HIGH-EARLY STRENGTH CONCRETE FOR RAPID BRIDGE DECK REPAIR AND REHABILITATION

Quarterly Progress Report
For the period ending August 31, 2022

Submitted by:
PI: Travis Thonstad
Co-PI: Fred Aguayo
Research Assistant: Jafet Guerrero-Estrada
Undergraduate Research Assistant: Vania Moreno-Colin

Affiliation: Department of Civil and Environmental Engineering
University of Washington

ACCELERATED BRIDGE CONSTRUCTION
UNIVERSITY TRANSPORTATION CENTER

Submitted to:
ABC-UTC
Florida International University
Miami, FL

Background and Introduction

Bridge deck cracking is a prevalent problem in the United States. While early-age cracking will not cause failure of the bridge deck system independently, the penetration of deleterious substances (e.g., deicing chemicals) through the cracks leads to costly serviceability issues. If left unchecked these issues could lead to severe distress and the loss of structural integrity of the deck and superstructure. Bridge deck deterioration, therefore, must be managed through preservation efforts that range in scope from patch repairs to full deck replacement, with bridge deck concrete overlays and overlay replacement falling somewhere in between. There is also a need to strengthen some bridges due to higher demands, including increasing deck thickness through a structural overlay. Regardless of the scope of the rehabilitation project, one of the continuing challenges in these efforts is selecting a suitable repair material that can achieve specified engineering and durability properties quickly while also being long-lasting. As traffic volumes continue to increase, long-term closures or lane restrictions are nearly impossible, and many of these preservation projects must be completed during overnight closure windows, often in congested and heavily trafficked urban transportation corridors.

Currently, there are a number of repair and overlay materials available for protecting bridge decks from additional deterioration and extending their service life (e.g., ultra high-performance concrete, latex modified concrete, low slump concrete, etc.) [Hunsucker et al. 2018, Wibowo and Sritharan 2018, Khayat and Valipour 2018, Newtson et al. 2021]. Many of these overlay systems have shown varying degrees of success, but mobility and safety issues have caused state DOTs to truncate construction times as much as possible, leaving less time for these conventional strength-gaining materials to be used. This has led to instances of using expensive polymer-based concretes (e.g., polyester polymer concrete or PPC) instead of preferred or higher-performing cementitious materials due to rapid traffic turnaround; PPC overlays set up very fast, but they do not address decks in poor condition and are expensive. Consequently, there is an urgent need in identifying, characterizing, and implementing sustainable and advanced high-early strength concrete (HESC) overlays to support rapid concrete bridge deck rehabilitation. The proposed research project explores the use of a calcium sulfoaluminate (CSA) cement-based overlay as alternative option.

CSA is preferred option for HESC because of its ability to set within a short time window (roughly 15 min) and easily surpass a compressive strength of 2,500 psi in under 3 hours. A primary reason for the rapid strength development in CSA is due to its finer particle size, when compared with ordinary Portland cement (OPC), and a chemistry that promotes rapid and significant ettringite formation in the first few hours [Juenger et al. 2011]. This rapid ettringite formation often leads to an early-age expansion characteristics resulting in a lower or neutral long-term shrinkage stress development and thus, reducing cracking potential. While the main incentive for using CSA is the rapid strength gain, it is worth noting that its lower calcium composition leads to a 30-50% reduction in CO_2 emission from calcination compared to OPC [Burris and Kurtis 2018]. Furthermore, the lower temperature needed in the kiln to produce the CSA compounds can reduce the energy of manufacturing by up to 60% [Thomas et al. 2018].

Problem Statement

A survey done in 2017 reported that California is the only state DOT recommending the use of CSA for high early strength concrete [Ghafoori et al. 2017]. However, another survey found that

9 other states, including Washington, have had success using CSA for repair applications [Burris et al. 2015]. While CSAs have the potential to be successfully used in producing HESC overlays, significantly more data is need in order to develop appropriate guidance and specification documents for their use. The construction of concrete overlays presents a unique problem, where sufficient bonding and compatibility between the overlay material and the substrate is essential for a long-lasting rehabilitation. The ideal material should possess high early-age strength, good adhesion to existing concrete substrates, and superior short- and long-term durability. These properties will be evaluated in the proposed testing program to develop a suitable CSA-based HESC overlay material specification for accelerated bridge construction and rehabilitation applications.

.

Objectives and Research Approach

The objective of this research project is to identify the obstacles to successfully and reliably use CSA cement for structural bridge deck overlays, with a particular focus on evaluating bond properties and performance. CSAs are gaining the attention of many state agencies, owing to their rapid setting and high-early-age strength gain, which can be leveraged to accelerate project delivery and shorten the duration of on-site concreting activities. These cements have great potential to be successfully used in repair and overlay applications, especially when minimal traffic disruption is crucial.

Description of Research Project Tasks

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

4 Task 1 – Literature Review

This task is ongoing. The objective of this task is to develop a comprehensive review of past experimental research involving high-early strength (HESC) concrete utilizing CSA binders, with particular emphasis on bridge overlays, including lab and field trials. The feasibility, constructability, and key mechanical properties of CSA-based concrete repair and overlay materials will be documented and disseminated in a format that will be valuable to state departments of transportation.

5 Task 2 – Mixture design and material optimization

This task is ongoing. The objective of this task is to screen potential HESC materials and mixture designs (e.g., CSA cements, mixture proportions, curing, construction, and placement techniques). It is anticipated that at least 2-3 CSA cements will be procured for characterization in consultation with the advisory panel members. This task will focus on mixture design development and material optimization on mortar mixes including workability, setting time, and early-age strength development (e.g., up to 24 hr). These tests will be used to optimize and identify 2-3 high potential overlay mixtures to undergo a more exhaustive series of performance tests in Task 3.

The research team has engaged CTS Cement Manufacturing Corporation, who has graciously offered to provide CSA cement as in-kind support for this research. RapidSet®, a CTS Cement product, has been acquired, and preliminary mortar mixes have been performed in accordance with ASTM C109, with minor modifications (lower water-to-cement ratio and water reducing admixtures were used to improve workability in the mortar mixes performed to-date).

A round of preliminary slant shear testing was also performed in accordance with ASTM C869 to assess the influence of surface roughness on the performance of the shear bond surface between high-strength and CSA concretes, without the addition of surface primers or latex modifiers. The high-strength parent concrete, or "substrate," portion of the specimens were cast using a 3/8th in pea gravel concrete mixture, and two different in-form retarders were used to achieve either a "sandblast" finish or an "exposed aggregate" finish at the interface between the two materials, as shown in Fig 1a. The results showed that the exposed aggregate surface exhibited a roughly 10% increase in slant shear strength, when compared to the sandblast finish. The results of these tests were presented by Vania Moreno-Colin at the Louis Stokes Alliance for Minority Participation (LSAMP) Summer Undergraduate Research Symposium on August 16th on the UW Campus, see Fig. 1b.

Fig. 1. Preliminary slant shear testing (a) achieved substrate surfaces (b) poster presentation

6 Task 3 – Materials characterization

This task is ongoing. The objective of this task is to evaluate key material and structural properties affecting the performance of concrete overlays (e.g., modulus, mechanical strength gain, setting time, and volume change), focusing particularly on bond strength and subsurface characteristics as a performance indicator of CSA concrete overlays.

Table 3 provides the planned test matrix for the substrate bond testing. Variables of interest in the study include CSA concrete mixture design, substrate surface finish, curing duration, and the use of admixtures/primers to enhance substrate bonding. For each variable, two alternatives will be evaluated for each, leading to at least 16 specimens.

Table 1. Testing matrix for bond strength of CSA overlay mixtures

No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Surface Finish	SB	SB	SB	SB	SB	SB	SB	SB	EA	EA	EA	EA	EA	EA	EA	EA
Primer/Admixture	LM	LM	LM	LM	SP	SP	SP	SP	LM	LM	LM	LM	SP	SP	SP	SP
Mixture Design	1	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2
Curing Duration	1d	7d	1d	7d	1d	7d	1d	7d	1d	7d	1d	7d	1d	7d	1d	7d

Note: SB = Sand Blast, EA = Exposed Aggregate, LM = Latex Modifier, & SP: Surface Primer

Fig. 2 shows a schematic of the test setup. The pull-off method (ASTM C1583) will be used to evaluate the bond strength between each CSA concrete overlay mixture and a standard concrete substrate, allowing comparisons between the different surface preparations. Similar testing has been done by others to assess the performance of latex-modified concrete and UHPC overlays [e.g., Konduru et al. 2010, Haber et al. 2017] and will enable comparisons between the different overlay systems.

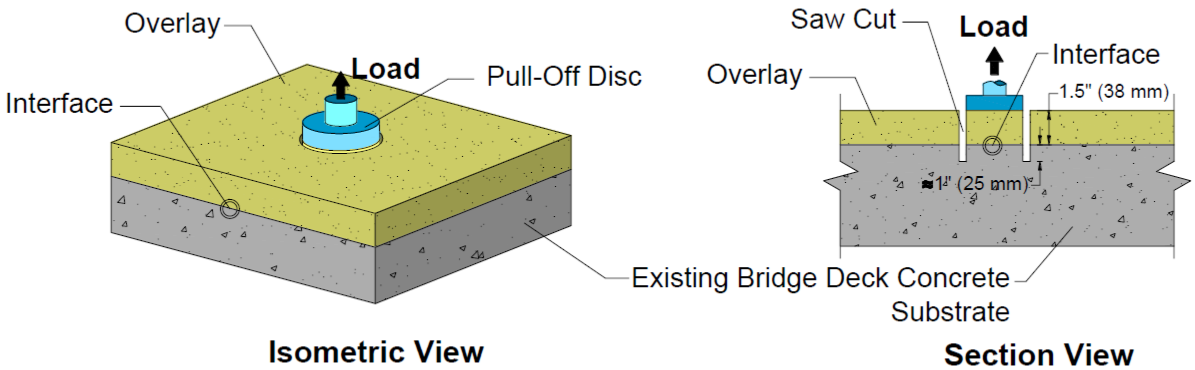

Fig. 2. Schematic showing direct tension pull-off bond test [from Haber et al. 2017]

Fig. 3 shows the formwork design for the test specimens. Miniature concrete deck specimens (or “slabs”), 3.5 in thick, will be cast using a WSDOT bridge deck concrete mixture design (Concrete Class 4000D), consistent with the 2004 WSDOT *Standard Specifications for Road, Bridge, and Municipal Construction* [WSDOT 2004]. The older, prescriptive, concrete specification was selected to maintain the project focus on bridge deck rehabilitation. Bridges where protective overlays are considered are typically at least 20 years old. To simulate different surface preparations conditions, the top surface of the slabs will be treated with two different spray-on surface retarders to obtain different surface textures. These specimens will be stored outdoors to ensure they have gone through most of their shrinkage before the overlays are placed. In addition, placement of the overlay, including consolidation, finishing, and curing will be done as close as possible to current construction methods (e.g., surface finish, curing application, etc.). All final design and construction considerations will be reviewed with advisory panels prior to overlay application.

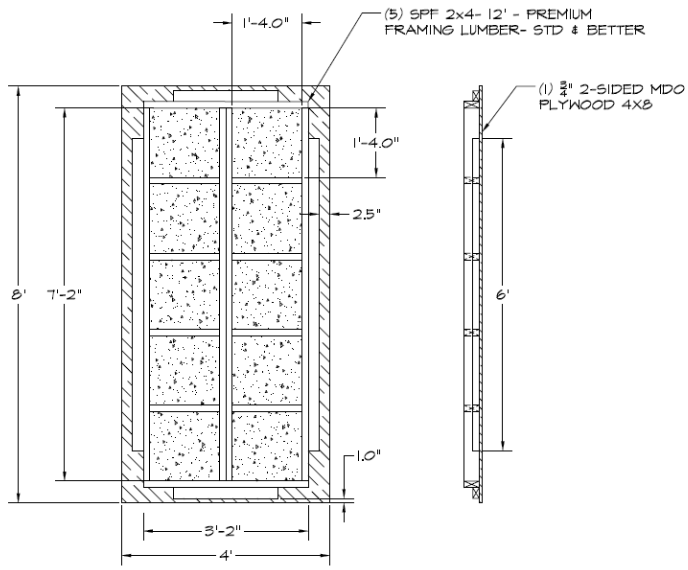

Fig. 3. Formwork drawings for substrate test specimens (note: there are 10 specimens per form)

7

8 Task 4 – Development of specifications

This task has not been started. Based on the results of Task 1-3, suitable CSA materials and mixture designs will be identified, in consultation with the advisory panel members. All material properties, characteristics, and performance data will be used to provide preliminary performance specifications for a CSA-based HESC repair and overlay mixture designs. A follow-on project, funded by the Washington State Department of Transportation will focus on further developing HESC performance-based specifications based on additional durability testing (e.g., freeze-thaw, salt scale, restrained shrinkage cracking, etc.). The key data generated on fresh, hardened, and bond performance testing in the proposed project will be used to inform additional testing required for future field-scale deployment of CSA-based HESC overlays.

9

10 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.

Expected Results and Specific Deliverables

The successful completion of the research project will directly impact the design/construction industry, by providing preliminary specifications for an optimized CSA-based, high-early strength concrete (HESC) mixture for repair and rehabilitation of bridge overlay projects.

The expected products resulting from this research will include:

- Bond strength performance data of CSA concrete overlay candidates,
- Recommended guidelines on surface preparation for a bridge intended to be placed with a CSA concrete overlay, and

- Provide preliminary specifications for an optimized CSA-based, high-early strength concrete (HESC) mixture.

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

Schedule

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

Item	% Completed
Percentage of Completion of this project to Date	25%

Research Tasks	2023								2024				
	M	J	J	A	S	O	N	D	J	F	M	A	M
Task 1 – Literature review													
Task 2 – HESC mixture design and material optimization													
Task 2 – HESC material characterization													
Task 4 – Development of HESC mixture design specification													
Task 5 – Interim and Final Reporting													

References

Burris, L.E. and Kurtis, K.E., (2018). Influence of set retarding admixtures on calcium sulfoaluminate cement hydration and property development, Cement and Concrete Research, 104, 105-113.

Burris, L., Kurtis, K., and Morton, T. (2015). Novel Alternative Cementitious Materials for Development of the Next Generation of Sustainable Transportation Infrastructure. United States. Federal Highway Administration.

Ghafoori, N., Najimi, M., and Maler, M. (2017). High-Early-Strength High-Performance Concrete for Rapid Pavement Repair

Haber, Z.B., Munoz, J.F., and Graybeal, B.A. (2017) “Field Testing of an Ultra-High Performance Concrete Overlay.” FHWA-HRT-17-096, Turner-Fairbank Highway Research Center, McLean, VA.

Hunsucker, D, Ashurst, K.J. JR, Rister, B.W., Allen, D., and Grade, E., (2018) "Longer Lasting Bridge Deck Overlays", Kentucky Transportation Center, Research Report – KTC-18-06/SPR14-472-1F

Juenger, M. C. G., Winnefeld, F., Provis, J. L., and Ideker, J. H. (2011). Advances in alternative cementitious binders. Cement and Concrete Research, 41(12), 1232–1243.

Khayat, K. H. andValipour, M., (2018) "Design and Performance of Cost-Effective Ultra High Performance Concrete for Bridge Deck Overlays", Missouri Department of Transportation, MoDOT Project # TR201704

Konduru, S., Ray, I., Davalos, J.F., and Chen, A. (2010) “Evaluations of Latex Modified Concrete Overlay Bonded to Normal Concrete Deck.” Proceedings, Earth and Space 2010: Engineering, Science, Construction, and Operations in Challenging Environments, Mar, 2010 Honolulu, HI.

Newtson, C.M., Weldon, B.D., Toledo, W.K., Alvarez, A., and Manning, M.P. (2021) "Field Implementation and Monitoring of an Ultra-High Performance Concrete Bridge Deck Overlay", Transportation Consortium of South-Central States

Thomas, R. J., Sorensen, A. D., Quezada, I., and Maguire, M. (2018). Calcium Sulfoaluminate Cement. Concrete International, 40(4), 65–69.

Wibowo, H. and Sritharan, S., (2018) "Use of Ultra-High-Performance Concrete for Bridge Deck Overlays", Iowa Highway Research Board, InTrans Projects 16-573.

WSDOT (2004) “Standard Specifications for Road, Bridge, and Municipal Construction.” Washington State Department of Transportation Manual, M 41-10, Olympia, WA.