Research on Concrete Applications for Sustainable Transportation

RE-CAST

Missouri S&T

Vol. 3 :: Issue 2 :: APRIL 2016

In this issue:

CONSORTIUM MEMBERS:

Missouri University of Science and Technology

University of Illinois at Urbana-Champaign

Rutgers, The State University of New Jersey

University of Miami

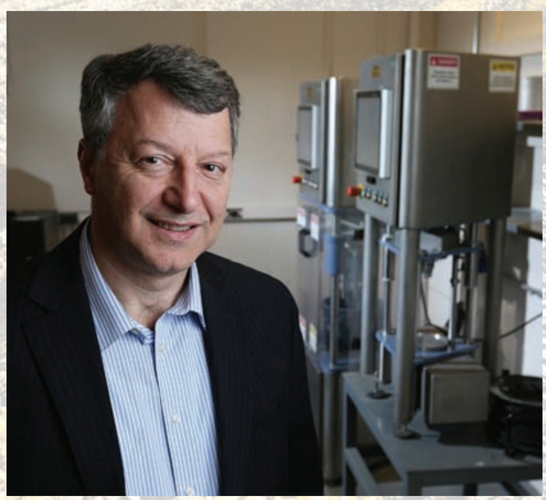
Southern University and A&M College

Director's Message

As Spring brings new life to the RE-CAST campuses, our team is hard at work as well.

In this issue, we provide a featured project update, highlighting some of the recent progress our faculty and students have completed at the University of Oklahoma and Missouri S&T.

We have hosted two very successful webinars, which are recorded and available in our RE-CAST Webinar Library. Dr. Saverio Spadea from University of Miami visited the Missouri S&T campus and gave a talk entitled "Bespoke FRP Reinforcement for Optimised Concrete Structures" and Dr. Maria Juenger of the University of Texas at Austin spoke about "The Future of Concrete may be in Its Past." Please watch our website for other upcoming webinars and events.



We are excited about an upcoming technology transfer conference that the RE-CAST team has helped organized. SCC2016 will be held in Washington, DC in May and we encourage our readers to read about it and attend.

Kamal H. Khayat
RE-CAST Director

OUTREACH

First Graders Become the Next Generation of Engineers

First graders learn about concrete at the University of Miami's Structures and Materials Laboratory

At the University of Miami's Structures and Materials Laboratory (SML) in the department of Civil, Architectural, and Environmental (CAE) Engineering, nothing is more fun than introducing young minds to the wonders of Engineering. The Laboratory often hosts high school and middle school students for demonstrations, activities, tours, and volunteer opportunities, but most recently they hosted a group of 37 first-grade students from Henry S. West Laboratory School.

The students enthusiastically crossed the campus pastures in a single file line, reminiscent of a group of ducklings following their mother. Only they were led by their teachers Mrs. Sadoian and Mrs. Duran with several of the students' parents as volunteers. One of the parents, Carolina Calzada, was appreciative of the event stating "thank you for having the kids here to learn about engineering today". The students arrived to the auditorium as quietly as they could manage to learn from Dr. Matthew Trussoni about what Engineers do. They eagerly raised their little hands to answer questions and offer opinions about the different types of engineering careers and how they relate to everyday things. Afterwards, they migrated to the lab for an exciting hands-on experience!

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OUTREACH

First Graders Become Engineers *(continued)*

"**Are you ready to make concrete?**" shouted Dr. Diana Arboleda, who showed the first graders the basic materials used to make concrete. They passed around bowls of gravel, sand, and "cement", which was actually flour since cement is not safe for children. One by one, the students picked up the loose concrete materials and compared the difference in textures. Immediately afterwards, they closely inspected a finished concrete block. They were then split into 10 smaller groups, guided by some of the lab volunteers, including, graduate students Seyedmorteza Khatibmasjedi, Phil Lavonas, Keith Holmes, and Valerie Zaldivar. Each group received a "recipe" card indicating the quantity of each component needed to make their concrete. Here, the first grade students learned how to properly measure different materials by weight, how to thoroughly combine ingredients, and the importance of water as a binding agent. In addition, they added coloring to their mixtures, which allowed each group to produce unique concrete mixtures of differing properties that were poured into cube molds.

Mr. Khatibmasjedi taught the final lesson on concrete strength by demonstrating the amount of force needed to break a concrete cube within a powerful compression machine. At the end, every first grader was awarded a miniature UM block as a prize for taking part in the event.

As the group left, Mrs. Sadoian said "The kids had so much fun, I loved that they were able to take part and actually mix the concrete. It was such a great field trip for them!"

As a part of the College of Engineering it is a very rewarding experience to introduce students of every age to the fundamental engineering concepts that have charted the course of humankind for centuries. **We aim to capture and develop the curiosity of students, so their dreams will include a career in STEM.**

The event was co-sponsored by RE-CAST and CICI, an NSF I/UCRC at University of Miami.

FEATURED PROJECT

Performance of FR-SCC for Repair of Bridge Sub-Structures and FR-SWC for Infrastructure Construction: *Full Scale Specimens*

- Jeffery S. Volz, PhD, Associate Professor of Civil Engineering, University of Oklahoma
- Jonathan Drury, PhD Candidate, University of Oklahoma
- Corey Wirkman, MS Student, University of Oklahoma

The goal of this study is to combine the beneficial aspects of self-consolidating concrete (SCC) with those of fiber reinforcement to develop the next generation of concrete repair materials. The high flowability of SCC is uniquely suited to concrete repair applications, which usually involve congested reinforcement, difficult placement conditions, and limited accessibility. Fiber reinforcement can significantly reduce the amount of cracking due to shrinkage of the repair material when placed over an existing hardened substrate. However, fiber reinforcement can have a negative effect on the flowability of SCC, and a balance is required between the flowability of the material and its ability to resist shrinkage cracking.

Researchers at the University of Oklahoma (OU) developed several potential fiber-reinforced, self-consolidating concrete (FR-SCC) mixtures for repair applications. One such mix design is shown in **Table 1.**

Table 1. FR-SCC Mix Design

FR-SCC Mix Design (per cubic yard)	
Material	**Amount**
Cement (Type I/II)	450 lb
Fly Ash (Class C)	225 lb (30% by mass)
Komponent (Type K Expansive Agent)	75 lb (10% by mass)
w/cm	0.40
Fine Aggregate (River Sand)	1371 lb
Coarse Aggregate (3/8 in. River Rock)	1233 lb
Macrosynthetic fiber (2.1 in)	7.7 lb (0.5% by Vol.)
Air Entraining Admixture	8.25 fl oz (1.1 fl oz/cwt)
HRWRA	67.50 fl oz (9.0 fl oz/cwt)

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FEATURED PROJECT
FR-SCC Full Scale Specimens *(continued)*

In addition to macrosynthetic fibers, this mix design incorporated a Type K expansive agent (Komponent) to further reduce the potential for shrinkage cracking. One of the problems is that as with the fibers, the Type K expansive agent initially had a negative effect on flowability of the material. Specifically, there was considerable slump flow loss over time, thus reducing the effectiveness of the material. The research team was able to counteract this process by using citric acid as a retarder to the rapid thickening action of the Komponent material.

The next phase involved full-scale beam specimens to evaluate the effectiveness of the FR-SCC repair material. The research team cast two sets of partial beams, three beams per set and shown in **Figure 1**, to be used for subsequent casting of the repair material. The beams measure 12 in. x 18 in. in cross section with an overall length of 14 ft. and were cast upside down, leaving a 6-in.-thick section for the subsequent repair material. The beams included two, 6-in.-diameter access ports formed near the beam ends and two, 1-in.-diameter vent holes formed near the beam third points.

Following a hydro-demolition phase to clean the surface and expose the underlying aggregate, the partial beams were rotated right-side up for installation of the flexural reinforcement and strain gages, as shown in **Figure 2**. The beams were then placed within the formwork, as shown in **Figure 3,** in preparation for casting the repair material.

Figure 1: Casting of two sets of partial beams, three beams per set

Figure 2: Installation of the flexural reinforcement and strain gages

Figure 3: Beams placed within formwork

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FEATURED PROJECT

FR-SCC Full Scale Specimens *(continued)*

Figure 4. Repair Material Placement

Figure 5. Completed Beam Specimens

Figures 4 and 5 show the repair material placement and a completed beam specimen after form removal, respectively. Testing of the beams is scheduled for late April.

SCC2016 - "Flowing Towards Sustainability"

Dates: May 15-18, 2016 **Location: Washington, D.C.**

Overview: The conference combines the 8th RILEM Symposium on SCC and the 6th North American Conference on the Design and Use of SCC and will be held jointly with the National Ready Mix Concrete Association (NRMCA) International Concrete Sustainability Conference. The conference is supported by Missouri S&T, the RECAST Center, NRMCA, the Center for Advanced Cement-Based Materials (ACBM), as well as RILEM and ACI. The joint *Flowing Towards Sustainability* conference will feature nearly 225 presentations, including case studies and recent developments in SCC and concrete sustainability.

Register today at: **www.scc2016.com**

FEATURED PROJECT

Development of Cost-Effective Ultra-High Performance Concrete

- Weina Meng, Ph.D. Candidate, Civil Engineering, Missouri S&T
- Kamal H. Khayat, Ph.D., Civil Engineering, Missouri S&T

With appropriate combination of cementitious materials, adequate sand gradation, and incorporation of fiber reinforcement and high-range water reducer (HRWR), ultra-high performance concrete (UHPC) can be produced to deliver high flowability (self-consolidation), superior mechanical properties, and exceptional durability. However, high material cost is restricting a wider acceptance of UHPC world-wide. The development of cost-effective UHPC is crucial for greater acceptance of this novel construction material.

High-volume replacement of cement with sustainable supplementary cementitious materials (SCMs), such as fly ash, ground granulated blast furnace slag (GGBS), and silica fume (SF), can reduce cement content without significantly changing strengths. A high-volume substitution of SCMs in proportioning UHPC can reduce HRWR demand and material costs. Ground quartz sand (0-0.6 mm) is typically used for producing UHPC. In this research, conventional concrete sand was used to replace the quartz sand, which also leads to considerable reduction in initial unit cost. Reducing the binder content can also decrease unit cost of UHPC. The binder content was reduced by optimizing the sand gradation to achieve high packing density. Reducing the steel fiber content is also vital in reducing unit cost of UHPC. While steel fibers greatly enhance tensile properties of UHPC, they impart an adverse effect on flowability. An optimum content of steel fibers should be adopted to balance the workability and mechanical performance.

A systematic mix design procedure was developed and implemented, which involved experimental validation and mathematical modeling. The mix design aims at achieving a densely-compacted cementitious matrix for UHPC with enhanced fresh and mechanical properties and relatively low unit cost. A number of cost-effective UHPC mixtures, which have high-volumes of SCMs, conventional concrete sand, and relatively low fiber content are proposed and evaluated in terms of workability, shrinkage, and durability characteristics.

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FEATURED PROJECT

Cost-Effective Ultra-High Performance Concrete *(continued)*

The designed mixtures are shown in **Table 1**. The characteristics of these mixtures are presented in **Table 2**.

Table 1. Proportioning of the designed UHPC mixtures (unit: kg/m³)

Code	Cemen	SF	FAC	GGBS	River sand (0–5 mm)	Masonry sand (0-2 mm)	HRWR	Total water	Steel fibers
G50SF5	548	42	-	535	694	304	16.0	167	156
G50	593	-	-	546	698	295	12.5	182	156
FAC40SF5	663	42	367	-	703	308	12.0	171	156
FAC60	486	-	556	-	715	304	5.5	188	156

Table 2. Characteristics of designed UHPC mixtures

Code		G50SF5	G50	FAC40SF5	FAC60
Flow time (s)		30	37	39	46
HRWR demand (%)		1.38	1.06	1.01	0.51
Mini slump flow (mm)		280	285	285	285
Yield stress (Pa)		35	37	34	30
Plastic viscosity (Pa·s)		39	50	44	29
Air content (%)		5	5	4	3.5
Specific gravity		2.45	2.43	2.44	2.41
Initial setting (h)		2	6	10	6
Final setting (h)		6	12	15	12
1 d – Standard curing (MPa)		52	64	65	69
28 d - Standard curing (MPa)		125	124	124	120
28 d – Heat curing (MPa)*		178	170	168	136
Splitting tensile strength (MPa)		14	12	12	10
Unit costs normalize by compressive strength ($/m³/MPa)		4.7	4.2	4.3	3.5
Modus of elasticity (GPa)		50	50	52	46
Flexural performance	First cracking load (kN)	21	24	21	20
	Peak load (kN)	29	33	31	28
	δ1 (mm)	0.085	0.080	0.093	0.089
	δp (mm)	0.690	0.653	0.820	0.635
	Peak strength (MPa)	20.2	22.8	21.3	20.1
	T150 (J)	48.8	51.5	51.1	49.4
Surface conductivity (kΩ·cm)		30	28	38	34
Durability factor (%)		99.8	99.8	99.7	99.7
Autogenous shrinkage at 28 d (µm/m)		602	253	545	593
Drying shrinkage at 98 d (µm/m)		430	56	466	500

*Heat curing: 24 hr steam curing at 90 °C after demolding, followed by 7-day moisture curing and then air drying until testing.

FEATURED PROJECT

Full-scale Investigation of Dynamic Segregation of Self-Consolidating Concrete

- Aida Margarita Ley Hernandez, M.S. Student, Civil Engineering, Missouri S&T
- Dimitri Feys, Ph.D., Civil Engineering, Missouri S&T
- Julie Ann Hartell, Ph.D., Civil Engineering, Oklahoma State University

Figure 1: Left: casting of beam 3. Right: beam 5 with three sets of prestress strands

Dynamic segregation of self-consolidating concrete (SCC) can lead to the separation of coarse aggregates from the suspending mortar during flow, resulting in an inhomogeneous distribution of the constituents which can affect the performance of the produced element. In recent studies, a characterization device, called the tilting box or T-box, was developed by Esmaeilkhanian et al. at the Université de Sherbrooke. Laboratory studies at Missouri S&T have further revealed the influence of SCC mix design and rheological parameters on dynamic segregation. However, the distinction between "segregating" and "non-segregating" concrete was based on principles of static stability and has not been validated. The purpose of the second part of this project, described below, is to investigate the upper limit of dynamic segregation evaluated from the T-box that does not negatively affect performance of the structural element.

For this purpose, nine beams were produced at Coreslab Structures, Inc. in Marshall, MO. Six of the beams were 30 ft in length, of which three were rectangular, 18" wide and 3 ft high, and three were MoDOT-approved I-beams. The three other beams were 60 ft long rectangular beams with the same dimensions as the shorter beams. Each beam was prestressed with six ½" strands in the bottom part and two at the top, combined with minimum stirrup reinforcement, spaced 18" apart beyond the anchorage zones for the lift points. Each beam was produced with a unique SCC mix design with different levels of yield stress, viscosity and segregation resistance. The SCC was allowed to flow freely from one end of the beam to the other. The delivery truck was not moved during casting, forcing the mixture to flow the full distance of 30 or 60 ft. In parallel to the casting, the fresh SCC was characterized by means of slump flow, T50, V-Funnel flow time, air content, density, static segregation (sieve stability), dynamic segregation (T-box) and rheology (ICAR).

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FEATURED PROJECT

Dynamic Segregation of SCC *(continued)*

After production and curing of the beams, ultrasonic pulse velocity (UPV) was used to evaluate homogenity of three of the rectangular beams. The measurements were done at 10 ft intervals and at five different heights. At each distance and each height, the ultrasonic pulse velocity values reported are the average of three measurements. The table below shows the value of the UPV measurements relative to the overall average value of 4130 m/s for beam 1. The column on the right and the row at the bottom show the standard deviation of the relative UPV measurement in horizontal and vertical direction, respectively. More variation is observed in the vertical direction of beam 1, which may be an indication of dynamic segregation.

UPV results, in % relative to the average value of 4130 m/s for beam 1.

		Distance from casting point (ft)				Stdev horizontal
		0	10	20	30	
Distance from top (in.)	6	96.9	97.8	97.1	99.5	1.2
	12	100.0	99.5	98.5	98.5	0.8
	18	99.7	100.8	99.2	99.1	0.8
	24	101.5	103.2	100.4	100.3	1.3
	30	103.3		103.8	101.0	1.5
Stdev vertical		2.4	2.3	2.5	1.0	

Figure 2. Dr. Hartell and her team performing the UPV measurements on the beams.

In addition, ½” strands were embedded in the top 12” and the middle 12” of beam, and the load necessary to cause a 1” slip of the strands was recorded. In the 30 ft beams, three sets (top and middle) of strands were incorporated, while the 60 ft beams had six sets. After the pull-out tests were completed, cores were drilled from each beam. At each flow distance, three cores were drilled at different heights: just above the bottom strands, in the middle and just below the top strand or under the casting line (the consequence of the beams not being entirely filled. Concrete was added afterwards to create the full beam, resulting in a cold joint). The first set of cores was drilled just outside of the anchorage zone and at each 10 ft, until just outside of the end anchorage zone. These cores are currently being tested for compressive strength, UPV, sorptivity and hardened air-void distribution. Deviations in these properties, combined with the onsite UPV measurements and bond strength results will lead to a performance-based recommendation for maximum dynamic segregation from the T-box that can correspond to uniform in-situ properties in SCC elements.

WEBINAR SERIES

Visit our Webinar Library at: recast.mst.edu/webinars

April 1, 2016

Presenter: Maria Juenger, Professor of Civil Engineering

University of Texas at Austin

"The Future of Concrete May be in Its Past"

February 10, 2016

Presenter: Dr. Saverio Spadea

Research Fellow at the University of Bath (UK)

"Bespoke FRP Reinforcement for Optimised Concrete Structures"

December 1, 2015

Presenter: Julie Hartell, Assistant Professor

Civil and Environmental Engineering

Oklahoma State University

"The Use of Resistivity Testing to Improve Concrete Quality"

October 22, 2015

Presenter: Charles Hanskat, P.E.

Executive Director, American Shotcrete Association

"Shotcrete for Repair and Rehabilitation of Highway Facilities"

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