Advancing Electrically Heated Pavements for Sustainable Winter Maintenance

tech transfer summary

An electrically conductive concrete heated transportation infrastructure system offers a more sustainable alternative to traditional snow removal methods, thus keeping concrete pavement surfaces in Iowa free of snow and ice during winter weather.

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RESEARCH PROJECT TITLE
Advancing Electrically Heated Pavements for Sustainable Winter Maintenance

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The overall goal of the Program for Sustainable Pavement Engineering and Research (PROSPER) is to advance research, education, and technology transfer in the area of sustainable highway and airport pavement infrastructure systems. The mission of the National Concrete Pavement Technology Center (CP Tech Center) is to unite key transportation stakeholders around the central goal of developing and implementing innovative technology and best practices for sustainable concrete pavement construction and maintenance.

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National Concrete Pavement Technology Center

IOWA STATE UNIVERSITY
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Objective

To facilitate construction of the Iowa City bus stop enhancement project under Iowa Highway Research Board (IHRB) Project TR-789, this research aimed to identify suitable production, transportation, and quality control/assurance techniques for ready mixed concrete plant-produced electrically conductive concrete (ECON).

Electrical safety evaluation tests were also conducted to determine safety protocols for mitigating electrical shock hazards during the system operation of the Iowa City bus stop enhancement project.

Background

In cold regions, transportation agencies face significant challenges during harsh winters with frequent winter weather events. Traditional snow and ice removal methods, such as the use of deicing salts and mechanical equipment like snowplows, are widely used but come with notable limitations and drawbacks.

ECON heated transportation infrastructure systems offer a promising solution. These systems operate on the principle of ohmic heating, in which electricity is applied to the pavement slab through embedded electrodes to convert electrical energy into thermal energy. This process raises the surface temperature of the pavement, effectively preventing ice formation or melting existing snow.

Electrical safety testing of an ECON pavement at the Iowa DOT facility

Problem Statement

The optimal performance of ECON heated transportation infrastructure systems depends on precise production methods that reliably achieve the required electrical properties of ECON. However, the existing literature lacks comprehensive insights into large-scale ECON production techniques during full-scale implementation.

Moreover, since this technology is intended for public use, conducting thorough electrical safety evaluations is essential to ensure that regulatory authorities, such as electrical inspectors, can confidently approve the implementation of this technology within their jurisdictions.

ECON beam at Iowa State University's Portland Cement Concrete Laboratory

Research Description

To establish effective techniques for ECON production, transportation, and quality control/assurance, 9 laboratory trials (LT-1 to LT-9) and 12 ready mixed concrete plant trials (PT-1 to PT-12) were conducted.

Two ready mixed concrete plants—Manatt's Inc. in Ames and Croell Inc. in Iowa City, approximately 200 miles apart—were selected to ensure that the developed production methods could be adapted to similar facilities. Each plant used aggregate materials sourced from different locations that exhibited distinct gradations.

To identify the most suitable carbon fiber length for large-scale ECON production, chopped carbon fibers with lengths of 0.5 in. and 0.25 in. were evaluated. Laboratory trials were performed at Iowa State University's Portland Cement Concrete Laboratory to optimize the mixture designs. These trials were essential for determining the optimal proportions while accounting for fiber length variations and material differences between the two selected plants.

For each trial, at least three beams (14 in. x 4 in. x 4 in.) were fabricated. Copper mesh electrodes were affixed to the two longer ends of each beam to facilitate further testing and evaluation.

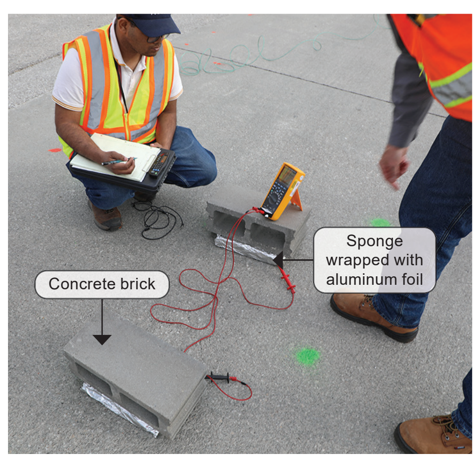
Chopped virgin carbon fiber

To establish electrical safety protocols for the ECON heated transportation infrastructure system, a series of electrical tests was conducted in collaboration with cdcmello Consulting LLC and a field evaluation group from Underwriters Laboratories (UL).

Initial testing was performed at two existing ECON heated transportation infrastructure sites: the main offices of the Iowa Department of Transportation (DOT) and the Des Moines International Airport. Surface voltage and surface leakage currents were measured at selected points to verify compliance with the safety limits defined by the National Electrical Code (NEC) and UL standards.

Subsequently, electrical evaluations were conducted on a laboratory-fabricated ECON slab to assess safety in the presence of a crack within the slab.

Finally, a small-scale demonstration sidewalk was constructed using the configurations recommended in IHRB Project TR-789, Implementing a Self-Heating, Electrically Conductive Concrete Heated Pavement System for the Bus Stop Enhancement Project in the City of Iowa City. Electrical testing on this demonstration system was performed to confirm its safety for public use during operation.



Electrical safety evaluation

Key Findings and Recommendations for Implementation

The following recommendations can be made to facilitate the successful construction of the Iowa City bus stop enhancement project under IHRB Project TR-789 and to mitigate electrical shock hazards during system operation:

Carbon Fiber Selection and Dosage

- Carbon fiber is recommended for ECON production because its noncorrosive nature ensures long-term performance. A fiber length of 0.5 in. minimizes the increase in electrical resistance caused by fiber degradation during ECON production in a ready mix truck mixer.

- For IHRB Project TR-789, a dosage of 0.40 vol.% (12.2 lb/yd³) of 0.5-inch carbon fiber is recommended, aiming for an electrical resistance between 10 and 20 Ω at 28 days in a 14 in. × 4 in. × 4 in. beam with copper mesh electrodes. Alternative recommended options are (i) use 0.45 vol.% (13.7 lb/yd³) of 0.5-inch carbon fiber for constructing the northside slabs, and 0.40 vol.% (12.2 lb/yd³) of 0.5-inch carbon fiber for the southside slabs (ii) use 0.45 vol.% (13.7 lb/yd³) of 0.5-inch carbon fiber for all slabs.

Fiber Addition Process

- Carbon fiber should be added in two steps at the job site. This approach minimizes the risk of fiber degradation and ensures uniform distribution of carbon fibers throughout the mix.

Batch Size Limitation

- For IHRB Project TR-789, the maximum truckload for a single batch of ECON in a ready mix truck mixer is recommended to be limited to 6 yd³. This reduces the risk of fiber balling and ensures proper fiber dispersion within the mixture.

Fresh-Stage Quality Control

- Before acceptance of any batch of ECON at the job site, fresh-stage electrical resistance should be measured and verified against the target values to ensure the system's efficiency and functionality.

- Batch acceptance or rejection can be determined by comparing the measured fresh-stage electrical resistance to the predicted value calculated using the prediction equation provided in the final report for this project.

- For IHRB Project TR-789, the fresh-stage electrical resistance for a 14 in. by 4 in. by 4 in. beam with copper mesh electrodes should fall within the range of 4 to 10 Ω.

Operational Voltage and Safety Recommendations

- A 24 VAC electrode supply voltage was confirmed to be safe for public use and is recommended for the operation of ECON heated transportation systems to mitigate electrical shock hazards. Additionally, an ungrounded supply system is suggested to enhance safety.

- Both the bare concrete and the ECON system must be designed with the primary consideration of preventing shock and burn hazards.

Implementation Readiness and Benefits

The findings of this study will ensure high-quality ECON production at ready mixed concrete plant during construction of the Iowa City bus stop enhancement project under IHRB Project TR-789. While applying the findings in other future projects within Iowa, minor adjustments might be necessary based on specific project needs.

By adopting ECON heated transportation infrastructure technology on a larger scale, especially in critical transportation infrastructure, Iowa can significantly enhance its ability to respond to winter weather conditions and efficiently maintain traffic mobility.