Quarterly Progress Report:
Project Number and Title: 2.7 High Performance Concrete with Post-Tensioning Shrinking Fibers
Research Area: Thrust 3 Use new materials and systems to build longer-lasting bridges and accelerate construction
PI: Dryver Huston, University of Vermont
Co-PI(s): Ting Tan, University of Vermont
Reporting Period: 10/1/20 – 12/31/20
Submission Date: December 21, 2020

Overview: (Please answer each question individually)

Laboratory studies continued with a focus on developing techniques for shrinking fibers.

- A set of chitosan fibers was obtained from a supplier in China. The fibers had a sisal form, which is a loose aggregation of fine fibers with geometry resembling many natural fibers. The commercial use of these fibers is to make yarns for specialty fabrics, including medical applications. It is available at modest cost in bulk quantities. The fibers were tested in both high and low pH solutions. The hypothesis was that high pH would cause the fibers to shrink, as previous tests on other chitosan fibers. A solution of water and CaO produced a pH more than 11. The results of the experiments were that this fiber did not shrink in the high pH as expected. Further investigation revealed that a manufacturing step for the fibers used high pH ammonia gas to stiffen the fiber as it emerges from the nozzle of an electrospinner. This step effectively pre-shrinks the fibers. Placing the fibers in a low pH solution formed with acetic acid caused the fibers to dissolve.

- The next series of tests are in progress and are examining an alternative method creating chitosan-based shrinking fibers. This method starts with domestically sourced chitosan acetate solution, in 1% and 2% concentrations. This solution has a pH of about 4. Previous tests used bulk chitosan acetate in extruded and dried form. These tests are soaking cotton and other fibers into the chitosan acetate as a structural base and then dried. These composite fibers are being prepped for pH sensitive shrinking tests in the near future.

Numerical studies examined the mechanics of shrinking fibers using the finite element technique.

- These studies considered fibers (0.01mm x 5mm) at various positions and with different levels of bonding length in concrete blocks (10mm x 30mm) loaded in 4-point bending. A 10% axial strain in the fibers imposed the prestress.

- Figure 1 shows results of a study that examined the effect of fiber bonding length. Experience with macroscale pre-stressing and post-tensioning tendons indicates that debond length can have a significant influence on performance. Figure 1.a shows the block with zero prestressing, 1.b with prestressing and 100% bonding, while 1.c and 1.d show the effect of partial midspan debonding. These results confirm that controlling debonding in the center reduces the overall tension stress in the bulk concrete but does introduce stress concentrations at the ends of the fibers.

- Figure 2 shows the results of a finite element analysis of the same block in 4-point bending with an array of fibers. Figure 2.a shows the behavior with fibers and no prestress. Figure 2.b shows the effect of prestress and how it can dramatically alter the internal stress distribution to reduce the tension stresses in the concrete matrix.

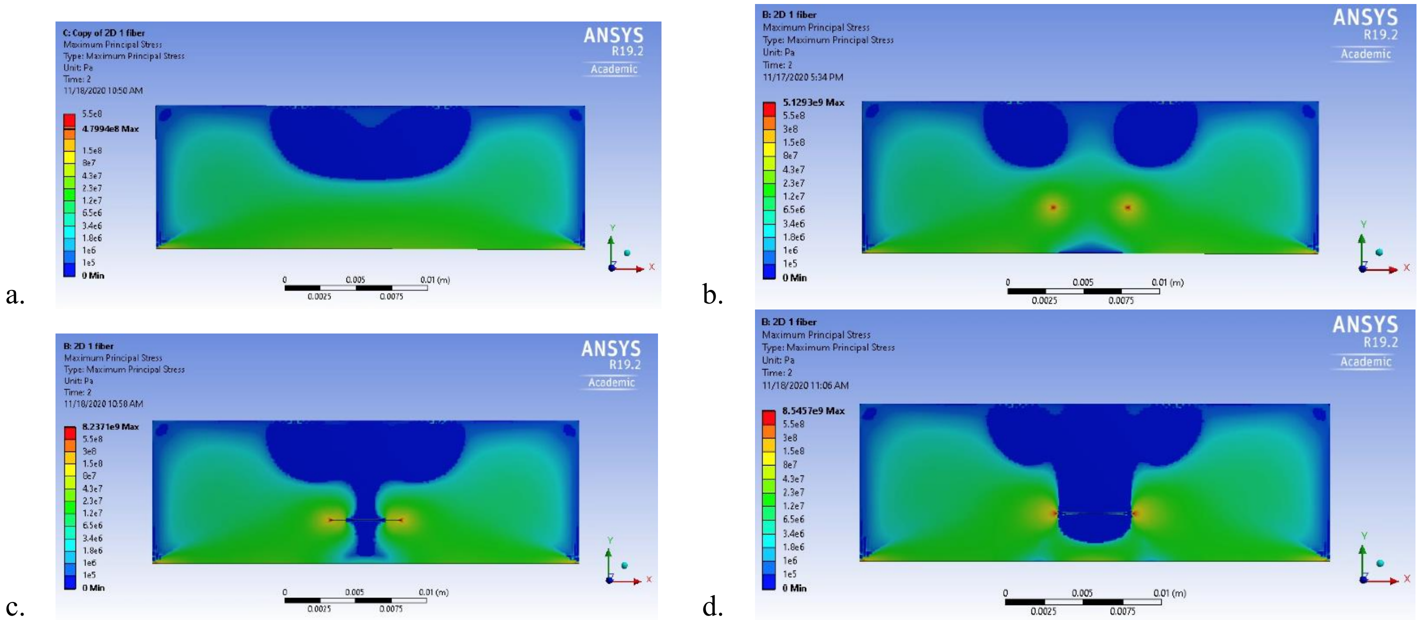

Figure 1 Results of finite element study of the effect of fiber center-span debonding on stress levels in concrete block in 4-point bending: a. No fiber, b. Whole fiber bonded to block, c. Middle 3 mm of fiber debonded, and d. Middle 4.8 mm of fiber debonded. Red to green to blue corresponds to high to low maximum principal stress.

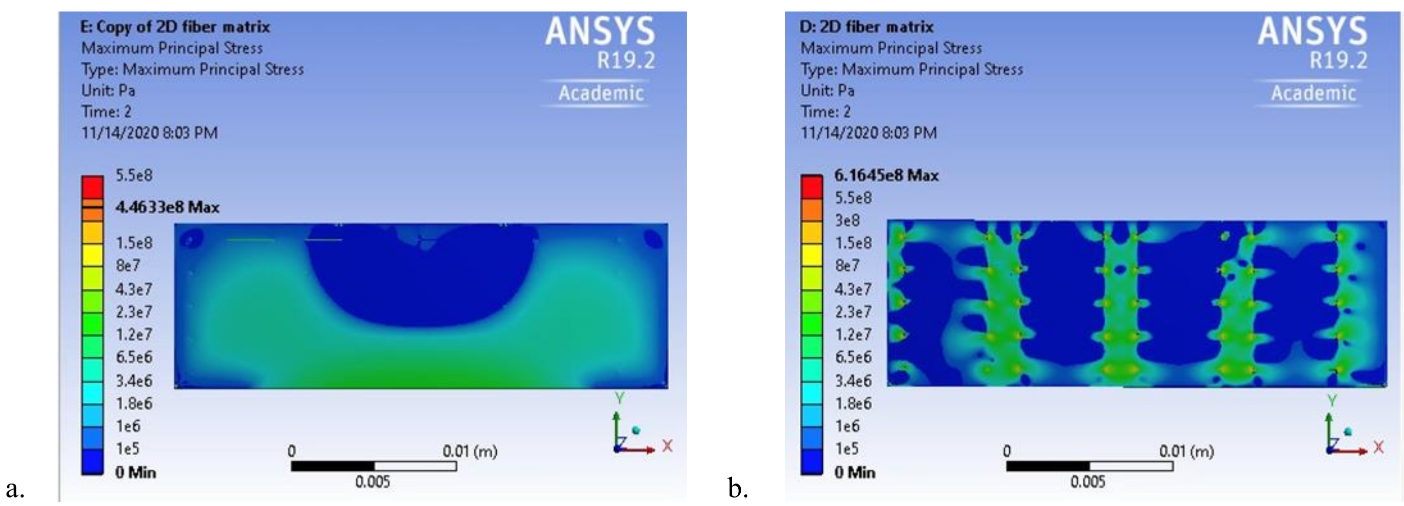

Figure 2 Results of finite element study of the effect of 5x4 array of prestressing fibers on stress levels in concrete block in 4-point bending: a. No prestress, and b. With prestress and entire fiber bonded. Red to green to blue corresponds to high to low maximum principal stress.

Table 1: Task Progress			
Task Number	**Start Date**	**End Date**	**% Complete**
Task 1: Shrinking Fiber Development and Manufacture	6/1/19	5/30/21	47.5%
Task 2: Laboratory Performance Testing	6/1/19	5/30/21	35%
Task 3: Mechanical Modeling	6/1/19	5/30/21	47.5%
Overall Project:	6/1/19	5/30/21	43.3%

Table 2: Budget Progress		
Project Budget	**Spend – Project to Date**	**% Project to Date***
$220,000	$142,623.69 – 12/21/20	64.83 %

Training/professional development – Graduate student Diarmuid Gregory presented posters on this project and attended the 2020 TIDC Annual Student Poster Contest, Univ. of Maine, and the 33rd Rhode Island Transportation Forum.

Table 3: Presentations at Conferences, Workshops, Seminars, and Other Events				
Title	**Event**	**Type**	**Location**	**Date(s)**
High Performance Concrete with Post-Tensioning Shrinking Fibers	2020 TIDC Annual Student Poster Contest	Student Poster Contest	TIDC, U Maine	October 2020
High Performance Concrete with Post-Tensioning Shrinking Fibers	33rd Rhode Island Transportation Forum	Forum and Poster, Poster was selected as best poster in the Forum	Rhode Island	October 30, 2020

Table 4: Publications and Submitted Papers and Reports				
Type	**Title**	**Citation**	**Date**	**Status**
NA				

<u>Participants and Collaborators:</u>

Table 5: Active Principal Investigators, faculty, administrators, and Management Team Members			
Individual Name	**Email Address**	**Department**	**Role in Research**
Dryver Huston	dryver.huston@uvm.edu	Mechanical Engineering	PI
Ting Tan	Ting.Tan@uvm.edu	Civil and Environmental Engineering	Co-PI

Table 6: Student Participants during the reporting period				
Student Name	**Email Address**	**Class**	**Major**	**Role in research**
Diarmuid Gregory		M.S./Senior	Mechanical Engineering	Graduate research assistant

Table 7: Student Graduates			
Student Name	**Role in Research**	**Degree**	**Graduation Date**
NA			

Table 8: Research Project Collaborators during the reporting period						
Organization	**Location**	**Contribution to the Project**				
		Financial Support	**In-Kind Support**	**Facilities**	**Collaborative Research**	**Personnel Exchanges**
NA						

Table 9: Other Collaborators			
Collaborator Name and Title	**Contact Information**	**Organization and Department**	**Contribution to Research**
James Wild	Vermont Agency of Transportation	Materials	Technical Champion

Who is the Technical Champion for this project?
Name: James Wild
Title: Concrete Materials Manager
Organization: Vermont Agency of Transportation
Location (City & State): Montpelier, VT
Email Address: Jim.Wild@vermont.gov

Changes:

Following the reopening of our laboratories in late summer 2020, we have started to undertake experiments directly related to this project. This delay has resulted in the need for a request for a no cost extension to be submitted in a separate document.

Planned Activities:

The planned activities in the next quarter will be twofold. The first is experimental where the plan is to develop more robust prestressing fibers. Polymer fiber experiments will look at methods to create thinner and longer fibers based on chitosan acetate-soaked yarns, possibly twisted. Metal fiber experiments will look at flexure-based compound mechanism geometries that use dissolution of a polymer, such as polyvinyl alcohol (PVA) to release internal forces to prestress the concrete. The goal would be to create a prestressing mechanism that is superior to the steel rings that demonstrated the technique in spring 2020. Numerical modeling methods will continue with efforts to understand the effects of random distribution of fibers and curved fibers. Assuming modest success with the efforts, we then plan to engage more closely with our Technical Champion (Jim Wild) at VTrans to see how this technique can be made practical for use as a potential performance concrete in transportation structures.