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Self-Healing Cementitious Composites (SHCC) with Ultrahigh Ductility for Pavement and Bridge Construction

Introduction

The formation of cracks in concrete structures is commonly observed due to the intrinsic brittleness of the concrete. Concrete structures, such as pavement and bridge decks, are prone to deformation and deterioration caused by shrinkage, temperature fluctuation, and traffic load. This in turn can significantly affect the service life of the structure. The rehabilitation of the concrete structure can be expensive and challenging since the structures are in continuous service. Therefore, it is critical to develop self-healing cementitious composites (SHCC) with ultrahigh ductility to potentially overcome the issues.

In this project, the team at Purdue University designed a series of cementitious composites to investigate their mechanical performance and self-healing ability. First, various types of fibers were investigated to improve the ductility of the designed SHCC. To enhance the self-healing of SHCC, we tested if the combination of the internal curing method with SHCC mixture design to improve the self-healing performance. Three types of internal curing agents were used on the SHCC mixture design, and the self-healing efficiency was evaluated by using multiple non-destructive tests, including resonant frequency test, ultrasonic pulse velocity test, and optical microscopic observation. The results indicated a significant improvement in the self-healing capacity with the incorporation of the internal curing agents. To control the fiber distribution and workability of the SHCC, the mix design was further adjusted by controlling the rheology using different types of viscosity modifiers. The team also explored the potentials of incorporating nano-silica into the mix design of SHCC. Better hydration was achieved by adding the nano-silica. The bonding strength of the SHCC with conventional concrete was also improved. The results suggest that a certain amount of nano-silica would positively influence the self-healing efficiency and mechanical properties of the SHCC. Finally, a standardized mixing procedure for the SHCC was also developed.

Findings

We have conducted a comprehensive investigation of a serial of self-healing cementitious composites with various mix designs. Extensive experiments were performed to investigate the effectiveness of different variables, such as fibers properties, internal curing agents, and various additives in SHCC. The findings of this project are detailed as follows.

- Mechanical property and the crack width control ability of six different types of fibers—PVA (Polyvinyl Alcohol) Fiber, Strux 90/40, Masterfiber Mac Matrix, Fiberforce 650, Suf-Strand SF, and Forta-Ferro One—were evaluated with SHCC design. Experimental results showed that SHCC samples with various fibers incorporated exhibited pseudo-strain-hardening behavior during the loading process due to the bridging effect of fibers. Among the six mixtures, samples with PVA fiber exhibited better performance.
- Two types of internal curing aggregates, Zeolite, and lightweight aggregate were used and evaluated with SHCC. Experimental results provide solid evidence that the internal curing aggregates

can enhance the healing efficiency by providing water internally to accelerate the autogenous healing.

- Three types of viscosity modifying agents were used, and the properties of the SHCC were evaluated. The viscosity results indicated that compared with thickening-type VMA, the binding-based VMA can better increase the viscosity of fresh SHCC. The increase of the viscosity of SHCC can prevent segregation, which improves the interfacial properties between fiber and matrix and fiber distribution.
- The team investigated the mechanical properties and self-healing performance of SHCC incorporated with the colloidal nano-silica. The experimental result shows that colloidal nano-silica can significantly improve mechanical strength. Self-healing evaluation suggests that the incorporation of nano-silica presents a positive impact on autogenous healing of the SHCC.
- To study the feasibility of utilizing designed material in the real field application, the team prepared the SHCC mixture on a large scale. The workability assessment by slump and J-ring tests indicates that the designed SHCC with VMA possesses excellent workability and passing ability which is comparable with self-consolidating concrete (SCC).

Implementation

The objective of this project was to develop ductile self-healing cementitious composites (SHCC), which can be used in various concrete applications, especially for link-slab. The SHCC was delivered to INDOT as a reference for the design of concrete materials with ultra-high ductility and self-healing ability that can reduce the need for conventional rehabilitation.

To ensure the quality of the fiber distribution and the ductility of the SHCC, PVA fiber with short fiber length, high tensile strength, and aspect ratio was chosen. Better mechanical properties and crack width control ability can therefore be expected.

A standardized mixing procedure for the large scale SHCC was developed based on the large batch mixing.

An internal curing method was applied into the design of the SHCC to further improve the self-healing performance. Internal curing aggregates with high porosity and small pore size, such as zeolite, performed better in the improvement of the healing efficiency.

The combination of the SHCC with conventional concrete can improve the flexural performance of the beam sample. A higher flexural strength with high modulus of rupture (MOR) can be achieved.

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