EXPLORING FIBER-REINFORCED POLYMER CONCRETE FOR ACCELERATED BRIDGE CONSTRUCTION APPLICATIONS

Quarterly Progress Report
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1. Background and Introduction

The use of precast concrete superstructure elements is a popular strategy for accelerated bridge construction (ABC) and rehabilitation projects. The major advantage is that precast concrete elements can be fabricated before, or in parallel with, on-site activities, thus expediting project delivery. To complete the superstructure, closure joints between adjacent precast superstructure elements are filled with a field-cast material, creating continuity between the concrete elements and splicing steel reinforcement that protrudes from the precast members into the joints. The geometry of the closure joints, the speed at which the connections can be completed, how long before the bridge can be opened to traffic, and the cost of the system are all dependent on the material that is used to fill the gaps between precast elements. The closure joint material must possess strength and durability equal to or better than the adjacent concrete and must be capable of transferring the tensile forces between reinforcement from adjacent elements.

2. Problem Statement

The tension and bond strengths of ultra-high performance concrete (UHPC) make it an excellent closure joint material. However, the time at which UHPC achieves its design strength is directly proportional to the rate of hydration of the cementitious binder. While UHPC may provide the best solution in many instances, alternative joint materials that utilize polymer binders, instead of cementitious ones, may be more suitable if rapid strength gain is needed. This project explores a potential alternative closure joint material, fiber-reinforced polymer concrete (FRPC), which displays levels of the two critical characteristics (bond and tension strength) that are comparable to, or potentially better than, those of UHPC. FRPC has the advantage of requiring shorter closure windows (approximately 4 hours versus 72 hours of UHPC) due to the very rapid strength gain of the polymer, which could be ideal for overnight construction or rehabilitation projects, and provides an additional option to the engineer and contractor when choosing a closure joint material for a particular circumstance.

3. Objectives and Research Approach

The objectives of the proposed research are to review the most promising FRPC materials, assess the temperature dependent properties of FRPC behavior, characterize the mechanical properties (tensile, flexural, and compressive strength) of cast FRPC, and characterize the splice performance of deformed bars embedded in FRPC materials. Based on the results of this experimental investigation, recommendations for the use of FRPC in ABC applications will be developed to maximize the benefit of this relatively new material for different ABC project applications.

4. Description of Research Project Tasks

The following is a description of tasks carried out to date.

Task 1 – Literature Review

This task is complete. Previous research on fiber reinforced polymer concrete has been compiled and separated into areas of interest pertinent to bridge construction applications. A summary of the compiled research can be found in the September 2021 Progress Report.

Task 2 – FRPC Material Characterization

This task is complete. The mechanical properties of a commercially available FRPC material, Kwik Bond Hybrid Composite Synthetic Concrete (HCSC), were determined at several test temperatures and ages using standard test methods that would be part of a typical quality control program (i.e. compressive strength, tension strength, and anchorage strength). An overview of the results can be found in the December 2021 Progress Report.

Task 3 – Testing of Splice Specimens

This task is complete. The tests investigated a simplified, non-contact splice configuration that isolates the behavior of reinforcement in a closure joint. The specimen size was selected to allow conditioning the specimens to different temperatures using conventional laboratory equipment and tested using a universal testing machine under precise displacement control. The variables that were investigated include the temperature at time of testing, overlap length between bars, side cover, and bar size. Additional details of the testing plan and the experimental results can be found in the March 2022 Progress Report and June 2022 Progress Report, respectively.

Task 4 – Development of Design Recommendations

This task in complete. Fig. 1 shows an example of a UHPC closure joint detail. Research conducted by the FHWA (Graybeal 2014) provides guidance on the structural design of closure joints that have been adopted into the *AASHTO LRFD Guide Specifications for Accelerated Bridge Construction* (AASHTO 2018). The guidance recommends the minimum embedment length of deformed steel reinforcement, l_d, be taken as $8d_b$ for #8 bars or smaller with f_y less than or equal to 75 ksi. The embedment length recommendation requires that the clear cover be greater than or equal to $3d_b$ with UHPC having a compressive strength of at least 14 ksi and 2% fibers by volume. The splice length for straight deformed steel reinforcement is recommended to be at least $0.75l_d$, or $6d_b$ if an l_d of $8d_b$ is used. This results in a minimum joint width of $10d_b$ with some allowance for construction tolerance in the field.

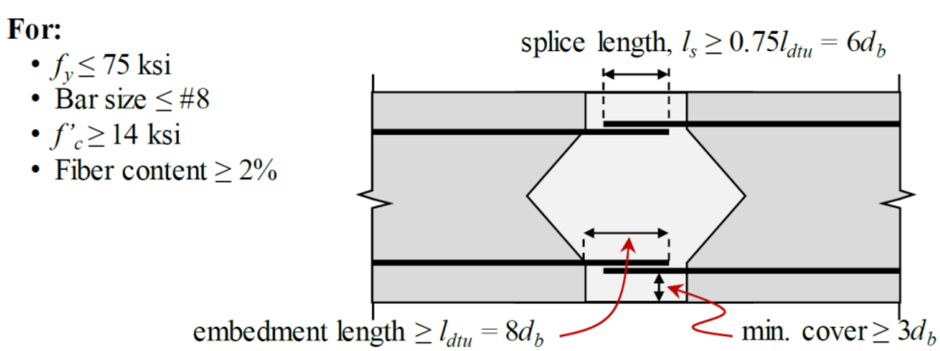

Fig. 1. UHPC Recommended joint geometry (Garber and Shahrokhinasab 2019)

Using the statistical software Minitab (Minitab 2022), a response surface model (RSM) was fit to the Task 3 experimental data, and the significance and adequacy of the regression was tested using analysis of variance (ANOVA). This regression estimated the relationship between bar stress at failure and non-contact splice length, side cover, test temperature, and bar size. The intent of this analysis was to assess the feasibility of using HCSC in a closure joint that meets the recommended geometry for UHPC. The final model was reduced one factor at a time to only include significant terms. Though P-values were typically kept below a significance level of 0.05, some interaction terms were retained in the selected model above this threshold to capture physical phenomena expected in the response.

Fig. 2 shows two-dimensional contour plots of the resulting response surface. Each plot shows estimated bar stress at failure versus normalized splice length and normalized bar cover. Each pane represents different combinations of testing temperature and bar size. The black dashed line denotes the yield strength, and the grey line denotes the 75 ksi limit included in the AASHTO *LRFD Guide Specifications for Accelerated Bridge Construction*. The white dashed lines show the UHPC closure joint design recommendation by the FHWA (Graybeal 2014). The design area is the upper right corner, in which sufficient cover and splice length are provided. For the bar sizes and temperatures shown, the design space specified by the FHWA is sufficient for bar yield at the most conservative edge (110 °F and #6 bars) and nearly meets the additional limit of a bar stress of at least 75 ksi.

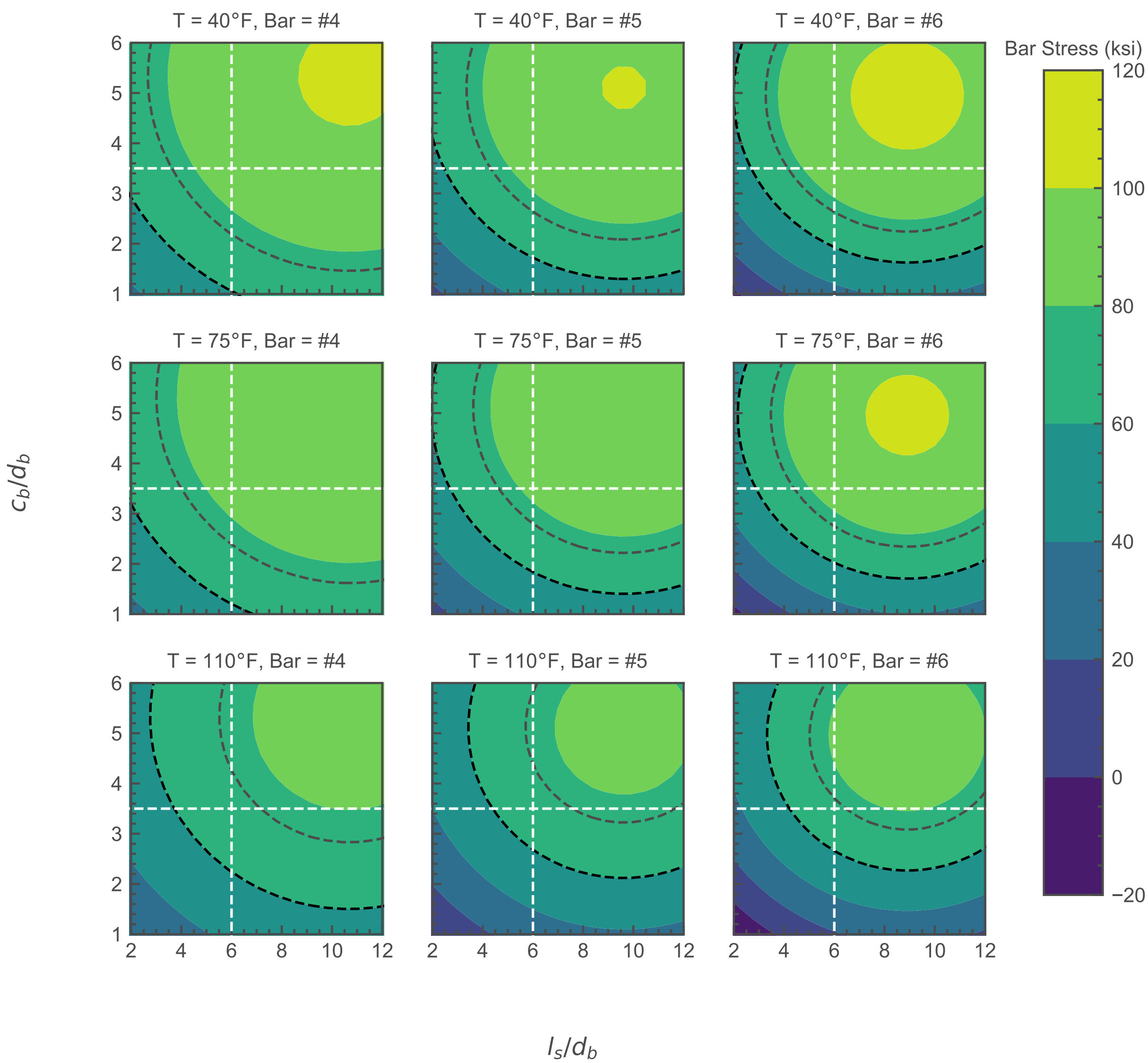

Fig. 2. Bar stress for varying temperatures and bar sizes

Based on the results of the non-contact splice tests, the bond strength of HCSC appears sufficient, for service temperatures in the range of 0-110 °F, to permit closure joints with identical geometries as those adopted in the AASHTO *LRFD Guide Specifications for Accelerated Bridge Construction* for UHPC. The capability of HCSC to permit the same joint geometry as UHPC helps increase the potential closure pour material options for a given ABC project, especially when rapid strength gain is beneficial.

With very limited evidence (there was only a single test conducted with a test temperature exceeding 110 °F), the required non-contact splice length to yield epoxy coated reinforcement for temperatures exceeding 110 °F would be larger than six bar diameters. At 140 °F the non-contact splice strength was roughly 30% of the room temperature value. Consideration of the expected material temperature at the closure joint location under service conditions is therefore critical before specifying HCSC or any other PC as a closure joint material. This analysis should consider the temperature distribution in the deck, the presence of any wearing course or overlay materials, and the temperature dependent properties of the polymer concrete used.

The use of primers aid in the adhesion of HCSC and other PCs to the adjoining elements and reinforcement. From the scoping study completed, the use of an HMWM primer increased bond by an average of 9%. Joint width and geometry designs should include the use of primer, whenever possible. If primer is not used, due to constraints on-site or for other reasons, the designer should be prepared to increase the splice length accordingly.

It should be noted that research by Peruchini et al. (2017) concluded that simulated deck specimens with UHPC closure joints exhibited splice strengths that were 85% of those determined using bond curb specimens with the same cover and embedment lengths. The change in bond strength from non-contact splice testing to a realistic joint in flexure should be further investigated.

For closure joints between precast girders, the splice length should account for any sweep that may occur in the structure. The minimal splice length over the length of the closure joint should be ensured in designs and that adequate edge cover is maintained. For closure joints in precast deck panels or precast girders without additional deck overlay, minimum side cover requirements should account for any cross slope or camber of the element.

Task 5 – Interim and Final Reporting

This task in ongoing. The research team will submit timely quarterly reports, present annually at the Research Days meeting, and complete a final report summarizing findings reached during the project. Writing for the final report is currently underway.

5. Expected Results and Specific Deliverables

The successful completion of the research project will directly impact the design/construction industry, by providing a better understanding of the properties of FRPC and its potential for use in closure joints between precast members, such as decked bulb tees, PCI NEXT beams, or precast deck panels. The main deliverable will be a report that summarizes:

- Recommendations for the selection of FRPC as a closure joint material in ABC applications,

- Design equations for the required development length of epoxy coated reinforcement embedded in FRPC, and
- Example closure joint geometry utilizing FRPC.

In addition, the results of the project will be summarized in a 5-min demonstration video and a journal publication.

6. Schedule

Progress on tasks in this project is shown in the tables below.

Item	% Completed
Percentage of Completion of this project to Date	90%

Research Tasks	2021											2022										
	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N
Task 1 – Literature Review																						
Task 2 – FRPC Material Characterization																						
Task 3 – Testing of Splice Specimens																						
Task 4 – Development of Design Recommendations																						
Task 5 – Interim and Final Reporting																						

7. References

American Association of State Highway and Transportation Officials. 2018. AASHTO LRFD guide specifications for accelerated bridge construction. Washington, DC. AASHTO

Garber, D., and E. Shahrokhinasab. 2019. "ABC-UTC Guide for: Full-Depth Precast Concrete (FDPC) Deck Panels."

Graybeal, B. 2014. Bond Behavior of Reinforcing Steel in Ultra-High Performance Concrete. Washington, D.C.: USDOT FHWA.

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Peruchini, T. J., J. Stanton, and P. Calvi. 2017. Investigation of Ultra-High Performance Concrete for Longitudinal Joints in Deck Bulb Tee Bridge Girders. 213. Olympia, WA: Washington State Department of Transportation.