Transportation Consortium of South-Central States (Tran-SET)

Self-Healing Concrete using Encapsulated Bacterial Spores in a Simulated Hot Subtropical Climate

Measuring the self-healing efficiency of microencapsulated bacteria in concrete, with respect to its crack-sealing capabilities and modulus of elasticity recovery

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PI: Dr. Marwa Hassan (LSU), Dr. Jose Milla, Dr. Tyson Rupnow (LTRC)

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Bacterial concrete has become one of the most promising self-healing concrete materials due to its capability to seal crack widths up to 1 mm through microbial induced calcite precipitation. It is developed by adding alkali-resistant bacteria, which do not impose hazards to human health, in the concrete mixing process. In this study, the authors aim to develop an encapsulation procedure that will allow for testing two bacterial strains at varying dosages (by weight of cement) in concrete. Beam specimens will be used to identify the maximum crack-sealing efficiency, while cylinder samples will be used to determine their effects on the intrinsic mechanical properties, as well as its healing over time after inducing damage. The concrete specimens will be cured in wet-dry cycles to determine their feasibility in subtropical climates.

Background

Self-healing materials have gained significant research attention in recent years, due to their ability to increase durability and alleviate the ever-increasing maintenance costs for concrete infrastructure. During a cracking event, a self-healing mechanism is triggered by any combination of (a) environmental conditions; (b) chemical agents; and/or (c) biological agents to produce a material to seal the cracks. Examples of self-healing materials include the introduction of mineral admixtures in concrete, microencapsulation of healing agents embedded in concrete, and bacterial concrete. These approaches have shown promise in sealing hairline cracks autonomously in the presence of moisture. Microencapsulation of healing agents has been proven to be an effective approach as it provides a localized response to damage. Hence, during a cracking event, the microcapsules will rupture due to tensile stresses and release the healing agent to react with the cementitious matrix. Other suitable encapsulation strategies include synthetic or biobased superabsorbent polymers, and impregnation in expanded clays, lightweight aggregates, and diatomateous earth.

Project Summary

The research project's main objective is to evaluate the performance of two bacterial strains (Diaphorobacter Nitroreducens and Bacillus Pseudofirmus) for self-healing concrete applications and its effect on concrete properties and crack-sealing in wet/dry cycles. The project tasks are the following:

Task 1: Bacteria cultivation;

Task 2: Development of encapsulation procedure;

Task 3: Concrete specimen preparation;

Task 4: Monitoring crack-healing in concrete beams;

Task 5: Image analysis of cracked beams;

Task 6: Assessment of intrinsic concrete properties; and

Task 7: Self-healing concrete testing.

Project tasks will be achieved by first selecting the ideal bacteria species that will enable a self-healing effect on concrete. It is recommended that the selected bacteria be alkali-resistant, and also capable of accepting both nitrate and oxygen electrons to enable the microbial induced calcium carbonate precipitation (MICCP) reaction. These bacterial strains will be cultivated, then subsequently encapsulated with calcium alginate beads.

A concrete mixture design representative of pavements in Louisiana will then be selected, but with the addition of 1.25" polymer fibers and a defoaming agent. The polymer fibers will be used to increase the ductility and prevent a sudden failure of the specimens subjected to high compressive or flexural loads, since it is important to first damage the samples to test the self-healing effect. The microcapsule dosages to be tested are at 0.5%, 1.5%, and 3% (by weight of cement). Once the samples are cast, beam specimens will be used to identify the maximum crack-sealing efficiency, while cylinder samples will be used to determine their effects on the intrinsic mechanical properties, as well as its healing over time after inducing damage. Since the bacteria is known to require water to initiate the MICCP reaction, the concrete specimens are being subjected to wet-dry cycles.

Status Update

To date, the bacteria strains were cultivated, encapsulated, and embedded into concrete at varying concentrations (0.5%, 1.5%, and 3% by weight of cement). 8 specimen groups have been prepared; their details are shown below.

Table 1. Specimen group details.

Specimen Group	Capsule Concentration	Bacteria Type
Control NC (no bacteria capsules)	0%	N/A
Control 3%C (3% capsules, no bacteria)	3%	N/A
DN-0.5%	0.5%	D. Nitroreducens
DN-1.5%	1.5%	D. Nitroreducens
DN-3.0%	3.0%	D. Nitroreducens
BP-0.5%	0.5%	B. Pseudofirmus
BP-1.5%	1.5%	B. Pseudofirmus
BP-3.0%	3.0%	B. Pseudofirmus

Compressive strength test results and modulus of elasticity results are preliminary and currently on-going; current results are shown below.

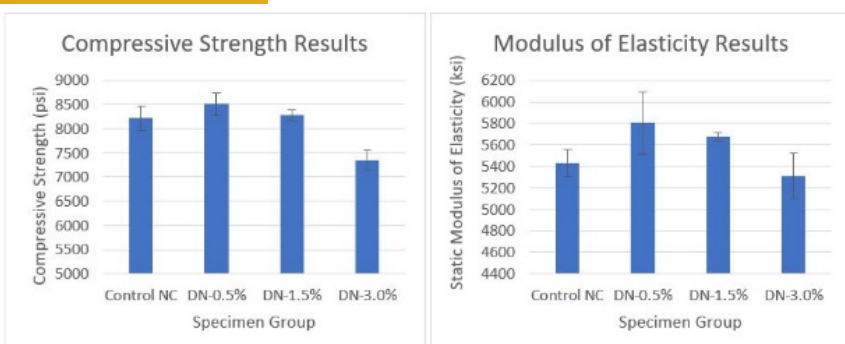

Figure 1. Preliminary compressive strength results (left), and static modulus of elasticity results (right).

Figure 2. Set-up for cracking beams, prior to monitoring self-healing (left); Set-up for the modulus of elasticity test, to be conducted before and after healing (right).

As expected, a higher concentration of microcapsules yields weaker compressive strength. This trend has been observed in numerous studies, since the capsules are generally the weakest link within the matrix and do not contribute to strength. A similar trend was found with the static modulus of elasticity results, where a higher capsule concentration yielded lower modulus values.

Impacts

This study will provide the foundation for field testing of self-healing bacterial concrete. If successful, bacterial concrete will be tested for suitability as a concrete pavement in actual climate conditions in Baton Rouge, LA. Its main benefits are economic and environmental, where the autonomous healing mechanism will save maintenance costs, and protect the steel reinforcement from corrosion caused by harmful agents seeping through microcracks.

In addition, it is expected that self-healing concrete through microencapsulated bacteria will increase the durability of concrete structures and reduce maintenance and repair costs.

Tran-SET

Tran-SET is Region 6's University Transportation Center. It is a collaborative partnership between 11 institutions (see below) across 5 states (AR, LA, NM, OK, and TX). Tran-SET is led by Louisiana State University. It was established in late November 2016 "to address the accelerated deterioration of transportation infrastructure through the development, evaluation, and implementation of cutting-edge technologies, novel materials, and innovative construction management processes".

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