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

Self-healing Microcapsules as Concrete Aggregates for Corrosion Inhibition in Reinforced Concrete Materials

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Testing the feasibility of microencapsulated corrosion inhibitors for reinforced concrete structures.

The objective of this research is to study the performance of different corrosion inhibitors at various microcapsule concentrations. Two types of inhibitors were used, namely, calcium nitrate and triethanolamine with microcapsule concentrations of 0.25, 0.5, and 2%. Corrosion testing was performed in continuous ponding and wet/dry cycles. The results showed that, for calcium nitrate, high concentrations of microcapsules is detrimental to mechanical properties of concrete and corrosion resistance of rebar. An increase in microcapsule was found to decrease the strength of concrete. During the continuous ponding in the corrosion test, all samples show corrosion activation in the first ten days of ponding which was then followed by repassivation from day 10 - 85. The highest magnitude of activation was found in the sample that has the highest microcapsule concentration (2%).

Problem Statement

The use of self-healing corrosion inhibiting solutions provides a technology capable of influencing surface properties and indirectly the transport properties, the rebar corrosion rate, and the mechanism of reaction at the steel/concrete interface. Microencapsulated corrosion inhibitors can be used to control and mitigate damage evolution processes in electrochemical systems such as reinforced concrete systems. These capsules are made of either urea formaldehyde or polystyrene, and can withstand the strenuous concrete mixing process. The selected corrosion inhibitors for this study are calcium nitrate, and triethanolamine, respectively. The advantage of the microcapsules lays in the fact that it can provide an autonomous, localized response to mitigate corrosion, thereby minimizing the need for maintenance or repair.

Summary

Sample Preparation: concrete cylinders were made for compressive strength (ASTM C39), and surface resistivity tests (AASHTO TP 95), while concrete beams were made for corrosion testing (ASTM G109). The concrete samples were cast and cured in laboratory settings per ASTM C192 guidelines. A total of three 100 mm x 200 mm cylinders and three 150 mm x 150 mm x 280 mm beams were poured per specimen group. All beam specimens associated with calcium nitrate were subjected to a 3point loading system, where a slow strain rate (0.005 in/s) was applied until a crack was induced. The crack sizes induced ranged from 0.2 - 0.45 mm.

Corrosion Characterization: this work presents the interfacial characterization of corrosion-inhibiting agents by exposing the concrete specimens to continuous ponding and wet/dry cycles. Corrosion normally occurs at a rate determined by an equilibrium between opposing electrochemical reactions. The first is the anodic reaction, in which a metal is oxidized, releasing electrons into the metal. The other is the cathodic reaction, in which a solution species (often oxygen or hydrogen ions) is reduced, removing electrons from the metal. When these two reactions are in equilibrium, the flow of electrons from each reaction is balanced, and no net electron flow (electrical current) occurs. The equilibrium potential assumed by the metal in the absence of electrical connections to the metal is called the Open Circuit Potential (OCP). Therefore, the corrosion tests for both exposures consist of open circuit potential (OCP) and voltage drop across a 100 Ω resistor, and electrochemical impedance spectroscopy (EIS).

For the continuous ponding, all the corrosion tests were performed every week for 85 days. However, in the first ten days, the measurement was taken every two days. In the wet/dry cycles, the ponding well was filled with a 3 wt.% NaCl solution and the specimens were alternately exposed to two-week periods with solution, then two weeks without solution. The corrosion testing was conducted at the beginning of the second week of ponding.

Findings

Concrete Testing: the compressive strength results indicate that for the calcium nitrate specimens, an increase in microcapsule concentration has a negative impact on strength, where the highest microcapsule concentration (2% by wt. of cement) resulted in an 18% strength reduction. Furthermore, the surface resistivity tests showed that the addition of microcapsules dropped the chloride permeability level from 'Low' to 'Moderate' for the tested mix design.

A statistical test using Fisher's least squares difference (LSD) was used to determine if the addition of microcapsules had a significant effect on the compressive strength of concrete. The analysis shows that the control specimen group is significantly different from those samples admixed with microcapsules at 0.5% and 2.0%. Even though the defoaming agent was shown to improve dispersibility of the microcapsules in water, it is possible that with the defoamer concentration used it was still insufficient to disperse the capsules throughout the concrete matrix adequately.

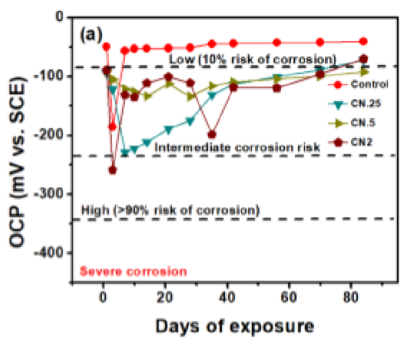

Figure 1. Open circuit potential measured for 85 days during the continuous ponding.

Corrosion Testing: The values of OCP measured for 85 days are presented in Figure 1. In general, all the samples show a corrosion activation in the first week of continuous ponding, as suggested by a sharp decrease in OCP in the first ten days. This phenomenon can be related to the chloride ingress through a diffusion that reached the rebar. However, since the continuous ponding does not result in a significant increase in the chloride accumulation on rebar, localized corrosion tends to cease, then repassivation occurs. This repassivation is evident by an increase in OCP in the noble direction from day 10 - 85.

The macrocell corrosion current measurements (obtained from voltage drop across a 100 ? resistor) show an unclear trend in the continuous ponding (Figure 1). This is in agreement with OCP trend in Figure 2. The effect of microcapsule concentration can be clearly seen in the wet/dry cycles where the current released tends to decrease with increasing the microcapsule concentrations.

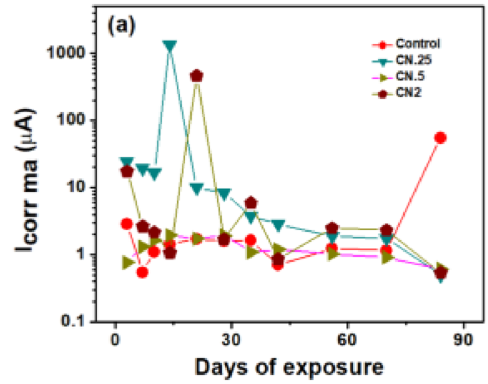

Figure 2. Macrocell corrosion current measured for 85 days of continuous ponding.

Impacts

The proposed research is testing the feasibility of a novel technology that inhibits corrosion damage in reinforced concrete structures to enhance the durability and resiliency of concrete structures. This will help preserve an important class of physical assets, reinforced concrete structures against corrosion-induced damages. The regional transportation system will benefit greatly if the proposed research is implemented to reduce the need for maintenance and repairs of RC structures affected by corrosion damage. This will result in significant savings to the DOTs in region 6.

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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For more information about Tran-SET, please visit our website, LinkedIn, Twitter, Facebook, and YouTube pages. Also, please feel free to contact Mr. Christopher Melson (Tran-SET Program Manager) directly at transet@lsu.edu.

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