



Investigating Bond and Flexural Performance of Thin Bonded Engineered Cementitious Composite Overlay for Concrete Bridge Decks

CTIPS-031 – Full Project Description

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Research Needs

Resilient and durable overlays are critical for enhancing the service life of bridge decks by shielding them against harmful effects of water, chemicals, and abrasion. Currently, concrete bridges in the U.S. widely utilize either Portland cement overlays or polymer-based overlays including polymer concrete and polymer-modified concrete [1,2]. Polymer-based overlays outperform conventional concrete topping overlays. However, instances of polymer concrete overlay debonding have been encountered [3]. Moreover, polymer concrete overlays utilize proprietary materials and are costly in price [4]. Within cementitious materials as overlays, thin ultra-high-performance concrete (UHPC) bonded overlay is gaining prominence as being effective in extending the service life of bridge decks [5]. The low water-to-binder ratio of UHPC can cause substantial autogenous shrinkage, which raises the possibility of overlay cracking and debonding at the overlay-substrate interface [6,7]. Further, while efforts for developing non-proprietary UHPC mixtures are ongoing, expensive proprietary mixes are still being used for field applications, which can be a barrier in its extensive implementation.

Meanwhile, a new class of cementitious material, Engineered Cementitious Composite (ECC) is emerging as a promising bridge-deck overlay material owing to its ultra ductile tensile crack-

resistance, lower elastic modulus, and high durability characteristics. ECC overlays applied at 25-mm (1-inch) thickness, can provide a lightweight, cost-effective, and sustainable solution for rehabilitating and protecting bridge decks [8,9]. ECC is a high-performance fiber-reinforced cementitious composite consisting of cement, fly ash, silica sand, water, and less than 2% (by total volume) polymer micro-fibers [10]. Polyvinyl alcohol (PVA) fibers are commonly used as the micro-fiber reinforcement in ECC. In addition, crumb rubber particles can be added to ECC, which results in a low elastic modulus and aids in reducing tensile stress development due to shrinkage effects [11]. As a consequence, the topping overlay cracking tendency is reduced, as is the degree of delamination at the overlay-substrate interface. Owing to its unique microstructure, ECC attains tensile strain capacity of 3 to 5%, which is 300 to 500 times superior to conventional concrete strain values. Under tension, ECC develops closely spaced fine micro-cracks of below 100 μm width, resulting in a ductile strain hardening behavior similar to metals [12–14]. A typical approach for improving concrete durability is to make the concrete denser, which in turn makes it less permeable. Nevertheless, such concrete is less durable after cracking. As opposed to localized cracking with larger crack widths in conventional concrete, ECC is tailored for crack-width reduction and non-localized cracking under tensile stresses. The tightly-held cracks contribute to high durability of ECC and prevent the degradation of substrate material by resisting penetration of water and harmful solutions into concrete. Also, ECC contains considerable amount of supplementary cementitious materials (such as fly ash) and the secondary hydration reactions have been observed to seal the fine cracks [15].

Previous studies on utilizing ECC in transportation structures have mostly focused on behavior of ECC as link slabs [16,17], while limited research has been carried out on ECC as an overlay material [18]. Moreover, studies comparing the effectiveness of ECC overlays for bridge decks with that of polymer concrete and UHPC overlays are currently lacking. Furthermore, research on non-proprietary ECC mixtures appropriate for overlay applications is scarce. Owing to these existing knowledge gaps, overlay applications of ECC remain restricted across the U.S., despite its excellent mechanical and durability properties. Thus, this study proposes to develop ECC using readily available non-proprietary ingredients and characterize its behavior for overlay systems. The proposed research will also compare the performance of ECC with polymer and UHPC overlays at a material and structural level. The results of this study will produce pertinent information on local ECC-based overlays for transportation stakeholders.

Research Objectives

The overarching goal is to develop a comprehensive understanding on the behavior of ECC as an overlay material. The primary objectives of the study are to:

- (1) Develop and characterize non-proprietary Engineered Cementitious Composite (ECC) mixture suitable for overlay applications
- (2) Evaluate and compare the strength, shrinkage, and bond characteristics of ECC with other polymer and cementitious (UHPC) overlays
- (3) Assess the flexural performance of overlay-substrate system by testing representative slabs with ECC, polymer, and UHPC overlay materials

Research Methods

The proposed research will evaluate the material and structural performance of ECC overlay materials. Majority of the research will be undertaken through experiments. The non-proprietary mix design will be developed through a comprehensive literature review and market survey. The selected ECC mixture will be characterized through property tests. The strength, shrinkage, and bond properties of ECC and the other overlay materials (UHPC, polymer concrete) will be measured through testing in the laboratory. The flexural performance of the slabs with ECC, UHPC, and polymer concrete will be also evaluated through experiments. More details on the testing program are provided under the Work Plan section. The post-processing of results will be performed using Excel and MATLAB.

Relevance to Strategic Goals

This project directly relates to the USDOT strategic goal of Climate and Sustainability. Engineered Cementitious Composite (ECC) exhibits high ductility and crack resistance which can lead to longer-lasting bridge decks, reducing the need for frequent repairs and lowering material consumption and associated carbon emissions. ECC overlays can be applied in thinner layers than traditional concrete, decreasing raw material use.

Educational Benefits

The majority of the research work on this project will be carried out by a dedicated Ph.D. level graduate student with assistance from other students in the PI's research group and under the PI's supervision. Students will gain invaluable experience in carrying out physical experiments on advanced materials, specimen fabrication, and large-scale structural experimental methods. It is anticipated that the students will also present the results of the research at national conferences.

Outputs through Technology Transfer

The expected output from this project will be in the form of test data from the comprehensive experimentation on different overlay materials, including ECC, UHPC, and PPC for improving service life of bridge decks.

The results of this research will be disseminated in the following ways: 1) research results will be presented at local, national and/or international conferences and events such as the annual Utah Department of Transportation Engineering Conference, Annual Transportation Research Board Meeting, American Concrete Institute Intermountain Chapter events, and American Concrete Institute conventions; 2) the final report will be sent to structures and transportation colleagues at state and local transportation agencies; 3) at least two manuscripts will be prepared and submitted for publication in journals related to highway infrastructure and construction materials; and 4) summary slides of research results will be shared for dissemination through the CTIPS website.

Expected Outcomes and Impacts

The outcome of this project will result in a non-proprietary Engineered Cementitious Composite (ECC) mixture design that can be utilized as overlays for bridge decks. The research results will also provide valuable insights into the behavior and performance of ECC, helping to inform its potential applications in transportation infrastructure. The high durability and crack-control

characteristics of ECC can enhance the long-term performance and service life of bridge deck overlays. This will reduce the need for frequent maintenance and repairs, and thus, result in significant cost savings. By extending the functioning lifespan of bridge decks and minimizing resource consumption over time, ECC also contributes to sustainable infrastructure development. Utilization of a non-proprietary overlay material can lead to self-reliance and cost-effectiveness in projects.

Work Plan

The proposed project will be carried out over a 19-month period:

Task 1 Literature Review (2 months): Conduct an extensive literature review to compile the recent information on developing and characterizing ECC materials for overlays, other prevalent cementitious and polymer overlay materials used by state DOTs, and overlay performance requirements.

Task 2 Mix design formulation and material procurement (2 months): Develop optimum mixture proportions for ECC, as well as a cementitious overlay material (ultra high performance concrete (UHPC)), and a polymer overlay material (polyester polymer concrete (PPC)). The performance of ECC will be compared with that of UHPC and PPC. Source raw materials for mixture ingredients of the designed mixes.

Task 3 Specimen fabrication and curing (2 months): Manufacture specimens for all the three batch mixes (ECC, UHPC, and PPC) to undertake strength, shrinkage, and bond tests and structural level tests. Fresh properties of the overlay materials will be measured, and the prepared specimens will be cured for 28-days.

Task 4 Strength and shrinkage tests (2 months): Evaluate compressive strength and tensile strength as well as tensile strain capacity for ECC, PPC, and UHPC. Measure autogenous shrinkage using corrugated tubes (ASTM C1698) and measure drying shrinkage using prismatic specimens (ASTM C157).

Task 5 Direct pull-off tests (2 months): Pull-off test specimens of 300 × 300-mm slabs with 50-mm thick conventional concrete substrate and 25-mm thick topping of the different overlay materials. The substrate surface will be prepared before applying the overlay material. Conduct direct pull off test following ASTM C1583 to evaluate overlay-substrate bond strength and failure interface.

Task 6 Flexural test of composite slabs (4 months): Design and fabricate ECC, UHPC, and PPC overlay slabs of approximate size 1200 × 600 × 100-mm. The substrate surface will be prepared before applying the overlay material for this task as well. The overlay slabs will be instrumented and tested under four-point bending. The cracking pattern, load-deflection response, and contribution of overlay material will be monitored.

Task 7 Post-process results (2 months): The results from the experimental tests on the different overlay materials at material and structural levels will be processed, analyzed, and summarized for comparing the performance of ECC with PPC and UHPC.

Task 8 Prepare final report and papers (3 months): The results and recommendations from this study will be presented in a technical report. Time is also allocated for the preparation of journal and peer reviewed conference papers to disseminate the findings of this study.

Project Cost

Total Project Costs:	\$188,453.66
CTIPS Funds Requested:	\$ 94,226.66
Matching Funds:	\$ 94,227.00
Source of Matching Funds:	Utah LTAP

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