Alternative Cementitious Materials in Transportation

Sustainable, Durable Substitutes for Portland Cement

Exploratory Advanced Research . . . Next Generation Transportation Solutions

As the world's second-most widely used material behind water, concrete is a core ingredient of American infrastructure, including its use to build roads and bridges on the National Highway System. Concrete, due to its long service life, has a low environmental cost; however, its major component, ordinary portland cement (OPC), in its manufacturing process, gives off a large amount of carbon dioxide; and by reducing or replacing OPC, significant sustainability improvements will result. To use less energy in cement production, the Exploratory Advanced Research (EAR) Program at the Federal Highway Administration (FHWA) is supporting research to increase access to potential replacements or alternatives for portland cement. These alternative cementitious materials (ACMs) are the focus of a project titled "Novel Alternative Cementitious Materials for Development of the Next Generation of Sustainable Transportation Infrastructure." The primary goal is to facilitate infrastructure construction and rehabilitation using concrete that is made with ACMs. The Georgia Institute of Technology is spearheading the research in partnership with Oklahoma State University, Tourney Consulting, and the U.S. Army Corps of Engineers. The three-phase project began in 2014.

The Cement-Making Process

Portland cement is created by combining calcium, silicon, aluminum, and iron in a controlled chemical process that involves heating the raw materials in a cement kiln. The raw materials come from limestone, clay, and other substances.

Researchers are exploring potential substitutes for portland cement to provide designers, owners, and contractors more choices in materials. ACMs currently are used largely for specialized applications, including to make small pavement and bridge repairs and to join precast elements. The raw materials are different from those in portland cement, most notably in terms of reduced calcium content, and the chemical processes that create ACMs require less energy and give off less carbon dioxide. ACMs also can be more resistant to heat, fire, sulfate attack, shrinkage, and cracking. "Greater use of alternative cements could extend the life of concrete in pavement and bridges, particularly when consideration is given to their special properties, the type and speed of construction, and the concrete's exposure to extreme environments," says Richard Meininger of FHWA's Office of Infrastructure Research and Development.

Exploring the Alternatives

The first phase of research into ACMs involved an extensive literature review, site visits to evaluate the long-term performance of pavements using ACMs, interviews with producers and users of ACMs, and tests of materials. The first round of testing involved ordinary portland cement as a control measure and nine commercially available ACMs—three calcium sulfoaluminate (CSA), one polymer-modified CSA, two calcium aluminate (CA), one portland/CA/calcium sulfate ternary blend, one chemically activated Class C fly ash (AA1), and one magnesium phosphate (MP) binder.

The initial research demonstrated a growing interest in using ACMs for large-scale transportation projects, particularly in large urban areas that benefit from the rapid setting characteristics and early strength of the materials. Those factors can shorten the time of road closures for construction. The research team identified five ACMs for further testing—two CSA cements (including the polymer-modified blend), two CA cements (including the ternary blend), and AA1. All of the materials met or exceeded performance standards in the first phase of research, and they showed promise for broader and large-scale use in transportation infrastructure (Burris, Kurtis, and Morton 2015).

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Another Round of Testing

During the second phase of work, the researchers subjected concretes using the five ACM binders to more detailed evaluation. The testing gauged the ability of the materials to resist various external and internal threats to concrete, from physical abrasion to progressive alkali silica reactivity deterioration. Researchers designed laboratory tests to maintain consistency across the mixtures, followed the producers' recommendations for the materials, and compared the results with concrete that uses portland cement. The results covered these aspects of performance of ACMs in concrete: sulfate resistance, resistance to chloride ion penetration, corrosion resistance, degradation from freezing and thawing, and shrinkage from drying.

© College of Engineering, Georgia Institute of Technology. Researchers tested several commercially available alternatives to portland cement, including the four pictured here, clockwise from top left: a calcium sulfoaluminate cement (CSA2), a calcium aluminate cement (CAC3), a ternal blend of portland cement, calcium aluminate cement, and calcium sulfate (CAC2), and a chemically activated binder produced with Class C fly ash (AA1).

Three of the ACMs tested by the researchers—one each with CSA, the CA ternary blend, and AA1—indicated superior resistance to external sulfate attack, while one with CA experienced deterioration.

To assess the effect of ACMs on corrosion of steel used in bridge decks, three chloride-related issues were studied: the resistance of the ACMs to chloride ions, the ability of the ACMs to bind chlorides, and rebar corrosion. Portland cement had the highest chloride-ion binding capacity, followed by the CA ternary blend. The CSA and AA1 mixtures had the lowest capacities. Overall, for the water-to-binder ratios that were examined, the polymer-modified CSA and the CA ternary blend showed the best corrosion resistance compared with portland cement and other ACMs.

The researchers found that all five ACMs, when subjected to freezing and thawing in water, benefit from entrained air bubbles, but the air content necessary to resist degradation from freezing and thawing varied among the ACMs. Early lab results also indicated that drying shrinkage is significantly lower in three of the ACMs compared with portland cement.

Plans for the third phase of the project call for additional corrosion tests, extended lab testing, long-term field exposure studies (including some with the U.S. Army Corps of Engineers), and forensic analysis of samples obtained from ACM pavements that have been in service for an extended period. Technology transfer activities include planned reports, short videos, and additional TechBriefs.

EXPLORATORY ADVANCED **RESEARCH**

What Is the Exploratory Advanced Research Program?

The EAR Program addresses the need for longer term, higher risk research with the potential for transformative improvements to transportation systems. The EAR Program seeks to leverage advantages in science and engineering that could lead to breakthroughs for critical, current, and emerging issues in highway transportation by experts from different disciplines who have the talent and interest in researching solutions and might not do so without EAR Program funding.

To learn more about the EAR Program, visit https://highways.dot.gov/research/exploratory-advanced-research. The website features information on research solicitations, updates on ongoing research, links to published materials, summaries of past EAR Program events, and details on upcoming events.

Learn More

For more information about this EAR Program project, contact Richard Meininger, FHWA Office of Infrastructure Research and Development, at 202-493-3191 (email: richard.meininger@dot.gov).

Photo credit, page 1: © College of Engineering, Georgia Institute of Technology. This slump test is performed on concrete made with calcium sulfoaluminate cement, one of the cements the researchers tested as a potential alternative for portland cement.

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Burris, L., Kurtis, K., and Morton, T. (2015). *Novel Alternative Cementitious Materials for Development of the Next Generation of Sustainable Transportation Infrastructure*, FHWA-HRT-16-017, Federal Highway Administration, McLean, VA. Available online: https://www.fhwa.dot.gov/advancedresearch/pubs/16017/index.cfm, last accessed June 28, 2018.