Initial Characterization of Geopolymer-Based UHPC Material Properties

tech transfer summary

Geopolymer-based ultra-high-performance concrete (UHPC) has the potential to be a more cost-effective and environmentally friendly option compared to traditional UHPC.

August 2018

RESEARCH PROJECT TITLE
Initial Characterization of Geopolymer-Based UHPC Material Properties

SPONSORS
Iowa Highway Research Board (IHRB Project TR-708A)
Midwest Transportation Center
U.S. Department of Transportation Office of the Assistant Secretary for Research and Technology

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The Midwest Transportation Center (MTC) is a regional University Transportation Center (UTC). Iowa State University, through its Institute for Transportation (InTrans), is the MTC lead institution.

MTC's research focus area is State of Good Repair, a key program under the 2012 federal transportation bill, the Moving Ahead for Progress in the 21st Century Act (MAP-21). MTC research focuses on data-driven performance measures of transportation infrastructure, traffic safety, and project construction.

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Problem Statement

Ultra-high-performance concrete (UHPC) has attracted much interest in the bridge engineering community due to its strength, ductility, and durability, but its high cement content has made it expensive and less environmentally friendly (due to the CO_2 emission resulting from cement manufacture).

Objective

The objective of this innovative pilot research project was to evaluate the important material properties of a cost-effective and environmentally-friendly geopolymer-based UHPC, also called ultra-high-performance geopolymer (UHPG), that may be a very attractive option for future bridge construction and repair.

Background

Increasing concerns about the environmental issues caused through the use of Portland cement in concrete have led to the development of a geopolymer binder that is a product made from the reaction of industrial aluminosilicate wastes (e.g., fly ash, slag, and metakaolin) and alkali solution.

UHPCs often contain significant amounts of Portland cement, along with other materials that help strengthen concrete. A unique UHPG has been developed in China, where geopolymer composites are used to replace Portland cement in conventional UHPC.

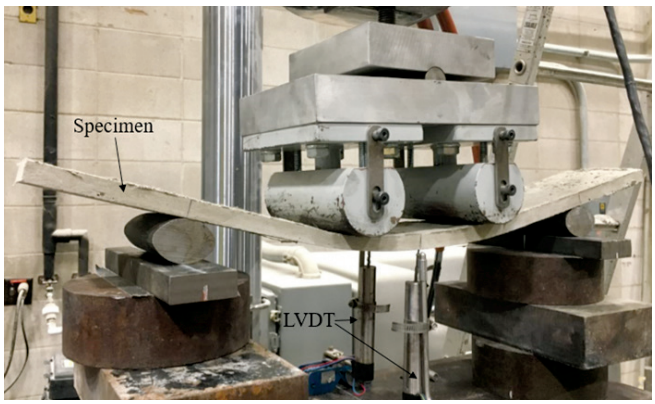
While some study has been done to replace Portland cement with UHPG, there has been little research reported particularly on fly ash-based UHPG.

Research Methodology

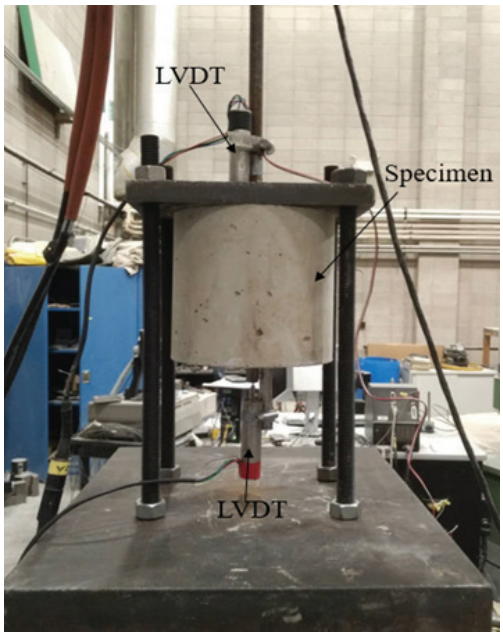
This research project was originally designed to evaluate the properties of the UHPG made in China and to explore the feasibility of its use for transportation infrastructure. However, due to difficulties in obtaining UHPG samples from China, the project was expanded to consider the development of UHPG using Iowa materials.

In addition to formulating UHPG mix proportions, the research team performed laboratory experiments to characterize the mechanical properties (compressive and tensile strength, flexural bending, and pullout bond strength) of a geopolymer sample prepared in China

(materials and mix proportion unknown) and those developed at Iowa State University (ISU). The team evaluated the samples according to ASTM International and/or American Association of State Highway Transportation Officials (AASHTO) test methods. The team also investigated the mix formulation and the effect of the curing method on UHPG.



UHPG specimen under bending test



UHPG specimen under pullout test

Key Findings

- The UHPG sample made in China and tested at ISU showed a compressive strength of 123 MPa (17,868 psi) and maximum compressive strain of 0.0047 microstrains.
- The mix design study at ISU revealed that compressive strength of fly ash based UHPG could be enhanced by replacing fly ash with ground-granulated blast-furnace slag. The optimal slag content was 20%, but it had a lower compressive strength than the UHPG sample from China when mixed with an activator solution.
- As slag content increased, the bond strength between geopolymer and steel rebar improved. The UHPG samples with 20% slag replacement gained a 77.1% increase in the bond strength when compared with that of pure fly ash UHPG.
- Use of slag as a replacement for fly ash improved strengths and elastic modulus of UHPG but noticeably reduced the deflection at failure and ductility of UHPG.
- When reinforced with 2% by volume of polyvinyl alcohol (PVA) fiber, the UHPG mixes developed at ISU (with 0–30% slag replacement for fly ash) exhibited strain and displacement hardening behavior in tension and flexure, indicating significant ductility.
- Among the curing methods used, steam curing at 50°C appeared to be the best condition for UHPG strength development.

Implementation Readiness and Benefits

The results of this study indicate that UHPG can be achieved through engineered formulation using locally available concrete materials. Further development of UHPG has the potential to be a more cost-effective and environmentally friendly option than UHPC.

Recommendations for Future Research

Only a limited number of UHPG mixes were studied in this project, so further study of the geopolymer-based mixes is necessary to understand and improve their properties. Particularly, future studies should be done to increase the density and decrease the porosity of the UHPG mix developed at ISU. To further reduce the cost of UHPG, future studies should look at ambient temperature curing for strength development.

This study focused on the mechanical properties of UHPG only. Although geopolymers were reported to have excellent chemical resistance, the durability properties of UHPG, such as freezing and thawing resistance, should be studied for its potential use in Iowa.