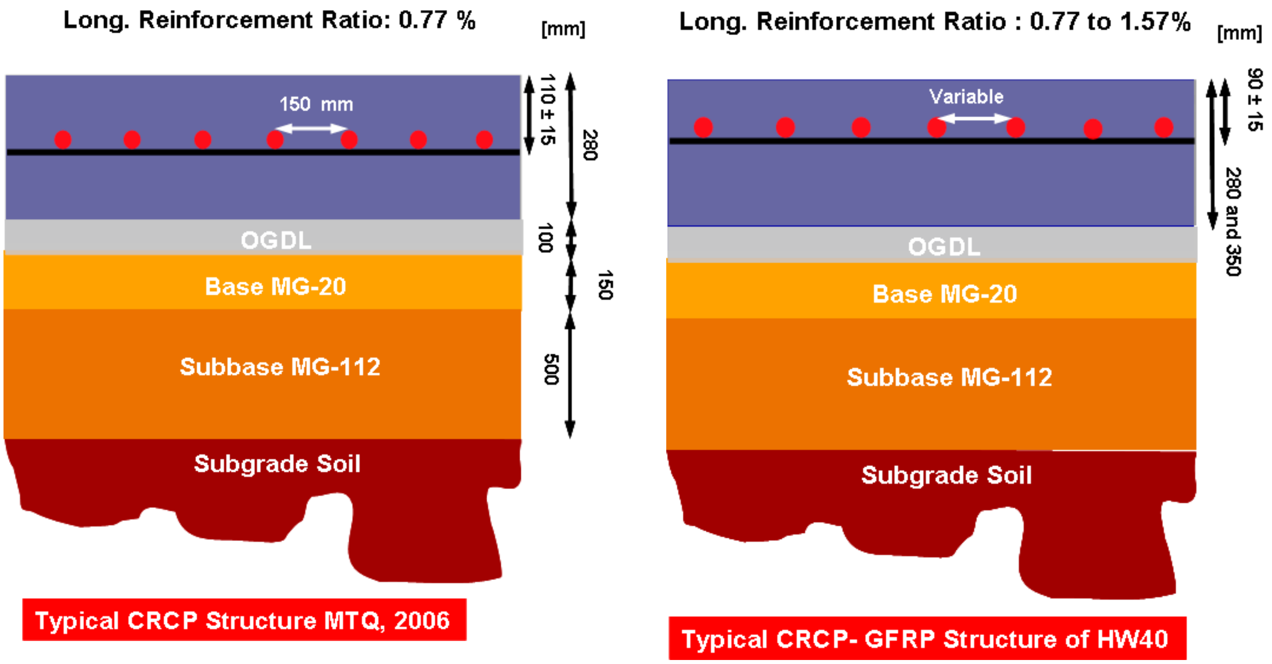
EXPERIMENTAL FRP FIELD PROJECTS

Two experimental FRP projects have been recently constructed in North America. One was constructed in Quebec in 2006 and contained 18 different experimental sections. A second project was constructed in West Virginia in 2007, featuring one FRP-reinforced CRCP section and one conventional steel–reinforced CRCP control section. The details of each of these experimental projects are provided below.

Highway 40, Montreal, Quebec

A research study was initiated in 2006 by the Quebec Ministry of Transportation to evaluate the use of GFRP bars for CRCP. A total of 18 different experimental pavement sections—consisting of 15 FRP sections and 3 sections with galvanized steel reinforcement—were constructed on Highway 40 eastbound in Montreal (Thebeau et al. 2008). The typical pavement cross sections used in the study are shown in figure 2. For this project, a 4-in. (100-mm) open-graded drainage layer (OGDL), stabilized with cement, was used as the base immediately beneath the slab.

The required longitudinal reinforcement content for the steel bars was determined to be 0.77 percent,



Long. = longitudinal; OGDL = open-graded drainage layer; CRCP = continuously reinforced concrete pavement; MTQ = Ministry of Transport Quebec; GFRP = glass fiber–reinforced polymer

Figure 2. Typical pavement structure of the test sections on Highway 40, Montreal, Quebec (Thebeau, Eisa, and Benmokrane 2008).

in keeping with the criteria found in the 1993 AASHTO Design Guide. Because of corrosion concerns, galvanized steel was used, consisting of No. 6 bars for the longitudinal reinforcement and No. 5 bars for the transverse reinforcement. For the GFRP bars, a range of longitudinal reinforcement contents (from 0.77 to 1.57 percent) was selected to determine the effects of various contents, bar sizes, bar spacings, and configurations on crack pattern development and performance (see table 1).

Sensors were installed on the project to monitor the early-age behavior and repeated-load effect on the CRCP slabs. They included strain gauges on the reinforcement and thermocouples for temperature measurements inside the concrete.

Crack widths, crack spacings, and temperature distribution within the slabs are being monitored as part of the research study. Measurements in February 2008 showed that the average crack spacing in the GFRP sections varied between 5 and 13 ft (1.5 to 4 m) in most of the CRCP slabs reinforced with GFRP (Thebeau et al. 2008). The average crack width varied between 0.03 and 0.035 in. (0.7 and 0.9 mm), which is less than the AASHTO design limit of 0.04 in. (1 mm). Average crack width was also matching the average value (0.035 in. [0.9 mm]) recorded for the galvanized steel–reinforced CRCP slabs. It should be noted that some researchers believe that the design crack width should be 0.023 in. (0.6 mm) (Walton and Bradberry 2005).

Route 9, Martinsburg, West Virginia

In September 2007, the West Virginia Department of Transportation constructed an experimental project on Route 9 near Martinsburg, featuring a 1,000-ft (610-m) conventional steel–reinforced CRCP section and a 1,000-ft (610-m) GFRP-reinforced CRCP section (Chen et al. 2008). The key design elements for each test section are summarized in table 2, with a more detailed discussion of the development of the designs provided elsewhere (Choi and Chen 2005; Chen et al. 2008). Figure 3 shows the continuous GFRP reinforcement prior to paving.

Both test sections were instrumented with strain gauges and thermocouples at the mid-length of the

Table 1. Reinforcement Variables on the Highway 40, Montreal, Project (Thebeau, Eisa, and Benmokrane 2008)

Series	Investigated Parameters	Slab	Slab Thickness (mm)	Longitudinal Reinforcement Ratio (%)
A	Reinforcement ratio (different spacing)	A1	280	1.05
		A2		1.16
		A3 (A2)		1.16
		A4		1.32
B	Transverse reinforcement ratio	B	280	1.16
C	Reinforcement ratio (fixed spacing)	C1	280	1.57
		C2		1.06
D	One bar	D1	280	1.27
		D2 (D1)		1.27
		D3		0.97
		D4		0.77
E	Crack control (saw cut each 1.2 m)	E1	280	1.16
		E2		1.03
F	Thickness	F	350	0.93
G	Two layers	G	350	0.93
S	Steel	S1, S2, S3	280	0.77

Note: The reinforcement layout for all series of sections, except the Series G Section, was single-layer. For the single-layer sections, some sections had two bars clumped together. Series D sections used single bars.

section. The researchers monitored the pavements continuously during the first 72 hours to investigate early-age cracking behavior and then obtained experimental results at 7, 28, and 38 days and at 4 months (Chen et al. 2008). Crack width data collected at 4 months showed 0.023 in. (0.58 mm) for the steel-reinforced CRCP and 0.034 in. (0.86 mm) for the GFRP-reinforced CRCP. Crack spacing data collected at about 6 months showed an average spacing of 7.1 ft (2.1 m) for the steel-reinforced CRCP and an average spacing of 12.6 ft (3.8 m) for the GFRP-reinforced CRCP. The greater crack spacing on the GFRP-reinforced CRCP is believed due to the relatively low reinforcement ratio and the use of the cement-stabilized open-graded permeable base, which likely increased the effective slab thickness and thereby further reduced the effective reinforcement content.

Figure 3. Glass fiber–reinforced polymer bars on grade prior to paving.

Table 2. Key Design Elements for Route 9, West Virginia, Project

Design Element	Steel-Reinforced	GFRP-Reinforced
Slab thickness	10 in. (254 mm)	
Base	4-in. (100-mm) cement-treated open-graded drainage layer	
Subbase	10.75-in. (274-mm) cement-treated aggregate	
Longitudinal reinforcement content	0.7 percent	1.12 percent
Longitudinal reinforcement	No. 6 black bar at 6-in. (152-mm) spacings	No. 7 GFRP bar at 6-in. (152-mm) spacings
Transverse reinforcement	No. 5 black bar at 4-ft (1.2-m) spacings	No. 6 GFRP at 4-ft (1.2-m) spacings

GFRP = glass fiber–reinforced polymer

SUMMARY

FRP bars are being evaluated as a material for reinforcing CRCP. They offer the potential to minimize corrosion and thereby provide increased long-term performance. However, there are concerns associated with the potential for large crack spacings and greater crack widths, which may compromise the long-term, aggregate-interlock load transfer needed to ensure long-term performance. Two field studies have been constructed and are being monitored to help evaluate and improve the performance of FRP-reinforced CRCP designs.

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THE CONCRETE PAVEMENT TECHNOLOGY PROGRAM

The Concrete Pavement Technology Program (CPTP) is a national program of research, development, and technology transfer that operates within the Federal Highway Administration (FHWA) Office of Pavement Technology.

The CPTP includes some 30 research and demonstration projects, each of which is delivering products for improved design, construction, repair, and rehabilitation of concrete pavements.

The focus areas for the CPTP include advanced designs, optimized concrete materials, improved construction processes, rapid repair and rehabilitation, and user satisfaction. The CPTP continues to produce implementable products that result in safer, smoother, quieter, and longer lasting concrete pavements. Longer lasting pavements, in turn, contribute to FHWA's success in the areas of safety, congestion mitigation, and environmental stewardship and streamlining.

Technology transfer of products resulting from the CPTP is being accomplished under CPTP Task 65. This 5-year activity was initiated in September 2003 and is overseen by an Executive Expert Task Group (ETG) that includes State department of transportation (DOT) chief engineers and representatives from industry and academia.

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