TRANSPORTATION POOLED FUND PROGRAM
QUARTERLY PROGRESS REPORT

Lead Agency (FHWA or State DOT): ____Kansas DOT__________________________

INSTRUCTIONS:
Project Managers and/or research project investigators should complete a quarterly progress report for each calendar quarter during which the projects are active. Please provide a project schedule status of the research activities tied to each task that is defined in the proposal; a percentage completion of each task; a concise discussion (2 or 3 sentences) of the current status, including accomplishments and problems encountered, if any. List all tasks, even if no work was done during this period.

Transportation Pooled Fund Program Project #		**Transportation Pooled Fund Program - Report Period:**
TPF-5(174)		☐Quarter 1 (January 1 – March 31) 2016 X Quarter 2 (April 1 – June 30) ☐Quarter 3 (July 1 – September 30) ☐Quarter 4 (October 1 – December 31)
Project Title: Construction of Crack-Free Concrete Bridge Decks, Phase II		
Project Manager: Rodney Montney	**Phone:** 785-291-3844	**E-mail:** Rodney@ksdot.org
Project Investigator: David Darwin	**Phone:** 785-864-3827	**E-mail:** daved@ku.edu
Lead Agency Project ID:	**Other Project ID (i.e., contract #):**	**Project Start Date:** **July 1, 2008**
Original Project End Date: **June 30, 2013**	**Current Project End Date:** **August 31, 2016**	**Number of Extensions:** 1

Project schedule status:

☐ On schedule X On revised schedule ☐ Ahead of schedule ☐ Behind schedule

Overall Project Statistics:

Total Project Budget	**Total Cost to Date for Project**	**Total Percentage of Work Completed**
$995,000*	$978,465.17**	97%

Quarterly Project Statistics:

Total Project Expenses This Quarter	**Total Amount of Funds Expended This Quarter**	**Percentage of Work Completed This Quarter**
$9,580.30	$9,580.30	3%

*$1,545,000 including KUTRI, BASF, and SFA funds, **$1,531,247.15 including KUTRI, BASF, and SFA funds

Project Description:
Cracks in concrete bridge decks provide easy access for water and deicing chemicals that shorten the life of the deck. Both materials increase the effects of freeze-thaw damage, while the deicing chemicals lead to higher concentrations of chlorides, and subsequently, corrosion of reinforcing steel. Measurements taken on bridges in Kansas show that dense, high quality concrete can significantly slow the penetration of chlorides to the level of the reinforcing steel. However, measurements taken at cracks show that the chloride content of the concrete can exceed the corrosion threshold at the level of the reinforcing steel by the end of the first winter. The formation of cracks, thus, significantly lowers the effectiveness of other techniques that are used to increase the life of a deck.

Research, some of which dates back nearly 40 years, has addressed the causes of cracking in bridge decks in North America. The research includes three detailed bridge deck surveys carried out by the University of Kansas since 1993. The results of the studies provide specific guidance on modifications in materials and construction techniques that will reduce the amount of cracking in bridge decks. In spite of this accumulation of knowledge, only a small number of these findings have been used to implement changes in bridge deck design and construction procedures. In specific cases, on-site observations indicate that it is possible to develop nearly crack-free bridge decks, if “best practices” are followed. Even with these few successes, most bridge decks exhibit significant cracking, exposing the reinforcing steel to deicing chemicals and subsequent corrosion and increasing the degree of saturation, which increases the impact of freeze-thaw cycles. The current level of understanding, however, offers strong direction for constructing bridge decks with minimum cracking.

This improved understanding was put to use during the first phase of this study, in which 20 low-cracking, high-performance concrete (LC-HPC) bridge decks, with an equal number of control decks, were planned for construction. The decks involved the use of low cement and water contents, increased air contents, optimized aggregate gradations that produce pumpable, workable, placeable, finishable concrete with cement contents as low as 535 lb per cubic yard, temperature control during placement, limited finishing, and early curing. The study was successful in identifying low-cracking portland cement concrete mixtures. Several additional approaches, however, have been identified that have the potential to increase the benefits of the project, including using mineral admixtures, new sources of aggregate, and new approaches to finishing. These approaches could not be fully exploited in Phase I. Data indicates that, when coupled with internal curing (provided by fully or partially saturated KsDOT approved limestone with 2½ - 3% absorption), using blast furnace slag as a replacement for portland cement can reduce drying shrinkage by an additional 40%. Two other mineral admixtures, fly ash and silica fume (microsilica), are also under investigation, although with less advantageous results. They will continue to be evaluated, however, because of their widespread use and the desire to construct decks with minimum permeability (achieved using silica fume) and environmentally beneficial waste materials (fly ash). The new mixtures must be investigated for their shrinkage and freeze-thaw properties, as well as construction qualities, especially the ability to use pumps to place the new mixtures. Optimum procedures for concrete placement and fogging will continue to be areas of special emphasis. Finishing techniques have been restricted in the current study. Additional work is necessary to determine if some of the restrictions (principally on the placement and finishing equipment) may be lifted.

Progress this Quarter (includes meetings, work plan status, contract status, significant progress, etc.):

TASK 1: Update plans to construct bridge decks with minimum cracking by incorporating “best practices” dealing with materials, construction procedures, and structural design. This step involves improving techniques in use in Phase I and meeting with department of transportation personnel from multiple states, as well as other experts, to select the procedures to be used and the bridge types to which they will be applied.

This task was largely completed during the Annual Meeting of Pooled Fund Sponsors held in Kansas City, MO at the Kansas City Airport Hilton on July 24, 2008, as well as in meetings with KDOT officials as reported in the report for the 1st quarter of 2009. This task will remain open until the end of the project to allow for slight modifications to LC-HPC bridge deck specifications and additional LC-HPC bridge deck construction as warranted.

90% COMPLETE

TASK 2: Perform laboratory work to evaluate the effects of slag cement, fly ash, silica fume, shrinkage reducing admixtures, and internal curing on the performance of concrete mixtures for use on LC-HPC decks.

Current laboratory work is addressing concrete mixtures containing various amounts and combinations of saturated lightweight aggregate (LWA) for the purpose of internal curing (IC) in conjunction with mineral admixtures (slag and silica fume), shrinkage reducing admixtures (SRA) and shrinkage compensating admixtures (SCA). The mixtures are evaluated through the following test methods: free shrinkage per ASTM C157, scaling resistance per Canadian Test BNQ NQ 2621-

900, freeze-thaw durability per ASTM C666 (Procedure B, for freeze-thaw cycles) and ASTM C215 (for testing), compressive strength per ASTM C39, and hardened air-void analysis per ASTM C457. Additional mixtures are tested for scaling per ASTM C672 and freeze-thaw durability per Procedure A of ASTM C666. The total paste volume of this series of mixes is 23.7% (equivalent of 520 lb/yd^3 of cement), with a w/cm ratio of 0.45.

In addition, to capture the early-age deformation of concrete mixtures (within 24 hours after casting and during wet curing), a revised free shrinkage test is performed. Specimens complying with ASTM C157 in dimensions are demolded 6 hours after casting (shortly after final set). Initial length readings are taken, after which the specimens are immediately placed in lime-saturated water. Additional length readings are taken approximately every hour for the first 5 to 6 hours after demolding, and then every day during the 14-day wet curing period (specified in ASTM C157). After the wet-curing period, the specimens are moved to an environmentally-controlled room with a relative humidity of 50 ± 4% and a temperature of 73 ± 3 °F; further length measurements are taken as specified in ASTM C157.

One series of mixtures being evaluated contains 3% and 30% volume replacements of cement by silica fume and slag, respectively (total paste volume is 24.7%, total cementitious material weight is 540 lb/yd^3), with a 0.44 w/cm ratio and 5%, 8.4%, 10%, or 15% volume replacement of total aggregate by saturated LWA. The purpose of this series is to study the impact of the amount of IC water provided by LWA on the performance of concrete.

Mixtures containing various dosages of SRA-5, a shrinkage reducing admixture (SRA), are currently undergoing free shrinkage tests. Freeze-thaw and scaling tests are complete for this series of mixtures. Air void analysis on hardened specimens will be performed at a later date.

Mixtures containing various dosages of SRA-4 have been cast and are being tested for free shrinkage. Freeze-thaw and scaling tests are also complete for this series of mixtures. Air void analysis on hardened specimens will be performed at a later date.

Mixtures containing SCA-1, a magnesium based SCA, and SCA-2, a calcium based SCA, are currently undergoing free-shrinkage tests; results for freeze-thaw durability and scaling tests for these mixtures were summarized in previous reports.

Mixtures containing various dosages of SRA-5, SRA-4, and SCA-2 are currently being evaluated for free shrinkage including deformations within the first 24 hours - data that is not normally collected when testing in accordance with ASTM C157.

97% COMPLETE

TASK 3: Work with state DOTs, designers, contractors, inspectors, and material suppliers to modify designs, specifications, contracting procedures, construction techniques, and materials to obtain decks exhibiting minimal cracking.

This task was largely completed during the Annual Meeting of Pooled Fund Sponsors held in Kansas City, MO at the Kansas City Airport Hilton on July 23, 2009, as well as in meetings with KDOT officials as reported in the report for the 1st quarter of 2009. Additional decks have been added since 2009 –primarily decks containing synthetic fibers. This task will remain open until the end of the project to allow for modifications to LC-HPC bridge deck specifications, construction methods and materials as warranted.

97% COMPLETE

TASK 4: Select and schedule bridges to be constructed using "best practices," and pre-qualify designers and contractors in application of the techniques. To date, 17 bridges in Kansas, two in South Dakota, four in Minnesota, and one in Missouri have been identified for construction. Twenty additional bridges are proposed for Phase II. Researchers from the University of Kansas and state DOT personnel will work closely with designers and contractors to achieve the desired results. Pre-qualification of designers and contractors includes the presentation of workshops sponsored by the University of Kansas to help educate and train engineers in implementing the "best-practices" identified in Tasks 1 and 3.

For Phase II, a total of seven LC-HPC bridge decks have been constructed to date. Four LC-HPC bridge decks have been constructed in Minnesota and three LC-HPC bridge decks have been constructed in Kansas, with the 3rd Kansas LC-HPC bridge deck completed on September 28, 2011. Details on the construction of the first two bridge decks can be found in the 4th Quarter report for 2010. Details on the 3rd deck can be found in the 3rd Quarter report for 2011. Additional bridges are planned in Minnesota and Kansas, although these will be constructed under the provisions of a follow-on Pooled-Fund Study.

Seven bridge decks containing fibers have been constructed in Kansas. Two of the seven were deck replacements of north and south bound I-635 over State Avenue located in Wyandotte County, each completed in two placements. Both decks contained polypropylene macrofibers; in addition, the south bound deck contained glass fiber-reinforced polymer reinforcement. The first deck was constructed in the third quarter of 2013 and the second deck was constructed in the fourth quarter of 2013. KU personnel were not present during construction of the first placement of the first deck while the other three placements were completed with KU personnel in attendance monitoring construction. The third deck is east bound US-24 over Union Pacific Road and contains polypropylene microfibers. KU personnel were not present during the construction of this deck. The fourth deck, east bound US-24 over Union Pacific Railroad, was constructed in two placements on August 19 and 26, respectively. The deck contained F-4 polypropylene microfibers, and was constructed with KU personnel in attendance. The fifth, west bound K-10 over North Canal located at Douglas County, was constructed on November 10 with KU personnel present at the site, this deck contained F-3 macrofibers, Class C fly ash and slag. The sixth (Haskell over K-10) and seventh (31st over K-10) decks, both located at Douglas county, were constructed on May 12 and June 1, respectively, with KU personnel present during the construction. These two decks contained concrete with F-3 macrofibers with type C fly ash and slag.

97% COMPLETE

TASK 5: Perform detailed crack surveys on the bridge decks one year, two years, and three years after construction. The surveys are performed using techniques developed at the University of Kansas that involve identifying and measuring all cracks visible on the upper surface of the bridge deck. The majority of the early surveys will be done by the University of Kansas. As the project progresses, teams outside of the State of Kansas will be trained in the survey techniques. Three teams in South Dakota have been trained to date.

Annual crack surveys on selected LC-HPC and associated control decks began this quarter. Additional crack surveys were also conducted on bridges that were constructed with prestressed or steel girders on US-59 south of Lawrence, KS. Initial surveys on three newly constructed fiber decks in South Lawrence Trafficway (SLT) project were performed this quarter. Bridge surveys will also be performed on the remaining fiber and associated control decks in Kansas this summer, including NB and SB I-635 over State Avenue, EB and WB US-24 over Union Pacific Railroad and Menoken Rd.

97% COMPLETE

TASK 6: Correlate the cracking measured in Task 5 with environmental and site conditions, construction techniques, design specifications, and material properties and compare with earlier data. Similar data from participating states, where it exists, will be incorporated in the analysis. Actual costs and future cost estimates will be compared with potential benefits.

The correlation of cracking with the factors listed above is completed when major summary reported are completed. The last correlation was made in January 2014 and is available at https://iri.drupal.ku.edu/sites/iri.drupal.ku.edu/files/files/pdf/SM%20107.pdf .

97% COMPLETE

TASK 7: Document the results of the study. A final report will be prepared and disseminated to participating states regarding the findings of Tasks 1-6.

The results of the study through 2012 are documented in:

Pendergrass, B. and Darwin, D., "Low-Cracking High-Performance Concrete (LC-HPC) Bridge Decks: Shrinkage-Reducing Admixtures, Internal Curing, and Cracking Performance ," *SM Report* No. 107, University of Kansas Center for Research, Inc., Lawrence, Kansas, January 2014, 625 pp. available at https://iri.drupal.ku.edu/sites/iri.drupal.ku.edu/files/files/pdf/SM%20107.pdf

In the report, the development, construction, and evaluation of LC-HPC bridge decks are described based on laboratory test results and experiences gained during the construction of 16 LC-HPC decks. Free shrinkage and durability of LC-HPC candidate mixtures are evaluated, with emphasis on internal curing and shrinkage reducing admixtures. A description of the construction and evaluation of LC-HPC and control bridge decks constructed in Kansas is presented in the report.

Crack survey data for 2011, 2012, and 2013 are presented in:

Bohaty, B., Riedel, E., and Darwin, D., "Crack Surveys of Low-Cracking High-Performance Concrete Bridge Decks in Kansas 2014-2015," *SL Report* 13-6, University of Kansas Center for Research, Inc., Lawrence, Kansas, December 2013, 153 pp. available at https://iri.drupal.ku.edu/sites/iri.drupal.ku.edu/files/files/pdf/SLR13_6.pdf

Crack survey data for 2014 and 2015 are presented in:

Alhmood, A., Darwin, D., and O'Reilly, M., "Crack Surveys of Low-Cracking High-Performance Concrete Bridge Decks in Kansas 2011-2013," *SL Report* 15-3, University of Kansas Center for Research, Inc., Lawrence, Kansas, September 2015, 116 pp. https://iri.ku.edu/sites/iri.ku.edu/files/files/pdf/SLR15_3.pdf

Results acquired after completion of Alhmood et al. (2015) will be documented in subsequent reports.

97% COMPLETE

TASK 8: Update the training program developed (and currently being presented) in Phase I to assist the participating states in implementing the findings of the study. The program consists of workshops to be held at the representative state DOT offices. These workshops are individually coordinated with each participating DOT. A technical committee, structured with one representative from each state providing funds, will oversee the project. A meeting of the committee will be held each year, as has been done for Phase I. The first meeting is scheduled for July 24, 2008.

Information was disseminated at the annual meeting on July 19th, 2012 at the Kansas City Airport Hilton. Meeting CDs were sent to all representatives.

100% COMPLETE

Anticipated work next quarter:

Evaluation of mixtures containing saturated intermediate sized LWA, mineral admixtures, SRA, and SCA will continue. Additional mixtures will be made to validate the test results from current mixes.

Mixtures containing viscosity modifying admixtures (VMA) from various manufacturers will be tested for free-shrinkage, scaling resistance, freeze-thaw durability, and strength. A hardened air-void analysis will also be performed. The purpose of this series of mixtures is to evaluate how VMAs affect concrete durability.

Mixtures containing various dosages of SRA-6 will be tested for free shrinkage, scaling resistance, and freeze-thaw durability; air-void analysis of hardened specimens will be also performed.

Mixtures containing SCA-1 and SCA-2 are currently being evaluated for early-age deformation and free shrinkage, results will be presented in next quarter. The purpose of this study is to verify the effectiveness of shrinkage compensating admixtures.

Air-void analysis on hardened concrete will continue. To validate the automated analysis method available at KU, a selection of specimens will be tested by the KDOT lab using the manual linear transverse method (ASTM C457), then tested at KU using an automatic linear transverse method (RapidAir 457)

A series of mixtures containing combinations of crack reduction technologies such as SCMs, LWAs, SCAs, SRAs, and synthetic fibers will be evaluated for free shrinkage (including their early-age deformation), freeze-thaw and scaling behaviors.

The effect of salt concentrations (2.5% vs. 3%) on scaling resistance of a series of mixtures containing SRAs, SCA-1, SCMs, and LWAs will be evaluated.

Significant Results this quarter:

<u>LABORATORY RESULTS:</u>

One series of concrete mixtures containing 3% and 30% volume replacements of cement by silica fume and slag, with 5%, 8.44%, 10%, or 15% volume replacement of total aggregate by saturated LWA (with a total paste volume content of 24.7%, equivalent to 540 lb/yd^3 of cement with a 0.44 w/c ratio) are currently being evaluated. After 50 days of drying shrinkage (including the deformations measured during the first day after casting), mixtures containing 5%, 8.44%, 10%, and 15%

volume replacement of total aggregate by saturated LWA exhibited an average drying shrinkage of 310, 210, 177, and 97 microstrain, respectively. While all the mixtures exhibited similar first-day deformations (an average expansion between 20 and 50 microstrain), an increase from 10% to 15% in LWA replacement level seems to reduce the drying shrinkage in a more significant way (about 80 microstrain reduction in shrinkage) than inducing early-age expansions (only about 10 microstrain increase in expansion). In scaling tests, the mixture containing 10% LWA exhibited a mass loss of 0.469 lb/ft^2 and failed the test after 56 freeze-thaw cycles. After 21 freeze-thaw cycles, the mixtures containing 5% and 8.44% LWA experienced a mass loss of 1.87 and 0.09 lb/ft^2, respectively. Mixtures containing 15% LWA replacement will be evaluated in the next quarter.

One series of concrete mixtures containing 3% and 30% volume replacements of cement by silica fume and slag, respectively (with a total paste volume content of 23.7%, equivalent to 520 lb/yd^3 of cement with a 0.45 w/c ratio) is under evaluation. For this series, crack reduction technologies such as internal curing (by replacing a portion of total aggregate volume by intermediate sized pre-wetted LWAs) and additions of SRAs and SCAs are also incorporated in the mixtures to evaluate their effect on shrinkage (both early (first 24 hours) and long term), freeze-thaw, and scaling performance of concrete. This series includes a control mixture containing 3% and 30% volume replacements of cement by silica fume and slag, respectively, with a 10% replacement of total aggregate volume by saturated lightweight aggregate. The remaining mixtures in this series added various admixtures to the control mixture; one containing 6% of SCA-2 by weight of cementitious material, one containing 1% of SRA-4 by weight of cementitious material, and one containing 7.5% of SCA-1 by weight of cementitious material. A mixture containing 3% and 30% volume replacements of cement by silica fume and slag with no LWA was also tested for comparison.

Early-age shrinkage results indicate that when saturated LWAs are added, a slight early-age (first day) expansion takes place (about 40 microstrain), which is not observed in the mixtures not containing LWAs. When SRAs and SCAs are added to the mixtures containing slag, silica fume, and LWAs, the early-age expansion is further increased-significantly in some mixtures. When compared to the mixture containing slag, silica fume, and LWAs, the addition of 7.5% SCA-1, 6% SCA-2, and 1% SRA-4 cause additional expansions of 77, 430, and 20 microstrain, respectively. After 50 days of drying, the significant early-age expansion (about 550 microstrain) induced in the mixture containing LWAs and 6% SCA-2 exceeds the amount of drying shrinkage to date; the average deformation of the specimens is -233 microstrain (the negative sign indicates a net expansion). Mixtures containing 7.5% SCA-1 and 1% SRA-4 exhibit an average shrinkage of 50 and 167 microstrain, respectively. The mixture containing slag, silica fume, and LWA (the control mixture for this series) exhibited an average shrinkage of 225 microstrain, the highest among all mixtures evaluated in this series. The results indicate that LWA used along with SCA-2 (a calcium oxide based additive) induces significant early-age expansion that can potentially help in reducing the early-age cracking of concrete. This significant expansion caused in the mixture containing LWAs and SCA-2 can be attributed to the formation of more calcium hydroxide crystals (also referred to as portlandite) due to the presence of more curing water through LWAs that act as internal water reservoirs. This behavior was not observed in mixtures with SCA-1 or SRA-4. In the scaling test, the mixture containing slag, silica fume, and LWA experienced a mass loss of 0.188 lb/ft^2 after finishing 35 freeze-thaw cycles, close to but below the failure limit of 0.2 lb/ft^2 specified by BNQ NQ 2621-900. The mixture containing slag, silica fume, LWA and SCA-1 exhibited a mass loss of 0.207 lb/ft^2 and failed the test after only 7 freeze-thaw cycles. Other mixtures in this series are either in the early stages of the test and exhibited low mass loss, or have not yet started testing. These test results will be updated next quarter. All mixes will be duplicated to validate current results. Freeze-thaw test specimens have not begun testing; test results will be presented next quarter.

Concrete mixtures containing SRA-5 at dosages of 8, 24 and 40 fl oz. per 100 lb of cement are undergoing free shrinkage, scaling, and freeze-thaw tests. (The recommended dosage range for this SRA is 8-40 fl oz. per 100 lb of cement.) After 350 days of drying, mixtures containing 8, 24 and 40 fl oz. of SRA-5 have average drying shrinkages of 590, 453 and 333 microstrain, respectively. The control mixture has an average drying shrinkage of 573 microstrain. The mixture with 8 fl oz. of SRA-5 exhibits 17 microstrain greater shrinkage than the control mixture. The mixture with 24 fl oz. of SRA-5 exhibits 120 microstrain less shrinkage compared to the control mixture. The mixtures containing 40 fl oz. of SRA exhibit significantly lower shrinkage than the control mixture, with a shrinkage reduction of 240 microstrain. These observations suggest that this SRA is performing well at the higher range of the recommended dosage (40 fl oz.) compared to when a dosage of 8 fl oz and 24 fl oz is used. The initial scaling tests on mixtures containing SRA-5 are complete. Test results indicate that the mixture with 8 fl oz. per 100 lb of cement maintained low mass loss through 56 freeze-thaw cycles (comparable to a control mixture with no SRA dosage); however, mixtures containing 24 and 40 fl oz. per 100 lb of cement failed the test, experiencing mass losses greater than the failure limit of 0.2 lb/ft^2 after 21 and 35 freeze-thaw cycles, respectively. Specimens for duplicate for mixtures that failed the test are currently in curing and will be tested to validate previous test results. In freeze-thaw tests, all the mixtures containing SRA-5 passed the test by maintaining at least 99.8% of their initial dynamic modulus at the end of 300 freeze-thaw cycles according to ASTM C666.

Concrete mixtures containing SRA-4 at dosages of 0.5% and 0.75% by weight of cement are undergoing free shrinkage, scaling, and freeze-thaw tests. Results indicate that after 365 days of drying, mixtures containing 0.5 and 0.75% of SRA-4 have an average drying shrinkage of 380 and 303 microstrain, respectively. The control mixture for this series has an average drying shrinkage of 420 microstrain. The results show a reduction of drying shrinkage (maximum of 117 microstrain compared to control specimens) after a year of drying. Scaling and freeze-thaw test results reported in previous reports.

Circumstances affecting project or budget. (Please describe any challenges encountered or anticipated that might the completion of the project within the time, scope and fiscal constraints set forth in the agreement, alon recommended solutions to those problems).

Nothing to report.