news

Missouri S&T

Center for Transportation Infrastructure and Safety

Summer 2012: Vol. 7 | Issue 2

From the Desk of the Director

As we transition from Spring to Summer here in Missouri, the temperature is not the only thing heating up. The forward- moving motion of the CTIS is also picking up speed and strength. We have recently hosted laboratory tours and presentations for several visitors, including a congregation from Westinghouse-Ameren on June 5th regarding small modular nuclear reactors (SMRs). The interactions between CTIS researchers and the Westing-house-Ameren group were very exciting and will hopefully lead to fruitful collaborative research projects in the future.

Lab Tour with Westinghouse-Ameren June 5, 2012

In addition to meeting with new collaborators, we are also excited to be in the process of acquiring a large collection of equipment that will be utilized in many of our current and pending research projects. The specialized testing equipment for the study of advanced cement-based materials will enable the development, manufacturing, and implementation of advanced and sustainable materials for transportation infrastructure, with an emphasis on concrete. Our faculty researchers are anxious to get the equipment up and running very soon.

We are also working on the lineup for our *First Annual Missouri S&T Transportation Infrastructure Conference*, to be held on the S&T campus on **Thursday, Sept. 27**. We are proud to present a top-notch line-up including the followin guest speakers:

- **Brahim Benmokrame**
  Professor of Civil Engineering
  Université de Sherbrooke, Canda
- **Saiid Saiidi**
  Professor of Civil Engineering
  University of Nevada, Reno
- **David Lange**
  Professor of Civil Engineering
  Univ. of IL, Urbana-Champagne
- **William Stone**
  Organizational Results Administrator
  Missouri Dept. of Transportation

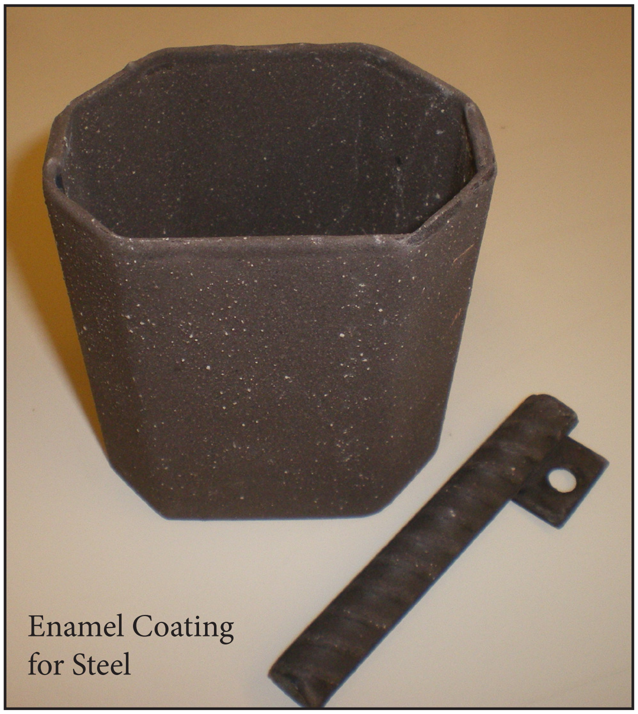
Further details will be posted on our website soon. Please be sure to check it out and save the date. transportation.mst.edu

- Kamal H. Khayat

In this issue:

FEATURED PROJECT:
Vitreous Enamel for Chemical Bond Between Steel and Concrete

- Genda Chen, Professor, Department of Civil, Architectural and Environmental Engineering, Missouri S&T



Enamel Coating for Steel

In 2007, Missouri S&T initiated a series of studies on the potential use of **chemically reactive, vitreous enamel as a coating of steel rebar** (application shown at left) in order to better bond steel rebar to concrete and protect the steel from corrosion. The following is a brief report on the progress of these studies. For more information, please contact Dr. Genda Chen by email at gchen@mst.edu.

Approximately $10B per year has been spent to remediate corrosion problems with our nation's bridges, and indirect costs push that annual expenditure up by a factor of 10. Thus far, epoxy-coating has been the most widely used method to protect steel rebar from corrosion. Once breached, however, the epoxy coating can actually accelerate the steel corrosion since its physical bond with the steel is too weak to prevent a moisture attack. Furthermore, use of the epoxy coating reduces the concrete-steel bond strength and thus requires longer development lengths for epoxy-coated rebar, which results in not only the use of more materials but also the non-assurance of construction quality in congested rebar areas such as beam-column joints. Similarly, other types of rebar, such as zbar, stainless steel, stainless steel clad, and fiberglass do not form chemical bonds with the surrounding concrete matrix, and so offer no opportunity to enhance the overall strength of reinforced concrete (RC) structures. Once in production, enamel coating is expected to cost comparable to the widely used epoxy coating in civil engineering construction.

Porcelain enamel is a vitreous or glassy inorganic material that can be bound to a substrate metal by fusing glass frits at 750 °C to 850 °C. It has been extensively used in domestic and industrial applications that require chemical, high temperature, corrosion and mechanical protection. The properties of enamel coating are flexible and can be controlled by altering the chemical composition, microstructure, and by pre-treating the metal substrate. Therefore, the enamel coating can be designed and used to improve corrosion resistance in an alkaline environment with an enhanced chemical bond to the steel substrate.

Porcelain enamel was first introduced as a steel rebar coating by the Army Corp of Engineers in 2006. Since then, in close collaboration with Pro-Perma Engineered Coatings managed by Mr. Michael Koenigstein, Dr. Genda Chen, Professor of Civil Engineering, and his colleagues, Dr. Richard Brow in Material Science and Engineering, and Dr. Jeffery Volz in Civil Engineering, have systematically characterized the microstructures, mechanical properties, and chemical reactions with concrete of both conventional and innovative cement-modified enamels. Up to date, three types of enamel coating have been investigated: pure (conventional) enamel, mixed enamel, and double enamel. Mixed enamel is a mixture of the pure enamel and calcium silicate directly taken from Porcelain cement. Double enamel consists of an inner pure enamel layer for corrosion protection and an outer mixed enamel layer for rebar bond performance in concrete.

(continued next page)

Figure A Figure B

Two RC Columns under Cyclic Loading
Figure A: Uncoated Reinforcement
Figure B: Enamel-Coated Reinforcement

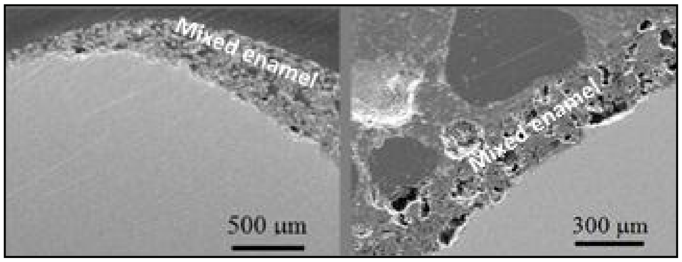


Figure C Figure D

Microstructure and Coating-Steel Inferface
Figure C: Deformed rebar
Figure D: Smooth rebar

From extensive experiments and simulations, the following **MAIN CONCLUSIONS** *c*an be drawn:

- The firing process of enamel-coated steel rebar does not change the ductile behavior of the steel rebar. During tensile tests, the enamel coating of steel rebar will not crack unless the rebar experiences approximately 1.5 times the yield strain.
- Steel-mortar cylinders fail in different modes from ductile steel pulling-out to brittle concrete splitting, and their bond strengths increase as the calcium silicate contained in mixed enamel coating increases.
- The mixed enamel coating can increase the 28-day bond strength of smooth steel rods in mortar by 7 or 8 times due to the increased adhesive (over 2 times) and surface roughness (over 3 times). For deformed steel rebar in concrete, the increase in bond strength by enamel coating is reduced to approximately 15% since the concrete bearing on rebar ribs exceeds the adhesive and fictional effects between the rebar and concrete.
- The coating effect on the bond strength of enamel-coated rebar in concrete can be well represented by a coating factor 0.85 in the ACI 318-08 development length equation.
- The corrosion performance of enamel coatings largely depended upon the coating thickness and the concentration of calcium silicate within the coating. In general, the double and pure enamel coatings outperform the mixed enamel coating that has many interconnected pores formed during the firing process. However, thin sections of coating around the ribs of deformed rebar due to low enamel slurry viscosity and gravity effects can significantly reduce the corrosion resistance of enamel coatings.
- Unlike epoxy coating, a damaged enamel coating remains bound to its steel substrate and thus causes no thin film corrosion underneath the coating. During ponding tests, 28% and 4% decrease in corrosion resistance were observed due to damage in epoxy and enamel coatings, respectively.
- It is recommended that pure, mixed, and double enamel coatings be respectively used for a moderate protection of steel rebar in corrosive environments, an enhancement of rebar-concrete bond strengths, and a design concern of both corrosion resistance and bond strength.

"It's a Girl Thing"

June 4-8, 2012

This program took place on the Missouri S&T campus on June 4-8 and is designed to enable young female students who will be in the 7th & 8th grades during the 2012-13 school term, to help them obtain a clearer picture of engineering and scientific/technological professions. Students get an opportunity to explore engineering, math, and science through "hands-on" experience. The sessions include laboratory experience, at least one having a transportation-related theme, such as building truss bridges with team engineering projects, and time to interact formally and informally with role models and peers. Students become acquainted with various fields of engineering and science and with the demand faced in these fields by practicing engineers and scientists. Another goal is to acquaint students with the type of effort required for college study.

Summer Solutions Camp

June 18-22, 2012

Summer Solutions Camp is designed to pique the interest of freshman and sophomore high school girls in engineering and science. The one-week program is designed to enable female students to obtain a clear picture of engineering and science as a profession. Several hands on projects took place to help the students learn more about career options and the demand faced in the fields of engineering, math, and science.

2011 CTIS Student of the Year
Nathan P. Muncy

Hometown and State: Kansas City, MO

Student Bio: Mr. Muncy obtained a B.S. degree in Civil Engineering with Cum Laude honors from the Missouri University of Science and Technology (Missouri S&T) in December 2010 and is expenced to complete his M.S. in Civil Engineering in December 2012.

During his undergraduate career, Mr. Muncy was a member of the Missouri S&T chapters of the American Society of Civil Engineers (ASCE) and the American Concrete Institute (ACI). He was also highly involved in the Missouri S&T Steel Bridge Team as a leader and coordinator of bridge fabrication. Nathan was also a member of the Concrete Canoe Mix Design Team where he served two years as the lead mix designer. As an undergraduate student, Nathan completed a National Science Foundation (NSF) supported OURE studying the long-term in-situ bond behavior of externally bonded carbon fiber reinforced polymer (CFRP) laminates subject to eight years of field conditioning. This work has added important field data to a very limited database on in-situ FRP strengthened bridges.

Nathan Muncy, 2011 CTIS Student of the Year

As a graduate student, Nathan studied the field performance of three bridge approach slab designs including a new most cost effective innovative prestressed-precast approach slab design. The research evaluated the field performance of bridge approach slabs including the deflection and rotation based on static and dynamic load testing. This work has been sponsored by the Missouri Department of Transportation (MoDOT) and the NUTC at Missouri S&T. He has also continued to document the field behavior of FRP strengthened bridges throughout Missouri creating a database of CFRP bond behavior under varied environmental and mechanical conditioning. During his graduate and undergraduate scholarly activities, Nathan was advised by Dr. John J. Myers.

Nathan was recognized at the TRB Conference in January 2012 along with the other UTC Outstanding Students' of the Year from UTC member institutions

Selection Criteria: Mr. Muncy was selected as the Outstanding Missouri S&T UTC Student of the Year for his outstanding academic performance, the technical merit and national importance of his research, as well as his service to the Missouri S&T campus and surrounding community.

FEATURED PROJECT:

Beneficial Reuse of Fly Ash with Organic Modifications in Earthen Structures in Transportation Systems

- Bate Bate, Assistant Professor of Civil, Architectural and Environmental Engineering, Missouri S&T

As coal remains the world's most abundant and accessible fossil fuel, the production of energy from coal will inevitably generate waste materials, i.e., the coal combustion products (CCPs). From 2002 to 2009, about 40% of CCPs was reused, while only 2.8% of the CCPs were used in pavement. On the other hand, organically modified soils show promising properties for earthen structures in transportation systems. Recent study indicates that fly ash has potentials in structural fill of bridges abutment, highway storm water erosion control, and embankment of pavement. This study intends to enhance the high volume reuse of fly ash (FA), a major component of CCPs, in these applications by modifying FA-soil mixture with organics.

Phase I of this study is to study the sedimentation behaviors on fly ash-kaolinite mixture in different salt concentrations. The pH and ionic strength are monitored throughout the tests. The addition of salt and fly ash leads to different structures of fine-grained particles, such as dispersion, aggregation, and flocculation. Fly ash was found to be more efficient than salt because the FA does not only interact with kaolin particles but can increase the ionic strength of bulk solution by the precipitation of calcium hydroxide and pozzolanic reaction products. These preliminary findings suggest that high CaO content in FA-clay mixture shrinks the electrical double layer of clay minerals, and enhance the flocculation fabric, which in turn could increase the strength of the mixture.

The second phase of this research was undertaken to determine the physico-chemical and microscopic properties of the soil-FA mixture, including the net surface charge (adsorption behavior), grain-size distribution, shape, and texture of the particles. These properties are then used to predict engineering properties, such as the soil water characteristic curve, hydraulic conductivity, and strength. The research also seeks to use polymers, such as polyacrylamide, polyethylate oxide, and polyacrylic acide, and surfactants as additives to enhance the interaction between FA and clay, to enhance engineering performance. The outcome of the research project will provide guidelines on the organic type and quantity, optimum FA to soil ratio, and water content of the mixture for optimum performance in engineering properties and performance.

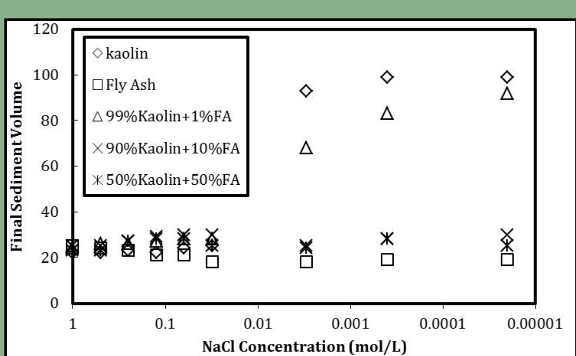


Figure 1. Final sediment volume of fly ash-kaolin mixture at different NaCl concentrations

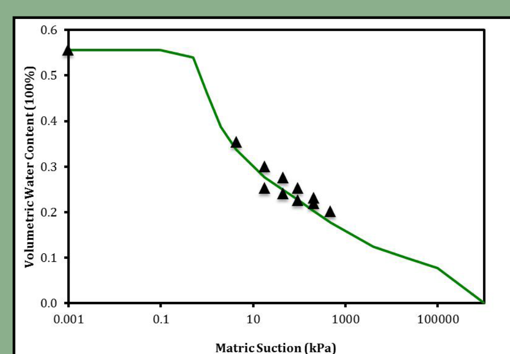


Figure 2. Measured (triangles) and predicted (solid line) soil water characteristic curve for Atchison soil in Missouri. Predicted curve is calculated from grain-size distribution and saturated volumetric water content

Local Transportation News:

Spring 2012 LTAP Advisory Board Meeting

April 25, 2012

In an effort to ensure that Missouri Local Technical Assistance Program (LTAP) provides the best services possible, an advisory committee made up of selected county commissioners, MoDOT and FHWA representatives, and individuals from various public agencies throughout the state provide input and feedback on strategic planning and program goals throughout the year. The intent of the committee is to assure that all four focus areas of Work Plan are discussed and evaluated in response to client needs. The focus areas include safety, workforce development, infrastructure management and organizational excellence. The committee also discusses potential areas for participant improvement and how to improve the overall cost-benefit of the program while offering input on strategic planning to the LTAP management team.

The committee met on April 25 on the Missouri S&T campus for its spring 2012 meeting. Ten committee members attended along with the LTAP staff. Those members included Sheila Barnett, Larry Benz, Phil Broyles, Bob Holthaus, Bonnie Prigge, Dan Ross, Gary Scheipeter, Bill Stone, Marc Thornsberry, and Skip Wilson.

Heath Pickerill, LTAP Director, gave an update on recent activities, which included the new LTAP website that will be unveiled this summer, the training fee increase for 2012 from $25 to $30/person for technical level and $50 to $60/ person for supervisory level courses, LTAP's partnership with MoDOT on recent Americans with Disabilities Act (ADA) training and Local Projects Administration (LPA) Basic training and a review of the 2011 training as well as the 2012 training to date. Several other topics were discussed. First was an assessment of the need for transitioning to an e-newsletter in an effort to save on printing and mailing costs. It was decided that it would be beneficial to give readers the option of continuing to receive a printed copy. Second was an update on the Local Traffic Practices Manual rewrite, which was funded by the Missouri Blueprint Coalition for Safety and will be provided to local agencies throughout the state. Follow-on training will also be provided in ten locations later this year. Third was a review of the LTAP Strategic Plan developed in 2011 focusing on the long-range goals of the program. Some of these include building a more self-sustaining LTAP center that is less dependent on grant funding, enriching the knowledge base of local government and transportation stakeholders, supporting the needs of state and local community leaders through partnerships, and using social media to stay better connected with agencies and customers. Next was a discussion of training development opportunities, such as more supervisory and leadership focused classes and various certification training. The final was suggestions of growth opportunities that included expanding current partnerships and exploring new ones, filling training gaps within MoDOT due to their realignment, developing workforce development partnerships and training, and finally identifying up-coming events and meetings at which to promote LTAP.

The next meeting will be held this fall. If anyone has an interest in serving on the Advisory Committee, please contact Heath Pickerill at pickerillh@mst.edu or 573-341-7637. For more information on Missouri LTAP please visit the LTAP website at www.moltap.org.

FEATURED PROJECT:

Bottom Ash as Aggregate Replacement In Concrete

- Jeffery Volz, Assistant Professor of Civil, Architectural and Environmental Engineering, Missouri S&T

Bottom ash (shown at left) is a waste product from the burning of coal in thermal power plants. Most modern plants pulverize the coal before it is injected into the boiler. The non-combustible material remaining after burning becomes either fly ash or bottom ash. Bottom ash results when the non-combustible material agglomerates in cooler sections of the boiler and eventually falls to the bottom, as opposed to fly ash, which travels upward with the combustion gases. Bottom ash is primarily comprised of fused coarser ash particles. Frequently, these particles are very porous and resemble volcanic lava. Although relatively unreactive compared to fly ash, bottom ash does have the potential to replace either all or a portion of the natural aggregates used in concrete. In particular, bottom ash holds considerable potential for use as internal curing of high-performance concretes (HPCs).

HPCs offer the potential for smaller element cross-sections and increased durability, reducing both first and life-cycle costs. However, to extend the benefits of HPCs, internal curing is required to reduce the potential for early-age cracking and develop the full strength potential of the material. Why the need for internal curing over traditional external curing methods such as fogging, misting, and wet burlap? Basically, the capillary porosity of higher performing concretes becomes disconnected during the first few days of hydration, such that external water may only penetrate less than one-tenth of an inch. In addition, with extremely low water-cement ratios, moisture can become trapped during early hydration due to cement particles reacting at different rates. Without internal sources of well distributed water, the concrete can self-desiccate, which results in significant internal stresses and unhydrated (wasted) cement. The purpose of internal curing is to provide water as needed throughout the interior of the concrete element, resulting in complete cement hydration and the elimination of autogenous stresses that can lead to early-age cracking. Furthermore, HPCs that use relatively high amounts of supplementary cementitious materials (SCMs) – fly ash, silica fume, slag – benefit even more from internal curing due to their longer hydration periods.

Preliminary results appear very promising. Measurements of fine bottom ash particles from several thermal power plants in Missouri indicate absorptions ranging from 9% to 12% compared with lightweight fine aggregate which ranges from 5% to 8%. Higher absorption allows a greater amount of water to be stored and thus available for internal curing. Preliminary results of the research indicate that mortar mixtures containing prewetted bottom ash (fine gradation) experienced early-age shrinkage comparable to the identical mixtures without prewetted bottom ash. However, long-term shrinkage was significantly reduced for the mixtures containing bottom ash, on the order of 50%. In addition, restrained shrinkage tests indicated reduced restraint stresses for the mortars containing prewetted bottom ash as well as a significant delay in the onset of shrinkage cracking.

FEATURED PROJECT:

Effect of Trona on the Leaching of Trace Elements from Coal Fly Ash

LEAF Leaching of CCP's - Phase I

- **Jianmin Wang, Associate Professor of Civil, Architectural and Environmental Engineering, Missouri S&T**
- **Honglan Shi, Assistant Research Professor, Chemistry, Missouri S&T**

Driven by federal regulations, many power plants are implementing technologies to control SOx emission. Trona is a natural material that can form sodium carbonate under high temperature. It is readily available, economical, and effective in removing SOx. Therefore, it has been tested by some electric power plants for SOx emission control. However, trona addition may change the leaching characteristics of trace elements from coal fly ash. The objective of this project was to determine the effect of trona addition on the leaching of a suite of trace elements of concern.

This project was started November 2011. Since that time, the project team has analyzed nine different types of fly ash samples, including control sample (no addition of any chemicals), ashes with trona addition, and ashes with addition of other chemicals, such as bicarbonate. Results indicated that the addition of trona and bicarbonate significantly enhances the leaching of major anions of concern, such as arsenic, selenium, vanadium, antimony, fluoride, etc. However, the effect of trona and bicarbonate on the leaching of cationic elements was not significant.

Figure 1 shows leaching data from control sample, and the ash with trona addition.
Figure 2 shows Research Specialist, Ms. Kun Liu, operating ICP-MS for trace elements analysis.

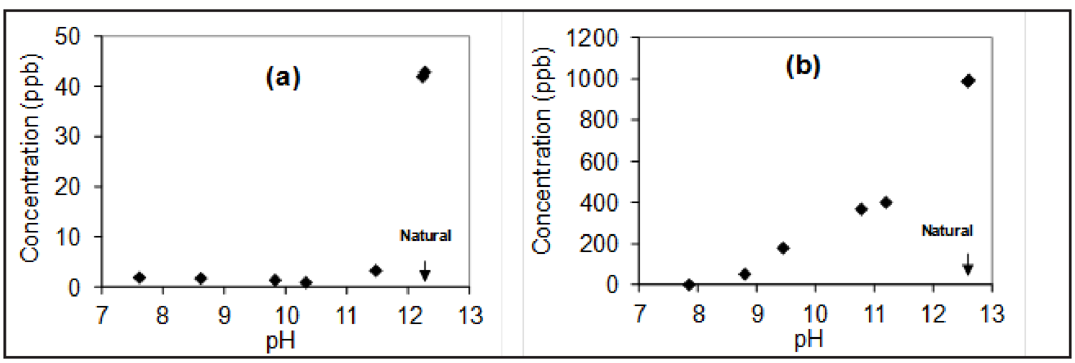


Figure 1. Arsenic concentrations in leaching solutions at different pHs -- (a) control ash; (b) trona ash

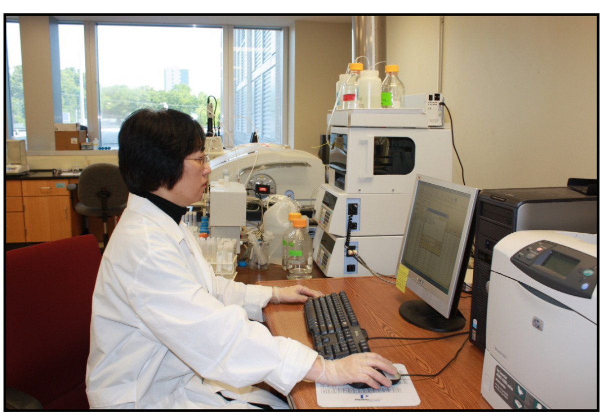


Figure 2. Ms. Kun Liu is analyzing samples with ICP-MS