

# PROGRAM PROGRESS PERFORMANCE REPORT #6

GRANT: DTRT13-G-UTC45  
Reporting Period: 4/1/2016 – 9/30/2016

**RE-CAST:**  
**REsearch on Concrete Applications for  
Sustainable Transportation**  
*Tier 1 University Transportation Center*

**Consortium Members:**

**Missouri University of Science and Technology**  
Rolla, MO

**University of Illinois at Urbana-Champaign**  
Urbana, IL

**Rutgers, The State University of New Jersey**  
Piscataway, NJ

**University of Miami**  
Coral Gables, FL

**Southern University and A&M College**  
Baton Rouge, LA

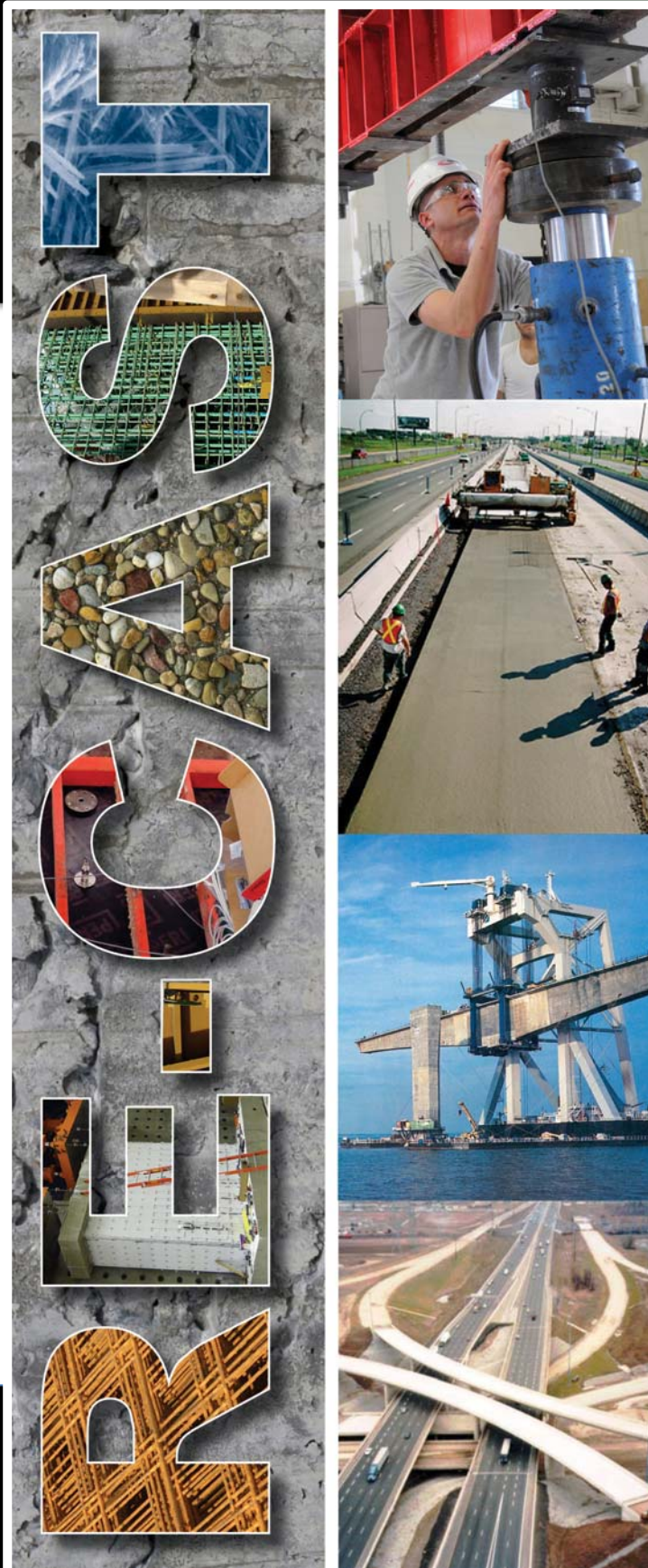


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## 1. ACCOMPLISHMENTS

### 1.A - What Are The Major Goals And Objectives Of The Program?

The overall goal of this grant is to develop the next generation of cement-based construction materials that are essential to address the growing technical and environmental requirements of the transportation infrastructure. The research program aims to fast-track the acceptance of these technologies and develop national standards and guidelines for their use in the reconstruction of the nation's infrastructure for the 21<sup>st</sup> Century.

#### Research Goals

The RE-CAST program goal stated above will be accomplished by performing the following research projects:

- 1-A. Ecological and Crack-Free High-Performance Concrete with Adapted Rheology
- 1-B. Formwork Pressure Measurements and Prediction of High-Performance Concrete with Adapted Rheology
- 1-C. Influence of Casting Conditions on Durability and Structural Performance of High-Performance Concrete with Adapted Rheology
- 2.A. High-Volume Recycled Materials for Sustainable Pavement Construction
- 2.B.1 Rapid Pavement Rehabilitation
- 2-B.2 Rapid Pavement Construction
- 3-A. Performance of Fiber Reinforced Self-Consolidating Concrete for Repair of Bridge Sub-Structures and fiber-reinforced Super-workable Concrete for Infrastructure Construction
- 3-B. Ultra-High Performance Fiber Reinforced Concrete for Infrastructure Rehabilitation
- 3-C. Performance of Reinforced Concrete Decks Strengthened with Fabric-Reinforced-Cementitious-Matrix Composites
- 3-C.2 FRP Reinforcement for Concrete: Performance Assessment and New Construction
- 1-A.2/3-C.3 Use of Internal Curing Materials to Improve Performance of Concrete Infrastructure

#### Education and Workforce Development (EWD) Goals

The main goal of RE-CAST's Education and Workforce Development program is to develop a workforce trained in the interdisciplinary scholarship needed to understand and address the complex issues facing the implementation of a durable, reliable, and sustainable infrastructure. This is to be achieved by creating multidisciplinary educational opportunities for undergraduate and graduate students in the theme areas of the Center, as well as outreach activities for practitioners.

#### Education Objectives:

- 1) RE-CAST faculty members will collaborate to create the following courses related to the major thrust areas of the Center:
  - Fundamentals of Rheology and Self-Consolidating Concrete (S&T and UIUC)
  - Structural Health Monitoring Applied to Transportation (Rutgers University and SUBR)
  - Repair Materials and Strategies for Civil Infrastructure (Multiple Universities)
- 2) RE-CAST is to collaborate with national laboratories and DOT research entities, such as NIST and MoDOT-R&D, to host students on scholarly efforts.
- 3) The Center will actively contribute to annual conferences in the transportation field organized by the consortium Universities, including the Transportation and Highway Engineering Conference and the Structural Engineering Conference at UIUC as well as the Transportation Infrastructure Conference at S&T.

## **Workforce Development / Outreach Objectives:**

### A. Outreach Activities to Attract New Entrants into the Transportation Field

- 1) RE-CAST members will seek opportunities to invite junior faculty from complementary fields, such as engineering management, mechanical engineering, chemical engineering and chemistry to team up with RE-CAST faculty on various research projects.
- 2) *Graduate Research Assistantship in Transportation Areas (GRATA)* - RE-CAST will provide graduate research assistantships to highly qualified Ph.D. students.
- 3) *Invited Speakers and Field Trip Visits* – RE-CAST will collaborate with the CIES at S&T and student societies at the participating Universities, including ASCE and ACI to organize bi-monthly seminars featuring invited speakers from industry
- 4) *ACI/Portland Cement Association (PCA)/Prestressed Concrete Institute (PCI) Co-Funded Scholarships* – RE-CAST will explore the possibility of providing matching funds to the scholarship programs that these organizations currently offer on a nation-wide basis for Fellowship students
- 5) *Student Competition* – RE-CAST will work with professional student societies to organize a new competition on sustainable construction materials.
  1. Two competitions will be organized at different locations: (a) design of concrete with a minimum of 50% of recycled materials with the highest strength at Rutgers University/SUBR; and (b) development of fiber-reinforced thin elements with minimum fiber content and maximum ductility at UM/S&T.
- 6) *UTC Student of the Year* – Each year, RE-CAST will select a Student of the Year based on scholarly merit and academic achievement.

### B. Primary and Secondary School Transportation Workforce Outreach

- 1) RE-CAST will support the *Minority Introduction to Technology and Engineering MITE* summer program.
- 2) *Proposed Activities with Career Technical Education System* – RE-CAST will reach out to local technical trade schools to offer short courses for students in construction-related degree programs to showcase recent developments within their trade.

## **Technology Transfer Goals**

The main goal of RE-CAST related to technology transfer is to work towards advancing transportation proficiency through technology transfer and educational opportunities and to make research results available to potential users in a form that can be implemented.

## **Technology Transfer Objectives:**

### A. Partnerships Across Sectors to Move Research into Practice

- 1) RE-CAST will collaborate with MO-LTAP and LA-LTAP to introduce and deliver new materials related to RE-CAST research themes that can be incorporated into workshops and technology transfer activities to service providers and professionals from the transportation industry.
- 2) RE-CAST will work with the Louisiana Transportation Research Center (LTRC) on technology transfer.

### B. Technical Assistance to Others in Applying Research Results

- 1) The Center's website will publish detailed documentation of special construction procedures through videos and photos and will also provide data from the research investigations.
- 2) Faculty from RE-CAST as well as technical staff will be available to provide technical assistance to practicing engineers and state and local agencies in the design and construction of the various materials developed by the RE-CAST program.
- 3) RE-CAST faculty will actively disseminate knowledge and develop guidelines and standards through numerous technical committees (TRB, ACI, ASCE, PCI, ACerS, RILEM, and CSA).

- 4) RE-CAST faculty members will also organize sessions at the technical conventions (e.g., TRB, ACI, ASTM, and ASCE) to disseminate the latest findings in the theme areas of sustainable construction materials, NDE and monitoring of infrastructure, service life prediction, and LCCA of transportation infrastructure.
  - 5) RE-CAST will also collaborate with various technical committees (e.g., ACI) to develop certification programs on special test methods dealing with the characterization of the materials developed in the research program, including rheological properties, dynamic segregation, and pumpability of HPC-AR.
  - 6) RE-CAST will also collaborate with other UTCs working in the State of Good Repair focus area as well as other national/regional centers, including the NSF Industry/University Coop. Research Center for the Integration of Composites into Infrastructure (CICI) at UM and the Infrastructure Monitoring and Evaluation (RIME) Group at Rutgers University.
- C. Technology Transfer Mechanisms/Creation of New Business Entities
- 1) The RE-CAST research team will work with the Technology Transfer and Economic Development Center (TTED) at S&T to develop marketing plans and subsequent commercialization of any product(s) and deliverables that can stem from the research program.
- D. Information Exchanges
- 1) The team will publish the findings of the proposed research in joint publications involving the different faculty and their students from the partnering consortium members.
  - 2) Social media (Facebook and LinkedIn) will be utilized to publicize on-going research, training, and technology transfer events, including field demonstrations, webinars, and educational videos stemming from research activities.
  - 3) Research outcomes of the RE-CAST program will be uploaded into the U.S. DOT Research Hub in a timely manner.
  - 4) A website with links to a listing of upcoming technology transfer events, educational seminars and workshops, presentations, and project reports.
  - 5) Quarterly newsletters highlighting project updates, featured faculty and students, and field implementations of research projects.

### **Diversity Goals**

The main goal of RE-CAST with regard to Diversity is to broaden participation and enhance diversity of the students, researchers, and practitioners involved in transportation-related activities and careers. In the consortium Universities, many initiatives have been created to ensure an inclusive environment related to race, ethnicity, gender, gender identity, sexuality, disability, economic class, religion, and country of origin.

### ***Diversity Objectives:***

- 1) Summer Internship for Underrepresented Students - SUBR and Rutgers University, through collaborative projects among faculty members of the Center, will offer summer internship programs to undergraduate students to undertake internship programs at partner institutions.
- 2) RE-CAST will provide support in educational and outreach activities and financial aid in the form of scholarships to bring underrepresented students into transportation engineering-learning opportunities through the following programs:
  - *The Women's Leadership Program* at S&T
  - *The Summer Transportation Institute* at SUBR
  - *The Gates Millennium Scholars Program* at UM
  - *The Hammond Scholars Program* at UM

## 1.B - What Was Accomplished Under These Goals?

### Research Objectives Accomplished:

University of Miami successfully completed the following projects and published the following reports:

Pino, V. and A. Nanni, “FRCM and FRP Composites for the Repair of Damaged PC Girders,” Project #00042134-04, RE-CAST: Research on Concrete Applications for Sustainable Transportation, USDOT: GRANT: DTRT13-G-UTC45, Project Period: 1/1/2014 – 12/31/16

O. Gooranorimi, T. Bradberry, E. Dauer, J. Myers, A. Nanni “FRP Reinforcement for Concrete: Performance Assessment and New Construction Volume I: Sierrita De La Cruz Creek Bridge” Project: # 00042134-04-103A, RE-CAST: Research on Concrete Applications for Sustainable Transportation, USDOT: GRANT: DTRT13-G-UTC45, Project Period: 10/1/15 – 7/1/16

G. Claire, M. Rossini, T. Cadenazzi, C. Morales, O. Gooranorimi, S. Spadea, and A. Nanni, “FRP Reinforcement for Concrete: Performance Assessment and New Construction Volume III: Construction and Monitoring of the Innovation Bridge” Project: # 00042134-04-103A, RE-CAST: Research on Concrete Applications for Sustainable Transportation, USDOT: GRANT: DTRT13-G-UTC45, Project Period: 10/1/15 – 7/1/16

### Project Updates

#### 1-A. Ecological and Crack-Free High-Performance Concrete with Adapted Rheology

##### Missouri S&T

The project seeks to develop and validate the behavior of a new class of ecological and crack-free high-performance concrete (Eco- and crack-free HPC) with the aim of reducing cement content and high resistance to shrinkage cracking designated for sustainable pavement (Eco-Pave-Crete) and transportation infrastructures (Eco-Bridge-Crete). Based on the obtained results from Phases 1, 2, 3, and 4 of the project, the effect of different binder compositions, aggregate characteristics, and shrinkage mitigating strategies were incorporated to design and optimize the Eco- and crack-free HPCs and evaluate key fresh and engineering properties. Full-scale sections, including slab and beam elements were constructed to evaluate the shrinkage deformation, cracking resistance, and flexural performance of the optimized Eco-Pave-Crete and Eco-Bridge-Crete. Concrete mixtures were prepared in local concrete batching plant to validate the ability of the proposed concretes to implement under actual field conditions. Based on the laboratory investigation and full-scale structural evaluation, guidelines and recommendations were established for the use of Eco- and crack-free HPC for pavement and transportation infrastructure applications. A Phase II project was also initiated to implement the findings on project Missouri DOT in collaboration with Rutgers University, Oklahoma University and NYU.

##### University of Oklahoma

The OU research team completed full-scale testing of bond and shear specimens constructed with eco-friendly concrete mix designs. The team also completed field implementation of concrete pavement constructed with eco-friendly concrete mix designs.

##### Rutgers University

In the effort to minimize cracks in concrete decks, the research team collected data on the performance of the crack free mix or HES-HPC mix post construction. The research team performed a survey of cracks observed in the concrete deck with the crack free mix after construction and prior to opening the bridge to truck traffic. (The information was included in crack maps and correlated with concrete test reports and data provided by the contractors. Each field pour was considered separately to eliminate other environmental parameters that may have an effect on the severity and extent of the observed cracks. Parameters that may affect the cracking potential of crack free mixes, such as curing hours, ambient temperature, concrete initial temperature, free shrinkage strain,

and structural type were considered in this analysis.) The results show that the curing time before opening the adjacent lane to the traffic is directly related to the crack severity. A longer curing time provides stronger concrete, and therefore cracking potential is minimized. The free shrinkage strain at 56 days also affects the cracking potential, and lower free shrinkage strain results in lower cracking potential. The ambient temperature and the initial concrete temperature have a clear effect on the cracking potential. Also, lower ambient temperature and higher initial concrete temperature result in higher cracking potential. Based on the coefficient of determination, the ambient temperature has higher influence on the cracking potential of crack free mixture than the initial concrete temperature.

### **New York University**

Life Cycle Cost Analysis:

- Designed and distributed surveys to team members

The team has designed surveys to get necessary LCCA input information from RE-CAST team members. The surveys have been distributed and filled out by Rutgers University team and Missouri S&T team and will be distributed to the other RE-CAST teams. This is done to create an interaction with the prospective users of our LCCA methodology and tools.

- Implemented proposed methodology to establish a step-by-step bridge LCCA example

Based on the information collected from the surveys, the NYU team performed a detailed LCCA for Rutgers team using proposed methodology. This methodology was implemented in easy-to-use spreadsheets and also in a Python programming environment. Beside agency cost, the team added “user costs” and “social costs” such as environmental costs of manufacturing used construction materials and other vehicle related costs, such as work zone delay cost, noise and emissions. A step-by-step presentation file is also provided for this example. In addition, three examples using Missouri S&T team’s new-technology material information were developed. The examples will be updated once more data are available after the lab / field tests.

- Development of a web-based tool for performing LCCA

The team made progress towards the development of a web based LCCA app, which is based on our developed methodology. Both deterministic and probabilistic approaches have been implemented and tested in the web app. Multiple scenarios and report generation capabilities were added as well. Such tools will be critical for asset management of concrete pavements and bridges.

These activities are carried out simultaneous with other projects, as indicated below.

### **Project 1-B. Formwork Pressure Measurements and Prediction of High-Performance Concrete with Adapted Rheology**

New sensors for formwork pressure measurement have been incorporated into our laboratory work. Sensors for this kind of work can be sensitive to temperature changes and impingement of aggregate on the sensor diaphragm in such a manner that error may be introduced. We are learning more about the robustness and reliability of pressure measurement, and this has drawn us to consider additional sensors. The granular fluid material model is proving to be a useful approach for concrete. Granular fluids models capture important characteristics of fresh concrete such as depth-dependent viscosity and change of measured yield stress when the fresh concrete is flowing or vibrated. When flowing, the action of aggregates will shear the paste and effectively overcome all yield stress. Thus when concrete is flowing or under vibration, the rheological behavior is closer to Newtonian than it is to Bingham.

We have conducted rheological studies of classic fluids and granular fluids under vibration. One of the motivations has been to understand the behavior of concrete under vibration (or flow). A simple yield-stress fluid (such as an aqueous polymer microgel particle suspension, Carbopol) does not de-air when vibrated like concrete.

Rather, concrete is a granular hard-particle suspension (such as glass beads in silicone oil) which does show the familiar de-airing behavior.

The literature is full of citations saying that concrete is a Bingham behavior, but these experiments are “static” in nature and the granular character of concrete is not having the same effect on rheology as it does when the material is moving. Thus, the granular structure of concrete is an essential part of understanding concrete flow, and in extension, formwork pressure.

Field investigation of the preplaced aggregate method for rapid repair of light cans embedded in O’Hare runways will continue with trial projects. We are working with our colleagues at O’Hare to find opportunities to execute these demo project in the coming months.

Follow-up to the Toronto “SCC Live” has continued with the publication of papers and presentations. The SCC2016 conference was held in Washington DC in May 2016. RE-CAST researchers were key organizers of SCC2016, and we had four students plus Prof. Lange in attendance at SCC2016 representing UIUC in addition to Prof. Khayat and another student working on form pressure from Missouri S&T.

### **Project 1-C. Influence of Casting Conditions on Durability and Structural Performance of High-Performance Concrete with Adapted Rheology**

#### **Project 1C-1: Dynamic segregation**

Based on the compressive strength and ultrasonic pulse velocity results, the homogeneity of nine precast beams, with lengths of 9 or 18 m, were analyzed. Results reveal that the beams were less homogeneous in the vertical direction at the casting point, and at the bottom in the horizontal direction. Characterization of concrete sections is ongoing to determine aggregate and air content, and durability parameters.

#### **Project 1-C-2. Changes in Rheology and Air Void System in SCC Due To Pumping**

Detailed analysis of the pumping tests from Toronto and Kansas City field trials has revealed that the spacing factor of air voids increases during pumping, and that this increase can be related to the applied pressure. Current ongoing research is looking into the physics of the lubrication layer formation to reduce pumping pressures.

### **Project 2-A. High-Volume Recycled Materials for Sustainable Pavement Construction**

#### **Missouri S&T**

Several concrete mixtures were produced in the laboratory to investigate mechanical properties, shrinkage, and durability of concrete for single-lift and double-lift pavement construction. These mixtures were proportioned with two water-to-cementitious materials ratios (w/cm) of 0.40 and 0.37. A binary composition of 75% Portland cement and 25% Class C fly ash, ternary composition with 50% Portland cement, 35% fly ash, and 15% slag, and a ternary blend with 50% Portland cement, 35% fly ash, and 15% glass powder were employed. Concrete mixtures with different fine and coarse RCA contents, were produced in the laboratory. Mixtures were tested for compressive strength, splitting tensile strength, flexural strength, modulus of elasticity, and drying shrinkage. In addition, durability against freeze and thaw cycles, durability against scaling caused by de-icing salts, abrasion resistance, sorptivity, and electrical resistivity were investigated. Candidate mixtures were proposed for different scenarios of field implementation. A phase II project was initiated to carry out field implementation in Missouri.

#### **UIUC**

The research team has advanced its work on lightweight foamed materials. We are studying how material design and admixtures provides for controlled set and strength control. These foamed materials are candidate materials for Engineered Material Arresting Systems (EMAS) which are used at the end of runways at airports. We believe that controlled low strength materials (CLSM) concepts can be used for EMAS applications, providing airports with sustainable and locally constructed options which have potential for cost savings.



The foamed materials used fines from crushing concrete for recycled aggregate applications. These fines have limited utility and are usually landfilled. But we hope to establish robust methods for producing foamed systems using recycled fines.

We have used x-ray computed tomography (XCT) to image the microstructure of cement foams. XCT is an advanced method that creates a 3-D image of structure that can then be used for finite element analysis to ascertain material properties of the bulk material. Our goal is to better understand the properties of foamed materials, and thereby establish mixture protocols for making foamed cement materials that can be used for airfield and pavement applications.

## **University of Oklahoma**

The OU research team completed field implementation of concrete pavement constructed with mixtures that maximized the percentage of recycled materials. The pavements are currently undergoing monitoring for thermal and shrinkage strains. The team has also begun investigating additional sources of RCA and developing a larger field implementation phase in collaboration with Missouri S&T and NYU.

## **New York University**

Life Cycle Cost Analysis: Refer to project update in Project 1-A.

### **Project 2-B-1. Rapid PCC Pavement Rehabilitation**

The research team continued on developing high early strength concrete (4,000 psi in 4 hours) to be used in rapid joint rehabilitation of PCC pavement. To minimize drying shrinkage and cracking, internal curing was adopted with light weight concrete and RCA. The early age strength of 3,500 psi was achieved with RCA stage to replace the recycled concrete aggregate with virgin limestone aggregate to further enhance the 4 hour strength. Field implementation is planned to observe surface cracking and any other potential problems of the optimized concretes, including joints.

### **Project 2-B-2. Rapid Pavement Construction**

#### **2-B-2-1. Research on Thixotropy and Workability Loss of Vibration-free Concrete in View Accelerating Pavement Construction by Slipforming**

Thixotropic build-up and breakdown of cementitious systems has been further investigated and revealed, preliminary, that the dispersing agent content has a major influence on thixotropic breakdown. An extensive literature review was performed on the behavior of concrete containing nano-particles, and an experimental plan has been laid out to further develop vibration free slipform concrete.

#### **2-B-2-2. Roller Compacted Concrete for Rapid Pavement Construction**

The research project seeks to develop guidelines for the use of RCC for rapid construction of concrete pavement. Work progress concentrated on the optimization of aggregate combinations to achieve maximum packing density, determining proper production techniques to adjust the air-void system in RCC. Work is underway to investigate ways to increase frost durability of RCC. For selected mixtures, compressive strength (ASTM C 39) at 7 and 28 days, surface resistivity (AASHTO TP95) up to 28 days, and freeze and thaw resistance (ASTM C 666, Procedure A) have been measured. The testing of the deicing salt-scaling (ASTM C 672) and permeable voids (ASTM C 642) is underway on the prepared samples. All tested concrete mixtures are found to satisfy strength requirements for pavement construction. The Surface resistivity of tested concrete shows all studied RCC mixtures are classified as moderate penetrability concrete. The optimized RCC mixtures made with high air-entraining admixture dosage and relatively high paste content was found to develop adequate air-void system. However, the frost durability of the concrete is not satisfactory in most cases. Work is under way to evaluate de-icing salt scaling resistance as well as drying shrinkage and other important mechanical properties for pavement design.

## **Project 3-A. Performance of Fiber Reinforced Self-Consolidating Concrete for Repair of Bridge Sub-Structures and fiber-reinforced Super-workable Concrete for Infrastructure Construction**

### **Missouri S&T**

Eight different types of fibers, including: propylene synthetic fiber (PLP), four types of hooked steel fiber (ST1), (3D), (4D) and (5D), carbon fiber (CA), hybrid of crimped steel fiber and polypropylene multifilament fiber (STPL), and micro-macro steel fibers (STST) were used to design Fiber-Reinforced Self-Consolidating Concrete (FR-SCC) with 0.5% fiber volume and Fiber-Reinforced Super-Workable Concrete (FR-SWC) mixtures with up to 0.75% fiber content were also designed. All of the investigated mixtures were tested for slump flow and visual stability index, mechanical properties and crack resistance were also performed for mixtures that showed acceptable workability. Overall performance evaluation using star diagram approach was then performed to evaluate rheology and passing ability, mechanical properties, and crack resistance. Mixtures that showed the highest overall performance were selected to undergo further evaluation in terms of drying shrinkage, restrained shrinkage, and freeze/thaw durability. Furthermore 20 monolithic full-scale beams were cast using conventional vibrated concrete (CVC), fiber reinforced conventional vibrated concrete (FR-CVC), SCC, FR-SCC, SWC and FR-SWC. Twelve reinforced concrete beams were cast using CVC to the two thirds then repaired with five different types of FR-SCC and one type of SCC. Macro fibers with fiber length  $\leq 50$  mm up to 0.5% fiber volume were successfully used with FR-SCC designated for repair. Macro fibers were successfully used with FR-SWC designated for construction with fiber length  $\leq 65$  mm up to 0.75% fiber volume. Field implementation phase is under planning to use candidate materials for bridge rehabilitation.

### **University of Oklahoma**

The OU research team completed development of several FR-SCC mix designs and constructed and tested full-scale flexural specimens repaired using these mix designs. The team has begun the implementation phase, which includes surveying the I-244 Bridge over the Arkansas River and developing repair drawings and specifications.

### **Rutgers University**

The team completely tested 10 full-scale beams with two layers (Class A substrate layer and FR-SCC repaired layer). The team evaluated the flexural strength of repaired beam with FR-SCC compared to control case. The results will be reported in the draft final report. The team is currently performing analytical modeling of various types of beams repaired with FR-SCC. A parametric study is underway and will provide more information on the sensitive parameters that would affect the performance of FR-SCC in structural repair applications.

### **New York University**

Life Cycle Cost Analysis: Refer to project update in Project 1-A.

## **Project 3-B. Ultra-High Performance Fiber Reinforced Concrete for Infrastructure Rehabilitation**

In this phase of the research, the coupled effect of using two expansive additives, CaO-based (5%, 7.5%, and 10%, by volume of cementitious materials) and MgO-based (5% and 7%, by volume of cementitious materials) expansive agents or shrinkage-reducing admixture (1.5% and 3%, by volume of water), and lightweight sand (25%, 40%, and 60%, by weight of total sand) on the performance of ultra-high performance concrete (UHPC) were evaluated. Investigated properties included workability, compressive strength, and total and autogenous shrinkage under different initial moist-curing durations (0, 3, and 7 days). The results indicated that shrinkage was considerably reduced (up to 60%) by increasing of lightweight sand content to 60% and moist-curing duration to 7d. The incorporation of lightweight sand was shown to have a greater influence on the shrinkage mitigation on enhancing the mechanical properties. The addition of either expansive agent type or SRA led to considerable reduction in total and autogenous shrinkage.

The team developed a rheology control method for improving steel fiber distribution and flexural performance of UHPC by adjusting the rheological properties of the mortar of PC before the incorporation of steel fibers.

Correlations between plastic viscosity of UHPC mortar, steel fiber distribution, and flexural properties of hardened UHPC are established. The optimal plastic viscosity of the UHPC mortar that allows for optimum fiber distribution and flexural performance was established. For UHPC with 2 vol. % micro steel fibers, the optimal mini V-funnel flow time was determined to be 46 s, which corresponds to plastic viscosity (53 Pa·s). Such viscosity level of the self-leveling UHPC can ensure the greatest fiber dispersion uniformity and flexural performance. Plans are underway to use UHPC of low shrinkage characteristics for thin bridge overlays (1-2 in.). In total, 20 slab section measuring 3 x 8 ft will be cast with conventional concrete and UHPC overlays of different compositions and thicknesses.

### **Project 3-C. Performance of Reinforced Concrete Decks Strengthened with Fabric-Reinforced-Cementitious-Matrix Composites**

#### **Missouri S&T**

During this reporting period much of the experimental laboratory work has been completed. A PhD student is expected to defend her dissertation by the end of the calendar year. The project Co-PI has successfully worked with the Missouri Department of Transportation to identify a four span candidate bridge for rehabilitation to serve as the implementation test bed. The design for the rehabilitation and strengthening is expected to be undertaken during the next reporting period is approved by the project director and co-directors.

#### **University of Miami**

During the reporting period, six beams were strengthened with 4 ply AR-Glass FRCM to be tested under cyclic loading. Testing of PBO and Carbon FRCM strengthened beams is complete. Consequently, testing of AR-Glass FRCM beams under static and cyclic loading was started. Static tests were done per test matrix. Based on the results of static tests, fatigue test were initiated. Fatigue tests were stopped upon reaching two million cycles or failure, whichever was the first to occur. Three beams strengthened with 4ply AR-Glass FRCM were tested under cyclic loading and the tests are ongoing for this FRCM system. Data analysis for static and fatigue beams strengthened with PBO and Carbon FRCM systems is complete. Analysis for AR-Glass FRCM strengthened beams under monotonic loading is in progress.

### **Education and Workforce Development (EWD) / Outreach Objectives Accomplished**

- 1) RE-CAST hosted its **13th research seminar** on April 6, 2016 – see Attachment A.
- 2) RE-CAST hosted its **14th research seminar** on July 29, 2016– see Attachment B.
- 3) RE-CAST hosted its **15th research seminar** on August 12, 2016 – see Attachment C.
- 4) University of Miami hosted a camp for first grade students to learn to make concrete and introduce student over very early age to the fundamental engineering concepts that have charted the course of humankind for centuries.
- 5) Cements Division meeting of the American Ceramic Society was held in Evanston, IL on July 10-12, 2016. UIUC sent eight students with poster presentations. Prof. Lange presented oral presentation on aspects of this project and contributed to a special session honoring Prof. S.P. Shah for his research career.
- 6) SCC2016 conference was held in May 2016. Many RE-CAST faculty and students attended/presented.
- 7) Prof. Khayat gave a keynote speech at the Materials, Systems and Structures in Civil Engineering Conference, MSSCE 2016, Lyngby, Copenhagen, Denmark, August 21- 24 2016 as well as at the 8th RILEM Conference on Self-Compacting Concrete, Washington, D.C., May 15-18, 2016.
- 8) Prof. Lange will deliver a Shortcourse at Southeast University in Nanjing, China in February 2017. The course is called “Innovations in Civil Engineering Materials” and is organized in collaboration with Prof. Yamei Zhang at SEU.

- 9) Prof. Lange presented a keynote lecture at “Advances in Concrete Technology” Symposium in Muscat, Oman on May 9, 2016. The symposium was organized by Assarain Concrete Products & Trading LLC and Sunanda Global LLC. The symposium attracted participation of about 150 professionals who learned about aspects of emerging concrete technology, including self-consolidating concrete.

### Technology Transfer Objectives Accomplished

- 1) Social media (**Facebook and LinkedIn**) pages have been utilized to publicize on-going research, training, and technology transfer events.
- 2) The RE-CAST **website has been updated** to contain links to listing of upcoming technology transfer events, educational seminars and workshops, presentations, and project reports.
- 3) The ninth quarterly **newsletter** was published in April 2016 – see Attachment D.
- 4) The tenth quarterly **newsletter** was published in July 2016 – see Attachment E.
- 5) On behalf of Missouri S&T and the RE-CAST UTC, Dr. Kamal Khayat and his team organized the Eighth International RILEM Symposium on Self-Compacting Concrete and the Sixth North-American Conference on the Design and Use of Self-Consolidating Concrete (SCC), from May 15-18, 2016, in Washington, D.C. Nearly 120 papers were presented during three parallel sessions in addition to 25 papers discussed during the poster session. The conference proceedings included a peer-reviewed volume (RILEM PRO 100) with 47 papers and a supplementary volume with the remaining papers. Over 300 participants from 32 countries attended the event.
- 6) RE-CAST students Weina Meng and Iman Mehdipour presented concrete materials and facilities of RE-CAST to high-school students in a Materials Summer Camp that took place in July 2016 in Rolla. Missouri S&T’s Materials Camp is a summer residential camp for high school juniors and seniors interested in the science, technology, engineering and math (STEM) fields. Campers learned about the fresh properties testing of concrete. Faculty members and students also gave campers a variety of demonstrations and trips that actively explored concrete materials science and helped them to learn how to use state-of-the-art research equipment.
- 7) Prof. Lange developed repair methods and transferred these methods to Chicago CDA personnel.
- 8) Prof. Lange presented a keynote lecture on “Innovations in Recycling Concrete Materials” at the 6th Amazon & Pacific Green Materials Congress and Sustainable Construction Materials LAT-RILEM Conference in Cali, Colombia on April 27-29, 2016, as well as an invited lecture on “Research with Impact at Airports” to students and faculty at the Universidad de Pilato in Bogata, Colombia on May 3, 2016.
- 9) Several RE-CAST faculty presented keynote and invited presentations. A few examples are included below.

### Diversity Objectives Accomplished

- 1) UIUC student Nanaissa Maiga, a black female student with French citizenship, participated as undergraduate researcher in Prof. D. Lange’s group in Summer 2016 as she did in the past. She worked on concrete materials testing under the supervision of graduate students sponsored by the UTC funding.
- 2) Jamie Clark, an African American female grad student, is a researcher in Prof. Lange’s group. She works on microstructural investigations that characterize the foamed cement materials mentioned earlier.
- 2) Southern University and A&M College hosted **Summer Transportation and Energy Institute (STEI)** during June 6 - 30, 2016. Dr. Alex Shin of RE-CAST, participated in the STEI as the speaker on June 20, 2016. He presented his on-going research on rapid pavement repair sponsored by RE-CAST and related subjects.

- 3) Oklahoma University sponsored a summer internship for Amy Crone and Candace Alsenay, two female undergraduate civil engineering students at OU. Amy and Candace were involved in the field implementation of RE-CAST Projects 2A and 3A. Candace is also a Native American.

## **1.C - What Opportunities For Training And Professional Development Has The Program Provided?**

The RE-CAST has provided **three research seminars** as professional development opportunities. The topics/dates of those seminars are:

1. Date: April 6, 2016
  - Presenter: Dr. Maria Juenger, Professor of Civil Engineering, Univ. of Texas at Austin
  - Topic: *The Future of Concrete may be in its past*
  - Recorded and posted on RE-CAST website
2. Date: July 29, 2016
  - RE-CAST Presenter: Dr. Antonio Nanni, University of Miami
  - Topic: *Extending the service life of new reinforced concrete structures by using advanced composite materials workshop - Joint workshop offered with University of Bath*
3. Date: August 12, 2016
  - Presenter: Dr. Kaan Ozbay, Professor of Civil Engineering, New York University
  - Topic: *An Overview of a Network-wide Probabilistic Life Cycle Cost Analysis Methodology and Implementation Framework for New Concrete based Materials and Construction Techniques*
  - Recorded and posted on RE-CAST website
4. UIUC student Nanaissa Maiga, a black female student with French citizenship, will continue as undergraduate researcher, thus advancing diversity goals through the UTC program.
5. Missouri S&T master student, Margarita Hernandez-Ley, a Spanish speaking female student, completed her M.S. with Professor Feys and is admitted for Ph.D. studies related to RE-CAST.

## **1.D - How Have The Results Been Disseminated?**

The recordings of the previous seminars are available on the RE-CAST website. A summary of all RE-CAST activities are outlined in the Center's quarterly newsletter, which is distributed to approx. 1200 recipients.

Initial findings of various research projects are being compiled to prepare scientific papers and technical presentations at various conventions. Some these findings have already been disseminated at the World of Concrete 2016 in Las Vegas, 2016 TRB Meeting in Washington, D.C., ACI Spring 2016 Convention in Milwaukee, as well as overseas, including the 14<sup>th</sup> International Congress on Cement Chemistry, ICCS 2015, in Nov. 2015 in Beijing, China.

## **1. E - What Do You Plan To Do During The Next Reporting Period To Accomplish The Goals And Objectives?**

- Publish ninth and tenth newsletters
- Schedule 14th, 15th and 16th bi-monthly research seminars, as follows:
  - Date: October 11, 2016
    - Presenter: Dr. Hani Nassif, Professor, Rutgers University
    - Topic: *Structural Health Monitoring (SHM) of Corrosion Potential in Concrete Bridge Decks*
    - Recorded and posted on RE-CAST website
  - Date: November 9, 2016

- Joint webinar with Center for Environmentally Sustainable Transportation in Cold Climates (CESTiCC) University of Alaska Fairbanks
  - Topic: TBD
- Date: November 17, 2016
  - Presenter: Dr. Raissa Ferron, Assistant Professor, University of Texas at Austin
  - Topic: *Engineering, smart, stimuli-responsive cementitious composites*
  - This webinar will be recorded and posted on RE-CAST website
- **Summer Transportation Institute at SUBR** - Southern University and A&M College will host National Summer Transportation Institute (NSTI) 2017. The College of Engineering will serve as the housing facility for the institute's classroom based activities and construction projects. Up to 20 high school participants (9<sup>th</sup> and 10<sup>th</sup> grades) will be selected from parishes in Louisiana. Dr. H. Shin from RE-CAST will participate in the NSTI as the speaker. He will present the Center's on-going research on rapid pavement repair and related subjects.
- **S&T Transportation Infrastructure Conference** - Planned for November 18, 2016 at Missouri S&T
- UM plans to continue work on and complete Project II as well as complete Task two of Project III.
- The Rutgers team will finalize the laboratory testing program to evaluate the shrinkage performance of FR-SCC with steel fiber. In order to simulate the restrained condition of bridge deck, a comprehensive restrained shrinkage ring tests in accordance with the ASTM and AASHTO standard will be performed. In addition, the team will design the long-term testing program to evaluate the effect of different fibers on the creep behavior. One control SCC and two FR-SCC with steel and polypropylene fiber will be utilized for this research. The team will also continue developing the finite element models of repaired beam tested. After calibrating the FE models using the laboratory testing results, a parametric study will be performed to provide more information on the sensitive parameters that would affect the performance of FR-SCC in structural repair applications.

## 2. PRODUCTS

### 2.A - Publications, Conference Papers, and Presentations

- 1) **13th research seminar** on April 6, 2016 – see Attachment A.
- 2) **14th research seminar** on July 29, 2016– see Attachment B.
- 3) **15th research seminar** on August 12, 2016 – see Attachment C.
- 4) **9th newsletter** published in April 2016 – see Attachment D.
- 5) **10th newsletter** published in July 2016 – see Attachment E.
- 6) Journal Publications:

Aïssoun, B., Hwang, S.D., and **Khayat, K.H.**, Influence of Aggregate Characteristics on Workability of Superworkable Concrete, *Materials and Structures*, 49 (2), 2016, pp. 597-609.

Aïssoun, B., **Khayat, K.**, and Gallias, J.-L., Variations of Sorptivity with Rheological Properties of Concrete Cover in Self-Consolidating Concrete, *Construction and Building Materials*, 113, 15 June 2016, Pages 113–120.

Arboleda, D., F. De Caso y Basalo and **A. Nanni**, “Comportamiento de materiales compuestos a base de matriz cementicia reforzada con tejido (FRCM),” *REHABEND 2016*, Burgos, España, May 24-27, 2016, pp. 1981-87.

Feys, D. De Schutter, G., **Khayat, K.H.**, and Verhoeven, R., Changes in Rheology of Self-Consolidating Concrete Induced by Pumping, *Materials and Structures*, 49 (11) Nov. 2016, pp. 4657-4677.

Feys, D., Khayat, K.H., and Khatib, R., How do Concrete Rheology, Tribology, Flow Rate and Pipe Radius Influence Pumping Pressure? *Cement and Concrete Composites*, 66, 2016, pp. 38-46.

Foudazi, A., Mehdipour, I., Donnell, K.M., and **Khayat, K.H.**, Evaluation of Steel Fiber Distribution in Cement-Based Materials Using Active Microwave. *Thermography, Materials and Structures*, V. 49, Issue 2, Dec. 2016, pp. 5051-5065 (on line since March 2016: <http://link.springer.com/article/10.1617/s11527-016-0843-3/fulltext.html>).

I. You, J. Choi, G. Zi, **D.A. Lange**, "Pozzolanic reaction of waste glass sludge incorporating precipitation additives," *Computers and Concrete*, Vol. 17, No. 2, (DOI: 10.12989.cac.2016.17.2.000), 2016.

J. Xiao, C. Sun, **D.A. Lange**, "Effect of joint interface conditions on shear transfer behavior of recycled aggregate concrete," *Construction and Building Materials* 105 (2016) 343-355.

Karim, Z., F. De Caso y Basalo and A. **Nanni**, "Durability Assessment of Advance Composite Technologies for Structural Rehabilitation," REHABEND 2016, Burgos, España, May 24-27, 2016, pp. 1905-11.

Mehdipour, I., **Khayat, K.H.**, Effect of Supplementary Cementitious Material Content and Binder Dispersion on Packing Density and Compressive Strength of Sustainable Cement Paste, *ACI Materials Jr.*, 113 (3), May 2016, pp. 361-372.

Meng, W., Valipour, M., and **Khayat, K.H.**, Optimization and Performance of Cost-Effective Ultra-High Performance Concrete, *Materials and Structures*, 50(1), pp. 1-6, on-line Aug. 10, 2016, DOI:10.1617/s11527-016-0896-3.

Meng, W., **Khayat, K.H.**, Mechanical Properties of Ultra-High-Performance Concrete Enhanced with Graphite Nanoplatelets and Carbon Nanofibers, *Composites Part B: Engineering*, on-line Sept. 23, 2016, DOI: : 10.1016/j.compositesb.2016.09.069.

**Nanni, A.**, G. Claire, F. De Caso and O. Gooranorimi, "Concrete and Composites Pedestrian Bridge," *Concrete International*, Nov. 2016, pp. 53-59.

R. Serpell, J. Henschen, J. Roesler, **D.A. Lange**, "Relative Proportioning Method for Controlled Low-Strength Material," *ACI Materials Journal*, Vol. 112, No. 2, pp 179-188, 2015.

S. Zhao, E. Van Dam, **D.A. Lange**, W. Sun, "Abrasion resistance and nano-scratch behavior of an ultra-high performance concrete," *ASCE J. Mat. Civil Eng.*, Accepted 2016.

Sadati, S., Arezoumandi, M., **Khayat, K.H.**, and **Volz, J.S.**, "Shear Performance of Reinforced Concrete Beams Incorporating Recycled Concrete Aggregate and High-Volume Fly Ash," *Journal of Cleaner Production*, V. 115, Mar. 2016, pp. 284-293.

Wu, Z., Shi, C., and **Khayat, K.H.**, Effect of Silica Fume Content on Microstructure Development and Bond to Steel Fiber in Ultra-High Strength Cement-Based Materials (UHSC), *Cement and Concrete Research*, 2016, 71, 97-109.

Wu, Z., Shi, C., **Khayat, K.H.**, Wan, S., Effects of Different Nanomaterials on Hardening and Performance of Ultra-High Strength Concrete (UHSC). *Cement and Concrete Composites*, 2016, 70, pp. 24-34.

Y. Song, R. Zou, D. Castaneda, K.A. Riding, and **D.A. Lange**, "Advances in Measuring Air-Void Parameters in Hardened Concrete Using a Flatbed Scanner," *ASTM J. Testing and Evaluation*, accepted 2016.

7) Keynote/Invited Presentations:

## **Kamal H. Khayat**

Keynote speaker, *Materials, Systems and Structures in Civil Engineering*, MSSCE 2016, Lyngby, Copenhagen, Denmark, August 21- 24 2016

Keynote speaker, 8th RILEM Conference on Self-Compacting Concrete, Washington, D.C., May 15-18, 2016

## David Lange

Keynote lecture on “Innovations in Recycling Concrete Materials” at the 6th Amazon & Pacific Green Materials Congress and Sustainable Construction Materials LAT-RILEM Conference in Cali, Colombia on April 27-29, 2016.

Invited lecture on “Research with Impact at Airports” to students and faculty at the Universidad de Pilato in Bogota, Colombia on May 3, 2016.

Invited lecture “Recycled Concrete for Airport Pavements” at the Universidad Nacional de Colombia in Manizales, Colombia on May 2, 2016.

## Antonio Nanni

Nanni, A. “The Role of Cementitious Materials in the Next Decade,” Fourth International Conference on Sustainable Construction Materials and Technologies (SCMT4), August 7-11, 2016.

Pino, V., H. Akbari Hadad, F. De Caso, A. Nanni, U.A. Ebead, A. El Refai, “Performance of FRCM Strengthened RC Beams Subject to Fatigue,” Fourth International Conference on Sustainable Construction Materials and Technologies (SCMT4), August 7-11, 2016.

Gooranorimi, O., G. Claire, F. De Caso, W. Suaris, and A. Nanni, “Residual Fire Resistance of GFRP Reinforced Concrete Elements,” Fourth International Conference on Sustainable Construction Materials and Technologies (SCMT4), August 7-11, 2016.

## Hani Nassif

Hani Nassif, Zeeshan Ghanchi, and Chaekuk Na, “Crack Resistance of Polypropylene Fiber Reinforced Self-Consolidating Concrete under Restrained Shrinkage Condition”, SCC2016, May 15-18, 2016, Washington D.C.

## Jeffery Volz

“Concrete Pavement Containing High Volumes of Recycled Materials,” 2016 Oklahoma Transportation Research Day, Oklahoma City, Oklahoma (Invited Presentation).

## Alex Shin

“Development of Rapid PCC Pavement Repair Materials,” 4th International Conference on Sustainable Construction Materials and Technologies (SCMT4), August 7 – 11, 2016, Las Vegas, Nevada.

## **2.B - Website(s) or Other Internet Site(s)**

**Website:** <http://recast.mst.edu>

**Facebook:** <https://www.facebook.com/RECASTCenter>

**LinkedIn:** [https://www.linkedin.com/groups/RECAST-University-Transportation-Center-6626216?trk=anet\\_ug\\_hm&gid=6626216&home=](https://www.linkedin.com/groups/RECAST-University-Transportation-Center-6626216?trk=anet_ug_hm&gid=6626216&home=)

**2.C - Technologies or Techniques - Nothing to Report.**

**2.D - Inventions, Patent Applications, and/or Licenses - Nothing to Report.**

**2.E - Other Products, Such As Data Or Databases, Physical Collections, Audio Or Video Products, Software Or Netware, Models, Educational Aids Or Curricula, Instruments, Or Equipment.**

Nothing to Report.

## **3. PARTICIPANTS & COLLABORATING ORGANIZATIONS**

### **3.A - What Organizations Have Been Involved As Partners?**

The main consortium members of this University Transportation Center remain the same as the proposal:



- Missouri University of Science and Technology, Rolla, MO - LEAD
- University of Illinois at Urbana-Champaign, Urbana, IL
- Rutgers, The State University of New Jersey, Piscataway, NJ
- University of Miami, Coral Gables, FL
- Southern University and A&M College, Baton Rouge, LA

As stated in the proposal, the RE-CAST team is also partnered with Dr. H. Celik Ozyildirim, as a consultant, from the Virginia Center for Transportation Innovation and Research, Charlottesville, VA. Dr. Ozyildirim's main implication is to provide input for field implementation and development of specifications and standards.

In addition to the main consortium members, two additional universities are collaborating with with RE-CAST, due to faculty moving to those universities after the proposal was submitted. Those new partners are:

- The University of Oklahoma, Norman, OK (Dr. Jeffrey Volz)
- New York University Polytechnic School of Engineering, Brooklyn, NY (Dr. Kaan Ozbay)

Several state governments and industrial partners are involved in RE-CAST projects and are providing financial and in-kind support to the research program. The highlighted agencies are new in this reporting period:

- AIG
- American Concrete Pavement Association, Oklahoma and Arkansas Chapter
- Bowman, Barrett and Associates, Chicago, IL, financial support
- **CBM-St-Mary's Toronto**
- Chicago Department of Aviation
- City University of New York
- Clayton Concrete Materials and Ready Mix, Edison, NJ
- Chicago Bridge and Iron Company (CB&I), Trenton, NJ
- Coreslab Structures Inc., Marshall, MO
- Dewberry, Bloomfield, NJ, financial support
- Dolese Bros. Co., Oklahoma City, OK financial support
- Eastern Concrete Materials and Ready Mix, Bogota, NJ
- **EllisDon, Toronto**
- Euclid Chemicals, East Brunswick, NJ
- Garver Engineering, Norman, OK
- Grand River Dam Authority, Vinita, OK
- Greenman Pedersen, Inc. (GPI), Lebanon, NJ, financial support
- Hanyang University (Korea)
- K-FIVE Construction Corp., Lemont, IL
- Kansas State University
- Kyunghee Univ. (Korea)
- LaFarge North America (Cement Plant), Whitehall, PA
- Louisiana Transportation Research Center (LTRC), Baton Rouge, LA, financial support
- Missouri Department of Transportation, Jefferson City, MO, financial support
- Missouri University of Science and Technology, Rolla, MO, in-kind support
- New Jersey Department of Transportation Research Division, West Trenton, NJ, financial support
- New Jersey Turnpike Authority, Woodbridge, NJ, financial support
- New York City Department of Transportation
- New York State Department of Transportation

- New York University Polytechnic School of Engineering, Brooklyn, NY, financial support
- Noblis
- O'Hare Modernization Program, Chicago, IL, financial support
- Oklahoma Department of Transportation, Oklahoma City, OK
- Oklahoma City, Norman, and Tulsa, OK, City Planning Departments
- Oklahoma State University
- Oklahoma Turnpike Authority, Oklahoma City, OK
- Small Modular Reactor Research and Education Consortium, financial support
- State University of New York Maritime College
- State University of New York at Stony Brook
- Structural Technologies, Hanover, MD, financial support
- University of Illinois, Urbana-Champaign, Champaign, IL, in-kind support
- University of Miami, Coral Gables, FL, financial support
- University of Nevada, Las Vegas
- University of Oklahoma, financial and in-kind support
- University of Sao Paulo (Brazil)
- **University of Sherbrooke (Canada)**
- Virginia Center for Transportation Innovation and Research (via VirginiaTech) Charlottesville, VA
- Qatar Foundation

### 3.B - Have Other Collaborators Or Contacts Been Involved?

The Research Advisory Committee (RAC) is composed of the following individuals:

**William Stone**, Research Administrator, P.E. (RAC President)

*Missouri Department of Transportation, Jefferson City, MO*

**Ross Anderson**, Senior Vice President

*Bowman Barrett & Associates, Chicago, IL*

**Casimir Bognacki**, Chief of Materials Engineering

*Port Authority of New York and New Jersey, New York, NY*

**Harvey DeFord**, Ph.D., Structural Materials Research Specialist

*Florida Department of Transportation State Materials Office, Gainesville, FL*

**Chiara "Clarissa" Ferraris**, Ph.D., Physicist

*National Institute of Standards and Technology, Gaithersburg, MD*

**Jim Myers**, P.E., Senior Staff Engineer

*Coreslab Structures, Inc., Marshall, MO*

**Karthik Obla**, Ph.D. P.E., Vice President, Technical Services

*National Ready Mix Concrete Association, Silver Spring, MD*

**Zhongjie "Doc" Zhang**, Ph.D., Pavement Geotechnical Research Administrator

*Louisiana Transportation Research Center, Baton Rouge, LA*

## 4. IMPACT

### 4.A - What Is The Impact On The Development Of The Principal Discipline(s) Of The Program?

We are delivering strategies for new materials that utilize recycled fine and coarse materials from concrete crushing operations that would otherwise be landfilled. The new materials are Controlled Low Strength Materials

that are suitable for backfill for construction projects around the airport as well as green concrete material that can be used for pavement and airfield applications.

The results of work on FR-SCC for repair will be implemented on job sites in MO, OK, and NJ. Technical specifications are developed. Similar efforts are done for the eco-crete projects

The field demonstration project can be used as case study that shows the applicability and encourages implementation of new mix design developed by RECAST member for concrete bridge decks, pavements, airfields or other application.

The customized LCCA tool created by the NYU team will enable prospective users to do their own LCCA without major effort. In case of the availability of their state's road shape files, they can easily extract information from these files. We are now capable of doing this automated data extraction from NJ shape files.

#### **4.B - What Is The Impact On Other Disciplines?**

Our work involves laboratory studies of flow and rheology of cement based systems, and the work involves fluid mechanics models of suspensions where properties are related to particle size and shape. This general knowledge applies to other disciplines such as Materials Science as it relates to generic suspensions. Our work also advances the state of the art in imaging microstructure of cement based materials by using x-ray computed tomography. These 3D images are being used to support numerical methods to assess mechanical properties.

The customized LCCA tool created by the NYU team will have an impact on all the disciplines of the program since it will help decision makers to compare alternative technologies / materials.

The field demonstration and SHM of FR-SCC deck will help the transportation agencies understand the benefits of FR-SCC applications and adopt such materials in future designs or repair and maintenance projects. Both demonstration projects can be used as case studies that show the applicability and encourages implementation of FR-SCC for concrete bridge decks.

#### **4.C - What Is The Impact On The Development Of Transportation Workforce Development?**

Several graduate and undergraduate students have been recruited to staff the RE-CAST projects for FY2014, FY2015, and FY2016. For the undergraduate students, working with graduate students and world-renown faculty helps them with experiential learning activities and raise their interest in the transportation field.

We have been involved in training activities related to new repair methods at the Chicago O'Hare Airport and some state DOTs.

The customized LCCA methodology and web-based tool created by the NYU team is expected to be easier to use and thus more people will be able to use it.

The technical specifications for use of FR-SCC will help transportation agencies understand the feasibility and adoption of FR-SCC in various infrastructure applications.

#### **4.E - What Is The Impact On Physical, Institutional, And Information Resources At The University Or Other Partner Institutions? - Nothing to report at this time.**

#### **4.F - What Is The Impact On Technology Transfer?**

Several invited speakers/keynote speaker lectures are scheduled for the Winter/Spring of 2016/2017, many of which will report on some of the research findings of RE-CAST projects.

SCC2016, an international conference focusing on the Design and Use of Self-Consolidating Concrete, was supported by RE-CAST. This event attracted engineers, architects, government officials, researchers, academics, students, contractors, and industry professionals from around the world. The international conference was held in

conjunction with the 11<sup>th</sup> annual International Concrete Sustainability Conference (2016 ICSC). The combined conferences (Flowing toward Sustainability) involved five parallel sessions with nearly 150 technical papers presented over three days. The conference provided learning opportunities on the latest advances, knowledge, research, tools and solutions for sustainable concrete manufacturing, design and construction. Engineers, architects, government officials, researchers, academics, students, contractors, and industry professionals were invited to share their knowledge.

The HES-HPC Specifications will be shared between the transportation agencies and the consortium universities as a case study of field implementation, and this will assist in transferring the knowledge gained throughout the implementation and demonstration.

#### **4.G - What Is The Impact On Society Beyond Science And Technology?**

The RE-CAST projects are developing the next generation of cement-based construction materials to address the growing technical and environmental requirements of the nation's transportation infrastructure. The ultimate goal of the RE-CAST program is to fast-track the acceptance of these technologies and develop national standards and guidelines for their use in the reconstruction of the nation's infrastructure for the 21st Century, which will have a lasting impact on our nation's society. This research theme addresses a Grand Challenge for our society and has been recognized recently at Missouri S&T as one of four strategic areas for future growth in education and research on campus.

The possibility of having a simple yet scientifically sound way of quantifying LCCA of new materials / construction techniques can help decision makers to adopt these more easily. This will have far bigger implication in terms of introducing new technologies to our infrastructure at large. This new LCCA approach will make it easier to adopt new construction materials and technologies.

The consortium continues to engage K-12 students and provides them hands on activities.

### **5. CHANGES/PROBLEMS**

#### **5.A - Changes In Approach And Reasons For Change**

Nothing to report at this time.

#### **5.B - Actual Or Anticipated Problems Or Delays And Actions Or Plans To Resolve Them**

Nothing to report.

#### **5.C - Changes That Have A Significant Impact On Expenditures**

Nothing to report at this time.

#### **5.D - Significant Changes In Use Or Care Of Animals, Human Subjects, And/or Biohazards**

N/A

#### **5.E - Change Of Primary Performance Site Location From That Originally Proposed**

No Change to Report.

### **6. SPECIAL REPORTING REQUIREMENTS**

Nothing to Report.

## APPENDIX A

RE-CAST April 6, 2016 Webinar:

*The Future of Concrete may be in its Past*

# WEBINAR

The **Future of Concrete** may be in its past

## ABSTRACT

The concrete industry is under increasing pressure to reduce the energy used in production of portland cement and the associated greenhouse gas emissions. There are several possible ways to address this challenge, but the most straightforward is to minimize the amount of portland cement used by substituting other materials to make concrete binders. We can learn a lot from the Romans, who made strong, durable concrete without any portland cement at all (though not without greenhouse gas emissions!). We are entering a natural pozzolan renaissance, where the industry is searching far and wide for alternative cementitious materials, including those that mimic the Roman pozzolana.

**This presentation will address current research on alternative concrete binders, including the characteristics and performance of North American natural pozzolans.**

Presented by:



***Dr. Maria Juenger***  
*Professor of Civil Engineering*  
*University of TX at Austin*

.....

**Wednesday, April 6**

Time:  
**12 pm - 1 pm CDT**

Register:  
<http://recast.mst.edu/webinars>



## APPENDIX B

RE-CAST July 29, 2016 Webinar:

*Extending the service life of new reinforced concrete structures by using advanced composite materials workshop*

*-Joint workshop with University of Bath (UK)*

## Department of Architecture and Civil Engineering

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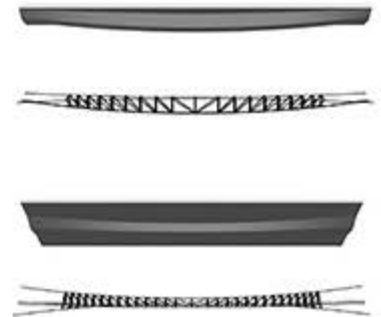
# Extending the service life of new reinforced concrete structures by using advanced composite materials workshop

Building a bridge across the ocean to stimulate the communication and exchange of knowledge on the use of composites for construction.

## Overview

- **Organisers:** [Dr Saverio Spadea](#), [Dr John Orr](#)
- **Co-organisers:** [Yuanzhang Yang](#), [Paula Villanueva](#)

Our workshop in July aimed to build a bridge across the ocean to stimulate the communication and exchange of knowledge on the use of fibre-reinforced polymer (FRP) composite materials for construction. The event was held on campus and online to allow international speakers and attendees to take part in the debate.



Particular attention was given to the new methods for manufacturing composites as internal reinforcement for optimised concrete structures. These methods have been developed at the University of Bath as part of the EPSRC-funded project '[Knitting bespoke reinforcement for new concrete structures](#)' (EP/M01696X/1).

## Presentations

Title	Speaker
<a href="#">Extending the service life of new reinforced concrete structures using advanced composite materials (PDF)</a>	<b>Dr John Orr (Chair)</b> Lecturer (Assistant Professor) in Civil Engineering, University of Bath
<a href="#">Introduction to workshop (PDF)</a>	<b>Professor Tim Ibell</b> Renowned expert in the field and Associate Dean for Research in the Faculty of Engineering & Design, University of Bath



<a href="#">Introduction to workshop (PDF)</a>	<b><u>Professor Tim Ibell</u></b> Renowned expert in the field and Associate Dean for Research in the Faculty of Engineering & Design, University of Bath
<a href="#">Standardisation of composites for repair – a US perspective (PDF)</a>	<b><u>Professor Antonio Nanni</u></b> University of Miami (USA), chairman of the ACI 549 Committee and member of the ACI 440 Committee for FRP reinforcement
<a href="#">Designing FRP reinforced concrete structures: the Canadian approach</a>	<b><u>Professor A Ghani Razaqpur</u></b> McMaster University (Canada), chairman of the CSA-S806: Design of Buildings with Fibre Reinforced Polymers and member of CSA-S807
<a href="#">Bespoke FRP reinforcement for new concrete structures (PDF)</a>	<b><u>Dr Saverio Spadea</u></b> University of Bath, Research Fellow in Structural Engineering and Fulbright Visiting Scholar at University of Miami for 2015–2016 academic year

## Demo session

### The winding machine prototype in action

**Mr Joe Evans**, Lab Technician, University of Bath

## Audience

The workshop was attended by students, academics, engineering practitioners and members of the construction industry worldwide.

- o 23 attended in person
- o 50 attended online via Adobe Connect

There were 44 unique participants at peak.

## Outcomes

The event was a success in bringing together attendees from across the world. The workshop provided participants with:

1. an appreciation of the extraordinary advantages that FRP offer
2. a new understanding of FRP materials, processes and methods
3. Ideas on how to extend the service life of concrete structures

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3. Ideas on how to extend the service life of concrete structures

## Survey

We asked attendees to provide us with feedback after the event. [View survey results.](#)

## Acknowledgements

Our workshop was supported by the University of Bath Research Development Fund and promoted by [RECAST](#) (Missouri University of Science & Technology).



# WEBINAR

## An Overview of a Network-wide Probabilistic Life Cycle Cost Analysis Methodology and Implementation Framework for New Concrete-based Materials and Construction Techniques

### ABSTRACT

The reconstruction of the nation's infrastructure should take into consideration the life cycle costs of major projects, including cost of new construction, replacement, maintenance and repair, cost of work zone delays, and various social-economic costs resulting from these activities. **Life Cycle Cost Analysis (LCCA)** is an effective tool that can assist decision-makers to develop optimum investment strategies by accurately assessing long-term internal and external costs of various types transportation projects while satisfying budget constraints imposed by transportation agencies. Recently, many new innovative concrete based materials and construction techniques have been developed to achieve a more sustainable transportation infrastructure. However, it remains a challenge to reliably estimate costs and technical performance of these new construction technologies / materials due to the very limited field implementation and historical data.

This webinar will present a comprehensive implementation framework to quantify the life cycle costs of these conventional and new high performance materials/construction technologies including novel methodologies to link laboratory-measured parameters to actual field performance. A computationally efficient probabilistic quantification methodology is also integrated into the proposed framework to be able to deal with the high level of uncertainty due to the length of analysis period as well as the lack of real-world performance data especially in the case of novel materials. A web-based user-friendly software tool that makes use of the existing network-wide infrastructure data allowing prospective users to perform state-wide LCCA will also be presented. This webinar will be concluded with a review of future work and challenges in the area of network-wide probabilistic LCCA with a focus on novel construction materials and technologies in the presence of limited field data.

Presented by:



***M. Kaan Ozbay, Ph.D.***

*Prof. of Transportation Engr.*

*New York University*

.....

**Friday August 12**

Time:

12 pm - 1 pm CDT

**REGISTER:**

[recast.mst.edu/webinars](http://recast.mst.edu/webinars)



## **APPENDIX D**

RE-CAST April 2016 Newsletter

# RE-CAST



Vol. 3 :: Issue 2 :: APRIL 2016

## In this issue:

- Director's Message
- Outreach to First Graders
- Featured Projects
- Events

### 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.

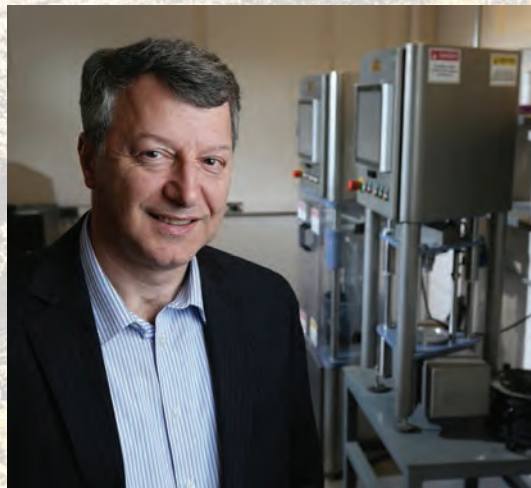
In this issue, we provide a featured project update, highlighting some of the recent progress our faculty and students have completed at the University of Oklahoma and Missouri S&T.

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 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)

- Continued Next Page -



## 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**

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

- Continued Next Page -

## 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.



# SCC 2016

MAY 15-18, 2016  
WASHINGTON, DC

## SCC2016 - "Flowing Towards Sustainability"

Dates: May 15-18, 2016

Location: Washington, D.C.

**Overview:** The conference combines the 8<sup>th</sup> RILEM Symposium on SCC and the 6<sup>th</sup> 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](http://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 worldwide. 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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- Continued Next Page -

## 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/m<sup>3</sup>)**

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 (\$/m <sup>3</sup> /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
	$\delta_1$ (mm)	0.085	0.080	0.093	0.089
	$\delta_p$ (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 (k $\Omega$ ·cm)		30	28	38	34
Durability factor (%)		99.8	99.8	99.7	99.7
Autogenous shrinkage at 28 d ( $\mu\text{m}/\text{m}$ )		602	253	545	593
Drying shrinkage at 98 d ( $\mu\text{m}/\text{m}$ )		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 Esmailkhanian 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).

- Continued Next Page -

## FEATURED PROJECT

### Dynamic Segregation of SCC (*continued*)

After production and curing of the beams, ultrasonic pulse velocity (UPV) was used to evaluate homogeneity 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

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Visit our Webinar Library at: [recast.mst.edu/webinars](http://recast.mst.edu/webinars)

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**April 1, 2016**

Presenter: Maria Juenger, Professor of Civil Engineering

University of Texas at Austin

*“The Future of Concrete May be in Its Past”*

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**February 10, 2016**

Presenter: Dr. Saverio Spadea

Research Fellow at the University of Bath (UK)

*“Bespoke FRP Reinforcement for Optimised Concrete Structures”*

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**December 1, 2015**

Presenter: Julie Hartell, Assistant Professor

Civil and Environmental Engineering

Oklahoma State University

*“The Use of Resistivity Testing to Improve Concrete Quality”*

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**October 22, 2015**

Presenter: Charles Hanskat, P.E.

Executive Director, American Shotcrete Association

*“Shotcrete for Repair and Rehabilitation of Highway Facilities”*

# STAY INFORMED STAY CONNECTED

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## Social Media:

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[facebook.com/RECASTCenter](https://facebook.com/RECASTCenter)

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'RE-CAST University Transportation Center' listed under Groups





## **APPENDIX E**

RE-CAST July 2016 Newsletter

# RE-CAST



Vol. 3 :: Issue 3 :: SUMMER 2016

## In this issue:

- Director's Message
- Outreach Activities
- International Conference
- Featured Project
- Student Spotlights
- Events

### 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

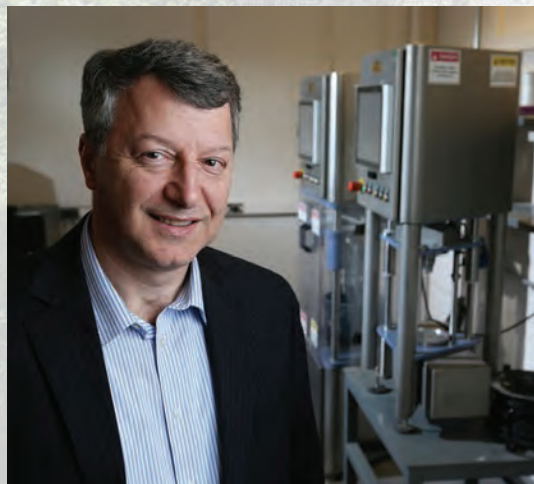
As the summer semester comes to an end, we would like to take a moment and let our readers see what our team has spent these summer months accomplishing.

We are excited to report the successful completion of a milestone technology transfer event that the RE-CAST team has helped organized. The SCC2016 international conference took place in Washington, DC in May and we are very happy with the outcome. Over 300 people from around the world attended the event. More

details about the event are in the pages to come.

We hosted a joint online international workshop on FRP with the University of Bath, UK on July 28. Dr. Antonio Nanni of the RE-CAST team was one of the presenters. We also have a webinar scheduled on August 12 which will feature the cutting edge work of RE-CAST research Dr. Kaan Ozbay from New York University. Please watch our website for other upcoming webinars and events.

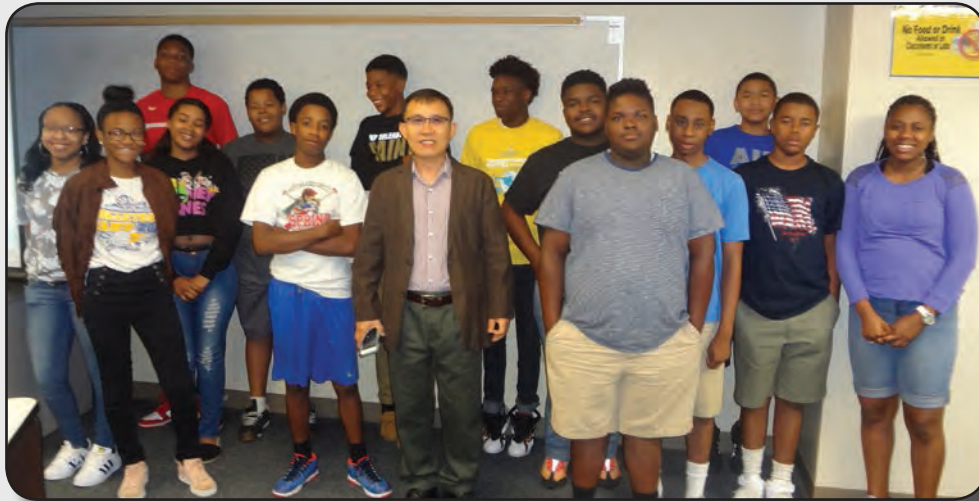
We would also like to share with you some of our students' recent successes, which we feel are recognition of their hard work and the importance of their research. See our Student Spotlights for more details.



Kamal H. Khayat  
*RE-CAST Director*

## OUTREACH

## High school students learn about engineering at Summer Transportation and Energy Institute



**Dr. Alex Shin, RE-CAST researcher (center), speaks at Southern University and A&M College Summer Transportation and Energy Institute (STIE)**

Southern University and A&M College hosted **Summer Transportation and Energy Institute (STIE)** during June 6 - 30, 2016. The College of Engineering served as the housing facility for the institute's classroom-based activities and construction projects. This year, seventeen high school students (9th and 10th grade) were selected to participate from the Baton Rouge metro area and other states including Arizona and Georgia.

Participants were engaged in engineering building projects (maps, planes, cars, and rockets), math enrichment, technical writing, and underwater robotics. Students also visited several Department of Transportation sites as well as the Johnson Space Center in Houston.

**Dr. Alex Shin** of RE-CAST, pictured above with this year's students, participated in the STIE as the speaker on June 20, 2016. He presented his on-going research on rapid pavement repair sponsored by RE-CAST and related subjects. RE-CAST financially has supported the STIE activities since 2015.

## TECHNOLOGY TRANSFER

## RE-CAST co-organizes international conference

- Kamal H. Khayat, RE-CAST Director / Jones Endowed Professor, Missouri S&T



Dr. Kamal Khayat with RE-CAST graduate students at SCC2016



Dr. Kamal Khayat with Dr. Surendra Shah (SCC2016 Distinguished Honoree)

On behalf of Missouri S&T and the RE-CAST UTC, Dr. Kamal Khayat and his team organized the Eighth International RILEM Symposium on Self-Compacting Concrete and the Sixth North-American Conference on the Design and Use of Self-Consolidating Concrete (SCC), from May 15-18, 2016, in Washington, D.C. This conference was held simultaneously with the 11<sup>th</sup> Annual International Concrete Sustainability Conference of the National Ready Mix Concrete Association (NRMCA). **SCC2016** (*Flowing toward Sustainability*) was designed to bring researchers and practitioners together to exchange the latest knowledge and tools used in building sustainable concrete structures with SCC.

Nearly 170 papers were submitted to SCC2016, from 32 countries, covering a wide range of timely and original subjects from around the world. Topics covered in the conference proceedings include SCC mix design, materials, test methods, rheology and workability, production and placement, flow modeling, pumping, formwork pressure, mechanical and physical properties, durability, structural performance, fiber reinforcement, sustainability, and case studies. These papers reflect the most recent advances in research, design, and implementation of SCC worldwide. Nearly 120 papers were presented during three parallel sessions in addition to 25 papers discussed during the poster session. The conference proceedings included a peer-reviewed volume (RILEM PRO 100) with 47 papers and a supplementary volume with the remaining papers. Over 300 participants from around the world attended the event.

The conference also honored over 50 years of outstanding contributions of Professor Surendra Shah to the field of concrete science and education (shown in photo above).

## FEATURED PROJECT

### All Concrete and Composites Pedestrian Bridge

- Antonio Nanni, Ph.D., Professor of Civil Engineering, University of Miami

Although this pedestrian bridge named “**Innovation Bridge**” is a simple, single-span, 70 ft.-long construction, it offers a number of striking features intended to ensure a 75-year service life to its owner, the University of Miami (UM). The project was initiated in November 2015 with the order to proceed issued to the precast fabricator and completed in May 2016. The bridge consists of the following concrete elements: auger-cast piles; cast-in-place pile caps, side blocks and back walls; precast prestressed girders; and, cast-in-place deck topping and curbs. Even though this project initially specified the use of steel-strand prestressed concrete (PC) girders supported on traditional steel RC piles and pile-caps, UM deliberately chose to adopt the use of composites as internal reinforcement to demonstrate its commitment to innovation and sustainability for this pedestrian bridge used by students to access the sports and intermural fields on campus. As a result, there is not a single pound of “black steel” in any element of the bridge; in fact, all reinforcement and tendons are made of FRP composites. In particular, the structure combines basalt FRP (BFRP), glass FRP (GFRP), carbon FRP (CFRP) and novel composite manufacturing technologies (continuous close stirrups and automated-preassembled pile cages) to ensure that degradation due to steel corrosion no longer reduces the longevity of the bridge. Reinforcing bars, prestressing tendons and concrete at various locations were instrumented with a total of 16 vibrating wire gages (VWGs) to allow for monitoring of the bridge elements over time and, in the case of the girders, during construction, to measure effective strains and transfer lengths.

#### Precast prestressed double-tees



In addition to CFRP tendons (nine per stem with a diameter of 0.6 in.), the reinforcement grids for both stems and flange were made of pre-assembled interwoven BFRP bars (#3 and #4 at spacing 6 in. o.c., respectively) (See **Figure 1**).

**Figure 1.**  
Double-tees casting bed and detail of reinforcement at casting

- Continued Next Page -

## FEATURED PROJECT

### All Concrete and Composites Pedestrian Bridge *(continued)*



**Figure 2.**  
Double-tee static load test at precast yard

The static load test of one of the two double-tees at the precast yard 26 days after casting is shown in **Figure 2**. The simply supported girder was loaded with three concrete blocks at its mid-span for a total load of 27 kips plus self-weight.

#### **Site construction**

The eight, 16-inch diameter, 40 foot-long auger-cast piles were reinforced with a prefabricated cage of six #6 BFRP bars and #3 equivalent BFRP spirals. The cages (in the shape of hexagons) were prefabricated at the composites manufacturer plant and delivered to the site, ready for installation. The pile caps, side blocks (to support the lampposts) and back-walls are made of concrete reinforced with straight BFRP bars, bent GFRP bars and continuous close BFRP stirrups. The application of continuous close BFRP stirrups is a U.S. “first” which takes advantage of performance efficiency of the composite reinforcement when continuity of the fibers is assured. **Figure 3** shows the completed assembly of the reinforcement cage for pile cap, side blocks and back-wall.



**Figure 3.**  
Reinforcement cage for pile cap, side blocks and back-wall

- Continued Next Page -

## FEATURED PROJECT

### All Concrete and Composites Pedestrian Bridge (*continued*)



**Figure 4.**  
Load testing with pick-up truck

#### Field Load Test

**Figure 4** shows the fully loaded pick-up truck used for the first field load tests. The total weight of the vehicle was 12,080 lb. with the heavier axle weighing 7,720 lb. Strains and deflections measured during the test were consistent with the analytical predictions.

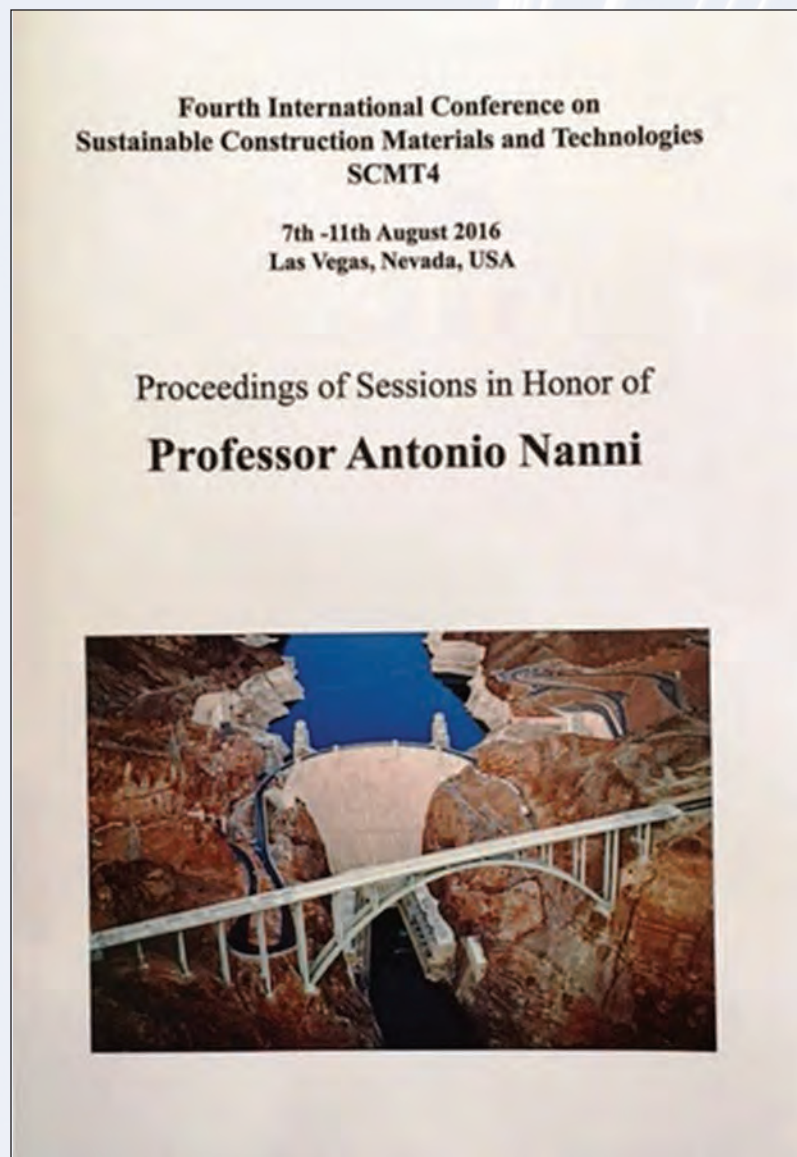
#### Credits

Industry and financial participants and their roles in the project were:

- RE-CAST UTC (Financial support)
- OHL Arellano Construction Co. (General Contractor)
- ANZAC Contractors Inc. (Bridge Subcontractor)
- Brill Rodriguez Salas & Associates Inc. (Engineer of Record)
- University of Miami (Architectural Design & Designated Engineer)
- University of Miami - Structures and Materials Laboratory (Research Coordinator)
- Coreslab Structures Inc. (Double Tees Fabricator)
- Tokyo Rope/Tokyo Rope USA (CFRP Manufacturer)
- No Rust Rebar (BFRP Manufacturer)
- Hughes Bros. (GFRP Manufacturer)
- Titan America (Concrete Supplier)
- MAPEI (Surface Products Supplier)

## LEADERSHIP SPOTLIGHT

### RE-CAST Associate Director honored with special session at international conference



RE-CAST Associate Director, **Professor Antonio Nanni**, from the University of Miami, was honored for his lifetime achievements in the field of materials for Civil Engineering during the Fourth International Conference on Sustainable Construction Materials and Technologies (SCMT4) held in Las Vegas, NV August 7-11, 2016.

Three technical sessions were organized in his name with 15 papers presented by former and current students and colleagues as well friends. The papers were collected in a separate proceedings volume, shown on the left.

Read more at <https://www.unlv.edu/scmt4/honorees>.



## STUDENT SPOTLIGHTS

### RE-CAST students receive ACI awards

*Iman Mehdipour: ACI Charles Pankow Student Fellowship recipient*



**Iman Mehdipour (pictured left)**, a RE-CAST graduate student pursuing a Ph.D. degree in civil engineering at Missouri S&T has been awarded the 2016-2017 American Concrete Institute (ACI) Charles Pankow Student Fellowship.

As part of the award, Mehdipour will receive an educational stipend for tuition, residence, books, and materials, as well as paid travel to the next two ACI conventions. Fellowships are offered to high-potential and outstanding graduate students whose research studies relate to concrete engineering and are identified by ACI-Member Faculty. The selection process consists of evaluating the applicants based on the resume and essay highlighting research

areas and all accomplishments. For the final selection,

finalists are then exposed to an interview process at the ACI Spring Convention that took place in Milwaukee in April 2016.

*“This award is not only a great honor for Mr. Mehdipour, but also for the RE-CAST UTC. It recognizes the quality of research our students conduct at Missouri S&T,”* says Dr. Kamal H. Khayat, the Vernon and Maralee Jones Prof. of Civil Engr. at Missouri S&T and Mr. Mehdipour’s advisor and nominator.

Mehdipour’s research area has focused on developing and designing advanced cement-based materials, such as environmentally friendly and crack-free cement-based materials and fiber-reinforced composites with adapted rheology. He was also given the opportunity to perform an interdisciplinary collaborative research project to evaluate fiber distribution in concrete and self-healing capability of cement-based materials using microwave and thermography nondestructive testing techniques with Drs. R. Zoughi and K. Donnell from the department of Electrical and Computer Engineering at Missouri S&T.

Over the span of his academic career, Mr. Mehdipour has authored and co-authored two books (“Soil Mechanics” and “Guidelines for Hot Weather Concreting”, both published in Persian), 10 peer-reviewed journal articles, and 25 conference papers. His research efforts and professional services have been recognized with several awards. He has received the ACI Missouri Chapter Honorary Abdeldjelil “DJ” Belarbi Scholarship for 2015-2016 and a travel grant award for the 25th ASNT (American Society of Nondestructive Testing) Research Symposium in Spring 2016.

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## STUDENT SPOTLIGHTS

### RE-CAST students receive ACI awards

*Weina Meng and Mahdi Valipour: ACI Abdeldjelil “DJ” Belarbi Scholarship*



**Weina Meng and Mahdi Valipour**, RE-CAST Ph.D. candidates at Missouri S&T under the direction of Prof. Kamal H. Khayat, were awarded the ACI Missouri Chapter Honorary Abdeldjelil “DJ” Belarbi Scholarship for 2015-2016.

The competition was very tough this year, and the RE-CAST Center is proud of these students’ achievement. Both Weina Meng and Mahdi Valipour are working on the field of ultra-high performance concrete and its application. Their academic achievements and community services experience made him a good candidate for this scholarship award.

## STUDENT SPOTLIGHT

### RE-CAST students win best poster at competition



Congratulations to RE-CAST students Weina Meng, Hayder Owayez, Valter Gora, and Rallabhandhi Sai Pavan! They received an Award of Excellence for Best Poster in the student competition at the First International Interactive Symposium on Ultra High Performance Concrete this July in Des Moines, Iowa.

From left to right: Weina Meng, Dr. John Myers (faculty advisor of Missouri S&T), Hayder Owayez, and Benjamin Graybeal of FHWA

## WORKFORCE DEVELOPMENT/OUTREACH

### RE-CAST students teach next generation about concrete materials



Dr. Aditya Kumar (pictured above), Weina Meng (pictured below), and Iman Mehdipour presented concrete materials and facilities of RE-CAST to high-school students in a Materials Summer Camp that took place in July in Rolla, Missouri. S&T's Materials Camp is a summer residential camp for high school juniors and seniors interested in the science, technology, engineering and math (STEM) fields.



Campers learned about the fresh properties testing of concrete (shown above left). Faculty members and students also gave campers a variety of demonstrations and trips that actively explored concrete materials science and helped them to learn how to use state-of-the-art research equipment (shown above right).

## LEADERSHIP/TECHNOLOGY TRANSFER

# RE-CAST directors participate in Gordon Research Conference on Advanced Materials for Sustainable Infrastructure Development in Hong Kong



RE-CAST researchers Drs. David Lange and Kamal Khayat participated in the Gordon Research Conference (GRC) on Advanced Materials for Sustainable Infrastructure Development. This conference was held at the Hong Kong University of Science and Technology (HKUST) from July 31 to August 5, 2016.

Dr. Lange served as co-chair of the conference along with Prof. Chris Leung from HKUST. Dr. Khayat was selected as the co-chair for the next GRC conference to be held in 2018 at HKUST, a position that places him in the chairmanship of the 2020 GRC conference which will be held in the USA.

The GRC conference format features invited speakers and extended discussion periods, and attendees often reflect on the quality of debate and collegial interactions. At this recent conference, Dr. Khayat gave an invited lecture on High Performance Concrete with Adapted Rheology, a topic that fits in well with the conference theme on sustainability and summarizes many of the recent research findings carried out by the RE-CAST team.

## WEBINAR SERIES

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Visit our Webinar Library at: [recast.mst.edu/webinars](http://recast.mst.edu/webinars)

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**August 12, 2016**

Presenter: Kaan Ozbay, Professor of Transportation Engineering

New York University

*“An Overview of a Network-wide Probabilistic Life Cycle Cost Analysis Methodology and Implementation Framework for New Concrete-based Materials and Construction Techniques”*

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### **Extending the Service Life of New Reinforced Concrete Structures by Using Advanced Composite Materials Workshop**

*- Joint workshop offered with University of Bath (UK)*

**July 29, 2016**

RE-CAST Presenter: Antonio Nanni, Professor of Civil Engineering, Univ. of Miami

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**April 1, 2016**

Presenter: Maria Juenger, Professor of Civil Engineering

University of Texas at Austin

*“The Future of Concrete May be in Its Past”*

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**February 10, 2016**

Presenter: Dr. Saverio Spadea

Research Fellow at the University of Bath (UK)

*“Bespoke FRP Reinforcement for Optimised Concrete Structures”*

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