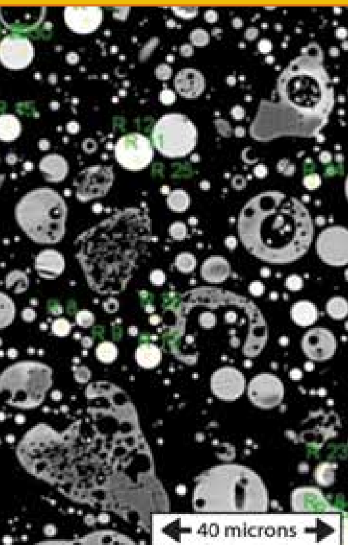
The Exploratory Advanced Research Program Fact Sheet

Inorganic Polymers:

Novel Ordinary Portland Cement-Free Binders for Transportation Infrastructure

Exploratory Advanced Research . . . Next Generation Transportation Solutions



Researchers are studying how building materials can be made in a way that is less energy intensive and can result in cost savings.

One such building material is concrete, which is used to make sidewalks and roads, among other structures. Concrete consists of cement, water, sand, and stones that are mixed together. When cement is mixed with water, it acts like a binder—or glue—to hold together all the sand and stones that make up concrete. However, producing ordinary portland cement, the type of cement most often used, can be energy intensive because cement manufacturing requires high heat. This is because the limestone used to make cement releases carbon dioxide when heated, while the kilns where cement production occurs burn fossil fuels for heat.

To address this concern, researchers at the University of California, Los Angeles (UCLA) have developed "cement-free" inorganic polymer binders (IPBs) for producing concrete. They studied how IPBs made from fly ash, an industrial byproduct that comes from coal-fired power plants, can completely replace the portland cement binders currently used to make concrete. With research partners at the University of California at Santa Barbara, University of Texas at Austin, and Boral Materials, along with support from the U.S. Department of Transportation's Exploratory Advanced Research (EAR) Program, the researchers defined fly ash's characteristics at the atomic level so that they could understand how those characteristics influenced binder behavior during concrete production.

How to Produce a Cement-Free Binder

Fly ash is an attractive supplement and alternative to cement as a binder for several reasons. Fly ash's chemical composition enables it to undergo desirable chemical reactions, producing an end product that performs similarly to traditional cement binders. Fly ash is also available on a large scale—often ending up in landfills—thereby offering a beneficial use for a material that would otherwise simply be disposed.

To produce an IPB, or cement-free binder, the researchers mixed a solid aluminosilicate precursor—fly ash—with a solution that prompts alkaline activation. Alkaline activation is a chemical process, during which the fly ash dissolves in the solution to form a product with binding properties similar to those of cement. Although the development of these cement-free binders made from fly ash is still maturing, the goal is to use these binders to produce building materials that are strong, durable, and suitable for construction.

However, the researchers sought to go beyond the successful production of an IPB using fly ash. They wanted to gain new insights into how fly ash reacts with certain chemical solutions so that they can better understand how those reactions affect binder performance and production. The researchers wanted to know how to control the speed of reactions, which would help in making real-world production more feasible. The researchers also looked at temperature settings during the production process. The proper curing of IPBs requires high temperatures, but the researchers wanted to explore facilitating reactions at typical temperatures versus high temperatures because real-world applications call for simpler production conditions.

By studying the fundamental variables that affected the formation of an IPB and examining how different chemical solutions could affect fly ash's reactivity, the researchers established foundational tools and methodologies that the construction industry can apply as it pursues ways to integrate industrial byproducts into the manufacturing of building materials.

How Atomic Changes Can Make a Big Difference

Establishing how fly ash might react when introduced into certain chemical solutions required the researchers to develop a

U.S. Department of Transportation
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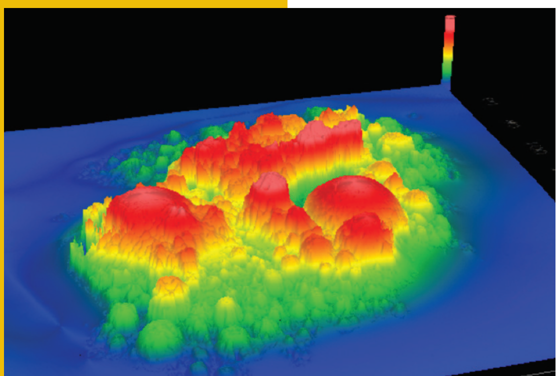

Photo credit: © Henry Samueli School of Engineering and Applied Science, University of California, Los Angeles. A three-dimensional image acquired using vertical scanning interferometry that shows a cluster of fly ash particles. The color gradient from blue to red indicates the height relative to the adjacent surface (low to high).

Photo credit, page 1: © The American Ceramic Society, courtesy of Wiley's Journal of American Ceramic Society. A gray-scale image of numerous fly ash particles embedded in a resin that was imaged using backscattered electrons using a scanning electron microscope.

molecular design strategy through the exploration of three themes. The first theme was determination of the desired characteristics of fly ash to produce cement-free binders. This also involved matching the aluminosilicate precursor—in this case, fly ash—with the activation solution. Gaining such insights necessitated analysis of the compositional and physical parameters of fly ash using various analytical methods to see how variations in those parameters may influence reactions and the composition of the final product.

The second theme was establishment of the molecular processes and products that result when cement-free binders react under typical conditions. The researchers examined this aspect by using solid- and liquid-phase nuclear magnetic resonance, vertical scanning interferometry, and molecular simulations to analyze materials at the atomic scale. These tools helped the researchers examine how fly ash-based substances dissolve, what kind of chemical species form in the solutions, and the composition of the inorganic polymer hydrates. Both the first and second themes served to develop a foundational understanding of the composition and reactivity of cement-free binders from their chemical structure to reaction evolution.

The third theme was exploration of how binders made from inorganic polymers evolve throughout a reaction. Researchers developed a sophisticated computational algorithm that can serve as a calculator for reactions. Using an embedded material properties database, the platform allowed construction technologists to input the solid and liquid compositions of the precursors. Outputs then provided calculated estimates of how a cement-free binder may perform across a range of chemical compositions.

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 advances 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.

By exploring these three themes, the researchers aimed to advance the understanding of cement-free binders, improve the ability to controllably manufacture such materials, and ascertain how these cement-free binders may perform in practical highway construction applications.

Learn More

For more information about this EAR Program project, contact Jack Youtcheff, FHWA Office of Infrastructure Research and Development, at 202-493-3090 (email: jack.youtcheff@dot.gov).

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