Fiber-Reinforced Concrete for Bridge Decks

tech transfer summary

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RESEARCH PROJECT TITLE
Fiber-Reinforced Concrete in Bridge Decks

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The Bridge Engineering Center (BEC) is part of the Institute for Transportation (InTrans) at Iowa State University. The mission of the BEC is to conduct research on bridge technologies to help bridge designers/owners design, build, and maintain long-lasting bridges.

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The results of this three-stage study can be used to determine a suitable mixture design for the application of fiber-reinforced concrete for bridge decks.

Problem Statement

Concrete is exposed to various stressors from the initial hours of pouring, making it prone to cracking. Because of these stressors and the multiphase nature of concrete, the design of concrete is a delicate task that requires consideration of several factors.

This is especially true for bridge deck concrete, which is exposed to destructive environmental and mechanical stressors simultaneously. Due to the low early-age strength of concrete, even small-magnitude tensions can result in cracking and consequently decrease the longevity of the bridge deck.

Goal and Objectives

This project investigated multiple crack mitigation strategies to address shrinkage-induced cracks, the most important cause of cracking in concrete bridge decks. The post-crack performance of concrete was also examined, with the workability of the concrete being considered as a key factor.

The three mitigation strategies investigated included the selection of a binder composition suitable for mitigating the early-age cracking potential of concrete, the use of different dosages of microfibers as reinforcement against early-age cracking, and the use of three different macrofibers to improve pre- and post-peak mechanical properties in hybrid fiber-reinforced concrete (FRC) mixtures (i.e., FRC containing both microfibers and macrofibers).

Background

Due to its large surface area, concrete used in bridge decks is significantly prone to shrinkage-induced cracking caused by water evaporation, either through plastic shrinkage when the concrete is in a semiplastic phase or through drying shrinkage over longer periods.

Cracks that develop and propagate into the concrete provide channels for corrosive agents, such as chloride ions, to penetrate directly into the concrete. The penetration of these destructive agents results in the corrosion of embedded reinforcing steel and subsequent structural deterioration. At that point, the superstructure would need to be either repaired, which hinders the operation of the bridge, or demolished and rebuilt.

Shrinkage-induced cracking can be addressed by modifying the binder composition or utilizing discontinuous fibers randomly distributed throughout the concrete matrix to provide additional tensile strength capacity.

Research Description

A three-stage investigation was designed for this project.

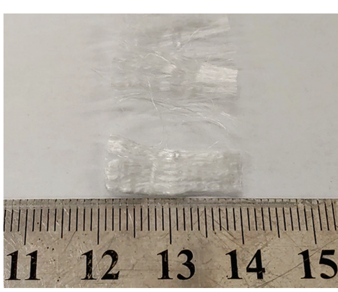
In Stage 1, multiple binder compositions and supplementary cementitious materials (SCMs) were studied for their performance in terms of early-age plastic shrinkage by recording capillary pressure development, monitoring crack width, and determining strain development by means of digital image correlation (DIC).

In Stage 2, different dosages of polypropylene (PP) microfibers were added to concrete mixtures to compensate for the concrete's low tensile strength and to control cracking. To measure the microfibers' efficiency, drying shrinkage, compressive and splitting tensile strength, and rapid chloride migration tests were carried out to determine the cracking potential, as well as mechanical and durability properties, of the developed FRC mixtures.

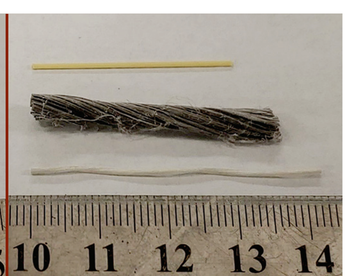
In Stage 3, to enhance post-peak strength, three types of macrofibers, i.e., PP, alkali-resistant (AR) glass, and polyvinyl alcohol (PVA), were incorporated into the FRC mixtures that already contained microfibers. The compressive, splitting tensile, and flexural strengths of the concretes were recorded as the pre-peak mechanical properties, and the toughness and residual flexural strengths were investigated as the post-peak mechanical properties.

Key Findings

- Class F fly ash, as opposed to silica fume and Type K expansive cement, was found to contribute most to the early-age cracking resistance of concrete. Therefore, Class F fly ash was incorporated into the mixture design of the FRC in subsequent stages of this research.
- Tensile strength increased with both age and PP microfiber percentage among all ages and mixtures of FRC for fiber dosages up to 1.0% by volume. The largest relative increase in tensile strength occurred at lower PP microfiber dosages in the range of 0.25%. The ability of PP microfibers to improve the tensile strength of concrete decreased in efficiency at fiber volumes of 1.0% or higher.
- Cracking potential, defined as the ratio of the maximum shrinkage-induced stress experienced by an FRC mixture to the tensile strength of the same FRC mixture, decreased with an increase in PP microfiber percentage for fiber dosages up to 1.0%. At volumes of 1.0% and higher, the relative reduction in cracking potential significantly decreased compared to the relative reduction in cracking potential at lower dosages.



PP microfibers used in the study



Macrofibers used in the study: PVA (top), PP (center), and AR glass (bottom)

- PVA macrofibers reduced the workability of FRC more significantly than AR glass and PP macrofibers due to the water absorption of the PVA fibers. On the other hand, PP and PVA macrofibers reduced the compressive strength of concrete, while AR glass macrofibers provided a compressive strength similar to that of the control sample.
- The mechanical test results suggest that AR glass macrofibers show a promising synergy with PP microfibers, which makes AR glass macrofibers an appropriate choice for hybrid FRC mixtures. In such mixtures, the addition of AR glass macrofibers resulted in superior strength, which was augmented by increasing the macrofiber dosage.

Conclusions

Replacing a portion of portland cement with Class F fly ash has a positive effect on workability, long-term durability, and resistance of concrete mixtures to plastic shrinkage. Although the addition of Type K cement showed promise in limiting the crack width, it increased the rate of capillary pressure development, which impedes resistance to plastic shrinkage.

The addition of PP microfibers, even in dosages as low as 0.25% by volume, significantly reduced cracking potential due to drying shrinkage. PP microfibers were also found to enhance mechanical and chloride resistance, though increasing the microfiber volume beyond a certain percentage decreased the fibers' efficiency. Like other microfibers, however, PP microfibers increase the water demand of concrete, which can be a restrictive operational parameter.

This study explored the addition of macrofibers for their ability to provide adequate post-peak strength. Twisted AR glass monofilament fibers showed superior performance over PP and PVA macrofibers.

Recommendations

It is recommended that Class C fly ash replace 20% of portland cement to address dimensional stability, workability, and durability concerns.

Practical considerations limit the dosage of PP microfibers. The maximum practical dosage is recommended to be 0.125%, which corresponds to 2 lb/yd^3.

Twisted AR glass monofilaments are recommended as macrofibers. The recommended fiber combination is 0.125% PP microfiber along with 0.25% AR glass macrofiber, which can satisfy practical requirements and provide suitable pre- and post-peak mechanical properties.

Implementation Readiness and Benefits

The results of this study can be used to determine a suitable mixture design for the application of FRC for bridge decks. The final report for this project provides details.