MPC-492
July 31, 2015

Project Title:
Early-Age Fiber-Reinforced Concrete Properties for Overlays

University:
University of Utah

Principal Investigators:
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Research Needs:
A common pavement rehabilitation technique for rutted or cracked hot-mixed asphalt concrete roadways is to mill the surface and then overlay with up to 6 inches of a portland cement concrete (PCC) layer (*1-3*). More recent advancements in research has proven that a feasible top wearing surface can be made at this 2 inch (50 mm) thin layer if it is comprised of fiber reinforced concrete (FRC) (*4; 5*). FRC has increasingly being used in UTW overlays since it has been proven through experimental lab and field testing improve the fatigue life and reduce deflections of jointed concrete overlay slabs (*6-11*).

Cracking and debonding of the overlay structure can initiate as a result of drying shrinkage, and temperature shrinkage, slab settlements, or external loads (*12; 13*). Temperature-induced curling and cracking has been researched many times and is currently recognized as one of the major failure mechanisms in concrete pavements (*14-17*). Slabs are designed to have joints cut at spacing sizes proportional to the thickness (*18-20*). These joints are cut in order to provide a specific location for thermal and humidity-induced cracking while also keeping net curling lift-off deflections to a minimum. It has experimentally been verified that with FRC overlays and pavements, not every joint cracks upon the first thermal cycle. Yet the few joints that do crack at early ages produce the lowest load transfer efficiency and widest crack widths at later ages (*21; 22*). There are no known publications or research performed which has studied why or how the addition of fiber-reinforcement in a thin concrete overlay affects the joint cracking and slab curling.

A full-scale test pavement of a 50 mm thick FRC overlay was constructed in July 2009, which has been subjected only to environmental loading since then (*4; 21*). This is a unique pavement section as well because it has no mid-panel slab cracking except in pre-placed constructed debonding zones. The cracking of joints was monitored at early ages between 3 and 20 days as well as climatic temperature data of the air and in 4 depths within the pavement structure. Existing temperature and joint opening models (*23*) overpredict the actual crack widths measured from the field. The proposed research will attempt to improve prediction of crack width for thermally-loaded FRC pavements. The early-age properties of FRC as measured in this research will be utilized in a cohesive zone finite element analysis of the same overlay design.

Research Objectives:
The main objective of this research is to perform experimental tests to determine the hardened properties of fiber-reinforced concrete as they change with time at early-ages. These properties and their function with time can be implemented into finite element modeling to improve overlay prediction at early ages.

Research Methods:
Experimental testing is needed for improving the accuracy of the finite element model. These will be done on plain and fiber-reinforced concrete mixtures. The early age properties are needed for 1, 3, and 7 days in addition to later age properties at 28 and 90 days. The material variables for this research will be to investigate two different synthetic fiber types and three different fiber contents (0.25, 0.5, and 1.0% volume fraction) in concrete or mortar. The standardized tests will be:

- Elastic Modulus (ASTM C469) vs time
- Coefficient of Thermal Expansion (AASHTO T336-11) vs time
- Split-Tensile Strength of Concrete (ASTM C496) with time

Additionally, non-standardized tests will be performed at different ages, as described herein, but still provide necessary information for improving accuracy of finite elment modeling.

1) Fracture Energy Testing

The wedge split tension test provides fracture properties with the lowest variability between specimens (*24-26*). The fracture properties associated with the maximum tensile load to induce cracking (P_{max}) and the energy (area under the load versus crack opening displacement curve) until complete failure (G_{FRC}) for the FRC mixtures will be obtained (*24; 25; 27; 28*). The specimen preparation requires a pre-formed notch be made for which the wedge assembly can fit into, as well as aiding in controlling the location of crack initiation at the tip of the notch. The sizes of the specimens are 150 x 150 x 150 mm (6 x 6 x 6 in) which are easily manageable. A wedge, roller assembly, and displacement gauge have been custom-made based on previous researched test dimensions for concrete. Previous research has found fracture properties of concrete do change significantly at early ages (*29*). It is presumed that with FRC a significant change will also occur, and this research will attempt to create regression analysis of how the FRC fracture properties change with age.

2) Ring Shrinkage

A newly recommended dual ring test (*30*) and the standardized concrete restraint ring shrinkage (AASHTO PP-334-08) will be built at the Utah DOT Central Materials Lab in the Fall of 2014. The new dual ring test is unique in that it can measure both shrinkage and possible expansion of a mortar mixture. It also has a heating and cooling wire and insulation coating as shown in Figure 1 to provide better humidity and temperature controls during testing. Plus with twice as many strain gauges (four) this dual ring test can provide more precise averaged shrinkage strain values of the mortar.

a)  b) 

Figure 1. Dual-Ring Shrinkage a) insulation box with rings ready for mortar to be cast, and b) heating/cooling coil unit on top of cast mortar sample.

3) Interfacial Bond Strength

Half FRC + half asphalt specimens such as shown in Figure 2 will be prepared and tested using the same wedge-split apparatus and loading rate in order to determine the tensile bond strength between FRC and asphalt at early ages. This type of bond testing is based off a paper by Tschegg in which epoxy was tested between two concrete layers (*31*). For this procedure, there will be no epoxy placed between the FRC and asphalt, but instead the original asphalt will be roughened with a sand-blasting media to resemble more of the milled surface expected for overlay construction.

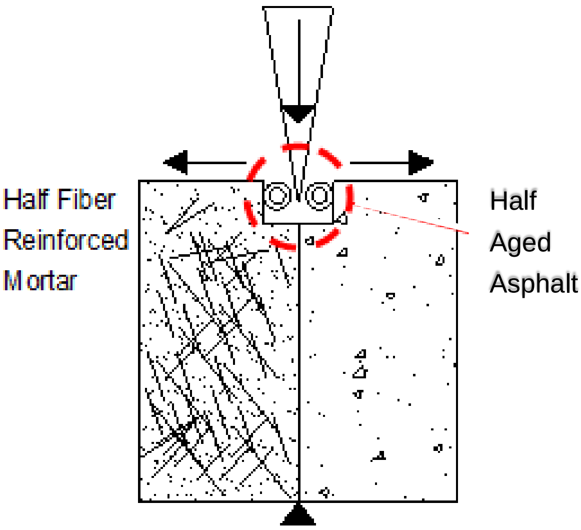

Figure 2. Interfacial Bond Test using the same wedge-split test apparatus with half FRC and half asphalt.

Expected Outcomes:

At least one journal reports will be created by the completion of this project. It is anticipated that a journal such as "Early-Age Properties of Fiber-Reinforced Concrete for Overlays" will be submitted to Transportation Research Board, International Journal of Pavement Engineering, or American Society of Civil Engineering Journal of Materials.

Relevance to Strategic Goals:
This proposed project and outcomes are directly related to the "State of Good Repair" strategic goal. This research will look at incorporating combined environmental loading and early-age effects on thin overlays or patch repair mixtures using fiber-reinforcement. It is not well understood what saw-cut joint spacing is needed or the net deflection or de-bonding effects can be expected when utilizing fiber-reinforcement in the top overlay material. Measurements will provide knowledge on how the FRC properties change at these early ages in which cracking is typically started.

Educational Benefits:
At least one University of Utah graduate course will be influenced by the project. The testing procedure will be covered in a lecture associated with a special topics course CVEEN 7290 Advanced Testing of Materials in the Fall of 2014. The technology transfer from the research findings will also be attempted at the local/regional level by asking to participate in presenting this research at the January 2015 Annual Workshop for the American Concrete Pavement Association Utah Chapter.

Work Plan:
The proposed experimental testing will take roughly 6 months to complete. It is anticipated that the journal paper will be completed in the summer of 2015.

Project Cost:
Total Project Costs: $37,434
MPC Funds Requested: $18,667
Matching Funds: $18,767
Source of Matching Funds: Utah Department of Transportation

TRB Keywords:
Concrete overlays, fiber-reinforced concrete, finite element modeling, early-age properties, fracture energy

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