RESEARCH ADMINISTRATION
Bureau of Field Services
Michigan Department of Transportation

Research Spotlight

Project Information

REPORT NAME: Development, Characterization and Applications of a Non-Proprietary Ultra-High Performance Concrete for Highway Bridges

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MDOT aims for lower-cost ultra-high performance concrete

In recent years, several vendors have developed ultra-high performance concrete (UHPC) that surpasses traditional concrete mixes by offering exceptional freeze-thaw resistance, reduced susceptibility to cracking and far less reinforcement corrosion from deicing salts. While the durability properties of UHPC are very attractive to MDOT, UHPC mixes are currently prohibitively expensive for widespread use and require specialized equipment and curing practices. The department's research to develop a less-expensive, non-proprietary version of UHPC is showing promise.

Problem

Existing UHPC products are proprietary and protected by patents. They require specialized mixing equipment and steam curing, making them up to 10 times more expensive than traditional concrete products. UHPC currently is used primarily in small applications such as precast element closure pours like bridge joints. But if cost were reduced, UHPC could have potential application in other bridge components, including thin overlays for decks that now need to be replaced every few decades.

Steel fibers added to the mix help UHPC resist cracking. There is currently only one domestic supplier for steel fibers, but Michigan's manufacturing industry is well-suited to begin offering them if more demand emerges.

In general, UHPC is created by using materials that pack together as densely as possible. Specific components include fine sand, silica powder, silica fume, cement, water, and steel fibers that hold the material together to help it resist cracking. MDOT undertook this study with the University of Michigan to evaluate the impacts of each of these components and to develop specifications for a non-proprietary and less-expensive UHPC product.

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> *"Even though the lab batch showed all the hallmarks of being successful, we haven't been able to implement it because the mix failed in a demo project. We're proposing a second phase of research to study how to scale up production and improve the product specification."*
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> **Steven Kahl, P.E.**
> Project Manager

Research

Silica fume, silica powder and steel fibers are the most expensive components of UHPC. Researchers conducted several laboratory tests to evaluate how changing the relative amounts of these materials affects the concrete's performance.

Researchers also tested three different cements: portland Type I white cement, portland Type V, and a mix of portland Type I and ground granulated blast furnace slag (GGBS). Traditionally white cement is used in UHPC, but the other types are less expensive options.

Researchers created 28 UHPC mixes with various combinations of these components, evaluating each mix's tensile strength and compressive strength with standard American Association of State Highway and Transportation Officials (AASHTO) laboratory tests.

To evaluate durability, researchers exposed specimens of selected mixes to at least 60 12-hour freeze-thaw cycles as well as to an air void analysis in accordance with relevant ASTM tests.

Results

The quantity of silica powder had very little impact on the concrete performance parameters tested. Post-cracking strength, number of cracks formed and fiber tensile stresses showed almost no change as the amount of silica powder changed. Compressive strength increased slightly as the amount of silica powder increased, but even mixes with no silica powder met the 22 ksi (kilopound per square inch) compressive-strength standard to be considered UHPC. This suggests that silica powder can be omitted from a UHPC mix to reduce its cost significantly.

Cement type and silica fume content had only minor impacts on sample performance in tensile, compression and durability tests.

Reducing fiber content did have a sizable impact on both compressive and tensile strength. In laboratory tests, even the lowest level of fibers tested (0.5 percent by volume) achieved a tensile performance sufficient to limit cracking and protect reinforcing steel from moisture and chlorides. However, the creation of samples for this test tended to align the fibers artificially, increasing their strengthening impact. In actual structures, fibers would be oriented randomly. While it is likely that fiber content of 1.0 percent still could achieve necessary performance, full-scale tests are necessary to confirm this assumption.

Value

This project represented MDOT's first attempt to create a non-proprietary UHPC product. Researchers recommended a mix that used the blend of portland Type I and GGBS as cement, 25 percent silica fume and no silica powder. In the lab, this mix achieved the standards to be considered UHPC at less than half the cost of a proprietary mix.

However, while this mix performed well in laboratory tests, it failed in an MDOT demonstration project that involved producing concrete on a commercial scale. Initial investigation suggests that the densified silica fume used in the project had a higher carbon content than that used to develop the mix. A follow-up project has been proposed to study how to produce the mix effectively in larger quantities. If that project is successful, UHPC may become cost-effective for use in bridge decks, in closure pours that join precast elements and in congested areas where consolidation is a problem, such as full-depth shear keys. While it is likely that the cost of UHPC will remain higher than the cost of traditional concrete, its greater durability, reduced traffic impact and lower maintenance costs would save money over its full life cycle.

In addition, thanks to its excellent strength properties, UHPC may make it possible for thinner structural components to be used in construction. The resulting reduction in weight might make precast elements easier to use and accelerated bridge construction more feasible.

Research Administration

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